UAS-B/MJAS/2024/GKVK/USN-01

THE MYSORE JOURNAL OF AGRICULTURAL SCIENCES

Since 1967

Vol. 58 (4) October-December 2024 ISSN-0047-8539

Online :
Website : www.mjas.co.in
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UNIVERSITY OF AGRICULTURAL SCIENCES BANGALORE, INDIA

A Peer-Reviewed Journal with a NAAS Score of 4.63

THE MYSORE JOURNAL OF AGRICULTURAL SCIENCES

NAAS Score 4.63

Frequency of Publication : Quarterly

MJAS 58 (4) 2024 : 1-461

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Membership	Inland (₹)	Foreign (US $)
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Edited and Published by Dr. K.H. Nagaraj
Assisted by Dr. H.B. Raghu
Communication Centre, University of Agricultural Sciences, GKVK, Bengaluru - 560 065, India

Mysore J. Agric. Sci., 58 (4) : 1-461 (2024)

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ABSTRACTS

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Gathering Performance of Combine Harvester in the Case of Tef Crop Harvesting in Ethiopia

KISHORE PURUSHOTTAM KOLHE, FITSUM ABEBE AND AMANA WAKO
Department of Mechanical Engineering, Adama Science and Technology University,
Ethiopian Institute of Agricultural Research (EIAR), Ethiopia
e-Mail : kishorkolhe05@gmail.com

AUTHORS CONTRIBUTION

KISHORE PURUSHOTTAM KOLHE & FITSUM ABEBE :
Conceptualization, data analysis, graphical representation, interpretation and prepration of manuscript;

AMANA WAKO :
Collection of review papers and drafting

Corresponding Author :
KISHORE PURUSHOTTAM KOLHE

Received : September 2024
Accepted : November 2024

ABSTRACT

The gathering performance of the combine harvester is affected by crop factor and machine setting parameters. The crop factor like the physico-mechanical behavior, has a profound effect on the performance of the combine harvester. Likewise, the machine setting parameters, *i.e.,* forward speeds, reel rotation speeds and cutter-bar settings, affect combine harvester performance. Over the years, different research was conducted to show the relationships and the effects of crop factor and machine setting parameters on the performance of combine harvesters. Following that, recommendations and further modifications have been performed on existing combine harvester units in different countries to improve combine harvester's efficiencies and adapt them to local crop conditions. However, when it comes to the Tef crop; a staple crop over 70 million Ethiopians depend on the initiatives to adapt existing combine harvesters to address the crop which are negligible owing to the nature of the crop and the very limited research works conducted on the theme so far. As a result of that, Tef farmers of Ethiopia continued to harvest the crop manually using rudimentary tools which entail a large sum of human labor and devotion of time. In this paper, the effects of crop factor and machine setting parameters on harvester's performance and the initiatives to improve existing combine harvesters are accounted indetail through a thorough review of published literature conducted in different countries. The reason why Tef farmers of Ethiopia do not employ existing combine harvesters is also documented along with the way forward to adapt such an important agricultural machine.

Keywords : Physico-mechanical behavior of crops, Combine harvesters machine settings, Header loss, Tef harvesting

ETHIOPIA is heavily dependent on agriculture as a predominant source of employment, income and food security for the vast majority of its population. The agriculture sector plays a central role in the life and livelihood of most Ethiopians (Benyam *et al.*, 2021). The agricultural sector of Ethiopia has a major share in country's GDP, creating employment opportunity and external earnings of 34.1, 79 and 79 per cent, respectively and also is the major source of raw materials and wealth for investment in international market (Diriba, 2020 and Kolhe *et al.*, 2024). Cereals have been the most produced crops in Ethiopia. According to the CSA (2018-19) main rainy season 'Meher' post-harvest crop production survey, about 71.6 per cent of the total area was covered by crops and more than 69.5 per cent of crop output was generated from cereals. In 2020-21, the area coverage of cereals increased to 81 per cent of the allotted 14.65 million ha of land for crop production out of which Tef crop took up about 29 per cent (CSA, 2021). Ethiopia is the largest Tef producer in the world accounting 24 per cent of the grain area followed by maize at 17 per cent and sorghum at 15 per cent (Table 1). Amhara and Oromia are the two major regions and collectively, those two regions that accounts for 85.5 per cent of the Tef area and 87.8 per cent of the Tef production (CSA, 2019).

Table 1

Production of cereal crops and Tef in Ethiopia

Crop	Area (ha)	Yield (ton/ha)
Grain crops	12,574,107 (100%)	-
Maize	2,135,571 (17%)	3.675
Sorghum	1,881,970 (15%)	2.525
Tef	3,017,914 (24%)	1.664

The demand for Tef in the country is continuously increasing day by day due to an increase in population. Table 2 shows the amount of cropped land area, production and yield of Tef across various cropping seasons. The increase in area, production, and yield consumed more labor and effort, which became a challenge for Tef growing farmer community and raised the need for mechanized Tef harvesting in the country.

Many findings associate the low productivity of the crop with low availability and use of modern inputs (seed and fertilizer) and the traditional method of production of the crop. However, most of the pertinent issues of Tef productivity are now being solved through integrated efforts of concerned governmental sectors and research institutes except the issue related to crop harvesting. Tef harvesting in Ethiopia is very time-consuming and resource-intensive work as the operation is done manually using sickles (Tadesse *et al.,* 2016). This harvesting method requires 8-12 human labour per day to harvest a 2000-2500 m^2 area of growing land and had there been mechanized harvesters, the number of days for labor per ha may have reduced by 70-80 per cent (Abraham, 2015). However, combine harvesters suitable for the Tef crop are not yet available and the existing harvesters have high lodging losses. This is mainly related to the nature of the crop (crop factor) and the way the gathering reel units of existing combine harvesters (machine factor).

The performance of a combine harvester is affected by crop factors (crop physical and mechanical properties), machine setting parameters and its design. This important agricultural machine's performance cannot be improved without in-depth knowledge of these relevant aspects. For this, it is imperative to review different literature which has been conducted on such themes. The purpose of this paper is, thus, to reveal the effect of crop and machine factors on the gathering performance of combine harvester.

Literature Review

Grain harvesting is the act of collecting grains from the field and separating them from the rest of the crop material with minimum grain loss while maintaining the highest grain quality (Ajit *et al.*, 2012). Harvesting time is a critical factor dictating the losses during the harvesting operations. Grain loss occurs before or during the harvesting operations if it is not performed at an adequate crop maturity and moisture content. Too early harvesting of crops

Table 2

Cultivated area, production and yield of Tef in Ethiopia (CSA reports, 2019-2021)

Production year	Area Covered		Production		Yield q/ha
	ha	Distribution (%)	q	Distribution (%)	
2017-18	3,023,283.50	23.85	52834,011.56	17.26	17.48
2018-19	3,076,595.02	24.17	54,034,790.51	17.12	17.56
2019-20	3,101,177.38	24.11	57,357,101.87	17.11	18.50
2020-21	2,928,206.26	22.56	55,099,615.14	16.12	18.82

at high moisture content increases the drying cost, making it susceptible to mould growth and insect infestation, resulting in a high amount of broken seeds. Whereas, too late harvesting operation leads to high shattering losses, exposure to bird and rodent attacks and losses due to natural calamities (rain, hailstorms, etc.). In addition to the moisture content of the crop at the physiological maturity stage, the availability of harvested grain processing and storage options is also a critical factor in deciding the harvesting time of crops. Thus, optimization of the moisture content of the crop and the availability of grain processing facility options need to be dealt critically before harvesting physiologically matured crops to minimize grain losses and the associated costs as well (Metz, 2006). Harvesting operations are done either with machines (combine harvesters or windrows) or manually using sickles. The choice of the method and equipment however depends on the type of crop, planting method and climatic conditions (Srivastava *et al*., 1993). A modern grain combine performs many functional processes (Fig. 1). These are gathering and cutting (or in the case of windrows, picking up), threshing, separation and cleaning.

The header is one of the major components of a combine by which crop gathering and cutting are done. Research studies reveal that the efficiency of gathering operation of a header of a combine is greatly influenced by crop type and its physico-mechanical properties (Chinsuwan *et al.*, 2002), the combiner forward speed, reel design and speed (Quick, 1999; Mohammed & Abdoun, 1978 and Chinsuwan *et al.*, 2004), cutter-bar type and speed (Hummeland, 1979), reel interaction with the crop and reel position (Kutzbach & Quick, 1999). Crop factors *i.e.,* physical condition and associated mechanical behavior have a profound influence on the gathering and processing efficiencies of combine harvester (Yore *et al.*, 2002). As information on crop factors is crucial for early design and further improvements of components of the combine (Chinsuwan *et al.*, 1997), many researchers have researched the physical and mechanical behaviors of crops. Shaw *et al*. (2007) and Yiljep *et al.* (2005) proved that the physical conditions of crops (moisture content, stem diameter and thickness, stalk height, panicle length and weight, crop density, posture and crop variety) affect the mechanical properties of crops (tensile strength, shear module, bending strength, flexural rigidity and modulus of elasticity) (Tefari and Kolhe, 2021). Shahbazi and Nazari (2012) studied the bending and shearing properties of safflower stalk and found that the average bending stress value varied from 21.98 to 59.19 MPa. They also reported that Young's modulus in bending also decreased as the moisture content and diameter of stalks increased and the shear stress and the shear energy increased with increasing moisture content and diameter of the crop

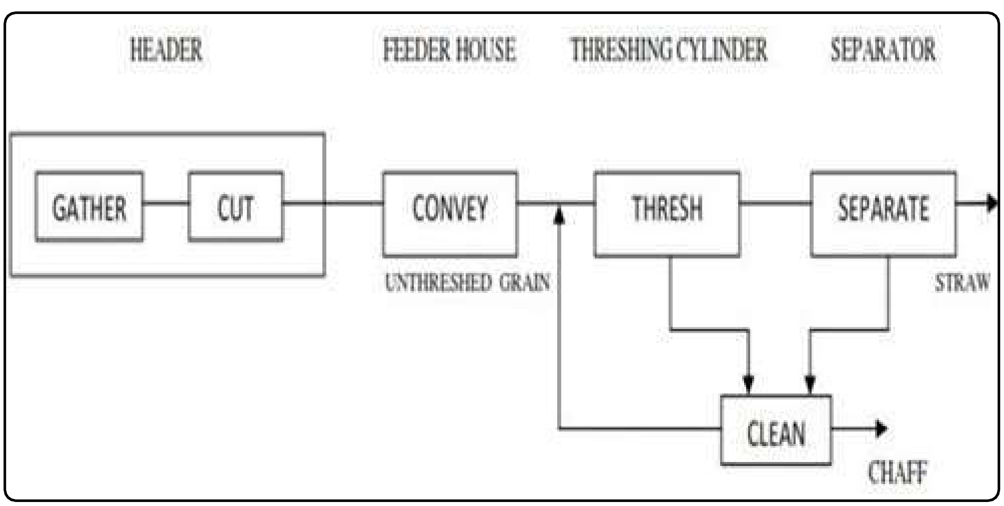

Fig. 1 : A process diagram of a combined harvester

stem. The maximum shear stress and shear energy were found to be 11.04 MPa and 938.33 MJ, respectively, both occurring at the bottom region of the stem with a moisture content of 37.16 per cent. Bending stress, Young's modulus, shearing stress and shearing energy were determined for Alfalfa (*Medicago sativa* L.) stem by Nazari *et al.* (2008) through the experiments conducted at a moisture content of 10, 20, 40, and 80 per cent wet basis. The results showed that the bending stress and the Young's modulus decreased as the moisture content and the diameter of the stalk increased, respectively. Tavakoli *et al.* (2010) and Yashwant *et al.* (2024) compared the mechanical properties of rice straw Hashemi and Alikazemi varieties. Moisture content taken for Hashemi was 71.6 per cent w.b. and for Alikazemi was 70.8 per cent w.b. at which the experiment was conducted. Shear strength was found to be 13.08 MPa for Hashemi and 8.56 MP for Alikazemi. Chandio *et. al*. (2013) worked on three different wheat varieties at different moisture content levels with three knife-cutting bevel angles at three shearing speeds of the pendulum. At 25 and 30 per cent moisture contents the shear strengths were less but at 35 per cent moisture contents shear strengths were greater. Shear strength was found to be increased with shearing speed and decreased with the decrease in bevel angle and moisture content. Tavakoli *et al*. (2009) in their research work to determine the effects of moisture content (at four levels) and internode position (three positions) on some physical and mechanical properties of wheat straw showed that the values of the physical properties and the shear energy increased with increasing moisture content and the diameter of the nodes. Geta (2020) reported that there were significant differences in the physico-mechanical properties of four varieties of Tef crops and suggested that further similar work should be done for other varieties of the crop. Machine parameters and settings have also a profound effect on the gathering performances and field efficiencies of combine harvester (Srivastava *et al.*, 1993). Martin *et al*. (2018) presented an overview of the combine harvester setting for barley and wheat crops. The custom setting differs from the one recommended by the manufacturer mainly in the gap between the basket, rotor and bottom sieve opening (20 and 29%, respectively) for barley reframe the sentence. The difference in custom setting for wheat is significantly greater than for barley, the gap between basket and rotor was increased by 146 per cent and the openings of upper and lower sieves were significantly changed by 42 and 72 per cent, respectively as shown in Table 3. During testing, lower losses were observed in the custom setting for both crops as shown in Table 4.

Omar *et al*. (2021) evaluated a combine harvester (CLAAS Crop Tiger 30) to see the effect of its forward and reel speeds on wheat gain losses in Gezira State, Sudan. The experiment was conducted in a split-plot design with three forward speeds (4, 5 and 6 km/h) in the main plots and three reel speeds (25, 35 and 45 rpm) in the sub-plots. The dependent parameters were total header loss, processing loss and total machine losses. According

TABLE 3

Overview of the combine harvester settings for different crops (Martin *et al*., 2018)

Crop Setting	Spring barley			Winter wheat		
	Recommended	Custom	Difference (%)	Recommended	Custom	Difference (%)
Rotor speed, min^{-1}	750	770	+2.66	900	900	0.00
Cleaning fan speed, mm^{-1}	20	24	+20.00	15	37	+146.60
Opening of upper sieve mm	900	900	0.00	980	1050	+7.14
Opening of upper sieve mm	16	17	+6.25	14	20	+42.58
	17	12	-29.14	9	16	+77.70

TABLE 4

Average harvest losses of spring barley and winter wheat depending on combine harvester settings and overall grain yield

Spring barley			Winter wheat		
Avg. yield (tha^{-1})	Avg. losses at recommended setting (%)	Avg. losses at custom setting (%)	Avg. yield (tha^{-1})	Avg. losses at recommended setting (%)	Avg. losses at custom setting (%)
4.284	0.52	0.41	4.759	0.58	0.49
5.581	0.61	0.55	5.829	0.69	0.55
6.188	0.71	0.59	6.531	0.75	.63
6.898	0.80	0.61	7.807	0.88	0.70
7.543	0.95	0.68	8.039	0.97	0.75

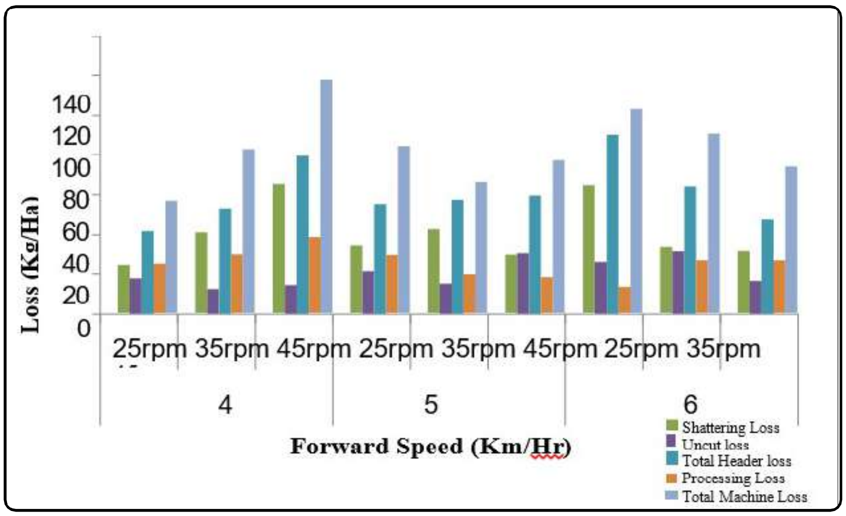

Fig. 2 : Effect of combine forward and reel speed on all losses

to the test result, the lowest (41.75 kg/ha) and the highest (90.10 kg/ha) total header losses were recorded from forward speeds of 4 km/h and 6 km/h at reel speed of 25 rpm in both cases, respectively. On processing losses, a forward speed of 6 km/h with a reel speed of 25 rpm recorded the lowest loss (13.2 kg/ha) while a forward speed of 4 km/h with a reel speed of 45 rpm was found to provide the highest loss (38.2 kg/ha). The lowest (56.74 kg/ha) and highest (118.02 kg/ha) total losses were recorded from a forward speed of 4 km/h at reel speeds of 25 rpm and 45 rpm, respectively (Fig. 2.).

Bawatharani *et al*. (2013) investigated the effect of reel index on header losses of two combine harvesters (Kubota DC-68G and Agroworld 4L-88) on long rice crop (Bg 94-1) in *Palugamam (*Sri Lanka) under a split-plot design with three replications. The main plots of the experiment were assigned to the forward speeds of the combiners i.e. 0.56 , 0.82 and 1.8 km/h for the Kubota harvester and 0.53 km/h, 0.76 km/h and 1.06 km/h for the Agroworld combine, and the sub-plots of were assigned to three levels of reel indexes (1.2, 1.7 and 2.5). The results revealed that reel index of 1.7 resulted insignificantly low header

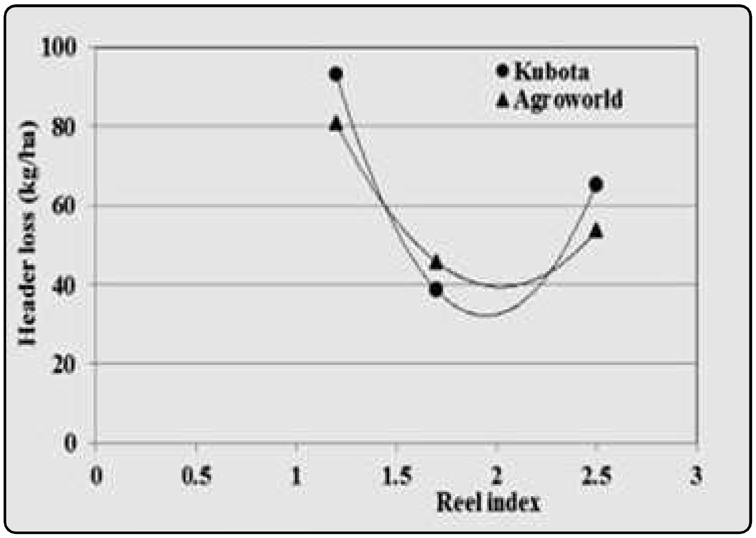

Fig. 3 : Header Losses at different reel index levels

losses of 38.8 kg/ha and 45.8 kg/ha for Kubota and Agroworld harvesters, respectively. Whereas, reel indexes 1.2 had resulted in higher header losses in both combiner sowing to a greater header advancement and an increased tine bar velocity. The losses recorded for both combiners were also found to be high at a reel index of 2.5 due to lesser header advancement and an increased number of impacts of the reel on panicles of the crop (Fig. 3.).

Ramadhan *et al*. (2013) conducted research on wheat crops in Babylon province (Iraq) to investigate the effect of three forward speeds (2.4 km/h, 3.34 km/h and 4.28 km/h) at three cutter-bar settings (10, 20, and 30 cm) of CLAAS combiner on the header and subsequent unit losses. The test result revealed that there were increased header losses as the forward speed increased from 2.4 km/h to 4.28 km/h. They also reported that a forward speed of 2.4 km/h at a 30 cm cutter-bar setting gave lower total harvester loss as compared to the other settings and there was a trend of increment in the total harvest loss as the forward speed increased.

Bawatharani *et al*. (2017) researched rice crops using a CLAAS C210 combine harvester equipped with a reel-type header at Anuradhapura (Sri Lanka) to investigate the header grain losses and quality of paddy grains for three levels of cutter-bar heights (10, 15, 20 and 25 cm) and forward speeds of 2.4, 3.84 and 4.28 km/h under RCBD design with split plot arrangement where the forwarded speed as the main plot factor and the cutting heights were considered as subplot factors. The result revealed that cutting heights of 10, 20 and 25 cm resulted in greater heading losses. The highest mean header loss, 37.04 kg/ha, was shown at 25 cm cutting height and the lowest, 23.71 kg/ha, was registered for 15 cm (Fig. 4.).

A forward speed of 4.28 km/h had shown statistically the highest significant loss, 42.41 kg/ha, whereas the lowest significant loss (23.96) was registered for a forward speed of 2.4 km/h. In terms of grain damage, the authors reported that cutting height hardly had a significant impact but forward speed had a strong negative relationship with grain damage (Fig. 5).

El-Nakib *et al.* (2003) used the Kubota combine as a mechanical harvester of rice crops for loss tracking under different conditions. They found that header, threshing, separating, and shoe losses increased with the increase of the forward speed and the decrease of grain moisture content. They also reported that optimum operating parameters for harvesting rice crops were a combined forward speed of 4.5 km/h and grain moisture content of 16.5 %.

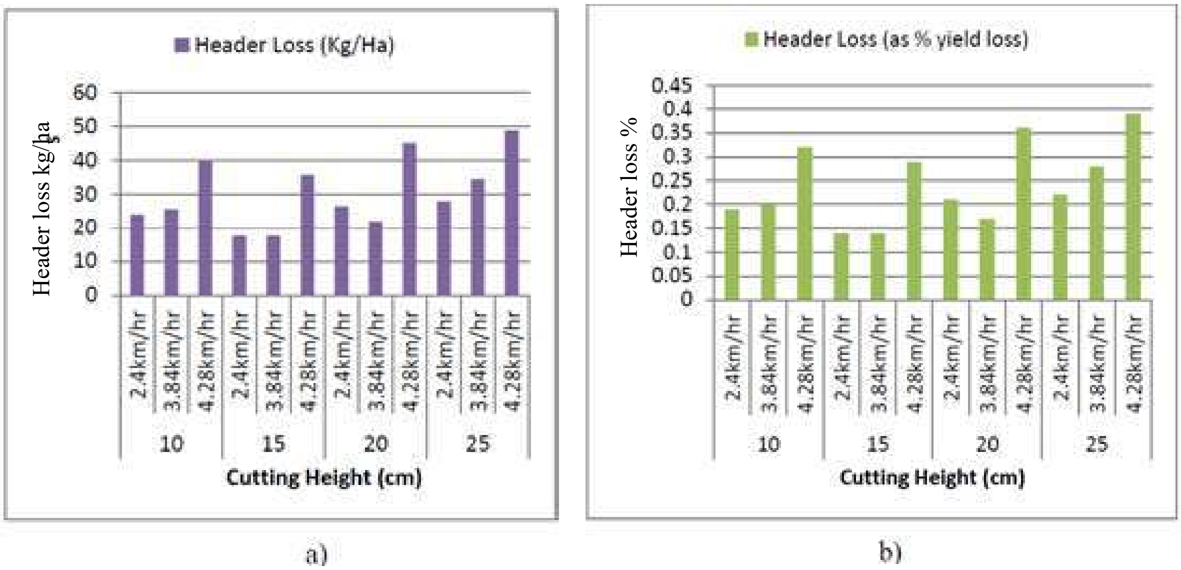

Fig. 4 : Header loss due to cutting height at different forward speeds

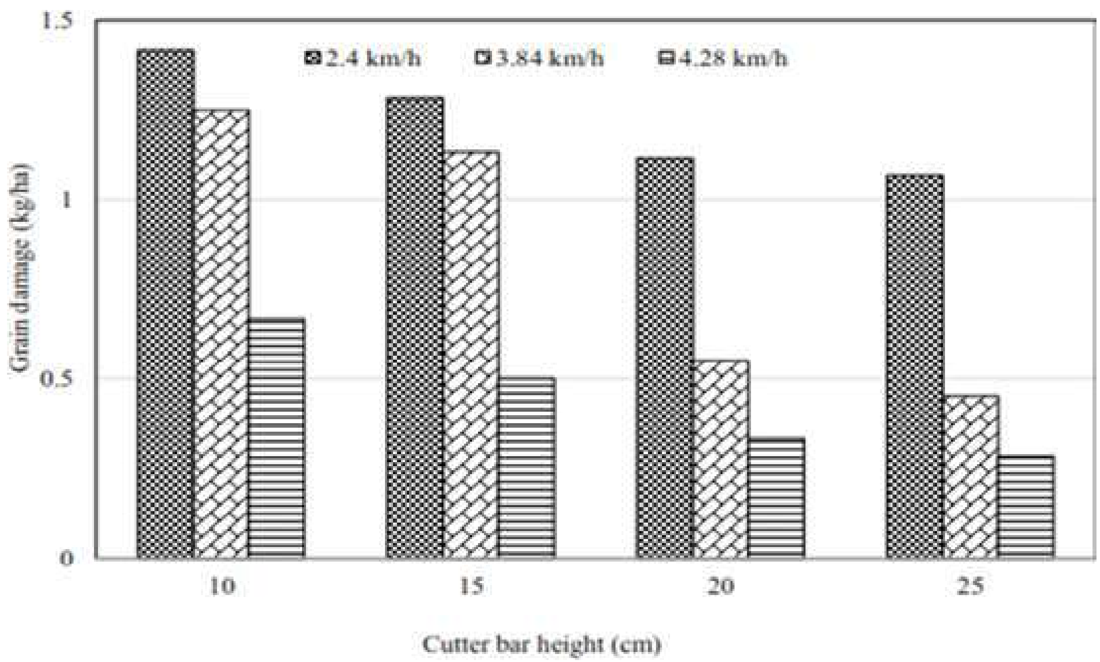

Fig. 5 : Effect of Cutter-bar height on grain damage

The comparative study conducted on different sizes of Yanmar combine concerning unit plot area by Badr (2005) indicated that increasing the forward speed from 1.0 to 4.0 km/h at a constant moisture content of 22 per cent, increased field capacity from 0.31 to 1.14 ha/h, while decreased field efficiency was from 89.3 to 82.7 per cent. El-Sharabasy (2006) indicated that increasing machine forward speed from 1.5 to 3.0 km/h increased effective field capacity from 0.277 to 0.452; 0.251 to 0.382; 0.208 to 0.349 and 0.181 to 0.296 fed /h different grain moisture contents of 21.45, 22.20, 23.12 and 24.60 per cent, respectively. The resulting assessment of the performance of the mechanized harvesting of grain crops indicates a very low degree of use of the potential of mechanization means. Victor *et al.* (2020),

TABLE 5

The calculated results of the coefficients to determine the performance of the processes of combine harvesting of grain crops

Coefficient name	Coefficient value
Planned performance (Sp), ha	1413.18
Coefficient of weather conditions (K_w)	0.58
Coefficient of Technical use (K_{TU})	0.83
Coefficient of technological adjustment (setting) (K_A)	0.86
Load Factor (K_L)	0.80
Coefficient of organizational downtime (K_o)	0.60
Actual performance (S_A), ha	480.57

elaborate on the contribution of various reasons for the decrease in the harvesting performance by the value of the indicators presented in Table 5.

Abdelmotaleb *et al*. (2009) reported that the increase of combine forward speed from 0.8 to 2.5 km/h leads to a decrease in the field efficiency from 84.96 to 62.35 per cent at a cutting height of 0.2 m without a control system. Fouad *et al*. (1990) studied a mechanism of self-propelled rice combine harvester and reported that raising travel speed from 0.8 to 2. km/h increased grain losses but decreased the field efficiency of the combine. Chaiyan Junsiri and Winit Chinsuwan (2009) developed prediction equations for losses of combine harvesters when harvesting. Thai Hom Malicerice, in their study, showed that grain moisture content (M), reel index (RI), cutter bar speed (V), the service life of cutter bar (Y), tine spacing (R), tine clearance over cutter bar (C), stem length (H), a product of M and Y (M×Y), a product of M and V (M×V), a product of RI and R (RI×R), a product of V and C (V×C), a product of V and H (VxH), V^2 and RI^2 were the major parameters affecting the losses. The prediction equations had $R^2 = 0.75$ and the average percentage header losses given by the estimation equation differed from the measurement by only 0.25.

Crop's interaction with the reel unit at the harvesting position is also a major factor influencing the gathering efficiency of a combine harvester (Srivastava *et. al.*, 1993 and Kolhe, 2009). In this connection, many researches were conducted to come up with equations useful to measure the deflection characteristics and the reaction forces of crops under the influence of reel engagement. Hirai *et al.* (2002a) developed a calculation method of flexural rigidity for materials with a heterogeneous cross-section using piano wire. An extended model that takes into account the effect of a crop ear was proposed and the relationships between the deflection and deflection force (horizontal force component) acting on a bunch of crops talks were analyzed understanding crop condition (Hirai *et al*., 2002a). The effects of frictional force and the vertical force component were considered and horizontal and vertical reaction forces on the bunch of crop stalks were analyzed under a standing crop condition utilizing a differential equation describing deflection (Hirai *et al*., 2002b). They reported that the equation was useful for investigating the deflection characteristics and also that the analytical accuracy of the reaction force would be increased by considering the effect of the initial shape of individual crop stalks. A redesign of tine kinematics and tine crop interaction was presented by Moses *et al*. (2012) with the view of increasing the pick-up performance of fixed tine combines for lodged and tangled crops. Such information/investigations are important especially at the design stage from the viewpoints of cost reduction, shortening of the development period and clarification of optimum machine operations according to crop conditions. Over the years, many research developments have been made on harvesting machines to account for local crops and conditions through various modifications. Prakash *et al.* (2015), designed a rice harvesting reaper binder with a field efficiency of 67 per cent and field capacity of 0.294 ha/h at a walking speed of 3.6 km/h. The labor requirement, fuel consumption, and the harvesting loss of the machine were 36 man-h/ha, 5.27 L/ha, and 1.44 per cent, respectively. Gupta *et al.* (2017) designed a pedal-driven, multi-crops cutter for small and large-scale farmers to reduce the harvesting time and labor force. Shalini P*etal* (2018), modified a tractor-driven heavy-weight reaper in to a self-propelled reaper which is less in weight and can be operated in both wet and dryland. Vilas *et al.* (2017), developed a multi-crop, mini harvester for small-scale farmers having less than 5 acres of land area. Chakaravarthi *et al.* (2016) designed a self-propelled, low-cost, cutter-bar mower to reduce the dependency on tractor mounted mover. Raut *et al.* (2013) designed a self-propelled, harvester useful for small scale farmers having land less than 2 acres. The harvester was found to have low operational cost and high field capacity as compared to the traditional methods. Narasimhulu *et al.* (2017), developed an engine-based reaper and evaluated its performance through different efficiencies, speeds and percentages of grain loss. They reported that the harvester could reduce labor costs by 67 per cent as compared with the traditional method.

However, when it comes to the Tef crop, one of the major cereal crops in Ethiopia, the attempts to come up with a solution to harvest the crop using self-propelled machines are limited. *Tef*, being a local crop, hasn't captured the required attention of the global scientific community and the wider agricultural machinery industry so far though it is a widely cultivated, staple crop in Ethiopia (Kebebew *et al.*, 2013; Berhane *et al*., 2011 and Fufa *et al*., 2011). Tef (*Eragrostistef)* is a warm-season annual grass, characterized by a large crown, many tillers and a shallow diverse root system. It is an essential food grain in Ethiopia but used as a forage crop in other countries like Australia; South Africa and the United States (Fikadu *et al*., 2019 and Kaleb, 2018). It is resistant to extreme water conditions, as it can grow under both drought and waterlogged conditions (Minten *et al*., 2013 and Teklu & Tefera, 2005). Combined with its low vulnerability to pests and diseases, it is considered a low-risk crop (Minten *et al*., 2013 and Fufa *et al*., 2011). Nutritionally, Tef grain is considered to have an excellent amino acid composition, higher lysine levels, gluten-free and excellent iron content as compared to other cereal crops (ATA, 2013c and Berhane *et al*., 2011).

Its importance is beyond being a principal food as it is connected to the socio-cultural heritage of the society (Siyum and Ummal, 2020). In terms of production, Tef has been produced largely throughout the country. In the main production season (*Meher*) of 2018-2019 for example, Tef was produced by 6.78 million farmers, resulting in a total production of over 5.03 million metric tons on 3.08 million hectares of land. This accounted for the largest share of cereals cultivated in Ethiopia (CSA, 2019 and Kolhe *et al.,* 2024). However, despite its being the primary crop and valued as a national heritage by many and produced in large areas, its productivity (1.756 ton ha^{-1}) is very low compared with the other cereal crops produced in the country (CSA, 2019). Many findings associate the low productivity of the crop with low availability and use of modern inputs (seed and fertilizer) and the traditional method of production of the crop. However, most of these pertinent issues of Tef productivity are now being solved through integrated efforts of concerned governmental sectors and research institutes except the issue related to harvesting the crop.

Harvesting of Tef crops is a very laborious and time-consuming activity that entails intensive investment and human forces although the grain loss associated with it is negligible (Tadesse *et al*., 2016). Tef harvesting in Ethiopia is done using sickles (Fig. 6). The operation requires a tremendous amount of time, human labor involvement and investment as well (Abraham, 2015). This is because of the lack of

Fig. 6 : Manual harvesting of Tef

an efficient mechanized harvester that can handle well the nature of the crop with minimum harvest loss. The Tef plant has a different structure of stem (as compared to other cereals) having different numbers of panicles containing different amounts of Tef seeds at each panicle. The crop is highly susceptible to lodging which is related to its morphological traits (Seyifu, 1997 and Gindo *et al.,* 2023) and partly to the high seeding rate farmers utilize for crop establishment (Tareke and Nigusse, 2008). Lodging is one of the causes for low productivity of the crop and the yield loss associated with it is estimated to be as high as 30 per cent (Seyifu, 1997).

The lodging nature of the crop is also one of the very factors that make harvesting Tef with combine harvesters challenging. Since the crop has a high and disarray lodging nature, even the existing combines with tine pickup reels couldn't successfully clear/ harvest the crop from the field. As a result of this, farmers are usually forced to harvest their Tef crops manually using sickles; which is a time and resource-intensive method. Even in areas where combine harvesting operations are well introduced, farmers employ the existing combines with pick-up reels just for threshing and cleaning activities through feeding the already manually harvested and gathered Tef crop onto the conveying platform of the machine since the loss associated with the header of the units is significant. Had there been efficient mechanized harvesters, the number of days spent on fields for harvesting the crop would have been reduced by 70-80 per cent (Abraham, 2015) and the resources and time allocated to such operations would have been used/redirected to other farming operations.

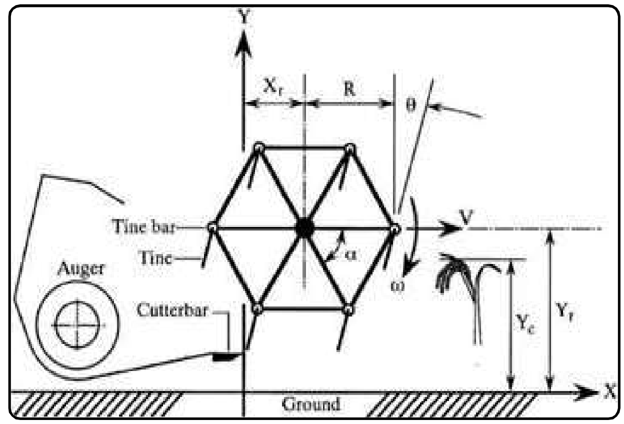

Fig. 7 : Tined combine harvester reel with a relevant parameter

This poor gathering performance of the existing combines may be associated with the way their pick-up reel units are designed and operated. The existing combine use tines with preset/fixed angles on the reel periphery that do not vary throughout the entire cycle of the reel rotation (Fig. 7). This may make the operation of the tines *i.e.* penetration and picking-up, feeding to the cutter-bar and releasing the already cut crop onto the gathering platform, inefficient during harvesting the already lodged crop as each of these three stages calls for a time orientation that is contradictory with the requirements of the other two stages (Moses *et al*., 2012).

According to Moses *et, al*. (2012), for lodged and tangled crops, the current practice of utilizing a preset tine rake angle may not be the most appropriate and this calls for an alternative reel design accommodating the different tine orientations angles at the harvesting zones of such crop (Fig. 8). However, in literature, very few studies observed on attempts to harvest tef by using a combine harvester, only limited research

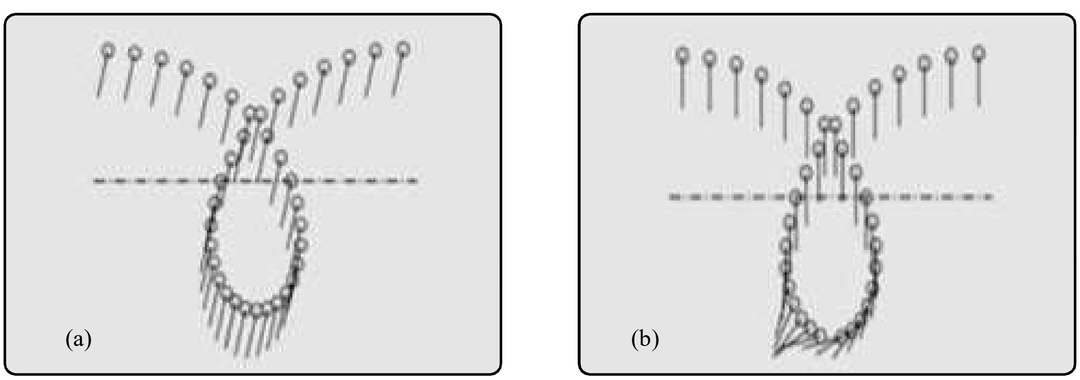

Fig. 8 : Tine kinematics; a) Conventional, b) Proposed (Moses *et al.,* 2012)

reported by Ephrem *et al.* (2014). In their research work using a crop mechanical model that was Hirai *et al.* (2003) developed for lodged and tangled wheat crops, they suggested that a reel unit having a fixed, preset tine angle but pitched 5^0C at its tip (penetrating side) would perform better for Tef crop harvesting. However, the efficiency of the suggested reel unit couldn't be measured as it was just theoretical research findings that were made based on the crop factor and kinematics of the tines. The absence of research and development works on the issue may relate to Tef being a local and 'orphan' crop (Kebebew *et al.*, 2013 and Asrat & Kolhe 2022). Thus, to have alternative solutions to Tef harvesting issues using combine harvesters, the following key points must be taken into consideration :

1) Well-coordinated and continuous efforts must be exerted by all stake holders to aware the wider scientific community about the crop and encourage in-depth research works to be conducted on the issue
2) The performance of the existing harvesters, which are developed for wheat or other crops that share more or less similar physico-mechanical characteristics, must be investigated thoroughly on lodging cultivars of Tef through different settings of the machines
3) The deflection characteristics of lodging varieties of Tef crop during their interaction with reel units of existing harvesters need to be studied under different machine settings to obtain optimal settings eventually accounting for the varieties' conditions
4) The physico-mechanical properties of various lodging cultivars of Tef crop must be studied along with their posture condition (shape factor) at harvesting time
5) The design of the existing harvesters reel system, in particular and the header units, in general, must also be reviewed again with Tef crop lodging condition. This should encompass further improvement works on such units to obtain alternative solutions

Tef harvesting is laborious and time-consuming, though, the physico mechanical properties of Tef crops are similar to other cereal crops. The researchers in different countries amended combine harvester utility and efficiencies to adapt it to local crop conditions by refining the reel mechanism and machine setting parameters. More focus needed on the reel unit having a fixed, preset tine angle that may perform better for the crop harvesting.

A combine harvester may be very useful for Tef crops by refining existing gathering performance for Tef crops due to their grain header design and the high lodging nature of the crop. That may be significant for increasing the production and harvesting efficiency of the Tef crop in Ethiopia.

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Cloning and *In Vitro* Restriction Analysis of the Sex Peptide Receptor Gene in Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae)

C. N. ANU[1], R. ASOKAN[2], D. JEMLA NAIK[3], M. MANAMOHAN[4] AND ANITA PETER[5]
[1,3&5]Department of Agricultural Entomology, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
[2&4]Division of Basic Sciences, ICAR- IIHR, Bengaluru - 560 089
e-Mail : anuento2022@gmail.com

AUTHORS CONTRIBUTION

C. N. ANU : Investigation, data collection, data curation and draft preparation;

R. ASOKAN, M. MANAMOHAN & ANITA PETER : Conceptualization, investigation, supervision, and fund acquisition;

D. JEMLA NAIK : Visualization, editing and supervision

Corresponding Author :
C. N. ANU

Received : August 2024
Accepted : August 2024

ABSTRACT

The polyphagous pest *Spodoptera frugiperda* (J. E. Smith) damage a number of important crops. The fertility and the reproductive rate of *S. frugiperda* can be altered by the CRISPR/Cas9 mediated mutagenesis of target genes, which produces a cascade of frame-shift mutations. The gene mediating reproductive behaviour in adult moths by suppressing the female receptivity in a variety of lepidopteran pests is the sex peptide receptor gene. PCR amplification and cloning of the *S. frugiperda* sex peptide receptor gene (1039 bp) was carried out. Utilizing CRISPOR, an online bioinformatics tool, SFSPR exons were used as input to create 'On target maximised and off target minimised sgRNA (20 bp)'. The *in vitro* restriction assay using designed sgRNA resulted in band size of 790 bp which is a release from the 1039 bp CDS which further verified the designed sgRNA's efficiency.

Keywords : *Spodoptera frugiperda*, CRISPR/Cas9, Single guide RNA, SPR gene, *in vitro* restriction

SPODOPTERA FRUGIPERDA (J.E. Smith, 1797) is a serious lepidopteran pest belonging to the Noctuidae family. As a larva it prefers to feed on leaves and young shoots, particularly buds and develops into a chewer of plant tissue (He *et al*., 2020). Due to its feeding habits and polyphagous nature, it is a devastating pest of crops in the Western Countries. Additionally, it prefers a wide range of host plants and possesses a great ability for adaptation and dissemination (Casmuz *et al*., 2010; Montezano *et al*., 2018 and Paredes-Sanchez *et al*., 2021).

S. frugiperda is regarded as a persistent pest in the Americas due to its behaviour in field and it has recently spread to Africa, India (Sharanabasappa *et al*., 2018) and China. Year-round prevalence of *S. frugiperda*, resulting in economic loss of major food crops, which encourages the inappropriate use of chemical pesticides (in terms of the type of pesticide used, increases in recommended application doses, number of applications per season/year, time and rate of application), which has resulted in the development of insecticide resistance and unfavourable impact on the environment and people (Bolzan *et al*., 2019 and Lira *et al*., 2020). Owing to the negative consequences of conventional chemical management strategies on the environment, animals and people, scientists investigated the novel approaches in genetic regulation of target pests.

The CRISPR/Cas9 system is the ground-breaking tool with exceptional accuracy and efficiency that can be exploited to effectively manage polyphagous pest like *S. frugiperda*. Studies on the genetic regulation of the fall armyworm, *S. frugiperda* are scanty. In this regard, the *sex peptide receptor* (*SPR*) gene which regulates the reproductive behaviour in adult moths can be a good candidate gene for the genetic control of *S. frugiperda*. Through employing CRISPR/Cas9 mediated genome editing of *SPR*, it is possible to alter the target insect's reproduction rate, which further aid in the development of appropriate genetic control for the target pest.

Effective sgRNA optimization is critical to the accomplishment of gene editing. The goal of the present work is to identify the *SPR* gene in *S. frugiperda* and validate the 'Off target minimized sgRNA' using an *in vitro* digestion assay to confirm the effectiveness of restriction of the target gene and the ribo nucleo protein (RNP) complex can be further proceeded for microinjection in the embryos of *S. frugiperda*.

Material and Methods

Mass Culturing of the *Spodoptera frugiperda*

The early instar larvae of *Spodoptera frugiperda* were reared individually on young maize leaves and the later instar were maintained on chickpea based diet. The insect culture was maintained under the controlled rearing environment of 25 ± 1 °C, 65 ± 5 per cent relative humidity with 14h:10h (L:D) photo period at the Division of Basic Sciences, ICAR-IIHR, Bengaluru, India. Adults were released in mating cages (30 x 30 x 30 cm), with glass on top and mesh netting covering three sides supplemented with a 10 per cent honey solution as immediate energy source upon emergence (Anu *et al*., 2024). Further experiments were conducted using insects that were acquired from this starting culture.

Identification of *Sex Peptide Receptor* (*SPR*) Gene and Designing Gene Specific Primers

The NCBI genome database was referred to retrieve the information about the *SPR* gene. Using ClustalW in BioEdit software (version 7.7.1), the multiple sequence alignment and the sequence similarity of the *SPR* gene of the *Spodoptera frugiperda* (*SFSPR*) with other insect species was discovered.

Total RNA Isolation and Complementary DNA (cDNA) Synthesis

The abdomen of the single adult female moth was dissected to isolate the total RNA. Using TRIsure™ reagent (BIOLINE), the complete RNA was isolated according to the manufacturer's instructions. On 1.5 per cent agarose gel, the RNA integrity was examined and it was then quantified using a Nano drop (Thermo Scientific, USA). Following the manufacturer's protocol, cDNA was synthesized from 2µg of total RNA using the Revert Aid First Strand cDNA synthesis kit (Thermo Scientific, USA). Internal control gene mtCOI, was used to confirm the cDNA synthesis and was verified on 1 per cent agarose gel.

PCR Amplification of *SFSPR* Gene

The complementary DNA was diluted using autoclaved milliQ water in the ratio 1:10 and then utilized as a PCR template to amplify the complete coding region (CDS) of the *SFSPR* gene using the gene-specific primers (Table 1) and optimized PCR conditions (Table 2 and 3). PCR amplicon was resolved on 1 per cent agarose gel and purified using a Favorgen Biotech Corp GEL/PCR purification micro kit.

Table 1

Gene specific primers for *Spodoptera frugiperda* Sex Peptide Receptors gene

Primers	Sequences (5'-3')
SFSPR Forward Primer	GACATCACAGATGACATAA
SFSPR Reverse Primer	GTACTAGATACATAGACAGAG
SFSPRsg	GAAATTAATACGACTCACTATAGGGAACGTTGTACTAATGGCTA gttttagagctagaaatagc
CRISPR reverse	AAAAGCACCGACTCGGTGCCACTTTTTCAAGTTGATAACGGACTA GCCTTATTTTAACTTgctatttctagctctaaaac

TABLE 2

PCR components for amplification of *SFSPR* gene

Reagents	Volume	Final Concentration
10X LA PCR buffer (Mg^{+2} free)	2.5 µl	1X
dNTPs mix (2.5 mM)	4.0 µl	0.4mM
$MgCl_2$ (25 mM)	2.5 µl	2.5mM
Template (cDNA)	1.0 µl	100ng
SFSPR Forward Primer	1.0 µl	0.2 µM
SFSPR Reverse Primer	1.0 µl	0.2 µM
TaKaRa Taq	0.2 µl	1 unit/ µl
Sterile PCR water	12.8 µl	-
Total Volume	25 µl	

Ligation of *SFSPR* gene

The general-purpose cloning vector pTZ57R/T (Thermo Scientific, Lithuania) was ligated with the eluted *SFSPR* gene amplicon. The total reaction volume of 20 µl includes 1X Ligase buffer, pTZ57R/T vector, T4 DNA ligase and *SFSPR* gene (Table 4). The vector's primary characteristics are the selection of blue and white colonies, the integration of M13 primers for sequencing and the presence of an ampicillin resistance marker gene. White colonies denote recombinant colonies, while blue colonies indicate non-recombinant colonies. The blue-white selection of the colony allowed recombinants to be identified from non-recombinants (Pradhan *et al.*, 2023).

TABLE 4

Ligation of *SFSPR* gene into pTZ57R/T cloning vector

Reagents	Volume	Final Concentration
MilliQ water	9.0 µl	-
5X Ligase buffer	3.0 µl	1X
pTZ57R/T vector	1.0 µl	55 ng
SFSPR gene template	1.0 µl	158 ng
T4 DNA ligase	1.0 µl	1 unit/ µl
Total Volume	15 µl	

TABLE 3

PCR conditions for *SFSPR* gene amplification

Steps	Temperature (°C)	Duration	Cycles
Initial Denaturation	95	2 minutes	1
Denaturation	98	10 seconds	
Annealing	56	10 seconds	35
Extension	68	45 seconds	
Final extension	68	10 minutes	1
Store	4	∞	

Cloning and Transformation

A chemically competent strain of *Escherichia coli*, DH5α, was used to clone the ligated products. The transformed *E. coli* cells were spread on Luria Bertani (LB) agar plates supplemented with IPTG (100 mM), X-gal (20 mg/ml) and ampicillin (100 µg/ml). Following an overnight incubation at 37 °C, the plates were screened for blue and white colonies. All of the positive colonies (white colonies) - those that harboured the insert - were then inoculated with ampicillin containing LB broth and incubated at 200 rpm for 37 °C.

Isolation of Plasmid and Sequencing

Using the Plasmid isolation kit (Thermo Fisher Scientific) and the manufacturer's instructions, plasmids were harvested from the transformed white colonies cultured in Luria Bertani (LB) broth. The recombinant plasmids were verified on 1 per cent agarose gel electrophoresis with control plasmid. Using M13 universal primers, sequencing of the aforementioned clones was done for three biological replicates using Sanger sequencing.

Analysis of Sequencing Outcomes and Interpretation of Data

In order to compare the *S. frugiperda SPR* sequence with other homologous sequences retrieved from the NCBI database, alignment was carried out using the default parameters of ClustalW (Version 7.7.1) in BioEdit software. The translation tool on SnapGene 7.2.0 was used to infer the target genes' amino acid sequence. Furthermore, MEGA 11 (Version 11.0.13)

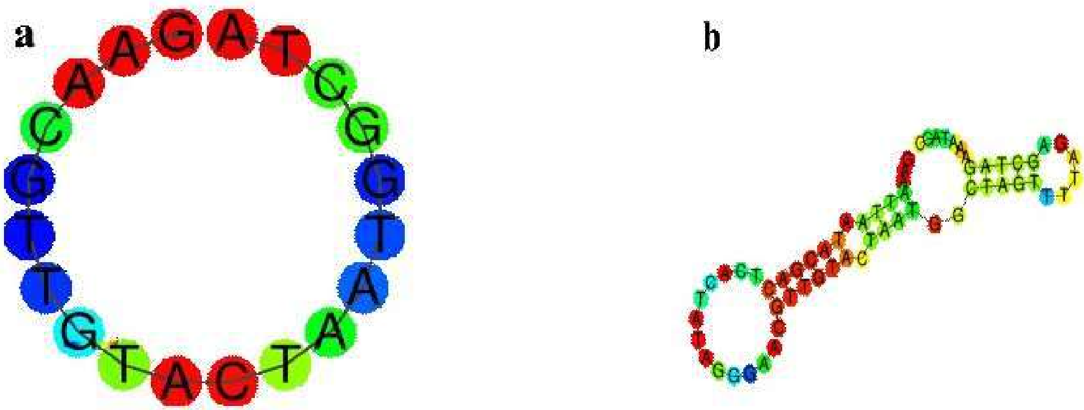

Fig. 1 : Structure of sgRNA for *SFSPR* gene (a) SFSPRsg (b) SFSPRSg casette

was used to create a phylogenetic tree using the greatest likelihood approach. To guarantee accuracy and resilience, the tree construction process underwent 1000 bootstrap replications and thorough gap deletion.

Identification of Single Guide RNA (sgRNA)

The exon sequence of *SFSPR* gene was submitted to the CRISPOR tool (http://crispor.tefor.net/) (Hwang *et al*., 2013) and using the criteria: 5' - GGN - 18nts NGG - 3', the off-target minimized and on-target maximized sgRNA was created. The sgRNA target site was found in exon 2 (5'- GAACGTTGT ACTAATGGCTA-3') (Fig. 1). Additionally, a sgRNA reverse complement was created (Bhargava *et al*., 2024). RNA fold web server (http://rna.tbi. univie.ac.at/cgi-bin/RNA WebSuite/RNAfold.cgi) was used to further verify the secondary structure of the chosen sgRNA.

***In vitro* Digestion Assay**

To confirm the effectiveness of sgRNAs, *SFSPR* CDS must be restricted *in vitro* using SpCas9 and sgRNA (SFSPRsg). For this experiment, all of the reagents were procured from New England Bio Lab. The reaction mixture consisted of 30nM of *SFSPR* template, 100nM of EnGen Spy Cas9 NLS enzyme, 1× NEB r3.1 buffer and an *in vitro* produced SFSPRsg cassette (Table 5). Following a 30-minute incubation period at 25°C, the *in vitro* digested products was verified on 1.5 per cent agarose gel electrophoresis.

TABLE 5

Components for *in vitro* digestion assay

Reagents	Volume	Final Concentration
MilliQ water	62 µl	-
5X Transcription buffer	30 µl	1X
NTP Mix	30 µl	10 mM
SFSPRsg template	20 µl	5 µg
RNase Inhibitor	3.0 µl	40 unit/ µl
T7 RNA Polymerase	5.0 µl	20 unit/ µl
Total Volume	150 µl	

RESULTS AND DISCUSSION

Total RNA Isolation and Complementary DNA (cDNA) Synthesis

Agarose gel electrophoresis (1.5%) was used to verify the integrity of the total RNA extracted from the female abdomen (Fig. 2), where the RNA content was verified using Nanodrop (Thermo Scientific, USA) and concentration was found to be 2348 ng/µl with the A260/280 value 2.01. By amplifying the mtCOI internal control gene *via.,* PCR, the cDNA was confirmed.

PCR Amplification of *SFSPR* Gene

By using gene-specific primers, the *SFSPR* gene CDS was amplified in polymerase chain reaction (PCR) using a thermo cycler (ABI Applied Biosystems), the results were visualized using 1 per

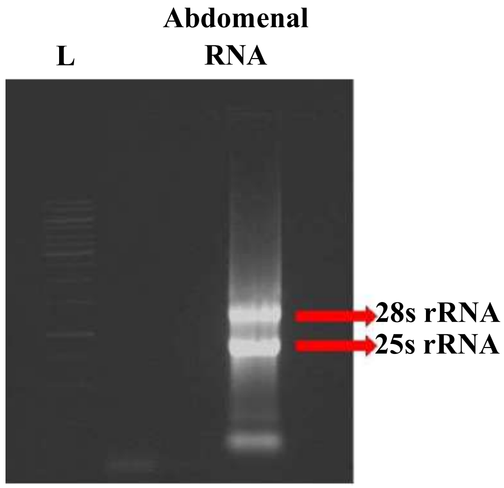

Fig. 2 : Total RNA isolation from abdomen of female *Spodoptera frugiperda*

cent agarose gel, which showed amplified band size of 1039 bp (Fig. 3). The band was excised and eluted from the gel and quantified using a Nanodrop (Thermo Scientific, USA), the concentration recorded was 158 ng/µl with the A260/280 value 1.82. The eluted product was subsequently utilized for cloning.

Cloning and Transformation

Cloning was done using gel eluted *SFSPR* gene product. Following the Blue-white screening the positive colonies were processed to harvest the recombinant plasmid. The isolated plasmids were analyzed on 1 per cent agarose gel alongside control reference plasmid to observe any shift in band size to higher size. All clones showed the presence of the insert, as evidenced by the higher band sizes compared to the control reference plasmid (Fig. 4).

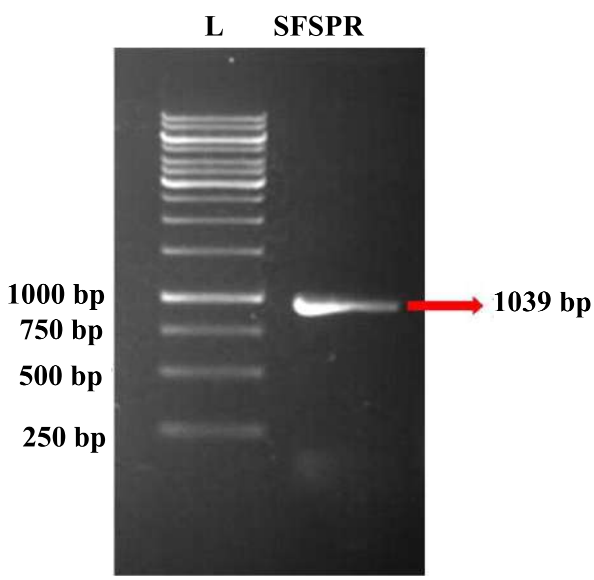

Fig. 3 : PCR amplification of *Spodoptera frugiperda SPR* gene

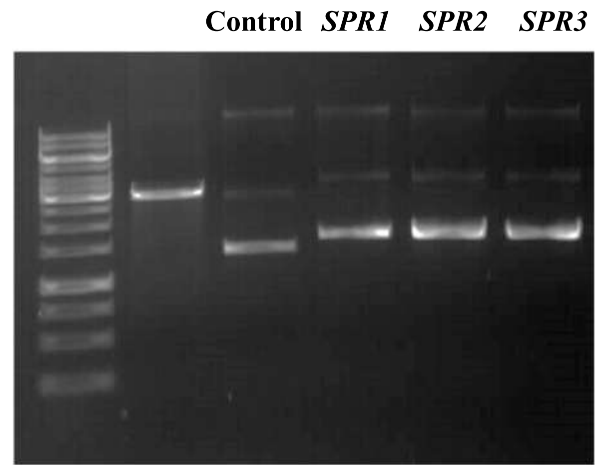

Fig. 4 : Control plasmid compared with *Spodoptera frugiperda SFSPR* gene clones

The cloned sequences were run through to BLAST at the NCBI, it was found that there was 100.00 per cent sequence similarity with the predicted *SPR* gene sequence in *Spodoptera frugiperda*, accession number XM_050699791.1. Additionally, it demonstrated a high degree of sequence similarity with 100 per cent query coverage for the anticipated *SFSPR* gene sequences of *Spodoptera litura* (XM_022973010) (91.22%), *Helicoverpa armigera* (XM_064042429) (82.05%) and *H. zea* (XM_047181648) (81.66%) (Fig. 5). This demonstrated that the expected domains are shared by all related lepidoptera.

Homology Modelling of SFSPR Protein

Using SWISS MODEL (http://swissmodel.expasy.org/), a three-dimensional (3D) model of the *S. frugiperda* SFSPR protein was produced. With the help of the UCSF Chimera software version 1.7, which can be accessed at https://www.cgl.ucSf.edu/chimera/ , the 3D protein structure was further examined (Anu *et al*., 2024). This allowed for a detailed analysis of the structural characteristics and interactions within

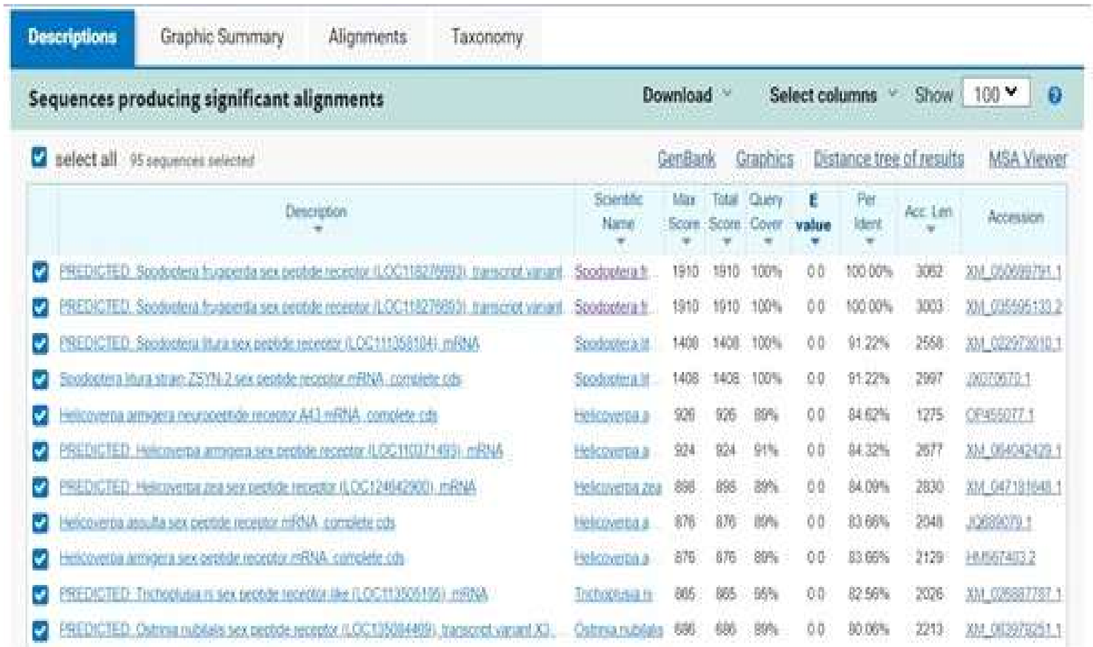

Fig. 5 : Sequence similarity of the *SPR* gene among related lepidoptera

the protein. The SFSPRsg location is indicated in lime color in the homology model (Fig. 6).

Amplification of sgRNA Cassette Using PCR and *in vitro* Transcription

The sgRNA cassette (T7 promoter + SFSPRsg + scaffold) was amplified in PCR thermo cycler using complementary SFSPRsg scaffold sequence. Thermo Fisher Scientific's MEGAscript™ T7 Transcription Kit was utilizsed to execute *in vitro* sgRNA transcription in accordance with the manufacturer's instructions (Table 6). Following *in vitro* transcription, the sgRNA was purified appropriately. The concentration of *in vitro* transcribed sgRNA, SFSPRsg was 1876 ng/µl.

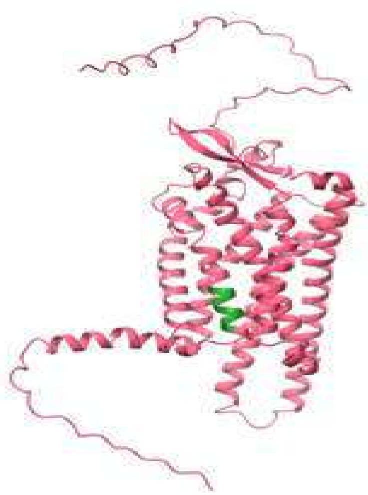

Fig. 6 : Three dimensional protein structure of *S. frugiperda* SPR. The lime color in the protein structure represents the SFSPRsg sequence

TABLE 6

***In vitro* transcription reaction components for sgRNA synthesis**

Reagents	Volume	Final Concentration
MilliQ water	62 µl	-
5X Transcription buffer	30 µl	1X
NTP Mix	30 µl	10 mM
SFSPRsg template	20 µl	5 µg
Ribolock RNase Inhibitor	3.0 µl	40 unit/ µl
T7 RNA Polymerase	5.0 µl	20 unit/ µl
Total Volume	150 µl	

In vitro Restriction Assay

An *in vitro* restriction experiment was used to confirm that the Cas9 protein and sgRNA could cleave the double stranded DNA in the target location and the results were visualized on a 2 per cent agarose gel. The first lane had one kb ladder, then an *SFSPR* gene CDS and the third lane has *SFSPR* gene CDS + Cas9 + SFSPRsg. In the second lane of the agarose gel visualization, there was only one distinct, 1039 bp firm band (*SFSPR* gene CDS). The band fragments, measuring 1039 bp and 790 bp (Fig. 7), were cut bands released from the 1039 bp.

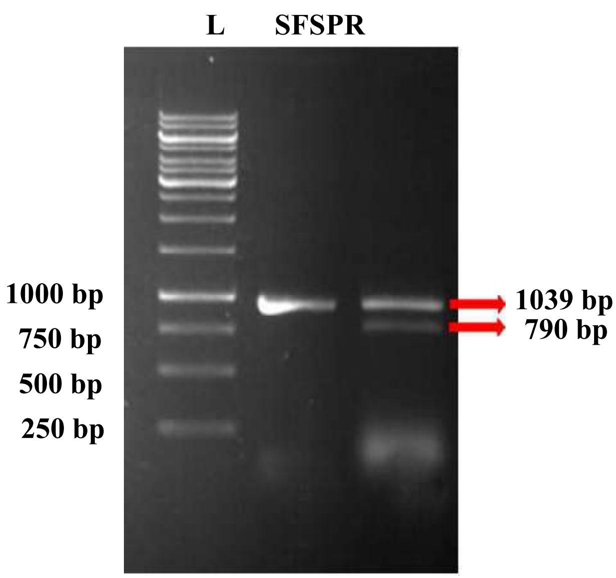

Fig. 7 : *In vitro* restriction assay of SFSPRsg

The *SFSPR* gene was expressed in adults of *Spodoptera litura* (Li *et al*., 2014) and *S. frugiperda.* The silencing of *SPR* gene in *S. litura* mediates changes in the female post-mating behavior which resulted in failed response of female towards male secretion and the mutant female continue to show virgin behaviors thus affecting the reproduction rate with very few number of eggs (Li *et al*., 2014) without affecting the male competitiveness. Similarly, in *Bactrocera dorsalis* silencing of *SPR* gene resulted in reduction in the egg laying capacity of the mutant females and greatly impacted the eclosion rate of their offspring (Zheng *et al*., 2015).

The current study characterized the *SPR* gene in *S. frugiperda* through cloning and sequencing and leads to unique avenue for further functional analysis in the adults. The sgRNAs' efficacy for restricting the target gene was validated by an *in vitro* restriction experiment. Due to its evolutionary conservation among lepidopterans, SFSPR can be a promising candidate target for the biorational/ genetic pest management of related lepidopteran pests. Furthermore, microinjection, edit characterization and mating studies can be used to understand its functionality and behaviour in mutant adult.

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Financial Viability of Hydroponic Firms in Bengaluru

K.V. CHAITHRA[1], G. RANGANATH[2], M. R. GIRISH[3], R. MOHAN KUMAR[4] AND DRONACHARI MANVI[5]
[1,2&3]Institute of Agribusiness Management, College of Agriculture, GKVK, Bengaluru;
[4]AICRP on Castor, ZARS, UAS, GKVK, Bengaluru; [5]Department of Processing and Food Engineering,
College of Agricultural Engineering, UAS, GKVK, Bengaluru - 560 065
e-Mail : ranganath.agmaco@gmail.com

AUTHORS CONTRIBUTION

K.V. CHAITHRA :
Data collection, analysis and drafting;

G. RANGANATH :
Conceptualization, methodology, supervision and editing;

M. R. GIRISH;
R. MOHAN KUMAR &
DRONACHARI MANVI :
Supervision and editing

Corresponding Author :
G. RANGANATH

Received : July 2024
Accepted : September 2024

ABSTRACT

Hydroponics is a cutting-edge agricultural method revolutionizing the way plants are grown in mineral nutrient solution without the use of soil. Hydroponic farming accommodates a wide spectrum of plants, including spinach, cauliflower, broccoli, mint, lettuce, parsley, rocket leaves, bok coy, celery, cherry tomatoes, cantaloupe melons, strawberries, bell peppers, cabbages, cucumbers and many more. Conducting a financial feasibility analysis for hydroponics is crucial to determine whether it is a viable and profitable venture and hence financial viability of hydroponic firms in Bengaluru was assessed in the study. A sample of 23 hydroponic firms (growing lettuce, spinach, celery, basil, amaranthus) in Bengaluru were selected through purposive and snowball sampling for analysing the financial viability of hydroponic firms in Bengaluru during 2022-23. Hydroponic firms were classified into 5 categories based on the land holding unit size (82,170 sq. ft., 43,560 sq. ft., 21,780 sq. ft., 10,700 sq. ft., 5,000 sq. ft.). Project appraisal techniques like NPV, B:C ratio and IRR were used to assess the financial viability of investment. The study revealed that, hydroponic firms' gross returns varied depending on its size, from Rs.11.00 lakhs to Rs.1.35 crores. The net returns were in the range of Rs.6.76 to Rs.68.16 lakhs. The NPV at 10.50 per cent of discount rate, demonstrated positively across all firm sizes, ranging from 5000 sq. ft acre to 2 acres (ranging from Rs.22 lakhs to Rs.230 lakhs). The highest B:C ratio was found in 43,560 sq. ft hydroponic firms (1.77) and lowest in 5000 sq. ft firm (1.21). However, it was more than one among all sample hydroponic firms. The hydroponic firms, with 43,560 sq. ft. of area had the highest Internal Rate of Return (30%), while the 5,000 square feet firms had the lowest Internal Rate of Return (17%). These findings clearly demonstrated that investment in any scale of hydroponic farming is a profitable business venture in Bengaluru.

Keywords : Financial viability and feasibility, Hydroponic firms, Cash flow analysis

HYDROPONIC farming can be defined as the science of growing plants in mineral nutrient solution without the use of soil. The word 'Hydroponics' has its derivation from combining the two Greek words 'Hydro' means water and 'Ponos' means labour (Sardare *et al.,* 2013). The primary advantage of hydroponics is its ability to minimize labour expenses due to controlled environments featuring automated irrigation and fertigation. According to growers, continuous production is possible only through hydroponic systems *i.e.,* production round the year and in a short growing period, requires less space and plants can be produced anywhere and even in a small space with a controlled growth environment. This approach can yield between 7 to 14 growth cycles compared to conventional methods. Growers often reply that hydroponics always allows them to have higher productivity without any constrains of climate and weather conditions.

Hydroponics is a cutting-edge agricultural method revolutionizing the way we grow plants. The market need for hydroponic operations is being driven by the desire for fresh produce in the given area. Urban environments like metropolitan cities are fostering the markets expansion with rooftop hydroponic gardening. In India attempts were made during the late 1980's for propagating hydroponics technology for forage production and research works were undertaken by several workers (Santosh *et al.*, 2021). The development of hydroponic production systems that are cost-competitive with open-field agricultural methods will have a significant impact on the future expansion of the hydroponics industry in India. Moreover, with hydroponics, there is a better opportunity to place the fresh produce in the market as their average nutritional quality and consumers acceptance are higher (Mehra *et al.,* 2018). Hydroponic farming accommodates a wide spectrum of plants, including spinach, cauliflower, broccoli, mint, lettuce, parsley, rocket leaves, Bok coy, celery, cherry tomatoes, cantaloupe melons, strawberries, bell peppers, cabbages, cucumbers and many more.

The demand for exotic greens and vegetables has been consistently rising, driven by the enhanced buying capability of consumers. These distinctive products come at a premium cost, primarily because a majority of them are produced through hydroponic techniques. As a result, numerous research institutions and universities are dedicating their efforts to develop more uncomplicated hydroponic setups. The goal is to expedite the cultivation of these exceptional fruits and vegetables, aiming to fulfil the growing demand in the market. Furthermore, a growing consciousness among consumers regarding the consumption of freshly produced vegetables could also act as a catalyst for the market's future expansion. The expected boost in sales within the projected timeframe can be attributed to the rising consumer interest in distinct vegetables like red and yellow bell peppers, red lettuce, cilantro and cherry tomatoes. This demand is especially prominent in well-known food and retail chains such as Burger King and KFC etc.

Commercial vegetable growers are paying close attention to hydroponic production due to its efficiency in input control and facility management, especially for effective reduction in disease and pest outbreaks. Moreover, accelerated urbanization has led to a surge in the demand for hydroponically cultivated vegetables and crops from diverse sectors including hospitality, dining establishments, quick-service franchises, non-governmental organizations and defence. This trend is motivating farmers to adopt hydroponic cultivation methods. This growing adoption of hydroponics as a viable cultivation technique is projected to be a key driver for market expansion. As of 2020, the Hydroponics market in India was valued at 1.56 Billion USD and is projected to reach 3.04 Billion USD by 2028, growing at a CAGR of 7.5 per cent between 2020 and 2028. There is a huge market for organic crops and hydroponics in metros and tier one cities. This market in India consists of consumers who are health conscious and will readily willing to pay a premium price for organically or hydroponically grown produce that is fresh, safe and healthy (https://datamintelligence.com/). Hence, conducting a financial feasibility analysis for hydroponics is crucial to determine whether it is a viable and profitable venture. It will assist in risk assessment, resource planning, revenue projections and overall decision-making, helping entrepreneurs to make informed choices about entering or expanding in the hydroponics market. In this regard, present study has been undertaken to analyse financial viability of hydroponic firms in Bengaluru.

Methodology

Study Area

Bengaluru (Urban and Rural districts) was purposively chosen for the study because it is a metropolis with one of the fastest increasing populations and has residents from a variety of cultures, economic background, languages, castes, jobs and food habits. Apart from this, study area offers a strategic advantage due to its unique blend of factors and also more than 70 hydroponic units are located in this region. Bengaluru's urban challenges and dynamic ecosystem, position it as a prime location to establish hydroponics firms that can contribute to sustainable and efficient agricultural practices and making it an ideal location to pioneer and scale such ventures profitably.

Sampling Framework

Purposive and snow ball sampling was used for the selection of the hydroponic firms. A sample of 23 hydroponic firms (growing lettuce, spinach, celery, basil, amaranthus) were selected for analysing the financial viability/feasibility of hydroponic firms in Bengaluru. Hydroponic firms were classified into 5 categories based on the land holding (82,170 sq. ft., 43,560 sq. ft., 21,780 sq. ft., 10,700 sq. ft., 5,000 sq. ft.) with different firm sizes as given in Table 1. The year of the study was 2022-2023 and the data collection was carried out during the month of July and August 2023.

Table 1

Categorization of sample hydroponic firms

Area (sq. ft)	Number of Hydroponic firms	Classification	Per cent
82,170 sq. ft	2	A	9
43,560 sq. ft	11	B	48
21,780 sq. ft	5	C	21
10,700 sq. ft	3	D	13
5,000 sq. ft	2	E	9
Total	23		100

Analytical Tools and Techniques

Financial Feasibility Analysis

Financial feasibility analysis was carried out to evaluate feasibility of investment on hydroponic farming. The discounted cash flow techniques which have an advantage of reducing cash flow to a single point of time were used to facilitate the test of feasibility. Project appraisal techniques like NPV, B:C Ratio and IRR were used in the study.

NPV (Net Present Value)

This is the discounted measure of cash flow analysis. It is simply the difference between the present worth of all the future benefit streams and the present worth of all the future costs. The project with positive NPV is the criterion for the selection of the project (Omar and Abdullah, 2016).

$$NPV = \sum_{t=0}^{n} \frac{Bt - Ct}{(1+r)t}$$

Where,

t = 1…… n years

n = Total number of years of the project

Bt = Present value of all the discounted benefits in the year t

Ct = Present value of all the discounted costs in the year t

r : discount rate

Positive NPV implies the viable investment and whereas if NPV is equal to zero then the investment breaks even.

Benefit Cost Ratio (BCR)

The Benefit Cost Ratio (BCR) was worked out by using the following formula discounted net cash flows the ratio must be more ≥ 1 for an enterprise to be considered worthwhile. This technique also ranks the project investment for selection.

B : C ratio = Discounted net cash flow/Initial investment

Internal Rate of Return (IRR)

The rate of discount at which the net present value of the project is equal to zero is Internal Rate of Return (IRR) to the project. The net cash inflows were discounted to determine the present worth following the interpolation technique. (Bheemagouda and Rajendra, 2016).

$$IRR = LDR + \left(\text{Diff.} \frac{b}{w} \text{2 discount rates}\right) \frac{\text{Present worth of cash flows at LDR}}{\text{Absolute diff. b/w present worth of cash flow stream at two discount rates}}$$

LDR : Lower Discount Rate

If the project being analyzed has Internal Rate of Returns which is more than the ruling rate of interest (opportunity cost), then the investment in the project could be feasible.

Results and Discussion

Cost and Returns from Hydroponic Firms of Different Scale

The total initial investment/installation cost includes costs for land development, building poly-houses-low cost or low tech poly-house, medium cost or medium-tech poly-house, expensive or Hi-tech poly-house (cold storage rooms, drip and sprinkler system, polyethylene material, natural vents, drip and fogger, materials, sliding doors, shade nets and gutters), implementation of technologies (Nutrient Film Technique (NFT), Deep Water Culture (DWC), Ebb and Flow system, Wick system, Drip irrigation system) and equipment purchasing cost. This equipment cost consists of cooling fans, pipes, a motor pump or pumping station, the motor pump assembly, as well as other elements made to last longer than the project itself.

The initial establishment costs, calculated on an annual basis, were considered over a project cycle duration of 10 years. Table 2 presents about the initial establishment costs for the selected hydroponic firms. It could be seen from the table that, the total initial establishment cost ranged from Rs.18 lakhs to Rs.179 lakhs. Table 3 and Table 4 presents the total annual costs comprising fixed and variable costs. The overall

Table 2

Initial establishment cost of hydroponic firms

(n=23) (Rs.)

Particulars	A	B	C	D	E
Land development cost	3,19,000 (1.7)	1,52,000 (1.7)	80,000 (1.5)	38,000 (1.1)	20,000 (1.0)
Installation of poly-house structures	73,30,000 (40.7)	36,15,000 (41.4)	23,05,500 (45.8)	16,85,750 (52.3)	10,50,075 (56.9)
Drip irrigation system cost	10,61,680 (5.8)	4,03,840 (4.6)	2,00,920 (3.9)	1,10,560 (3.4)	60,000 (3.2)
Implementation of Technology (NFT/DWC etc.) cost	67,31,600 (37.4)	32,85,800 (37.7)	18,92,900 (37.6)	10,56,450 (32.7)	5,90,200 (32.0)
Equipment setup and installation cost	25,53,600 (14.1)	12,56,800 (14.4)	5,53,400 (10.9)	3,31,700 (10.2)	1,54,985 (8.4)
Total initial establishment Cost	1,79,95,880	87,13,440	50,32,720	32,22,460	18,42,270
Initial establishment Cost/ sq. ft	216.50	200.03	231.92	301.16	368.45

Note : Values in parentheses indicate per cent of total initial establishment cost respectively. Hydroponic firms are classified into Five categories : (A - 83,120 sq. ft, B - 43,560 sq. ft, C - 21,700 sq. ft, D - 10, 700 sq. ft, E - 5,000 sq. ft).

Table 3

Total Annual fixed cost of sample hydroponic firms

(n=23) (Rs.)

Particulars	A	B	C	D	E
Depreciation on irrigation equipments	69,149 (3.8)	26,302 (2.8)	13,086 (2.1)	7,201 (1.5)	3,907 (1.3)
Depreciation on poly-house structure	4,77,418 (26.3)	2,35,452 (25.3)	1,50,162 (24.6)	1,09,797 (23.0)	68,393 (24.2)
Depreciation on equipment and machineryvii.	1,66,321 (9.1)	75,344 (8.1)	36,044 (5.9)	21,604 (4.5)	10,094 (3.5)

Continued....

TABLE 3 Continued....

Particulars	A	B	C	D	E
Other costs (license fee, insurance)x.	7,90,500 (43.6)	3,48,230 (37.4)	2,12,190 (34.8)	1,55,280 (32.5)	87,780 (31.0)
Rental value of land	1,21,462 (6.7)	1,38,461 (14.8)	1,20,560 (19.8)	1,12,000 (23.4)	82,220 (29.1)
Interest on fixed cost @ 12 per cent/ annum	1,80,406 (9.9)	83,021 (8.9)	49,377 (8.1)	35,265 (7.3)	20,420 (7.2)
Total Fixed Cost (TFC)	18,12,595 (100)	9,29,940 (100)	6,08,346 (100)	4,76,987 (100)	2,82,435 (100)

Note : Values in parentheses indicate Per cent of total fixed cost respectively. Hydroponic firms are classified into Five categories : (A – 83,120 sq. ft, B – 43,560 sq. ft, C- 21,700 sq. ft, D- 10, 700 sq. ft, E – 5,000 sq. ft)

TABLE 4

Total Annual variable cost of sample hydroponic firms

(n=23) (Rs.)

Particulars	A	B	C	D	E
Labour Charges	14,01,160 (25.4)	6,98,080 (26.3)	3,89,040 (26.9)	1,25,520 (20.2)	88,550 (22.5)
Repairing charges	2,65,150 (4.8)	1,15,450 (4.3)	87,560 (6.0)	40,050 (6.4)	22,240 (5.6)
Electricity cost	2,05,150 (3.7)	1,08,100 (4.0)	73,890 (5.1)	30,500 (4.9)	16,750 (4.2)
Transportation cost	3,25,352 (5.9)	1,55,176 (5.8)	94,088 (6.5)	42,044 (6.7)	25,552 (6.4)
Marketing and distribution cost	1,50,720 (2.7)	91,360 (3.4)	50,680 (3.5)	20,340 (3.2)	10,560 (2.6)
Plant Protection Chemicals cost	9,00,789 (16.3)	4,00,160 (15.0)	1,89,730 (13.1)	1,00,065 (16.1)	98,980 (25.1)
Nutritional Solution cost	9,80,789 (17.8)	4,50,940 (17.0)	2,15,420 (14.9)	1,00,010 (16.1)	52,555 (13.3)
Maintenance cost	1,60,890 (2.9)	90,240 (3.4)	44,340 (3.0)	30,000 (4.8)	14,580 (3.7)
Planting Material cost	6,06,880 (11.0)	3,15,670 (11.9)	1,60,220 (11.0)	74,610 (12.0)	18,980 (4.8)
Harvesting and Packaging cost	1,50,560 (2.7)	91,760 (3.4)	54,340 (3.7)	21,450 (3.4)	20,540 (5.2)
Miscellaneous cost	1,00,150 (1.8)	54,000 (2.0)	26,500 (1.8)	10,050 (1.6)	7,100 (1.8)
Interest on working capital @ 10.5 per cent per annum	2,61,381 (4.7)	84,392 (3.1)	48,246 (3.3)	28,841 (4.6)	17,904 (4.5)
Total Variable cost (TVC)	55,08,971 (100)	26,55,328 (100)	14,34,054 (100)	6,18,481 (100)	3,93,341 (100)
Total Annual Cost (Total Fixed Cost + Total Variable Cost)	73,21,566	35,85,268	20,42,401	10,95,468	6,76,726
Total Annual Cost/ sq. ft	88.08	82.30	94.11	102.38	135.34

Note : Values in parentheses indicate Per cent of total variable cost respectively.

TABLE 5

Cost and returns of sample hydroponic firms

(n=23)

Yield and income	A	B	C	D	E
Average Yield / year (Kg)	30,080	19,000	11,000	6,900	4,100
Average Price (Rs.)	470	400	360	330	330
Gross returns (Rs.)	1,41,37,600	76,00,000	39,60,000	22,77,000	13,53,000
Total Annual cost (TVC + TFC)	73,21,566	35,85,268	20,42,401	10,95,468	6,76,726
Net returns (Rs.)	68,16,033	40,14,731	19,17,598	11,81,531	6,76,273
Net returns (Rs.)/ sq. ft	82.00	92.16	88.36	110.42	135.25

Note : (A - 83,120 sq. ft, B - 43,560 sq. ft, C - 21,700 sq. ft, D - 10, 700 sq. ft, E - 5,000 sq. ft)

project total annual cost varied from Rs.6.76 lakhs to Rs.73.21 lakhs, wherein the total fixed cost ranged from Rs.2.82 lakhs to Rs.18.12 lakhs, while the total variable cost ranged from Rs.3.93 lakhs to Rs.55.04 lakhs.

Table 5 presents the total costs and returns. The drastic changes in the yield and returns can be attributed to difference in land holding of the hydroponic firms. The hydroponic firms gross returns varied depending on its size, from Rs.13.53 lakhs to Rs.141 lakhs. The sales prices of the crops had a direct impact on this income. Depending on the size of the farm, which can be anywhere between 5000 square feet to 2 acres, the total annual expenses ranged from Rs.6.76 to Rs.73.21 lakhs. The net returns were in the range of Rs.6.76 to Rs.68.16 lakhs. In the given region, most farmers/firms utilized hydroponic systems to cultivate exotic crops in response to consumer preferences. Hydroponically grown produce, such as basil, commanded a price of Rs.110 per kilogram, while lettuce ranged from Rs.110 to Rs.130 per kilogram. Celery and spinach were priced between 90 to 120 rupees per kilogram and Amaranthus and Kale prices ranged from 130 to 160 rupees per kilogram, depending on the specific location. The findings of the present study are in line to the study conducted by Kaveri (2021), wherein it was reported that hydroponic farming required high initial investment.

Financial Feasibility of Selected Hydroponic Firms

Financial feasibility analysis was carried out to evaluate feasibility of investment on hydroponic firms. For the hydroponics firms, cash flow estimates were generated over a 10-year time period. An initial cash investment was made to purchase capital items for the facility's construction. Operating expenses were incurred and sales revenues were generated after the gestation period. The project lifespan of 10 years is considered for the hydroponic units. In this present objective, a discount factor of 10.5 per cent was used to discount the net cash inflows representing the opportunity cost of capital. Crops selected were Lettuce, Spinach, Celery, Basil, Amaranthus as they were the major crops cultivated in majority of the firms.

Discounted Cash Flow Analysis of the Selected Hydroponic Firms

Table 6 presents the initial investment (Rs.1,79,95,880) made for hydroponic firms with 2 acres of land and the average annual working cost was Rs.73,21,566. Further, it can be seen that annual working cost of hydroponic system remained constant from first year to tenth year. The returns from hydroponics system started flowing from first year (Rs.1,41,37,600) and assumed as constant up to tenth year. Table 7 presents the initial investment made (Rs.87,13,440) for hydroponic firms with 43,560 sq. ft. of land and the average

TABLE 6

Discounted cash flow analysis for sample hydroponic units (A*)

(n=2)

Years	Outflows (Rs.)	Inflows (Rs.)	Net cash flows (Rs.)	Discount factor (r) at 10.50%	Net present value (Rs.)
0	1,79,95,880	0	-1,79,95,880	1	-1,79,95,880
1	73,21,566	1,41,37,600	68,16,033	0.9049	61,68,356
2	73,21,566	1,41,37,600	68,16,033	0.8189	55,82,223
3	73,21,566	1,41,37,600	68,16,033	0.7411	50,51,785
4	73,21,566	1,41,37,600	68,16,033	0.6707	45,71,751
5	73,21,566	1,41,37,600	68,16,033	0.6069	41,37,331
6	73,21,566	1,41,37,600	68,16,033	0.5493	37,44,191
7	73,21,566	1,41,37,600	68,16,033	0.4971	33,88,408
8	73,21,566	1,41,37,600	68,16,033	0.4498	30,66,433
9	73,21,566	1,41,37,600	68,16,033	0.4071	27,75,052
10	73,21,566	1,41,37,600	68,16,033	0.3684	25,11,359
Total				2,30,01,014	

Note : *A-87,120 sq. ft.

TABLE 7

Discounted cash flow analysis for sample hydroponic units (B*)

(n=11)

Years	Outflows (Rs.)	Inflows (Rs.)	Net cash flows (Rs.)	Discount factor (r) at 10.50%	Net present value (Rs.)
0	87,13,440	0	-87,13,440	1	-87,13,440
1	35,85,269	76,00,000	40,14,731	0.9049	36,33,241
2	35,85,269	76,00,000	40,14,731	0.8189	32,88,001
3	35,85,269	76,00,000	40,14,731	0.7411	29,75,566
4	35,85,269	76,00,000	40,14,731	0.6707	26,92,820
5	35,85,269	76,00,000	40,14,731	0.6069	24,36,941
6	35,85,269	76,00,000	40,14,731	0.5493	21,05,376
7	35,85,269	76,00,000	40,14,731	0.4971	19,95,816
8	35,85,269	76,00,000	40,14,731	0.4498	18,06,168
9	35,85,269	76,00,000	40,14,731	0.4071	16,34,541
10	35,85,269	76,00,000	40,14,731	0.3684	14,79,223
Total					1,54,34,257

Note : *B - 43,560 sq. ft.

annual working cost was Rs.35,85,269. Further, it can be seen that annual working cost of hydroponic system assumed as constant from first year to tenth year. The returns from hydroponics system started flowing from first year (Rs.76,00,000) and assumed as constant up to tenth year.

TABLE 8

Discounted cash flow analysis for sample hydroponic units (C*)

(n=5)

Years	Outflows (Rs.)	Inflows (Rs.)	Net cash flows (Rs.)	Discount factor (r) at 10.50%	Net present value (Rs.)
0	50,32,720	0	-50,32,720	1	-50,32,720
1	20,42,401	39,60,000	19,17,598	0.9049	17,43,271
2	20,42,401	39,60,000	19,17,598	0.8189	15,84,792
3	20,42,401	39,60,000	19,17,598	0.7411	14,40,720
4	20,42,401	39,60,000	19,17,598	0.6707	13,09,745
5	20,42,401	39,60,000	19,17,598	0.6069	11,90,678
6	20,42,401	39,60,000	19,17,598	0.5493	10,82,434
7	20,42,401	39,60,000	19,17,598	0.4971	9,84,031
8	20,42,401	39,60,000	19,17,598	0.4498	8,94,574
9	20,42,401	39,60,000	19,17,598	0.4071	8,13,249
10	20,42,401	39,60,000	19,17,598	0.3684	7,39,317
Total					67,50,095

Note : *C - 21,780 sq. ft.

TABLE 9

Discounted cash flow analysis for sample hydroponic units (D*)

(n=3)

Years	Outflows (Rs.)	Inflows (Rs.)	Net cash flows (Rs.)	Discount factor (r) at 10.50%	Net present value (Rs.)
0	32,22,460	0	-32,22,460	1	-32,22,460
1	10,95,468	22,77,000	11,81,531	0.9049	10,74,119
2	10,95,468	22,77,000	11,81,531	0.8189	9,76,472
3	10,95,468	22,77,000	11,81,531	0.7411	8,87,701
4	10,95,468	22,77,000	11,81,531	0.6707	8,07,001
5	10,95,468	22,77,000	11,81,531	0.6069	7,33,637
6	10,95,468	22,77,000	11,81,531	0.5493	6,66,943
7	10,95,468	22,77,000	11,81,531	0.4971	6,06,312
8	10,95,468	22,77,000	11,81,531	0.4498	5,51,193
9	10,95,468	22,77,000	11,81,531	0.4071	5,01,084
10	10,95,468	22,77,000	11,81,531	0.3684	4,55,531
Total					40,37,537

Note : *D - 10, 700 sq. ft.

Table 8 presents the initial investment made (Rs.50,32,720) for hydroponic firms with 21,780 sq. ft. of land and the average annual working cost was Rs.20,42,401. Further, it can be seen that annual working cost of hydroponic system assumed as constant from first year to tenth year. The returns from hydroponics system started flowing from first year (Rs.39,60,000) and assumed as constant up to tenth year. Table 9 presents the initial investment made (Rs.32,22,460) for hydroponic firms with 10,700 sq. ft. of land and the average annual working cost was Rs.10,95,468. Further, it can be seen that annual working cost of hydroponic system assumed as constant from first year to tenth year. The returns from hydroponics system started flowing from first year (Rs.22,77,000) and assumed as constant up to tenth year.

Table 10 presents the initial investment made (Rs.18,84,270) for hydroponic firms with 5,000 sq. ft. of land and the average annual working cost was Rs.6,76,726. Further, it can be seen that annual working cost of hydroponic system assumed as constant from first year to tenth year. The returns from hydroponics system started flowing from first year (Rs.13,53,000) and assumed as constant up to tenth year. In the present paper, outflows and inflows from year 1 to year 10 are assumed constant for the sake of computation.

Financial Feasibility Analysis for Sample Hydroponic Units

Table 11 presents the financial feasibility analysis for sample hydroponic units measuring 83,120 sq. ft,

TABLE 10

Discounted cash flow analysis for sample hydroponic units (E*)

(n=2)

Years	Outflows (Rs.)	Inflows (Rs.)	Net cash flows (Rs.)	Discount factor (r) at 10.50%	Net present value (Rs.)
0	18,84,270	0	-18,84,270	1	-18,84,270
1	6,76,726	13,53,000	6,76,273	0.9049	6,14,793
2	6,76,726	13,53,000	6,76,273	0.8189	5,58,903
3	6,76,726	13,53,000	6,76,273	0.7411	5,08,093
4	6,76,726	13,53,000	6,76,273	0.6707	4,61,903
5	6,76,726	13,53,000	6,76,273	0.6069	4,19,912
6	6,76,726	13,53,000	6,76,273	0.5493	3,81,738
7	6,76,726	13,53,000	6,76,273	0.4971	3,47,035
8	6,76,726	13,53,000	6,76,273	0.4498	3,15,486
9	6,76,726	13,53,000	6,76,273	0.4071	2,86,805
10	6,76,726	13,53,000	6,76,273	0.3684	2,60,732
Total					22,71,135

Note : *E - 5,000 sq. ft.

TABLE 11

Financial feasibility indicators for sample hydroponic firms

(n=23)

Particulars	A	B	C	D	E
Net present value (Rs.)	230 lakhs	154 lakhs	67 lakhs	40 lakhs	22 lakhs
Benefit-cost ratio	1.28	1.77	1.34	1.25	1.21
Internal rate of return (%)	19	30	19	17	16

Note : Discount rate @ 10.50 per cent
(A - 83,120 sq. ft, B - 43,560 sq. ft, C - 21,700 sq. ft, D - 10, 700 sq. ft, E - 5,000 sq. ft)

43,560 sq. ft, 21,700 sq. ft, 10, 700 sq. ft and 5,000 sq. ft. The NPV criterion helps to evaluate the benefits accrued and costs incurred during the project life. The present value of the net cash flows at 10.50 per cent discount rate was worked out to Rs.2.30 crores (83,120 sq. ft), Rs.1.54 crores (43,560 sq. ft), Rs.67 lakhs (21,700 sq. ft), Rs.40 lakhs (10, 700 sq. ft) and Rs.22 lakhs (5,000 sq. ft). This positive net present value of hydroponic firms for all firm sizes, had clearly indicated that investment on hydroponics was financially feasible. Benefit-Cost ratio is another tool for appraising the worthiness of investments. The BCR indicated expected returns for each rupee of investment. The BCR ranged between 1.21 to 1.77 among sample hydroponic firms at 10.50 per cent discount rate. It may be recalled that even though the investment on hydroponic firms was high, the rewards were commensurate with investment requirement. The formal selection criterion of IRR is to accept the projects with IRR more than the opportunity cost of capital. The IRR was found to be 19 per cent (83,120 sq. ft), 30 per cent (43,560 sq. ft), 19 per cent (21,700 sq. ft), 17 per cent (10, 700 sq. ft) and 16 per cent (5,000 sq. ft)., which was higher than the discount rate (10.50%) considered as an opportunity cost in the analysis. The IRR represents the average earning power of money invested on hydroponics during its life span. Since IRR was more than the discount rate, investment on hydroponic firms in Bengaluru was financially viable.

The formal selection criterion of IRR is to accept the projects with IRR more than the opportunity cost of capital. The IRR represents the average earning power of money invested on hydroponic farming during its life span. Since, IRR was more than the discount rate, investment on hydroponic farming in Bengaluru was financially viable. The hydroponic firms with 43,560 sq. ft. of area had the highest Internal Rate of Return (30%), while the 5,000 square feet firms had the lowest Internal Rate of Return (16%). These findings clearly demonstrated that investment in any scale of hydroponic farming is a profitable business venture in Bengaluru.

The study findings affirm the viability of the project within the examined region. The project would become more appealing/enhanced through the cultivation of crops like olives, strawberries, english cucumber, oregano, bok choy, rocket leaves etc. particularly those of exotic in nature. The above findings are in line with Ganesh Thapa *et al.* (2021), who analyzed the financial feasibility of hydroponic farms inside Kathmandu valley and it was reported in the study that investment on hydroponics was financially viable. Similar results were also obtained by Likin Bopanna *et al.* (2016) who analysed the financial viability of Coorg mandarin cultivation.

Conclusion and Policy Implications

These findings clearly demonstrated that investment in any scale of hydroponic farming is a profitable business venture in Bengaluru. As this technology is capital intensive and requires technical knowledge, there is a need to provide financial assistance under a separate credit line for the hydroponic farms with low interest rate. This can enhance the rate of adoption of in the state and country.

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Positive and Negative Soil Relations in Intensive Tomato Cultivation in the Eastern Dry Zone of Karnataka, India

Deepa Shettar[1], D. V Naveen[2], P. Veeranagappa[3], R. Srinivasan[4], V. Venkatachalapathi[5] and G. Narasareddy[6]
[1&2]Department of Soil Science and Agricultural Chemistry, [6]Department of Entomology, College of Sericulture, Chintamani; [3]ICAR-KVK, Hodonahalli, Doddaballapur;
[4]NBSS and LUP, Regional Centre, Hebbal, Bengaluru, [5]Agricultural Research Station, Chintamani
e-Mail : dvnaveena@gmail.com

Authors Contribution

Deepa Shettar : Conceptualization, draft writing and investigation;
D. V Naveen : Design of experiment, supervision and editing;
P. Veeranagappa ; R. Srinivasan & V. Venkatachalapathi : Guidance and editing;
G. Narasareddy : Data analysis and software application

Corresponding Author :
Deepa Shettar

Received : June 2024
Accepted : August 2024

Abstract

Over exploitation of nutrients in the eastern dry zone of Karnataka has had an adverse effect on the natural environment, highlighting the need for research on soil characteristics and their influence on the cultivation of tomatoes. The objective of the study was to assess the pros and cons of different soil properties for the intensive farming of tomatoes in Karnataka's eastern dry zone. The present study analysed the effects of annual tomato cultivation, which cultivated once, twice and three times a year on the correlation between soil physical, chemical and biological properties in intensively cultivated soils in Karnataka, India. By using SPSS and XLSTAT for correlation was assessed. it was found positive correlations between soil properties and 19 soil parameters indicators out of 26 parameters, including exchangeable Mg and volume of expansion. However, it also an inverse correlation between 07 soil properties in intensive cultivation of tomato. By implementing appropriate soil management strategies, farmers can mitigate the adverse effects of nutrient over exploitation and ensure sustainable tomato cultivation in the region.

Keywords : Correlation, Soil properties, Tomato, Intensive cultivation

Intensive tomato cultivation involves maximizing soil interactions for plant growth, crop yield and fruit quality. Start by conducting a thorough soil analysis to evaluate nutrient levels (Sanchez and Swaminathan, 2005), pH and organic matter content. Adjust the soil based on the results to optimize nutrient levels and pH. Use organic amendments like compost and manure to enhance soil structure and fertility (Chang *et al*., 2007). Implement crop rotation and cover crops to disrupt disease cycles and improve soil fertility. Utilize organic mulches to retain moisture, control weeds and regulate soil temperature (Azarmi *et al.,* 2008). Install drip irrigation systems to minimize water wastage and foliar diseases. Monitor soil moisture levels and adjust irrigation schedules accordingly. Minimize soil disturbance and promote diverse microbial populations for soil health. Apply fertilizers judiciously based on soil nutrient deficiencies and plant requirements. Use slow-release or organic fertilizers to reduce leaching and runoff. Optimize soil interactions through targeted soil management.

Intensive tomato cultivation in dry zones has both benefits and drawbacks. High-density planting and controlled irrigation can lead to higher crop yields per unit area, maximizing production in limited arable land. Drip irrigation reduces water wastage, making efficient water usage crucial in regions with scarce water resources. Intensive cultivation utilizes technology and inputs like fertilizers, enhancing resource utilization efficiency (Barche *et al.,* 2011). Mechanization and automation decrease labour demands, making production economically feasible in areas with high labour costs or limited availability. Intensive systems allow for closer monitoring of crops, aiding in early detection and control of pests and diseases, reducing yield losses. Intensive farming methods require significant upfront investment in infrastructure, technology and resources. This can deter small-scale farmers or those with limited finances. Improper management can lead to soil degradation, especially in regions with fragile soils. Intensive farming relies heavily on external resources like water and energy, which can exacerbate droughts or water scarcity in arid regions. Excessive use of fertilizers and pesticides can contaminate water sources and degrade soil quality (Afolabi *et al.,* 2017). Inadequate handling of agricultural chemicals can harm ecosystems and human health. Intensive farming is more susceptible to crop failures due to pests, diseases and extreme weather events, particularly in arid regions. While intensive tomato farming in arid regions offers benefits, careful management is necessary for long-term sustainability. Strategies that prioritize soil health, water conservation and ecological resilience are crucial for minimizing adverse effects.

Intensive tomato cultivation can impact soil properties positively by adding organic amendments like compost or manure to enhance soil fertility (Ewulo *et al.,* 2008). This increases soil organic matter, improving soil structure, water retention and nutrient cycling. Regular fertilization meets high nutrient demands of tomato plants, replenishing essential nutrients and maintaining balance (Deepak *et al*. 2020). Reduced tillage and cover crops promote soil aggregation and porosity, enhancing water infiltration, root penetration and gas exchange for healthy plant growth. Minimizing soil disturbance through practices like no-till or minimum tillage can reduce soil erosion, especially in dry zones with limited vegetation and high wind speeds (John *et al.,* 2019).

Intensive cultivation practices, like heavy machinery and repeated cultivation can lead to soil compaction in fine-textured soils. This reduces pore space, hindering root growth, water infiltration and nutrient uptake, impacting plant growth and soil health. Overuse of fertilizers can cause nutrient imbalances and disrupt soil pH levels, affecting nutrient cycling and increasing pollution. Intensive irrigation can lead to soil salinization, impeding plant growth and decreasing yields (Saikumar and Nagendra Rao 2016). Frequent soil disturbance can decrease soil organic matter, reducing fertility and increasing erosion. These practices can contribute to soil degradation, reducing productivity and resilience in arid regions. Sustainable intensification methods that prioritize soil health and conservation practices are essential for long-term productivity and sustainability in intensive tomato cultivation (Salahin *et al*., 2011: Ananthakumar and Meghana, 2022).

Soil characteristics may display different relation ships based on variables such as soil type, climate, land use and management techniques. Various connections between soil properties exist, such as how soil texture impacts drainage - sandy soils drain faster due to larger pore spaces, while clay soils drain slower due to smaller pore spaces. The presence of organic matter affects soil fertility by enhancing nutrient retention, water holding capacity and microbial activity. Soils with higher organic matter content are generally more fertile. Soil pH plays a role in nutrient availability; acidic soils may have higher aluminium and manganese toxicity, while alkaline soils can limit the availability of micronutrients like iron and zinc. CEC indicates the soil's capacity to retain and exchange positively charged ions (cations) like calcium, magnesium, potassium and ammonium. Soils with higher CEC typically have better nutrient retention capabilities. Bulk density, influenced by soil compaction, is the mass of soil per unit volume (Colla *et al.,* 2008). Compacted soils have higher bulk density, which can hinder root growth, water infiltration and aeration. Soil texture also affects water holding capacity, with clay soils retaining more water due to smaller pore spaces compared to sandy soils. Soil colour can impact temperature, as darker soils absorb more solar radiation and warm up faster than lighter-coloured soils. These relationships are crucial in soil management and agriculture, influencing crop productivity, water management and environmental sustainability (Brzezinska *et al.,* 1998). It is important to note that soil properties interact in complex ways and correlations can vary based on specific local conditions and management practices. Under standing these connections can aid in soil management and agricultural practices, enabling adjustments to optimize soil conditions for plant growth and productivity.

Karnataka, specifically Kolar and Chickballapur districts, is a major tomato producer, yielding around 4,00,000 tons annually. Chintamani, in Chickballapur is famous for its silk, milk and tomato production, boasting the largest markets in the state. The area benefits from a hot and dry climate, sufficient rainfall and potassium-rich soil. Farmers in Chintamani grow tomatoes in small plots during kharif, moderately during rabi and extensively in the summer. They use mulching techniques and practice three crop rotations per year on the same land. However, improper use of nutrients, chemicals will harm the soil in heavily cultivated tomato fields. An investigation was conducted to study the impact of continuous tomato cultivation on soil through positive and negative correlation between the soil properties.

Material and Methods

The research site is located in south eastern Karnataka, India on the Deccan Plateau. It covers an area of 867 square kilometres and is GPS between 13°16' to 13°42'N latitude and 77° 51' to 78' 12'E longitude. Chintamani has a tropical semi-arid climate with hot and dry weather conditions. Summer maximum temperatures can reach up to 38°C and the average annual rainfall ranges from 400 to 750 mm. Most of the rainfall occurs during the South West Monsoon

Table 1

Meteorological data of Chintamani taluk during 2021-22

Month	RF *(mm)	MaxTemp (°C)	MinTemp (°C)	RH I (%)*	RH II (%)*
Jan	16.81	27.92	17.01	83.77	80.19
Feb	27.20	29.89	15.84	73.64	65.86
Mar	0.00	33.99	17.72	61.42	53.29
Apr	41.70	35.22	19.54	66.07	58.67
May	87.20	34.46	21.16	70.32	66.23
Jun	64.30	30.87	20.81	75.73	66.20
Jul	196.00	29.27	20.39	83.23	73.35
Aug	251.30	29.17	20.16	81.35	70.26
Sep	177.60	29.62	20.20	80.17	68.97
Oct	504.50	28.99	19.79	82.48	71.10
Nov	285.42	25.93	19.04	89.97	83.33
Dec	14.80	26.99	15.17	84.97	68.48
Mean	138.90	30.19	18.90	77.76	68.83
SD	151.44	2.95	1.99	8.46	8.17
CV (%)	91.72	1023.65	948.98	918.65	842.24
Min	0.00	25.93	15.17	61.42	53.29
Max	504.50	35.22	21.16	89.97	83.33

* RF = Rain fall, * RH = Relative Humidity

Fig. 1 : Map of the study area

and North East Monsoon seasons, with the highest amount in the month October and November (Table 1 and Fig. 2). The region is classified as the Eastern Dry Zone of Karnataka (Fig. 1). The soil composition in the area is Sandy Clay Loam (SCl), which is suitable for growing mulberry, cereals, vegetables and pulses. Tomato cultivation is prominent and finger millet is intercropped with red gram and field bean during the *kharif* season. Maize is grown during the rabi season and irrigation is used for mulberry, groundnut and vegetable cultivation.

Ninety soil samples were collected from extensively cultivated tomato soils in the Kasaba cluster of Chintamani in order to conduct analysis (30 samples yearly one time, 30 samples yearly two times and 30 samples yearly three times tomato growing soils). GPS tools were employed to ensure precise sample collection. Standard methods as described by

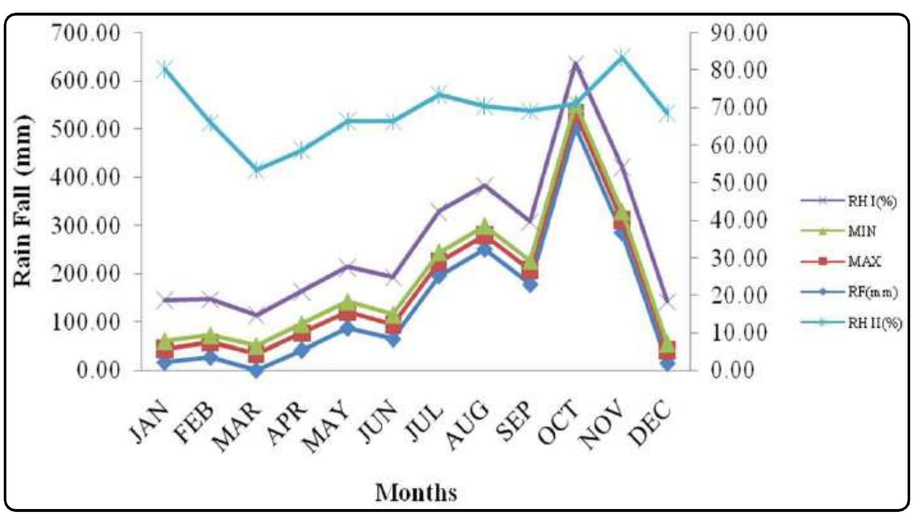

Fig. 2 : Weather data of Chintamani taluk during 2021-22

Jackson, 1973 were adopted for the analysis of the soil samples. Particle sizes distribution was determined by Bouycous hydrometer method (Bouyoucos, 1936), Bulk density and moisture content by gravimetric method (as expressed by the weight of the soil before and after over-dried and the volume of the soil), by keen's cup method (Piper, 1966). The soil pH in water (1:2.5) was determined using potentiometric analysis using glass electrode pH meter. Conductivity cell is used for estimation of EC of soil water suspension, Organic matter content was determined by (Walkey-Black, 1934) wet digestion method. The available N of soil was distilled with 25 mL of 0.32 per cent $KMnO_4$ and 25 mL of 2.5 per cent sodium hydroxide (NaOH). The liberated ammonia was trapped in 4 per cent H_3BO_3 containing bromo-cresol green and methyl red mixed indicator and titrated against standard sulfuric acid (Subbiah and Asija 1956) Available P_2O_5 in soil samples were extracted with Bray's-1 (NH_4F+HCl) and Olsen's Method (0.5 M $NaHCO_3$). Phosphorus content in the extract was determined by ascorbic acid-molybdate complex method and the blue colour intensity was recorded at 660 nm using spectrophotometer (Jackson 1973). The exchangeable cations were extracted with 1M NH_4OAC (pH 7.0) to determine K using flame photometer and exchangeable Ca and Mg by ion complex with EDTA solution while available sulphur was estimated by using Turbidometry method. Micronutrient cations (Fe, Mn, Cu and Zn) are extracted with DTPA and estimated by atomic absorption spectrophotometer (Lindsay and Norell, 1978) and Hot water-soluble boron was estimated by colour development with azomethane and intensity was recorded at 430 nm using spectrophotometer (Jackson 1973). Dehydrogenase activity in the soil was measured using spectrophoto metry. Dehydrogenase activity was reported as µg TPF g^{-1} soil material hr^{-1}. The colorimetric estimation of acid and alkaline phosphatase activity was conducted using the method outlined by Tabatabai and Bremner (1969). Two sets of 1g soil samples were placed in 50 mL centrifuged tubes, with one set serving as the control. Toluene and modified universal buffer (MUB) at pH 6.5 were added to all the tubes. One set of samples had P-nitrophenyl phosphate added as a substrate. The tubes were gently swirled and incubated at 37°C for one hour. After incubation, $CaCl_2$ and NaOH were added and briefly swirled. The suspensions were filtered and the yellow colour intensity of the filtrates was measured at a wavelength of 440 nm. The amount of p-nitrophenol formed in each sample was determined using a standard curve. The acid phosphatase activity was expressed as µg p-nitrophenol released per gram of soil per hour. The urease activity in the soil was assessed using the method proposed by Tabatabai and Bremmer (1972). This involved measuring the amount of NH_4 released during the assay. To conduct the assay, 5 g of soil (< 2 mm) was placed in a 50 ml volumetric flask with the assay medium. The assay medium consisted of 0.2 mL of toluene, 5 mL of THAM buffer (pH 9.0, 0.05 M) and 1 mL of urea (0.2 M). The reaction mixture was incubated at 37°C for 2 hours for urea hydrolysis. After incubation, a KCl-Ag, SO_4 solution was added to stop the enzymatic reaction. The resulting content was extracted multiple times to measure the release of ammonia. The NH_4-N in the soil suspension was determined through distillation and the urease activity in the soil was expressed as mg NH_4 -N per 100 g of soil per hour. Halvorsun and Zeiglar's (1993) approach for studying microbial populations in tomato cultivation soils was modified by Chhonkar *et al.* (2007) to quantify CFU per gram of soil. Bacteria, fungi and actinomycetes were quantified using the serial dilution pour plate method with specific media from (Nutrient agar medium for Bacteria, Martin's rose Bengal agar for Fungi and Kusters agar for Actinomycetes). Three plates per sample and microbial group were incubated at 28 ± 1°C for one week. The population of each group was determined using a colony counter and recorded as CFU per gram of dry soil. The statistical analysis will involve calculating correlations using the standard method provided by Panse and Sukhatme (1967) and conducted using Stastical

TABLE 2 (a)

Pearson correlation between soil quality indicators and yearly one time tomato growing soils

	pH	EC	OC	AK	Ca	Mg	AS	Zn	Cu	Fe	Mn	MWHC	VE	APA2	AAP1	SMF	TB	TF	TA
pH	1																		
EC	0.638	1																	
OC	0.074	0.243	1																
AK	0.481	0.275	0.042	1															
Ca	0.2	0.183	0.595	0.148	1														
Mg	0.121	0.257	0.58	0.148	0.773	1													
AS	0.341	0.356	0.458	0.167	0.314	0.227	1												
Zn	0.224	0.291	0.329	0.051	0.429	0.169	0.228	1											
Cu	0.322	0.06	0.1	0.215	0.051	-0.138	-0.267	0.389	1										
Fe	-0.351	-0.105	-0.294	-0.142	-0.23	-0.343	-0.428	0.204	0.198	1									
Mn	-0.323	-0.22	-0.206	-0.193	-0.218	-0.313	-0.312	-0.068	0.087	0.442	1								
MWHC	0.348	0.458	0.284	0.362	0.323	0.151	0.285	0.362	0.163	0.074	-0.283	1							
VE	0.301	0.368	0.007	0.126	0.149	-0.021	0.236	0.39	0.19	0.239	-0.274	0.709	1						
AAP1	0.011	0.102	-0.085	0.138	-0.166	-0.311	-0.266	0.129	0.402	0.29	0.238	0.397	0.263	1					
APA2	0.28	0.244	0.008	0.302	0.02	-0.051	0.037	0.26	0.399	-0.044	-0.125	0.603	0.318	0.643	1				
SMF	0.095	-0.158	0.466	0.125	0.377	0.33	0.517	0.228	-0.141	-0.284	-0.198	-0.261	-0.074	-0.433	-0.255	1			
TB	-0.134	-0.031	0.354	-0.049	0.296	0.354	0.192	0.197	-0.132	-0.273	0.053	-0.124	-0.219	0.014	0.002	0.367	1		
TF	-0.169	-0.086	0.096	-0.111	0.131	0.173	-0.188	-0.107	-0.028	-0.142	0.25	0.068	-0.439	0.199	0.085	-0.208	0.424	1	
TA	0.434	0.399	-0.008	0.385	0.092	0.212	0.12	0.386	0.238	0.102	-0.321	-0.087	0.328	-0.254	0.116	0.187	-0.215	-0.382	1

*EC- Electrical conductivity, *OC– Organic carbon, *AK– Available potassium,*Ca- Exchangeable calcium, *Mg- Exchangeable Magnesium, *AS-Available sulphur, *Zn-DTPA extractable zinc, *Cu-DTPA extractable copper, *Fe- DTPA extractable iron, * Mn-DTPA extractable manganese, *MWHC-Maximum water holding capacity, *VE-Volume of expansion, *AAP1-Acid phosphatase activity, *AAP2-Alkali phosphatase activity, *SMF-Soil micro-fauna, *TB-Total bacteria, *TF-Total fungi, *TA-Total actinomycetes

Package for Social Science (SPSS) (Version 18.0) and Microsoft XL (XLSTAT software).

Results and Discussion

Positive Correlation Between Soil Properties in Yearly One Time Tomato Growing Soils

A correlation analysis was conducted on the soil properties in soils used for yearly one-time tomato cultivation, revealing a positive correlation between 19 soil quality indicators and soil properties (Table 2a). A partial correlation was then performed to explore the relationship between each individual soil quality indicator and the other 19 parameters considered in the study. Notably, exchangeable Mg (r = 0.773) and volume of expansion (r = 0.703) exhibited a strong positive correlation with the soil properties in soils used for yearly one-time tomato cultivation. The pH of the soil samples showed a positive correlation with EC (r = 0.63), which was statistically significant at a 5 per cent level of significance across all sample observations.

Additionally, the pH was significantly positively correlated with available potassium (r = 0.481) and actinomycetes activities (r = 0.434) similar findings was noticed by (Ranjith *et al.,* 2016) in cotton. Furthermore, the electrical conductivity of the soil samples was positively correlated with MWHC (r = 0.458), while it showed a non-significant positive correlation with acid phosphatase enzyme activity (r = 0.102). Organic carbon in the soil samples displayed a significant positive correlation with exchangeable calcium (r = 0.59), exchangeable Mg (r = 0.588), available Sulphur (r = 0.458) and micro-fauna (r = 0.46). On the other hand, exchangeable Ca exhibited a highly significant positive correlation with exchangeable Mg (r = 0.773) and a significant positive correlation with DTPA Zn (r = 0.429). Available Sulphur in the soil samples was significantly correlated with micro-fauna (r = 0.517) at a 5 per cent level of significance, while DTPA Cu showed a significant positive correlation with acid phosphatase (r = 0.402). Similarly, DTPA Fe was significantly correlated with DTPA Mn (r = 0.442) at a 5 per cent level of significance.

Negative Correlation between Soil Properties in Yearly One Time Tomato Growing Soils

There was an inverse correlation observed among soil properties in soils used for tomato cultivation on a yearly basis (Table 2b). The bulk density of soil samples exhibited a negative association with

Table 2 (b)

Pearson correlation between soil properties in yearly one time tomato growing soils

	AS	Fe	BD	MWHC	VE	Urease	DHA	AAP1	SMF	TF
AS	1									
Fe	-0.428	1								
BD	-0.006	-0.165	1							
MWHC	0.285	0.074	-0.433	1						
VE	0.235	0.239	-0.285	0.709	1					
Urease	0.199	-0.534	0.352	-0.262	-0.285	1				
DHA	0.189	-0.499	0.077	0.066	-0.162	0.388	1			
AAP1	-0.266	0.29	0.088	0.397	0.263	-0.144	0.114	1		
SMF	0.517	-0.284	0.227	0.044	-0.074	0.259	-0.078	-0.433	1	
TF	-0.188	-0.142	0.213	-0.217	-0.439	0.399	0.254	0.199	0.424	1

*AS-Available sulphur, *Fe-DTPA extractable iron, *BD-Bulk density, *MWHC-Maximum water holding capacity, *VE-Volume of expansion, *Urease-Urease activity, *DHA-Dehydrogenase activity, *AAP1-Acid phosphatase activity, *SMF-Soil micro-fauna, *TF-Total fungi

TABLE 3 (a)

Pearson correlation between soil quality indicators and yearly two times tomato growing soils

	pH	EC	OC	AN	AP	AK	Ca	Mg	Zn	Cu	Fe	Mn	B	MWHC	VE	Urease	DHA	AAP1	AAP2	SMF	TB	TF
pH	1																					
EC	0.359	1																				
OC	0.138	0.25																				
AN	0.025	0.293	0.129	1																		
AP	0.326	0.457	0.358	0.583	1																	
AK	0.369	0.432	0.475	0.281	0.172	1																
Ca	0.524	0.367	0.088	0.129	0.14	0.544	1															
Mg	0.484	0.353	-0.06	-0.145	0.068	0.202	0.734	1														
Zn	-0.033	-0.134	0.058	-0.068	0.251	-0.118	-0.099	-0.145	1													
Cu	0.062	-0.165	0.087	-0.142	0.142	-0.17	-0.101	-0.061	0.462	1												
Fe	-0.135	-0.242	-0.066	-0.085	-0.094	-0.098	0.043	0.182	0.03	0.336	1											
Mn	-0.135	-0.242	-0.066	-0.085	-0.094	-0.098	0.043	0.182	0.03	0.336	1	1										
B	0.177	0.179	0.422	0.145	0.251	0.496	0.016	-0.049	0.009	0.096	-0.096	-0.022	1									
MWHC	0.358	0.283	0.128	0.209	0.142	0.522	0.686	0.375	0.046	0.232	0.232	0.167	0.257	1								
VE	0.13	0.174	0.08	0.271	0.057	0.227	0.579	0.404	0.201	0.054	0.054	0.069	-0.099	0.652	1							
Urease	-0.62	0.14	-0.058	-0.042	0.16	-0.014	0.046	0.209	-0.165	0.076	0.076	0.082	0.066	0.156	0.152	1						
DHA	0.425	0.347	-0.048	0.122	0.128	0.331	0.581	0.688	-0.411	-0.219	-0.219	-0.111	-0.047	0.32	0.522	0.199	1					
AAP1	0.173	0.18	0.03	0.215	0.012	0.139	0.241	0.035	-0.057	0.113	0.113	0.305	-0.036	0.539	0.247	-0.034	-0.188	1				
AAP2	0.351	0.144	0.252	0.164	0.147	0.474	0.409	0.111	0.019	0.193	0.193	0.319	0.298	0.632	0.238	0.071	-0.127	0.797	1			
SMF	0.326	0.086	0.552	0.066	0.137	0.381	0.172	0.017	0.11	0.26	0.26	-0.031	0.202	0.322	0.154	0.001	0.193	0.016	0.185	1		
TB	0.341	0.219	0.089	0.234	0.087	0.277	0.262	0.216	-0.323	0.076	0.076	-0.177	-0.055	0.354	0.244	0.193	0.4	0.262	0.252	0.121	1	
TF	0.27	0.096	-0.26	-0.092	-0.156	-0.084	0.057	0.049	-0.091	0.01	0.01	-0.33	-0.063	0.097	0.038	-0.399	0.009	0.489	0.296	-0.115	0.237	1

*EC- Electrical conductivity, *OC– Organic carbon, *AK– Available potassium, * Ca- Exchangeable calcium, *Mg- Exchangeable Magnesium, *AS-Available sulphur, *Zn-DTPA extractable zinc, *Cu-DTPA extractable copper, *Fe- DTPA extractable iron, * Mn-DTPA extractable manganese, *MWHC-Maximum water holding capacity, *VE-Volume of expansion, *AAP1-Acid phosphatase activity, *AAP2-Alkali phosphatase activity, *SMF-Soil micro-fauna, *TB-Total bacteria, *TF-Total fungi, *TA-Total actinomycetes.

maximum water holding capacity (r = -0.433) and a non-significant negative correlation with volume of expansion (r = -0.288). Furthermore, the volume of expansion of soil samples was significantly negatively correlated with fungi population (r = -0.439), while Acid phosphates activities showed a negative relationship with micro-fauna (r = -0.433) at a 5 per cent level of significance. Mishra (2005) stated that soil productivity can be certainly be lost through land degradation, erosion, nutrient mining or other processes such as salinization, sodification, compaction and water logging. The linkage between soil productivity and its quality is apparent when changes in soil attributes used to assess soil quality are linked to causes of productivity loss. The effects of management practices on productivity can also be assessed using soil quality attributes.

Positive Correlation between Soil Properties in Yearly Two Times Tomato Growing Soils

The information provided in Table 3(a) displays the positive correlation coefficients between various soil quality indicators in soils used for growing tomatoes twice a year in the Kasaba cluster of Chintamani taluk. The results clearly show that soil pH is significantly and positively correlated with Ca (r= 0.524), Mg (r= 0.484) and DHA (r= 0.425), and also significantly correlated with AK (r= 0.369). Soil EC is highly significant and positively correlated with available P (r= 0.457), AK (r =0.432) and significantly correlated with Ca (r =0.367) at a 5 per cent level of significance. Organic carbon is highly significant and positively correlated with SMF (r = 0.552) and significantly correlated with AK (r = 0.475) and B (r = 0.422). AN is highly significant and positively correlated with AP (r = 0.583). AK content is positively correlated and highly significant with Ca (r = 0.544), B (r = 0.496), AAP2 (r = 0.474) and SMF (r = 0.381) at a 5 per cent level of significance. Ca is highly significant and positively correlated with Mg (r = 0.779), DHA (r = 0.581) and AAP2 (r = 0.409). On the other hand, Mg is significantly and positively correlated with MWHC (r = 0.375), VE (r = 0.404) and DHA (r = 0.688). A positive correlation between Zn and Cu (r = 0.462) was observed in the soils used for growing tomatoes twice a year. Similarly, MWHC is highly positively

Table 3 (b)

Pearson correlation between soil properties in yearly two-time tomato growing soils

	pH	BD	Ca	AN	AS	Zn	Urease	DHA	SMF	TF	TA
pH	1										
BD	-0.389	1									
Ca	0.524	-0.475	1								
AN	0.025	-0.15	0.129	1							
AS	0.091	0.173	0.073	-0.511	1						
Zn	-0.033	0.198	-0.099	-0.068	0.178	1					
Urease	-0.063	0.146	0.046	-0.042	0.239	-0.165	1				
DHA	0.425	0.092	0.581	0.122	-0.039	-0.411	0.199	1			
SMF	0.326	0.014	0.172	0.066	0.166	0.11	0.001	0.193	1		
TF	0.27	-0.019	0.057	-0.092	0.239	-0.211	-0.399	0.009	-0.015	1	
TA	0.294	-0.245	-0.01	-0.155	-0.063	-0.091	-0.052	-0.097	-0.375	0.192	1

**BD-Bulk density, *Ca-Exchangeable calcium, *AN-Available nitrogen, *AS-Available sulphur, *Zn-DTPA extractable zinc, *Urease-Urease activity, DHA-Dehydrogenase activity, *TF-Total fungi, *TA-Total bacteria

TABLE 4 (a)
Pearson correlation between soil quality indicators and yearly three times tomato growing soils

	pH	OC	AN	AP	AK	Ca	Mg	AS	Zn	Fe	Mn	B	BD	MWHC	VE	Urease	AAP1	AAP2	TA
pH	1																		
OC	0.405	1																	
AN	-0.107	-0.203	1																
AP	-0.18	-0.164	0.411	1															
AK	0.173	-0.097	0.234	0.332	1														
Ca	0.104	0.156	-0.074	0.172	0.335	1													
Mg	0.151	0.269	-0.22	-0.187	0.156	0.672	1												
AS	0.089	0.222	0.128	0.242	0.115	0.222	0.281	1											
Zn	0.077	-0.003	0.295	0.641	0.161	0.337	0.107	0.289	1										
Fe	-0.113	-0.22	0.515	0.075	-0.172	-0.187	-0.045	0.062	0.179	1									
Mn	-0.249	-0.04	0	0.222	0.411	0.29	-0.006	0.052	0.038	-0.225	1								
B	0.048	0.31	0.319	0.376	0.095	0.39	0.171	0.745	0.421	0.245	0.168	1							
BD	-0.079	0.052	0.151	0.088	-0.022	0.015	0.28	0.348	0.381	0.181	-0.159	0.256	1						
MWHC	0.061	-0.168	0.396	0.122	0.334	0.182	-0.192	-0.19	0.032	0.145	0.263	0.019	-0.522	1					
VE	0.195	0.21	0.32	0.337	0.58	0.1	-0.285	0.087	0.207	-0.018	0.227	0.237	-0.211	0.523	1				
Urease	0.162	-0.191	0.464	0.344	0.449	0.047	0.016	-0.039	0.191	0.208	-0.137	-0.036	0.123	0.055	0.2	1			
AAP1	-0.41	-0.185	0.1	-0.028	0.336	0.021	-0.008	-0.093	-0.168	-0.296	0.595	-0.128	0.129	-0.002	0.168	0.235	1		
AAP2	0.138	-0.194	0.153	0.046	0.505	0.053	-0.209	-0.14	-0.168	-0.07	0.434	-0.087	-0.427	0.664	0.549	-0.35	0.064	1	
TA	0.111	0.009	0.141	0.17	0.147	0.428	0.302	0.37	0.257	0.008	-0.043	0.498	0.169	-0.128	-0.169	0.227	-0.231	-0.231	1

*EC- Electrical conductivity, *OC– Organic carbon, *AK– Available potassium, * Ca- Exchangeable calcium, *Mg- Exchangeable Magnesium, *AS-Available sulphur, *Zn-DTPA extractable zinc, *Cu-DTPA extractable copper, *Fe- DTPA extractable iron, * Mn-DTPA extractable manganese, *MWHC-Maximum water holding capacity, *VE-Volume of expansion, *AAP1-Acid phosphatase activity, *AAP2-Alkali phosphatase activity, *SMF-Soil micro-fauna, *TB-Total bacteria, *TF-Total fungi, *TA-Total actinomycetes correlated with VE (r = 0.652), AAP1 (r = 0.539) and AAP2 (R = 0.632). The VE of soil samples is significantly and positively correlated with DHA (r = 0.522) at a 5 per cent level of significance. Meanwhile, DHA is highly significant and positively correlated with bacteria (r = 0.408) and AAP1 is highly and positively significant with AAP2 (r = 0.797) at a 5 per cent level of significance similar finding was recorded by Pillai and Natarajan, 2004.

Negative Correlation between Soil Properties in Yearly Two Times Tomato Growing Soils

The data provided in Table 3 (b) illustrates a clear negative correlation between soil quality indicators in soils used for growing tomatoes twice a year. The correlation between AN and soil AS was highly significant and negative (r = 0.511). Similarly, pH showed a significant negative correlation with BD (r = 0.389). BD (r = 0.389) and Ca (r = 0.475) exhibited a highly significant negative correlation at a 5 per cent level of significance. Zn was highly significant and negatively correlated with DHA (r = 0.411). Urease and SMF were significantly negatively correlated with fungi (r = 0.309) and actinomycetes (r = 0.375) at a 5 per cent level of significance, respectively. Among all soil quality indicators, available nitrogen had the highest negative correlation with AS (r = 0.511) at a 5 per cent level of significance.

Positive Correlation between Soil Properties in Yearly Three Times Tomato Growing Soils

The correlation analysis between soil properties and soils used for growing tomatoes three times a year is presented in Table 4(a). The findings revealed a strong positive correlation between pH and OC (r = 0.405), AN and AP (r = 0.411), AN and Fe (r = 0.515), AN and MWHC (r = 0.396), AN and urease (r = 0.464), AP and Zn (r = 0.641), AP and B (r = .0.376), AK and Mn (r = 0.411), VE (r = 0.58) and urease (r = 0.449), Ca and Mg (r = 0.672), Ca and B (r = 0.39), Ca and actinomycetes (r = 0.428), AS and B (r = 0.745), AS and actinomycetes (r = 0.37), Zn and B (r = 0.421), Zn and BD (r = 0.381), Mn and AAP1 (r = 0.595), Mn and AAP2 (r = 0.434), B and actinomycetes (r = 0.498), MWHC and AAP2 (r = 0.664), MWHC and VE (r = 0.523) and VE and AAP2 (r = 0.549) at a significance level of 5 per cent. Notably, the highest positive correlation was observed between AS and B (r = 0.745), followed by MWHC and VE (r = 0.664).

Table 4 (b)

Pearson correlation between soil properties in yearly three times tomato growing soils

	pH	Fe	BD	PS	MWHC	AAP1	AAP2	TF	SMF
pH	1								
Fe	-0.113	1							
BD	-0.079	0.181	1						
PS	-0.282	0.188	0.066	1					
MWHC	0.061	0.145	-0.522	-0.333	1				
AAP1	-0.41	-0.296	0.129	-0.124	0.002	1			
AAP2	0.138	-0.07	-0.427	-0.171	0.664	0.342	1		
TF	0.233	-0.248	-0.184	-0.402	0.257	0.192	0.233	1	
SMF	0.111	-0.378	-0.198	-0.349	0.306	0.064	0.236	0.262	1

*Fe-DTPA extractable iron. *BD-Bulk density. *PS-Pore space. *MWHC-Maximum water holding capacity, *AAP1-Acid phosphatase activity, *AAP2-Alkali phosphatase activity, *TF-Total fungi, *SMF-Soil microfauna

Negative Correlation between Soil Properties in Yearly Three Times Tomato Growing Soils

In yearly three times tomato growing soils, there is a negative correlation between various soil properties (Table 4b). The correlation coefficients indicate a significant and highly negative relationship between pH and AAP1 (r = 0.41), Fe and SMF (r = 0.378), BD and MWHC (r = 0.522), BD and AAP2 (0.427), pore space and fungi (r = 0.402) and pore space and SMF (r = 0.349) at a 5 per cent level of significance. Among these correlations, the highest negative correlation is observed between BD and MWHC (r = 0.522), followed by BD and AAP2 (r = 0.427).

The study found positive correlations between soil properties and 19 soil quality indicators, with exchangeable Mg and volume of expansion showing strong positive correlations. Other factors such as pH, electrical conductivity, organic carbon, exchangeable calcium, and micro-fauna also showed positive correlations. However, there was an inverse correlation between soil properties and tomato cultivation, with bulk density negatively affecting water holding capacity and expansion volume. Acid phosphates activities negatively impacted micro-fauna. The study also found a negative correlation between soil quality indicators in tomato-growing soils.

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Development and Quality Evaluation of Banana Pseudo Stem RTS (Ready to Serve) Beverage

N. K. Gagana[1], D. Shobha[2], R. Shekhara Naik[3], Jayashree Ugalat[4] and M. Manjunatha[5]
[1&3]Yuvaraja's College (Autonomous), University of Mysore, Mysuru - 570 006
[2&5]ICAR-AICRP (PHET), UAS, GKVK, Bengaluru; [4]College of Horticulture, UHS, GKVK Campus, Bengaluru
e-Mail : shobhafsn@gmail.com

Authors Contribution

N. K. Gagana:
Conducted the experiments;
D. Shobha:
Conceptalization, supervision and manuscript writing;
R. Shekhara Naik:
Manuscript editing;
Jayashree Ugalat:
Assisted in biochemical analysis;
M. Manjunatha:
Guidance and logistics support

Corresponding Author :
D. Shobha

Received : May 2024
Accepted : June 2024

Abstract

The ready to serve (RTS) beverage prepared from disposed part (Banana pseudo stem - BPS) of banana plant with natural flavours was explored by incorporating different levels of BPS in RTS beverage preparation. Among different formulations tested, the amla flavor added beverage was scored significantly higher overall acceptability (7.68) on nine point hedonic scale and it was further compared with control (100% BPS). The effect of addition of natural flavours such as amla, ginger, *Indian pennywort*, mint and sweeteners (sugar and honey) on RTS beverage physico-chemical, nutritional and sensory quality parameters was examined. The best accepted combination of RTS beverage was in the ratio of (banana pseudo stem 80: honey 10 and amla 10). The parameters such as antioxidant activity (324.82 mg100^{-1}g), vitamin C (73.64 mg100^{-1}g), total phenols (1612.1 mg100^{-1}g) flavonoids (124.69 mg100^{-1}g), saponins (286.0 mg100^{-1}g) and potassium (1137.01 mg100^{-1}g) were reported in the banana pseudo stem based RTS beverage with amla flavour. The banana pseudo stem RTS beverage can be stored up to two months in PET bottles at room (25±5° C) and up to six months under refrigerated (4±°C) conditions. The study revealed that the disposed part of BPS can be utilized for value added RTS beverage preparation with neutraceutical content.

Keywords : Banana pseudo stem, Natural flavours, Antioxidant activity, Total phenols, Saponin

Banana is one of the major fruit crop grown in India and stands second position in area and production. The banana stem other wise known as pseudo stem which is inner central core of the pseudo stem. It is cultivated primarily for its fruit and to a lesser extent to make fiber and as ornamental plant. The global production of banana is around 102.03 million tonnes out of which India contributes 29.19 per cent. Except fruit, it generates huge quantity of biomass waste in the form of pseudo-stem, leaves, suckers etc. and out of these, BPS contributes on an average of 60 to 80 t ha^{-1}. Currently, stem biomass after harvesting of fruit is going as an organic waste in the form of manures, dumping on the field itself and utilizing for decoration purposes. Due to this, it creates major agro-waste problem and environmental nuisance (Desai *et al*., 2016). The banana tender core mainly contains 90 per cent of moisture and cannot be stored for longer period of time due to its perishable nature which affects the shelf life. The banana tender core is consumed due to high fiber which helps in weight loss, hyper acidity and relieves the constipation (Kumar *et al*., 2012). It also rich in potassium and pyridoxine (B6), which helps to detoxify the body being a diuretic and production of haemoglobin and insulin. Its potassium content helps in the functioning of muscles, including cardiac muscles. Hence, the stem tender core juice will be the best remedy for kidney stones (Abhirami *et al*., 2014). The BPS has been reported to contain high quality starch including digestible and non-digestible (resistant) starch. The BPS juice also contains good amount of calcium, sodium, magnesium and chlorides; all of them are essential for maintaining body fluid and electrolyte balance. Moreover, in many parts of India, the BPS has been used as a vegetable (Mohapatra *et al*., 2010). Nowadays, the food habits of people are significantly changing towards the natural, safer foods and drinks over synthetic foods or aerated drinks. Consumers are also giving preference for banana pseudo stem juice due to its high nutritional and medicinal properties especially minerals and high fiber. The acceptability of fruit based beverages may be improved further by blending two or more different fruits pulp or natural flavour and other plant based functional ingredients. Blending of BPS juice with other plant based ingredients and natural flavours is unexploited area, which not only enhances the nutrient content in terms of vitamins and minerals, also imparts the flavour, taste and other sensory quality parameters. Previous workers used BPS in the production of edible products like candy, RTS beverage juice (Shagiwal *et al*., 2022), BPS flour (Aziz *et al*., 2011) and cookies (Sree *et al*., 2022). However, published data reports that due to high phenolic content, it imparts browning after extraction of juice or when it get exposed to air. So, for preventing the browning, pre-treatment of BPS is necessary. The juice extracted from BPS core cannot be consumed directly since it imparts bitter taste, due to the presence of saponin content in the BPS. Therefore, there is a need to develop acceptable juice by blending with natural flavours or sweeteners to increase the acceptability of BPS juice. Apart from this, the wastage of BPS can be reduced by converting the BPS into valuable by product. With this background a study was planned to develop RTS beverage enriched with functional ingredients or flavoring agents and evaluated their acceptability in terms of nutritional, phytochemical and shelf life quality.

Material and Methods

The present investigation was carried out at the ICAR-AICRP (PHET), UAS, Bangalore. The raw material for the study, *i.e*., Banana pseudo stem (BPS) locally known as '*baaledindu*' were collected from Yalahanka market and other raw materials such as natural flavours (amla, ginger, *Centella asiatica* (Indian pennywort) and mint) and sweeteners (sugar and honey) were procured from local market and refrigerated till use. Procedure for RTS beverage preparation is followed as shown in Fig. 1. The sensory evaluation was carried out to determine the best acceptable product among 50 (50:40:10), 60 (60:30:10), 70 (70:20:10), 80 per cent (80:10:10) BPS incorporation using 9-point hedonic scale as per Ranganna (1998) method.

Analysis of Chemical and Phytochemical Content : The RTS beverage were analysed for proximate composition such as dietary fiber (Ranganna 1986). The minerals such as calcium, magnesium, sodium, potassium, phosphorous, manganese, iron and zinc were estimated according to standard AOAC (2005) method. Bioactive compounds such as antioxidant activity using DPPH method (AOAC, 2005), total polyphenol and flavonoid content were determined by the method of Sadasivam and Manickam (1997) and Onivogui *et al*., (2014) respectively.

Colour Analysis : The colour of RTS beverage wasa estimated by spectrophotometer (Konica Minolta Instrument, Osaka, Japan; Model-CM 5) and the colour values were expressed in terms of lightness (L*), (a*-green to red) and (b*-blue to yellow) values.

Analysis of Shelf Life Quality : RTS beverage was assessed under ambient (25±5°C) and refrigerated (4±°C) conditions. The sensory analysis was carried out by using standard method suggested by Ranganna (1986). The changes such as pH, TSS and titratable acidity were analyzed every month as per as Raghuramulu (2003) method.

Statistical Analysis : The data in triplicate values was analysed with SAS software 9.3 using two way analysis of variance. The difference between the means were tested using the least significant of difference at 5 per cent level.

Results and Discussion

The results pertaining to changes in physico-chemical properties of BPS beverage during storage period. The organoleptic scores of different functional ingredients (flavoring agents) added is presented in Table 1. The sensory scores for taste and flavor of fresh BPS core juice with ginger, centella and mint added RTS beverage were significantly lower than amla added beverage. Amla flavour juice was acceptable in terms of taste, appearance and color. Hence, amla flavored juice was further tried with sweeteners (sugar and honey).

Perusal of Table 2 indicates sensory assessment of RTS beverage of amla with honey and sugar (two types of sweetener addition). Among two treatments, the T_2 honey based RTS beverage received the significantly higher scores for all the sensory attributes compared to T_1 (sugar).

The results of Table 3 depicts the chemical and phyto-chemical characteristics of the fresh BPS-RTS beverage. Due to the high content of flavonoids (151.13 mg/100 g) and total phenols (1612.86 mg/ 100 g), it has a high antioxidant content (343.61 mg/ 100 g) compared to control. It may protect the cells against free radicals in the body. Minerals include potassium (1194.3 mg/ml), calcium (6.49 mg/ml) and phosphorus (4.56 mg/ml) are abundant in it. Potassium act as a diuretic that aids in the body's detoxification and synthesis of insulin and hemoglobin. The results discussed above are in consistent with those of the

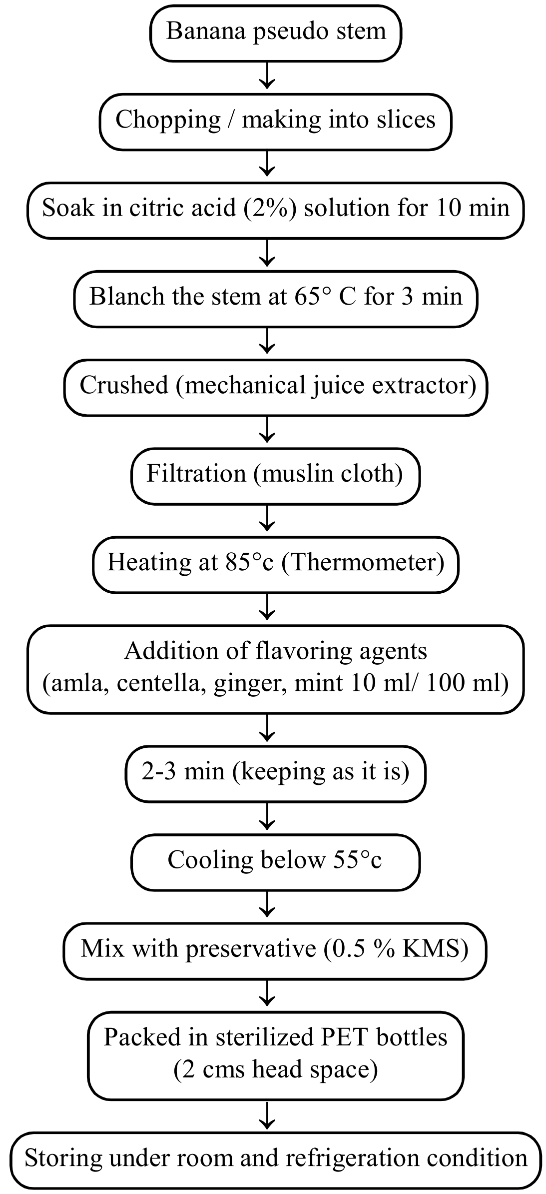

Fig. 1 : Flow chart of Banana pseudo stem based RTS beverage

Table 1

Sensory evaluation of Banana pseudo stem- RTS beverage

Treatments	Appearance	Color	Flavor	Taste	Overallacce ptability
T_1	7.00	7.01	5.84	5.87	7.47
T_2	7.68	7.62	6.70	7.70	7.68
T_3	7.24	7.36	6.45	6.32	6.32
T_4	5.76	5.64	5.54	5.60	5.70
T_5	6.39	6.36	5.54	6.30	6.50

Continued....

TABLE 1 Continued....

Treatments	Appearance	Color	Flavor	Taste	Overallacce ptability
F- value	*	*	*	*	*
S.E (m)	0.001	0.001	0.116	0.085	0.172
CD at 5%	0.002	0.002	0.370	0.273	0.548

CD - Critical difference, S.Em ± - Standard error of mean, * -Significant. T_1 - Control, T_2 - Amla (10%), T_3 - Ginger (10%), T_4 - Centella (10%), T_5 - Mint (10%)

TABLE 2

Sensory evaluation of Banana pseudo stem RTS beverage with sweeteners

Treatments	Appearance	Color	Flavor	Taste	Overallacce ptability
T_1	7.09	7.10	5.58	5.87	7.09
T_2	7.70	7.42	6.62	7.74	7.73
F - value	*	*	*	*	*
SE (m)	0.035	0.010	0.206	0.021	0.041
C D at 5%	0.141	0.039	0.830	0.083	0.167

CD - Critical difference, S.Em± - Standard error of mean, * -Significant. T_1 - Sugar, T_2 - Honey

TABLE 3

Chemical and phytochemical composition of developed BPS - RTS beverage

Chemical and phytochemical parameters	Observations		t- value
	T_1	T_2	
Antioxidant activity (mg /100 g)	304.7	343.61	39.31 *
Vitamin C (mg/100 g)	67.70	73.65	17.29 *
Total phenols (mg/100g)	603.06	1612.86	1614.14 *
Flavonoids (mg/100 g)	133.13	151.13	17.2 *
Tannins (mg/100 g)	7.82	9.463	109.79 *
Saponins (mg/100g)	313.6	286	19.04 *
Reducing sugar (%)	4.45	4.05	12.5 *
Non- Reducing sugar (%)	8.27	8.98	15.55 *
Total sugar (%)	12.72	13.03	51.78 *
Total dietary fiber (%)	0.80	1.00	22.87 *
Soluble fiber (%)	0.45	0.50	27.65 *
Insoluble fiber (%)	0.35	0.50	29.58 *
Macro minerals (mg/ml)			
Calcium	5.3	6.49	20.43 *

Continued....

Table 3 Continued....

Chemical and phytochemical parameters	Observations		t- value
	T_1	T_2	
Magnesium	0.363	1.54	80.98 *
Potassium	1136	1194.3	36.88 *
Phosphorus	5.56	4.56	68.62 *
Micro minerals (mg/ml)			
Iron	1.43	1.3	2 *
Zinc	4.03	3.54	52.32 *
Manganese	0.38	0.14	38.98 *

T_1 -Control, T_2- Honey

earlier researchers Bhaskar *et al.* (2011); Anusuya *et al*. (2012); Aziz *et al*. (2011) and Latharani & Jamuna (2023) for herbal enriched fingermillet based composit flour mix.

The values for L*, a* and b* are shown in Table 4. The L*, a* and b* values of the T2 RTS beverage increased the lightness and yellowness values and reduced the redness with compared to T1 (control). Browning of BPS juice treated with different flavors indicated by an increase in a* and b* value and decrease in L* value (Chandrakala *et al*., 2017) similar type of colour values for Krishna Tulasi herb enriched jaggery was reported by Pooja and Jamuna (2022).

Physico-chemical changes that occur in BPS-RTS beverage stored at room temperature and refrigerated condition is depicted in Table 5 and 6. Over the six-months of storage period, no visual growth of microorganisms was noticed in the refrigerated condition whereas under room temperature, microbial growth and color change occurred during two months of storage period. Hence, study was stopped at that point. The RTS beverage under refrigerated condition remained clear over six months of storage period as shown in the Fig. 2.

Table 4

Colour value of Banana pseudo stem RTS beverage

Treatments	Colour parameters		
	L*	a*	b*
T1	70.24	3.90	22.14
T2	77.34	2.64	22.91
t-value	38.14 *	22.64 *	34.14 *

L* (*i.e.*, [-] to [+] lightness coordinate), a* (*i.e.*, green [-] o red [+]) and b*(*i.e.,* blue [-] to yellow [+]).
T_1 - Control, T_2 - Honey

Fig. 2 : Banana pseudo stem RTS beverage

TABLE 5

Changes in physico-chemical characters of BPS (Honey) based RTS beverage during storage under ambient temperature

Storage period (months)	Clarity		Visual growth		pH		TSS (°Brix)		TTA (% of citric acid)	
	Control	Amla	Control	Amla	Control	Amla	Control	Amla	Control	Amla
0	Clear	Clear	Nil	Nil	4.64 ± 0.32	4.04 ± 0.24	12.0 ± 0.27	13.2 ± 0.33	0.102 ± 0.34	0.21 ± 0.24
1	Clear	Clear	Nil	Nil	4.05 ± 0.21	3.97 ± 0.27	12.9 ± 0.25	13.9 ± 0.35	0.082 ± 0.38	0.15 ± 0.26
2	Clear	Clear	Nil	Nil	3.85 ± 0.28	3.81 ± 0.18	13.5 ± 0.32	14.5 ± 0.29	0.079 ± 0.28	0.10 ± 0.34
3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

	-	-	-	-	-	-	F-value	S.Em ±	CD at5%	F-value	S.Em ±	CD at5%	F-value	S.Em ±	CD at5%
	-	-	-	-	-	-	*	0.012	0.034	*	0.013	0.035	*	0.011	0.032
	-	-	-	-	-	-	*	0.011	0.032	*	0.012	0.034	*	0.014	0.045
	-	-	-	-	-	-	*	0.023	0.063	*	0.023	0.065	*	0.021	0.059

* Significant at 5%, Values are mean ± standard deviation (n=3).CD- Critical difference, S.Em± - Standard error of mean, *- Significant
pH: potential of hydrogen, TSS: Total soluble solids, TTA: Total titratable acidity, NA- Not analysed

Table 6

Changes in physico-chemical characters of BPS (Honey) based RTS beverage during storage under refrigerated condition

Storageperiod (months)	Clarity		Visual growth		pH		TSS (°Brix)		TTA (% of citric acid)	
	Control	Amla	Control	Amla	Control	Amla	Control	Amla	Control	Amla
0	Clear	Clear	Nil	Nil	4.64±0.32	4.04±0.24	12.0±0.27	13.2±0.33	0.102±0.34	0.211±0.24
1	Clear	Clear	Nil	Nil	4.41±0.35	4.38±0.27	12.1±0.25	13.4±0.34	0.086±0.35	0.198±0.19
2	Clear	Clear	Nil	Nil	4.35±0.24	4.15±0.34	12.3±0.25	13.7±0.36	0.083±0.37	0.196±0.24
3	Clear	Clear	Nil	Nil	4.27±0.22	3.95±0.32	12.4±0.22	13.9±0.25	0.080±0.28	0.182±0.27
4	Clear	Clear	Nil	Nil	4.01±0.25	3.72±0.20	12.6±0.32	14.0±0.28	0.078±0.28	0.180±0.37
5	Clear	Clear	Nil	Nil	3.95±0.19	3.64±0.20	12.8±0.31	14.1±0.29	0.075±0.26	0.177±0.18
6	Clear	Clear	Nil	Nil	3.82±0.12	3.45±0.18	13.0±0.27	14.3±0.19	0.070±0.22	0.174±0.17

						pH			TSS (°Brix)			TTA (% of citric acid)		
-	-	-	-	-	-	F- value	S.Em ±	CD at5%	F- value	S.Em ±	CD at5%	F- value	S.Em ±	CD at5%
-	-	-	-	-	-	*	0.012	0.034	*	0.013	0.035	*	0.011	0.032
-	-	-	-	-	-	*	0.013	0.035	*	0.013	0.035	*	0.012	0.034
-	-	-	-	-	-	*	0.013	0.065	*	0.024	0.065	*	0.018	0.050
-	-	-	-	-	-	*	0.023	0.065	*	0.017	0.047	*	0.023	0.065
-	-	-	-	-	-	*	0.018	0.039	*	0.032	0.089	*	0.027	0.068
-	-	-	-	-	-	*	0.030	0.055	*	0.033	0.078	*	0.022	0.062
-	-	-	-	-	-	*	0.040	0.059	*	0.027	0.069	*	0.017	0.049

* Significant at 5%, Values are mean ± standard deviation (n=3).CD- Critical difference, S.Em± - Standard error of mean, *- Significant
pH: potential of hydrogen, TSS: Total soluble solids, TTA: Total titratable acidity

There was a decreasing trend in the pH of the RTS beverage during storage period. pH decreased from 4.04 ± 0.24 to 3.81 ± 0.18 and 4.04 ± 0.24 to 3.45 ± 0.18 under room and refrigerated conditions over two and six months respectively. The pH value decreased due to the conversion of sugar into alcohols and acids or the sedimentation of certain electrolytes during storage. The TSS of RTS beverage increased from 13.2 ± 0.33 to 14.5 ± 0.29 and 13.2 ± 0.33 to 14.3 ± 0.19 at room and refrigerated temperature, respectively. Similar trend of increase in TSS was observed in control sample also. The increase in TSS was due to the hydrolysis of polysaccharides (starch) into monosaccharides (sugar), the dehydration and degradation of pectic components in the juice along with increase in juice concentration lead to TSS content increase over the course of the storage period. Significant reduction of total titratable acidity over a period of two and six months respectively for room and refrigerated condition in T2 sample. Similar trend was noticed even in control sample also (Table 5 & 6). The fruit's organic constituents interacted chemically with one another through temperature and enzyme action, resulting into drop of TTA which is responsible for extension of shelf life. Significant differences were noticed among the treatments (control and best accepted) under the study. Boghani *et al.*, (2012) who also reported the similar trend in pH, TSS and TTA for blended papaya-aloe vera RTS beverage.

In this study, RTS beverage from the BPS with natural flavours such as amla, ginger, mint and Indian pennywort along with sweeteners like sugar and honey was explored. Among the two sweeteners, honey based amla flavoured RTS beverage was highly acceptable compared to sugar in terms of sensory parameters and also it is nutritionally superior with respect to control (100% BPS). It is rich in anti-oxidant, total phenols, flavonoids, vitamin C and minerals like potassium, phosphorus and calcium. Under refrigerated storage RTS beverage can be stored up to six months without affecting the quality parameters.

Acknowledgment : Authors gratefully acknowledged the financial support of UAS-B under the project entitled 'Development of immunity boosting value added products from Centella leaves and Banana pseudo stem'. (AB/AC: 6676), logistics and facilities for ICAR-AICRP (PHET), UAS, Bangalore.

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Development of Iron Rich Til Ladoo Incorporated with *Moringa olifera* Leaves Powder

HOITINKIM SINGSON AND S. THILAKAVATHY
Department of Food Science and Nutrition, Avinashilingam Institute of Home Science and Higher Education for Women, Coimbatore - 641 043
e-Mail : thilakavathy_fsn@avinuty.com

AUTHORS CONTRIBUTION

HOITINKIM SINGSON :
Conceptualisation, conducting experiment, analysis, interpretation and drafting of the manuscript;

S. THILAKAVATHY :
Supervision and critical revision of the manuscript

Corresponding Author :
S. THILAKAVATHY

Received : July 2024
Accepted : September 2024

ABSTRACT

Iron deficiency anaemia is a primary issue around the globe, particularly among women and children in developing countries, causing a significant risk to overall wellbeing. Therefore, an attempt was made to develop iron-rich ladoo by incorporating *Moringa olifera* leaf powder (MOLP) at 0, 5, 10 and 15 per cent and assess for sensory acceptability, nutritional quality, anti-nutrient and antioxidant properties. The result shows that 5 per cent MOLP incorporated in Til ladoo was the most acceptable prototype. The protein, energy, dietary fibre, calcium, iron, β-carotene, thiamine, vitamin C, riboflavin, pyridoxine and vitamin B_{12} increased significantly ($p < 0.05$) with the incorporation of 5 per cent MOLP, whereas fat, energy and zinc decreased. The anti-nutrients oxalate, phytate and lectin decreased significantly ($p < 0.05$), while tannin and trypsin inhibitors increased. The radical scavenging activity of 5 per cent MOLP incorporated Til ladoo was significantly higher than the Control Til ladoo.

Keywords : Til ladoo, *Moringa olifera* leaf powder, Black sesame seeds, Iron-rich foods, Sensory characteristics

ANAEMIA is a severe health issue that causes social, developmental and medical challenges around the globe. About 40 per cent children 6-59 months of age, 37 per cent pregnant women and 30 per cent women 15-49 years of age globally are anaemic (WHO, 2023). Iron deficiency anaemia (IDA) has prevailed worldwide for several decades. It broadly affects the health condition of all age group particulary the pre-schoolers, children, adolescent girls and pregnant and lactating women (Bathla and Arora, 2022). In most cases, anaemia is due to iron deficiency, insufficient consumption of foods rich in iron, malabsorption, intestinal parasites and hemorrhage (Okuturlar *et al.,* 2016).

Ladoo is one of the most versatile and popularly consumed traditional Indian sweets. Value-added nutrient-dense laddoo has also been quite popular in recent years as ladoos are liked and preferred by many as their snacks. Til ladoo prepared with Black sesame seeds, roasted Bengal gram and Jaggery was used as a basic ingredient and *Moringa olifera* leaves powder was incorporated in the present study. Sesame, an ancient oil crop, is well known for its versatility and high nutrient content. Research indicates that both sesame seeds and sesame oil boast a higher concentration of phytochemicals and more significant nutritional benefits (Wei, 2022). Sesame seeds also boast significant levels of iron and zinc, contributing to their nutritional value (Kurt, 2018). Moringa leaves are rich in various micronutrients, including β-carotene, thiamin (B_1), riboflavin (B_2), niacin (B_3), iron, magnesium, calcium, phosphorus and zinc. Moringa is an excellent source of iron, a nutrient often lacking in most plant-based diet (Loa, 2021). Various studies have explored incorporating moringa leaf flour in different ranges of food products due to its potential health benefits, exploring different processing methods to ensure optimal consumer acceptance. Therefore, this study aims to develop iron rich Til ladoo incorporating with *moringa olifera* leaves powder and to assess its quality.

Material and Methods

Procurement and Processing of Raw Materials

The ingredients used to prepare Til ladoo were black sesame, roasted bengal gram dhal, ground nut, cucumber seeds, jaggery and *Moringa olifera* leaves powder. The black sesame was collected from the local farmer of Langting town in Dima Hasao District, Assam. Roasted Bengal gram dhal, ground nut, cucumber seeds and jaggery were obtained from the local market of Guwahati. *Moringa olifera* leaves were collected from Guwahati City, Assam.

The sesame seeds were manually cleaned for impurities like stones and yellowed seeds, washed thoroughly in cleaned water using a strainer with a little rubbing to facilitate the removal of the seed coat and then shade-dried for 12 hours in a well-ventilated area and then stored in an airtight container. The roasted bengal gram dhal, ground nut and cucumber seeds were also manually checked and cleaned for impurities. The ground nut and cucumber seeds were roasted in a thick bottom pan for 3-4 minutes and stored in an airtight container separately. *Moringa olifera* leaves were separated from the stem, yellowed leaves, insect-infested leaves and then washed thoroughly with clean water and drained water from the leaves and shade dried on a flat circular bamboo tray for two days in a well-ventilated room till it was thoroughly dried and ground into powder in a mixie grinder, sieved in a fine wire mesh sieve (60 mesh size-0.25 mm) and stored in an airtight container for further use.

Standardisation of Til Ladoo for Ingredients

Black sesame seeds and jaggery are the basic ingredients commonly used to prepare Til ladoo in Assam. To add value to this basic Til ladoo, other ingredients like groundnut, cucumber seeds and roasted bengal gram dhal were incorporated alongside sesame seeds, replacing 10 per cent of sesame seeds as shown in Table 1. Black sesame seeds are roasted separately in a low flame, stirring occasionally till the sesame seeds pop and roasted aroma is achieved and cooled. Groundnut and cucumber seeds are also roasted separately and cooled. Groundnut is crushed once it is cooled. Roasted bengal gram was used as it is. The jaggery is heated in low heat with a tablespoon of water till it reaches a soft ball stage. The heat is turned off, all the other ingredients are added to the jaggery solution and a ladoo ball is formed while still hot.

Table 1

Standardization of Til ladoo

Ingredients	TL-1	TL-II	TL-III	TL-IV
Black sesame seeds (g)	50	45	45	45
Groundnut (g)	-	5	-	-
Roasted Bengal gram dhal (g)	-	-	5	-
Cucumber seeds (g)	-	-	-	5
Jaggery	50	50	50	50

Preparation of MOLP Incorporated Sesame Ladoo

Using the best organoleptically accepted standardised Til ladoo, three variations with the addition of 5, 10 and 15 per cent of *Moringa olifera* leaves powder were prepared as shown in Table 2, to select the organoleptically best-accepted incorporation of Til ladoo. The sesame seed was roasted in a thick bottom pan for 10 minutes on a low-medium flame and then cooled. Jaggery was melted in a thick bottom pan. The roasted sesame seed, roasted Bengal gram dhal and *Moringa olifera* leaves powder (MOLP) were added to the jaggery syrup and mixed with a wooden ladle and laddoos were made while still hot. The prepared ladoos were cooled at room temperature and stored in an LDPE package.

Table 2

Composition of Til ladoo incorporated with *Moringa olifera* leaves powder

Ingredients	TLC	TLV-I	TLV-II	TLV -III
Black sesame seeds (g)	45	40	35	30
Roasted Bengal gram dhal (g)	5	5	5	5
Jaggery (g)	50	50	50	50
Moringa leaves powder (g)	-	5	10	15

Organoleptic Evaluation

The prepared ladoos were evaluated for their organoleptic attributes by 20 semi-trained panel members from Handique Girls' College Guwahati. A 9-point hedonic scale depicting sensory acceptance as 1-dislike extremely, 2-dislike very much, 3-dislike moderately, 4-dislike slightly, 5-neither like nor dislike, 6-like slightly, 7-like moderately, 8-like very much, 9-like extremely (Lim, 2011) was used for this purpose. The panellists were asked to evaluate the ladoos and score the ladoo with reference to hedonic scale for their attributes *i.e.,* appearance, texture, colour, flavour and overall acceptability to find out the best-accepted standardised Til ladoo as well as the best-accepted level of incorporation of *Moringa olifera* leaves powder (MOLP) incorporation. Based on the organoleptic evaluation data, the highest recorded score was finalised as the accepted product, which was further subjected to nutrient analysis and anti-nutrient analysis.

Nutrient Analysis

Moisture, ash content, protein, fat and dietary fibre were determined by the AOAC method (AOAC, 1999). Carbohydrate was calculated by differential method *i.e.,*

Carbohydrate % = 100 - (% Fat + % Protein + % Ash + % Moisture)

The Energy/Calories was calculated by

Energy = (Total Fat x 9) + (Protein x 4) + (Carbohydrate x 4)

Thiamine, riboflavin and niacin were determined by the AOAC method (AOAC, 1999). Other nutrients, namely, carotene, vitamin C, pyridoxine, vitamin B_{12}, folic acid, iron, calcium, phosphorous, iodine and zinc, were assessed using the procedures recommended by Raghuramulu *et al*., (2003).

Anti-nutrient Analysis

Phytate was analysed according to Haug and Lantzech (1983) method. Lectin was extracted in a buffer with salt precipitation and estimated by Lowry method (1951). The tannins were analysed by Folin - Ciocalteu method as suggested by Tambe and Bambar (2014). Oxalate was determined by titrating against boric acid solution (AOAC, 1999). Trypsin inhibitor was analysed as suggested by Marzo *et al*., (1998).

DPPH Assay

The free radical scavenging activity of the extracts was determined by using DPPH assay as described by Wright *et al.* (2017). The decrease in the absorbtion of the DPPH solution after the addition of an antioxidant was measeured at 517 nm.

Statistical Analysis

The data obtained were analysed for descriptive analysis for mean and standard deviation. The result for sensory analysis was analysed using One-way Analysis of variance (ANOVA) and then subjected to Tukey test of mean separation at $p< 0.05$, while an Independent t-test was used to analyse the significance ($p < 0.05$) between the nutrients, anti-nutrient of TLC and the highly accepted product. All the analysis was done using IBM SPSS 21 software.

Results and Discussion

Organoleptic Evaluation

The prepared Til ladoos using different ingredients were evaluated based on their organoleptic characteristics and the finding are summerized in Table 3.

The results shows that for all the parameter TL-III ladoo shows that higher score with 8.20 ± 0.83 for appearance and colour, 8.10 ± 0.85 for flavour, 7.50 ± 0.89 for texture, 7.50 ± 0.82 for taste and 7.65 ± 0.88 for overall acceptability. Although the score for TL-III was highest in term of value yet there was no statistical differences between the variation which shows that all the variation was accepted well by the penellist. As TL-III being the higest scorer, it was considered as a control varaiotion for further studies *i.e.,* incorporation of MOLP.

Moringa olifera leaves powder (MOLP) incorporated Til ladoo was subjected to Organoleptic evaluation

TABLE 3

Organoleptic evaluation for standardization of Til Ladoo

Variation	Appearance and colour	Flavour	Texture	Taste	Overall acceptability
TL-I	8.05 ± 0.89 [a]	7.90 ± 0.79 [a]	7.05 ± 1.00 [a]	7.15 ± 0.93 [a]	7.25 ± 0.91 [a]
TL-II	8.10 ± 0.85 [a]	7.85 ± 0.81 [a]	7.30 ± 0.98 [a]	7.30 ± 0.98 [a]	7.45 ± 0.83 [a]
TL-III	8.20 ± 0.83 [a]	8.10 ± 0.85 [a]	7.50 ± 0.89 [a]	7.50 ± 0.82 [a]	7.65 ± 0.88 [a]
TL-IV	8.15 ± 0.81 [a]	8.05 ± 0.83 [a]	7.45 ± 0.94 [a]	7.50 ± 0.95 [a]	7.55 ± 0.88 [a]

Values are presented as means ± standard deviation. Treatment values within columns with different letter are significantly different at $p \leq 0.05$, as determined by the Tukey test

and the results are depicted in Table 4. The result showed a significant difference at $p<0.05$ between the TLC and MOLP incorporated Til ladoo for all the sensory attributes.

The incorporation of MOLP decreases the acceptability of the Til ladoo. The appearance and colour of the Til ladoo ranges from 8.22 ± .76 in TLC to 6.40 ± .64 in TLV-III, which is due to the loss of lustre in the ladoo with the addition of MOLP and an increase in its volume make a ladoo appear duller in appearance and colour. The score in the flavour ranges from 8.16 ± .74 in TLC to 6.34 ± .59 in TLC-III. The decrease in the score may be attributed to the strong flavour of the MOLP, which is not characteristic of the commonly consumed Til ladoo, which may have led to grading it as a low score. The texture ranges from 7.64 ± .85 in TLC to 4.84 ± .51 in TLV-III, as adding MOLP leads to hardening. The score for the taste ranges from 7.68 ± .84 in TLC to 5.38 ± .67 in TLV-III, which may be again attributed to the distinct flavour and bitterness of leaf powder due to high phenolic and flavanoid compounds (Sankhalkar and Vernekar, 2016), which many people do not prefer. Similarly, when herbs with high phenolic and flavanoid compounds was incorporated in a flour mix, the acceptabily decreases (Rani and Jamuna, 2013). The overall acceptability of the product ranges from 7.66 ± .85 in TLC to 5.18 ± .87 in TLV-III. Similar studies with 5 per cent, 10 per cent and 15 per cent incorporation of MOLP on millet RTE snacks show the same result where TLC had the highest score in all attributes and 5 per cent incorporated snack was the only acceptable treatment (Mounika *et al.*, 2021). Other studies with MOLP incorporation shows that 1 per cent MOLP and Tulsi being acceptable in cookies, 8 per cent MOLP incorporated in cakes and 10 per cent in cookies were the most acceptable and the sensory acceptability

TABLE 4

Organoleptic evaluation of different variations of Til ladoo

Variation	Appearance and colour	Flavour	Texture	Taste	Overall acceptability
TLC	8.22 ± 0.76 [a]	8.16 ± 0.74 [a]	7.64 ± 0.85 [a]	7.68 ± 0.84 [a]	7.66 ± 0.85 [a]
TLV -I	8.02 ± 0.74 [a]	7.82 ± 0.52 [b]	7.02 ± 0.74 [b]	7.14 ± 0.67 [b]	7.14 ± 0.61 [b]
TLV-II	6.74 ± 0.83 [b]	7.08 ± 0.53 [c]	5.48 ± 0.79 [c]	5.94 ± 0.62 [c]	6.02 ± 0.59 [c]
TLV-III	6.40 ± 0.64 [bc]	6.34 ± 0.59 [d]	4.84 ± 0.51 [d]	5.38 ± 0.67 [d]	5.18 ± 0.87 [d]

Values are presented as means ± standard deviation. Treatment values within columns with different letter are significantly different at $p \leq 0.05$, as determined by the Tukey test decreases significantly with increase in MOLP concentration (Alam *et al.,* 2014; Kolawole *et al.,* 2013 and Dachana *et al.,* 2010). Therefore, based on the organoleptic scores of the incorporation of MOLP, TLV-I was found to be the most acceptable and was chosen for further study.

Nutritional Profile of *Moringa olifera* Leaves

The Nutritional profile of *Moringa olifera* leaves powder (MOLP) and Fresh *Moringa olifera* leaves (FMOL) is depicted in Table 5.

The proximate composition analysis of Fresh *Moringa oleifera* Leaves (FMOL) and *Moringa oleifera* Leaves Powder (MOLP) revealed substantial differences. FMOL had a high moisture content of 73.4 per cent, whereas MOLP exhibited effective dehydration with 4.7 per cent. MOLP showed a significant increase in energy content from 101 Kcal in FMOL to 373 Kcal, emphasising nutrient concentration. Carbohydrate content rose from 15.5 g in FMOL to 57.4 g in MOLP. Fat content increased from 1.4 g in FMOL to 4.8 g in MOLP. Protein content notably rose from 6.9 g in FMOL to 25.1 g in MOLP, emphasising amino acid concentration. Dietary fibre content significantly increased from 5.5 g in FMOL to 21.4 g in MOLP, highlighting its potential for digestive health.

Table 5

Nutrient profile of *Moringa olifera* leaves powder (MOLP) and Fresh *Moringa olifera* leaves (FMOL)

Nutrients	MOLP	FMOL
Moisture (%)	4.7 ± 0.06 a	73.4 ± 0.25 b
Energy (Kcal)	373 ± 2.55 a	101 ± 1.48 b
Carbohydrate (g)	57.4 ± 0.2 a	15.5 ± 0.15 b
Fat (g)	4.8 ± 0.15 a	1.4 ± 0.06 b
Protein (g)	25.1 ± 0.1 a	6.9 ± 0.12 b
Dietary fibre (g)	21.4 ± 0.06 a	5.5 ± 0.10 b
β-carotene(mg)	23.6 ± 0.15 a	6.5 ± 0.15 b
Thiamine (mg)	0.29 ± 0.02 a	0.08 ± 0.01 b
Riboflavin (mg)	0.21 ± 0.01 a	0.05 ± 0.01 b
Niacin (mg)	3.8 ± 0.06 a	1.1 ± 0.12 b
Pyridoxine (mg)	3.1 ± 0.06 a	0.92 ± 0.02 b
Folate (µg)	134 ± 1.0 a	40 ± 0.58 b
Vitamin C (mg)	720 ± 2.52 a	21 ± 1.53 b
Calcium (mg)	1750 ± 2.0 a	460 ± 1.15 b
Iron (mg)	24.2 ± 0.06 a	7.5 ± 0.06 b
Zinc (mg)	5.1 ± 0.1 a	1.4 ± 0.15 b

Values are the means of triplicate measurements ± standard deviation. Values in rows with different letter are significantly different ($p < 0.05$)

The vitamin and mineral analysis of Fresh *Moringa oleifera* Leaves (FMOL) and *Moringa oleifera* Leaves Powder (MOLP) demonstrates a notable increase concentration of essential micronutrients during the dehydration process. MOLP exhibited enhanced levels of vitamin A (23.6 mg), thiamine (0.29 mg), riboflavin (0.21 mg), niacin (3.8 mg), pyridoxine (3.1 mg), folate (134 µg) and vitamin C (720 mg) compared to their respective values in FMOL. Additionally, MOLP displayed increased mineral content, including calcium (1750 mg), iron (24.2 mg) and zinc (5.1 mg) compared to FMOL. These findings underscore the potential of MOLP as a concentrated source of vitamins and minerals with diverse health benefits.

Nutritional Composition of Til Ladoo

The nutritional composition of TLV-I, *i.e.,* Til ladoo with 5 per cent MOLP, was found to be the most acceptable in terms of its organoleptic score. Therefore, the best accepted Til ladoo variant (TLV-I) was analysed for nutritional composition and compared with the control Til ladoo- TLC, which is presented in Table 6.

The moisture content in TLV-I ladoo was 4.3 per cent while that of TLC was 4.1 per cent, showing no significant difference at $p < 0.05$. The fat content in TLV-I ladoo was 16.18 g, significantly lower than 18.7 g in TLC. This higher fat content in TLC ladoo can be attributed to the higher fat content in sesame seeds. The protein in TLV-I ladoo was 17.2 g compared to 16.1 g in the TLC ladoo. The significant increase protein in TLV-I could be due to the higher percentage of protein in the MOLP. Although ash content in TLV-I was 3.7 g which is more than

TABLE 6
Nutrient content of TLV-I and TLC ladoo

Parameter	TLC	TLV-I
Moisture (%)	4.1 ± 0.06 [a]	4.3 ± 0.20 [a]
Fat (g)	18.7 ± 0.31 [a]	16.8 ± 0.44 [b]
Protein (g)	16.1 ± 0.20 [a]	17.2 ± 0.26 [b]
Ash (g)	3.6 ± 0.10 [a]	3.7 ± 0.10 [a]
Carbohydrate (g)	57.5 ± 0.61 [a]	58 ± 0.66 [a]
Energy (Kcal)	462.7 ± 1.11 [a]	452 ± 2.18 [b]
Dietary fibre (g)	2.3 ± 0.10 [a]	3.1 ± 0.10 [b]
Calcium (mg)	170 ± 2.65 [a]	196 ± 4.58 [b]
Iron (mg)	11.5 ± 0.26 [a]	12.8 ± 0.20 [b]
Zinc (mg)	8.2 ± 0.20 [a]	7.1 ± 0.17 [b]
β-carotene (mg)	2.5 ± 0.10 [a]	3.3 ± 0.10 [b]
Thiamine (mg)	0.41 ± 0.04 [a]	0.45 ± 0.02 [a]
Vitamin C (mg)	1.3 ± 0.10 [a]	1.8 ± 0.10 [b]
Riboflavin (mg)	0.12 ± 0.02 [a]	0.21 ± 0.02 [b]
Niacin (mg)	2.7 ± 0.10 [a]	2.9 ± 0.20 [a]
Pyridoxine (mg)	0.38 ± 0.04 [a]	0.5 ± 0.03 [b]
Vitamin B_{12} (µg)	0.1 ± 0.03 [a]	0.18 ± 0.03 [b]
Folate (µg)	45 ± 3.61 [a]	52 ± 4.58 [a]

Values are the means of triplicate measurements ± standard deviation. Values in rows with different letter are significantly different ($p < 0.05$)

3.6 g in TLC, no significant difference was observed between the two. There was also no significant difference among the ladoos in terms of their carbohydrate content, which was 58.0 g for TLV- I ladoo and 57.6 g for TLC ladoo. The total energy of the TLV- I ladoo was 452 KCal, which was significantly lower than that of the TLC ladoo, which was 463 Kcal. This decrease is basically because 5 per cent of the sesame is replaced with MOLP in TLV-I ladoo, as sesame is rich in fat and energy. The dietary fibre content was 3.1 g in TLV-I ladoo and 2.3 g in TLC ladoo; this significant difference is due to more fibre in the MOLP.

Moringa Olifera leaves powder (MOLP) is rich in minerals like calcium and iron. Therefore, it was observed that there was a significantly higher amount of calcium content in TLV-I ladoo, which was 196 mg, as compared to 170 mg in TLC. Similarly, Iron increases significantly with the incorporation of MOLP. The TLV-I ladoo has 12.5 mg, while TLC ladoo has 11.5 mg. MOLP leaves are a rich source of iron (25-28 mg/100g) (Gopalakrishnan, 2016); therefore, incorporating Til ladoo with MOLP enhances its iron content. MOLP-incorporated products have also been shown to be effective in improving haemoglobin. It was also observed that iron and calcium content increases in the MOLP-incorporated bread (Sengev *et al.,* 2013). Iron and calcium also increased in the MOLP-incorporated utappam, idly and snacks (Gupta *et al.,* 2017 and Zungu *et al.,* 2020). Zinc content in TLV-I ladoo was 7.1 mg, significantly lower than 8.2 mg in TLC, which may be accredited to the higher Zinc content in Sesame seeds.

Moringa olifera is also a powerhouse of vitamins. Therefore, the incorporation of MOLP increases the vitamin content of a product. It is observed that the Vitamin A content of TLV-I ladoo was 3.3 µg, which was significantly higher than that of TLC ladoo with 2.5 µg. Thiamine content in TLV-I ladoo was 0.45 mg which was higher than 0.41 mg although no significant difference was observed between the two. Vitamin C content in TLV-I ladoo is 1.8 mg, significantly higher than the TLC ladoo with a Vitamin C content of 1.3 mg. Riboflavin content in TLV-I ladoo was 0.21mg, significantly higher than 0.12 mg in TLC ladoo. There is no significant difference in the niacin content of 2.9 mg in TLV-I ladoo with 2.7 mg in TLC ladoo. The pyridoxine content in TLV-I ladoo is 0.5 mg which is significantly higher than TLC ladoo. Vitamin B_{12} content in TLV-I ladoo is 0.18 µg, significantly higher than 0.01 µg in TLC ladoo. The folate content of TLV-I ladoo is 52 µg and TLC ladoo is 45 µg, with no significant difference.

Anti-nutrient Content in *Moringa olifera* Leaves

The anti-nutrient content of *Moringa olifera* leaves powder (MOLP) and Fresh *Moringa olifera* leaves (FMOL) is depicted in Table 7.

The analysis of anti-nutrient content in Fresh Moringa oleifera Leaves (FMOL) and Moringa oleifera Leaves

TABLE 7
Anti-nutrient content in MOLP and FMOL

Parameters	MOLP	FMOL
Oxalate (mg/g)	3.4 ± 0.10 [a]	0.93 ± 0.03 [b]
Phytate (mg/g)	0.12 ± 0.01 [a]	0.03 ± 0.01 [b]
Tannin (mg/g)	0.78 ± 0.01 [a]	0.25 ± 0.02 [b]
Lectin (mg/g)	0.23 ± 0.02 [a]	0.08 ± 0.02 [b]
Trypsin inhibitor (mg/g)	89 ± 1.73 [a]	26 ± 1.0 [b]

Values are the means of triplicate measurements ± standard deviation. Values in rows with different letter are significantly different ($p < 0.05$)

TABLE 8
Anti-nutrient present in TLC and TLV-I ladoo

Parameters	TLC	TLV-I
Oxalate (mg/g)	0.9 ± 0.02 [a]	0.81 ± 0.01 [b]
Phytate (mg/g)	3.5 ± 0.05 [a]	2.7 ± 0.17 [b]
Tannin (mg/g)	0.4 ± 0.02 [a]	0.76 ± 0.02 [b]
Lectin (mg/g)	0.15 ± 0.01 [a]	0.12 ± 0.01 [b]
Trypsin inhibitor (mg/g)	18 ± 1.73 [a]	23 ± 1.0 [b]

Values are the means of triplicate measurements ± standard deviation. Values in rows with different letter are significantly different ($p < 0.05$)

Powder (MOLP) reveals variations in key parameters. MOLP exhibited higher levels of oxalate (3.4 mg/g), phytate (0.12 mg/g), tannin (0.78 mg/g), lectin (0.23 mg/g) and trypsin inhibitor (89 mg/g) compared to FMOL, where these values were 0.93 mg/g, 0.03 mg/g, 0.25 mg/g, 0.08 mg/g and 26 mg/g, respectively. The increase in anti-nutrient levels in MOLP is due to the concentration of anti-nutrient during the powdering process. This also implies that the anti-nutrients levels increase during the dehydration process with the increase in nutrients.

Anti Nutrient Content in Til Ladoo

The anti-nutrient content of TLV-I and TLC ladoo is shown in Table 8.

Oxalate content of TLV-I ladoo is 0.81 mg/g, which is significantly lesser than that of 0.9 mg/g in TLC ladoo. The phytate content of TLV-I ladoo is 2.7 mg/g, which is also significantly lower than that of 3.5 mg/g in TLC ladoo. The tannin in TLV-I ladoo is 0.76 mg/g, which is significantly higher than that of 0.4 mg/g in TLC ladoo and this may be accredited to

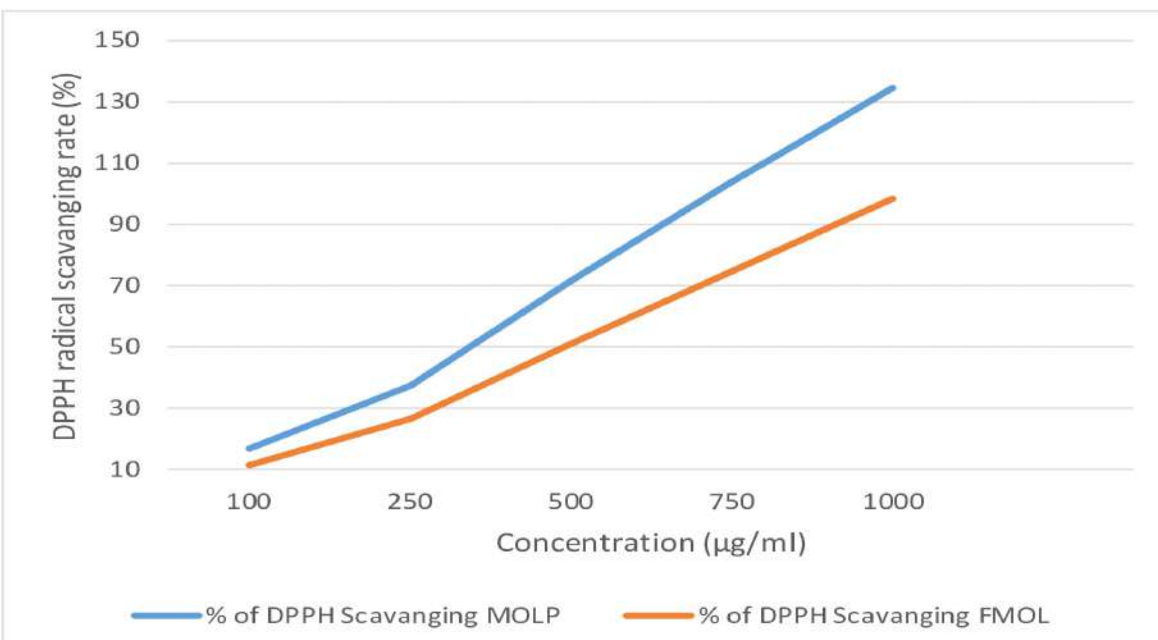

Fig. 1 : DPPH Scavenging activity of Fresh *Moringa olifera* leaves (FMOL) and *Moringa olifera* leaves powder (MOLP)

the higher tannin content in MOLP. The higher amount of oxalic and phytic acids in TLC and lower in tannin is because oxalic and phytic acid are the main antinutrients in sesame seeds, while tannin is present in small amounts (Farran *et al.,* 2000). The lectin in TLV-I ladoo is 0.12 mg/g, significantly lower than 0.15 mg/g in TLC ladoo. The trypsin inhibitor in TLV-I ladoo is 23 mg/g, significantly higher than 18 mg/g in TLC.

Antioxidant Activity (DPPH) of *Moringa olifera* Leaves

The dose-dependent DPPH radical scavenging activities of *Moringa olifera* leaves powder (MOLP) and Fresh *Moringa olifera* leaves (FMOL) are shown in Fig. 1.

Moringa olifera leaves are known to have a high antioxidant potential (Kashyap *et al.,* 2022). Fig. 1 illustrates the DPPH scavenging activity of Fresh Moringa oleifera leaves (MOFL) and Moringa oleifera Leaves Powder (MOLP). The IC_{50} value of MOLP is 345 and FMOL is 494. The graph depicts the antioxidant capacity of both samples as measured by their ability to scavenge DPPH radicals. MOLP exhibited a significantly higher scavenging activity than MOFL, suggesting an augmentation of antioxidant potential during the powdering process. This enhancement aligns with the concentration of bioactive compounds observed in the nutritional analysis. The results underscore the potential health benefits of MOLP, positioning it as a valuable source of antioxidants with implications for addressing oxidative stress-related conditions and promoting overall well-being.

Antioxidant Activity (DPPH) of Til Ladoo

The dose-dependent DPPH radical scavenging activities of TLC and TLV-I are shown in Fig. 2.

The IC_{50} of TLC and TLV-I was 659 µg/ml and 345 µg/ml, respectively, indicating that TLV-I has significantly higher antioxidant activity as compared with TLC ladoo. Moringa leaves, including the dried leaves, have a high antioxidant content with a high free radical scavenging activity (Aly *et al.,* 2022). A similar result was found in MOLP-incorporated products, where incorporating biscuits with moringa leaf powder increases the product's antioxidant content. (Kc *et al.,* 2022).

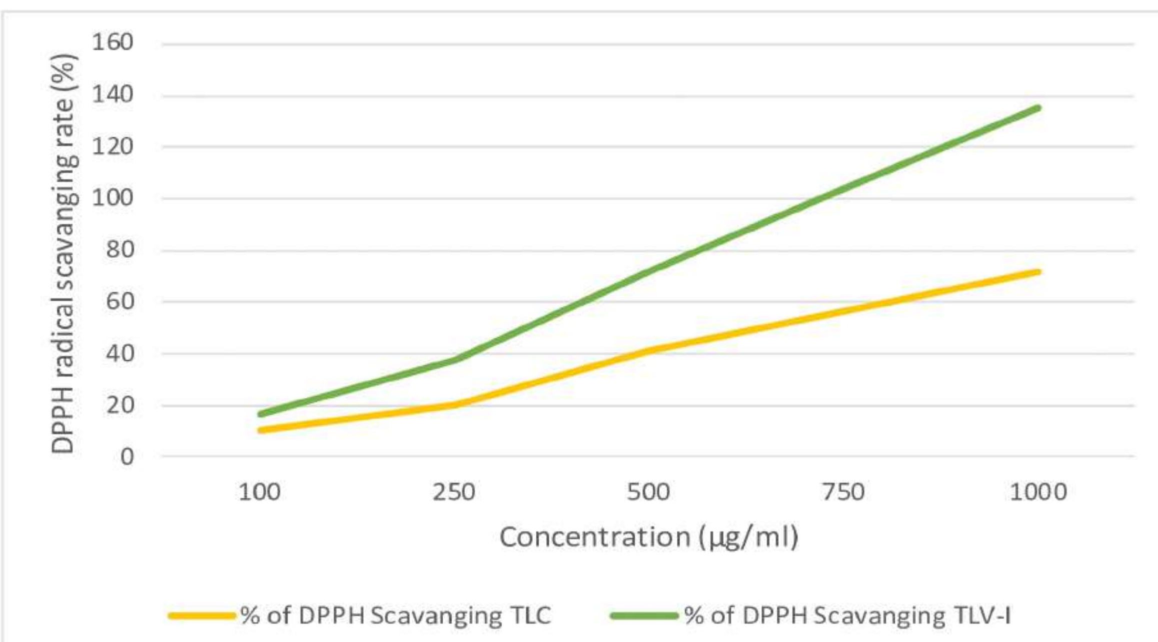

Fig. 2 : DPPH Scavanging activity of TLC and TLV-I

The present investigation demonstrated that the percentage of nutrient, anti-nutrient as well as antioxidant concentration is concentrated when the fresh *Moringa olifera* leaves are converted to *Moringa olifera* leaves powder. It is also seen that the incorporation of MOLP beyond 5 per cent decreases the sensory acceptability of the Til ladoo. While fat and energy decrease significantly, carbohydrates, fat and all the micronutrients increase in quantity with MOLP incorporation. The radical scavenging properties of Til ladoo have also improved with MOLP incorporation. Therefore, the developed product could be considered a novel product with nutritionally improved quality.

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Isolation, Identification and Characterization of Microbes Associated with Leaves of Roadside Tree Species under Different Pollution Levels

JYOTI VERMA[1], PARMINDER SINGH[2] AND PRIYA KATYAL[1]
[1&2]Department of Floriculture & Landscaping and [3]Department of Microbiology,
Punjab Agricultural University, Ludhiana - 141 004, Punjab
e-Mail : jayothiverma@gmail.com

AUTHORS CONTRIBUTION

JYOTI VERMA :
Experimentation, data collection and manuscript writing;

PARMINDER SINGH :
Data analysis, manuscript editing and supervision;

PRIYA KATYAL :
Conceptualization, experiment planning and interpretation

Corresponding Author :
JYOTI VERMA

Received : July 2024
Accepted : August 2024

ABSTRACT

Air pollution is a significant issue in urban areas today. Plants play a crucial role in absorbing and adsorbing air pollutants, making them the first line of defense. Prolonged exposure to pollution leads to changes in various aspects of plants, including their appearance, functions, biochemistry and even the microorganisms that live on their leaves. In this study, researchers compared the phyllosphere (the microbial community on leaves) of eight common roadside trees between a control and polluted site. They observed that exposure to air pollution alters both the plants and the microbes associated with them. Interestingly, the microbial count was highest at the less polluted site (13.50 CFU/ml for bacteria and 3.44 CFU/ml for fungi) compared to the polluted site (2.50 CFU/ml for bacteria and 2.44 CFU/ml for fungi). Trees in polluted areas showed an abundance of specific bacteria such as *Shigellae*, *Enterobacter* and *Streptococcus* and fungi like *Absidia*, *Mucor*, *Phialophora* and *Aspergillus*. Additionally, these trees exhibited increased production of secondary metabolites such as phenols and ascorbic acid. Among the different species studied, *Acacia auriculiformis* showed the highest relative abundance of these characteristics. These findings underscore how changes in air quality affect the phyllosphere of plants. They provide valuable insights into how plants adapt to polluted environments and suggest that the phyllosphere could be a cost-effective resource for bioremediation of air pollution in urban settings.

Keywords : Air pollution, Phyllosphere, Secondary metabolites, Urban setting, Roadside trees

VEHICLE emissions are a significant contributor to air pollution in urban areas. The levels of air pollutants such as particulate matter, nitrogen oxides, sulfur dioxide and volatile organic compounds have reached alarming levels (Archibald *et al.*, 2017). In India, for instance, people are exposed to approximately 90 $\mu g/m^3$ of PM 2.5 daily, well above the national standard *i.e.,* 60 $\mu g/m^3$ (Balakrishnan *et al.*, 2017). The World Health Organization has identified air pollution as the largest environmental health threat globally (WHO, 2016). In India alone, air pollution is responsible for around 600,000 premature deaths annually (Ghude *et al.*, 2016). Continuous exposure to pollutants, especially along roadways, is causing a rise in health problems. Planting vegetation along side roads can effectively serve as a surface to capture air pollutants. Plant leaves, which cover approximately 4×10^8 km² of the earth's surface (Kembel *et al.*, 2014), along with the micro organisms on their surfaces (known as phyllosphere), play a crucial role in enhancing air pollution tolerance. Air pollutants get adsorbor /absorb to plant leaves, microflora associated with their aerial parts known as phyllosphere (Last 1955) contributes towards plants air pollution tolerance and reported to be able to biodegrade or transform pollutants into less toxic molecules (Last, 1955; Mueller *et al*., 1996 and Ma *et al*., 2016). It is an important aspect to have a reliable economic way out for future air pollution-related increasing problems. In the polluted environment, changes in plant's morphological, physiological and biochemical parameters are associated with a change in phyllosphere composition. Even different tree/ plant species vary in their phyllosphere composition (Redford *et al*., 2010). Micro organisms such as bacteria, fungi and algae that inhabit leaves are crucial for plant health and ecosystem functioning (White *et al*., 2013). The microbiome of the plant phyllosphere has been shown to play an important role in the adaptation of the plant host to different environmental stressors by enhancing tolerance to heat, cold, drought and salinity (Whipps *et al.,* 2008; Kembel *et al.,* 2014; Martirosyan & Steinberger, 2014; Agler *et al*., 2016 and Saleem *et al*., 2017). These microorganisms form complex communities that can influence leaf function, nutrient cycling and plant disease resistance (Selosse *et al*., 2017). For example, certain bacteria can fix nitrogen, enhancing soil fertility, while fungi such as mycorrhizae form symbiotic relationships with plant roots, aiding in nutrient absorption (Jones *et al*., 2009). Additionally, some fungi and algae can help protect leaves from pathogens by outcompeting harmful microbes (Anderson *et al*., 2009). Overall, these micro organisms contribute to the dynamic balance of plant ecosystems and the overall health of vegetation. With prolonged exposure to the polluted environment, some plants and so their phyllosphere acquire tolerance and thus, it becomes necessary to find out microflora associated with trees in different localities so that trees can be smartly used in landscaping either for phylloremediation (tolerant trees and their leaf associated microflora) or as biomonitor (susceptible trees) of air pollution. But the potential of trees and their leaf associated microbes for air remediation and their distribution in polluted and non-polluted phyllosphere is still unexplored. Microorganisms play a crucial role in enhancing plant tolerance to pollution, helping to mitigate the impact of contaminants on ecosystems. For instance, rhizobacteria such as *Pseudomonas putida* and *Bacillus cereus* can improve plant resilience to heavy metals like lead and cadmium by either detoxifying these metals or stimulating the plant's own stress response mechanisms (Khan *et al*., 2019). Similarly, arbuscular mycorrhizal fungi like *Glomus intraradices* are beneficial in contaminated soils, where they enhance plant growth by improving nutrient uptake and reducing metal toxicity (Alvarado *et al*., 2019). Endophytic fungi, such as *Fusarium oxysporum*, assist plants in tolerating organic pollutants, including pesticides and hydrocarbons, by degrading these substances or aiding in their removal (Davies *et al*., 2012). In the context of air pollution, algae like *Chlorella vulgaris* are used in biofilters to absorb airborne pollutants, including carbon dioxide and particulate matter (Xu *et al*., 2018). Lastly, nitrogen-fixing bacteria such as *Rhizobium* species maintain plant growth and soil health in polluted environments by fixing atmospheric nitrogen, which is crucial for plant nutrition (Garcia *et al*., 2018). These microorganisms not only support plant health but also contribute to broader environmental remediation efforts.

From the information provided, it's evident that roadside greenery serves as a natural buffer against air pollution from vehicle emissions, absorbing pollutants directly through their leaves. However, there's a notable absence of detailed studies on how roadside trees in India, particularly in Ludhiana, Punjab, contribute to phylloremediation the process by which plants and their associated microbes mitigate air pollution. To address this gap, the current study aims to conduct preliminary research focused on isolating and identifying bacteria and fungi found on the leaf surfaces of selected roadside trees in Ludhiana, Punjab. This initial step is crucial for identifying microbes that may play a role in enhancing plant tolerance to pollution.

Material and Methods

Study Area

Ludhiana city (30°-34' and 31°-01' and N to75°-18' and 76°-20' E latitude) has spread over an area of 159.37 km^2 having population of 1.86 million in 2019 with growth rate of 1.48 per cent with a height of 247 m above the sea level. Eight most common roadside trees (*Acacia auriculiformis*, *Alstonia scholaris*, *Cassia fistula*, *Cassia siamea*, *Chukrasia tabularis*, *Dalbergia sissoo*, *Heterophragma adenophyllum* and *Putranjiva roxburghii*) were selected at control /less polluted site (Punjab Agricultural University, Ludhiana) and Polluted site (NH-5). As reported by many earlier studies that particle concentrations will be highest closest to than 100-250 meters from the highway (De Winter *et al*., 2018; Ridem, 2019 and Rattigan *et al*., 2020). The samples were collected 100 m away from roadside from interior area of the campus which was treated as control site. Due to rapid industrialization and urbanization in Ludhiana, air pollution levels is reported quite high which makes it a suitable place for air pollution related studies (Rajesh Kumar *et al*., 2010 and Goel *et al*., 2021).

Sample Collection

Trees of uniform age, size and canopy spread were carefully selected to ensure consistency across the study. The research encompasses eight common roadside ornamental trees, each treatment replicated three times at both control and polluted sites. Leaf samples were collected from selected trees from control (100 m away from main road) and polluted site (next to road) at mid canopy height (1 to 2 m). These samples were immediately placed in ice-filled containers and stored in plastic zip-lock bags. Microbiological analysis commenced within 8 hours of sampling. The isolation of microbes followed a two-step process as outlined by Dickinson (1971). Firstly, the leaves were aseptically shredded into small pieces within a laminar flow hood. Approximately one gram of leaf sample was transferred to peptone water, which served as an enrichment medium. The suspension was then incubated under shaking conditions for 2 hours to detach all microorganisms from the leaf surfaces. After enrichment, the microbial suspension was serially diluted and spread onto specific media: nutrient agar (NA) for bacteria and glucose yeast extract (GYE) for fungi. Incubation followed at 37°C for 24 hours for NA plates and at 25°C for 3-5 days for GYE plates to facilitate optimal growth. Subsequently, the plates were examined for various parameters including total plate count, relative abundance (adapted from Walag and Canencia, 2016), colony characteristics, Gram staining as per Bergey's Manual and biochemical tests such as catalase, oxidase, nitrate reductase, starch hydrolysis, citrate utilization, gelatin liquefaction, methyl red and Voges-Proskauer reactions (Cheesbrough, 2006; Aneja, 2006; Olutiola *et al*., 2000 and Hunter & Barnett, 2000). These steps were part of the phenotypic characterization to identify and study

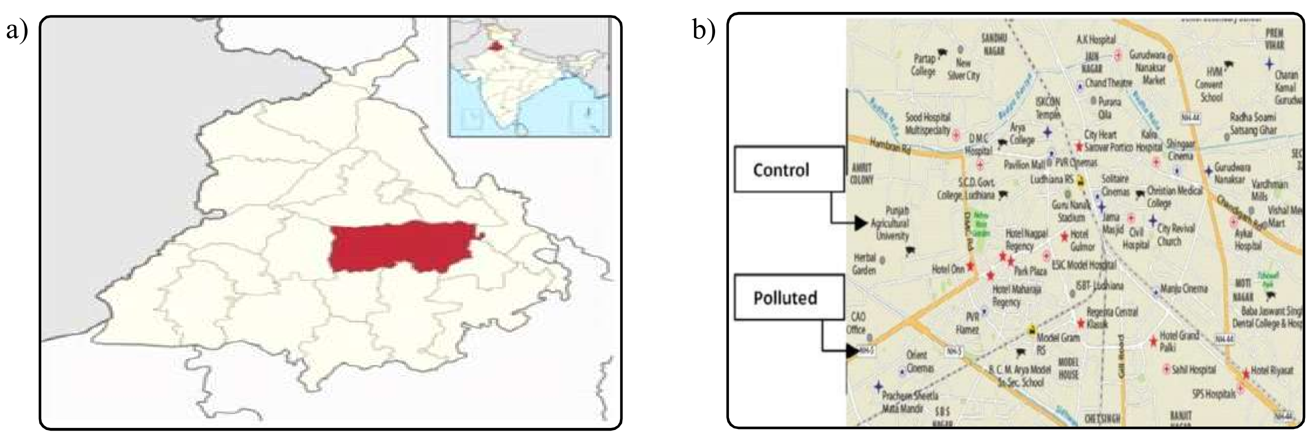


Fig. 1 : Map showing study area; a) Ludhiana District; b) Locations PAU campus (Control), NH-5 (Polluted)

the microbial communities associated with the leaf surfaces of roadside trees in Ludhiana, Punjab.

The identification of fungi involved morphological and microscopic analysis, which included examining the type of spores and conidia. This examination was conducted after staining with cotton blue lactophenol, following the method described by Hunter and Barnett (2000).

Statistical Analysis

The data were analyzed using a factorial Completely Randomized Design. Mean comparisons were conducted using Tukey's test at a significance level of 5 per cent, employing SAS software version 9.2 on a computer.

RESULTS AND DISCUSSION

Microbial colony forming units (CFU/ml) from bacterial and fungal cultures were assessed at both sites: Control and Polluted (Devakumar *et al*., 2018) (Fig. 2). CFU counts were higher at the control location compared to the polluted site. Abdelfattax *et al.,* 2015; Venkatachalam *et al.,* 2016; Bhattacharyya *et al*., 2017; Alsohaili & Bali-hasal, 2018 and Ray *et al*., 2019. At control site, bacteria's were found dominating as compare to fungi (Thamchaipenet *et al*., 2010 and Sanchez-Lopez *et al*., 2018). A total of six bacterial isolates were purified from leaves of selected roadside trees at both control and polluted locations, based on their distinctive visual characteristics. These isolates were subsequently characterized by their colony morphology, which varies among bacterial genera.

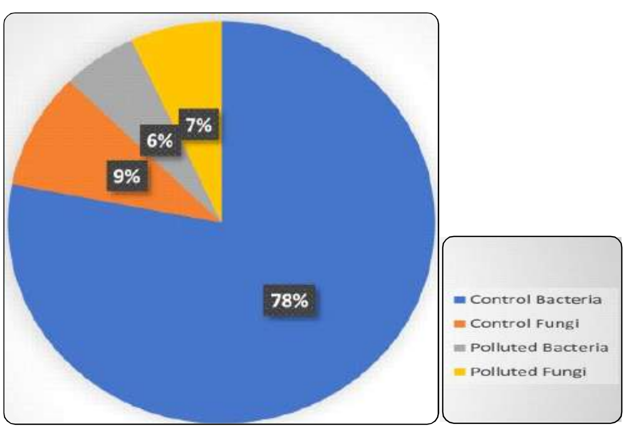


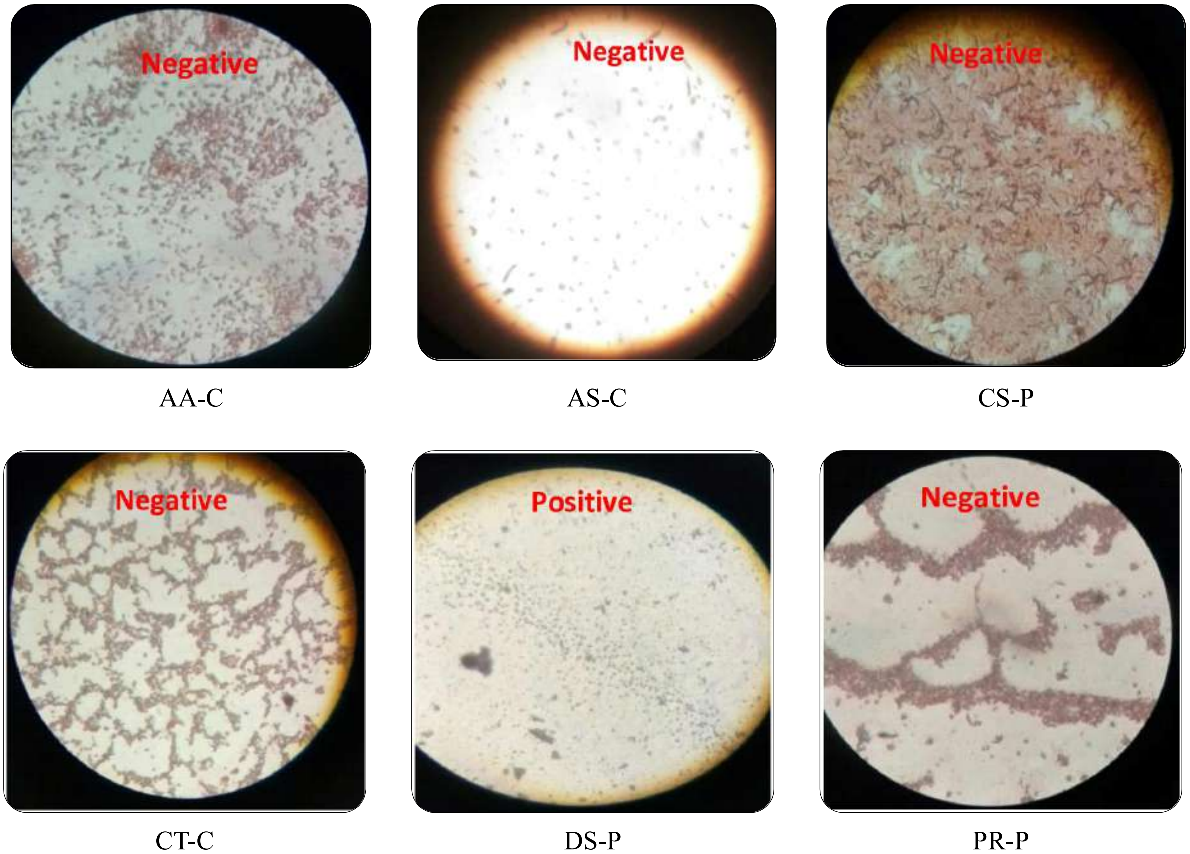
Fig. 2 : Plate count of bacteria isolated from leaves of roadside trees from control and polluted locations

TABLE 1

Morphological and biochemical characteristics of bacterial isolated from leaves of roadside trees from control and polluted locations

Sample	Colour	Optical Property	Texture	Shape/ Colony	Elevation	Appearance	Gram's test	Starch	Citrate	Oxidase	Catalase	Nitrate reductase	MR test	VP test	Gelatin	Expected genera
AA-C	Creamish	Opaque	Smooth	Cocci/ Undulate	Flat	Dull	-	+	+	+	-	-	+	-	+	*Yersinia*
AS-C	Creamish	Translucent	Smooth	Short Rods /Undulate	Flat	Shiny	-	+	+	+	-	-	+	-	-	*klebsiella*
CS-P	White	Opaque	Smooth	Bacillus/ Round	Flat	Dull	-	+	-	+	-	+	+	-	+	*Shigellae*
CT-C	Whitish Cream	Opaque	Smooth	Cocci/ Undulate	Flat	Dull	-	+	+	+	-	-	-	-	-	*Enterobacter*
DS-P2	Creamish	Opaque	Smooth	Cocci/ Undulate	Flat	Shiny	+	+	-	+	-	-	-	-	+	*Streptococcus*
PR-P	Creamish	Opaque	Smooth	Cocci/ Undulate	Flat	Dull	-	+	+	+	-	-	-	-	-	*Enterobacter*

AA-C: *Acacia auriculiformis* (Control); AS-C: *Alstoniascholaris* (Control); CS-P: *Cassia siamea* (Polluted); CT-C: *Chukrasia tabularis* (Control); DS-P: *Dalbergia sissoo* (Polluted); PR-P: *Putranjiva roxburghii* (Pollution)



AA : *Acacia auriculiformis* (Control); AS-C : *Alstonia scholaris* (Control); CS-P : *Cassia siamea* (Polluted);
CT-C : *Chukrasia tabularis* (Control); DS-P : *Dalbergia sissoo* (Polluted); PR-P : *Putranjiva roxburghii* (Polluted)

Fig. 3 : Microscopic examination of Gram's Test on isolated pure bacterial cultures from control and polluted locations

Various morphological and biochemical traits of these isolates were analyzed and are summarized in Table 1 and Fig. 3.

The study involving selected roadside tree species, seven fungal cultures were chosen for detailed microscopic examination based on their distinctive appearance. Morphological characterization was conducted on these fungal isolates purified from leaves collected at both control and polluted sites. Table 2 and Fig. 4, present various macroscopic and microscopic features observed in these fungal isolates. Characteristics such as colony morphology, spore type, hyphal structure, septation and branching patterns were assessed to identify the fungal isolates up to the genus level, following the methodology described by Wang *et al*. (2016). Fig. 5, depict the levels of phenol and ascorbic acid content in eight ornamental roadside trees across two locations. The content was consistently higher at the polluted location compared to the control site for all trees examined.

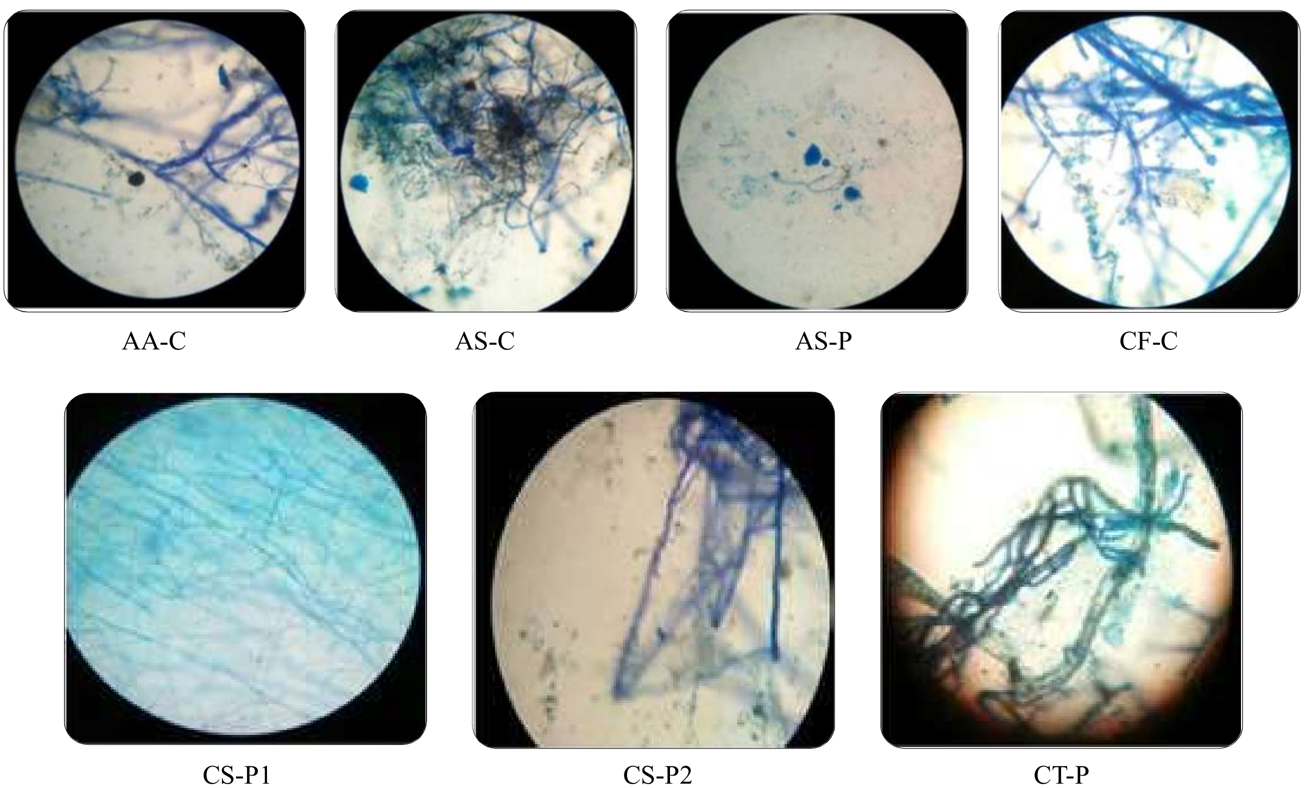
Our study investigated the effects of air pollution on leaf-associated microbial communities across eight tree species, revealing significant impacts on both microbial abundance and plant biochemical responses. At the control site, where pollution levels were lower, trees showed significantly higher colony-forming unit (CFU) counts, suggesting a more favorable environment for microbial growth. In contrast, the polluted site, characterized by elevated particulate matter, showed a marked reduction in microbial populations (Joshi, 2007 and Chaudhuri, 2017) Notably, specific bacterial genera such as *Shigella* and *Enterobacter* along with fungal genera like *Absidia*, *Mucor*, *Phialophora* and *Aspergillus* were more abundant at the polluted location (Kang *et al*.,

TABLE 2

Morphological characteristics of fungal isolated from leaves of roadside trees from the control and polluted locations

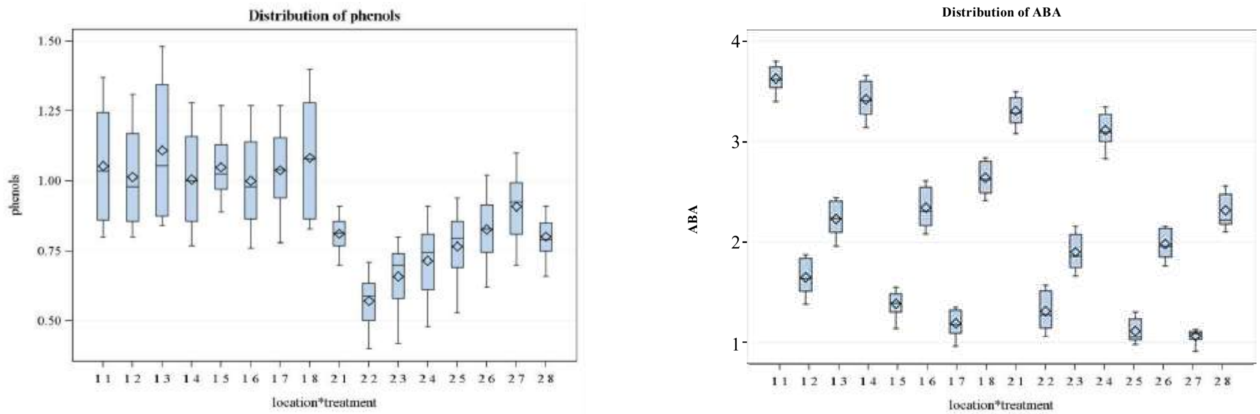
Source of culture	Microscopic features	Macroscopic features	Expected genera
AA-C	Sparsely septate broad hyphae	Cottony growth	*Rhizopus*
AS-C	Waxy bent broad mycelia with intercalating spores	The growth rate of colonies slow, texture velvety, with black colour	*Cladosporium*
AS-P	Small pear-shaped sporangia	Wooly grey colour fast-growing colonies	*Absidia*
CF-C	aseptate hyphae with sporangiospores	Cottony growth	*Rhizopus*
CS-P1	Ribbon like aseptate hyphae with right-angle branching	Fluffy cottony growth	*Mucor*
CS-P2	Branched coenocytic mycelium	Black velvety growth	*Phialophora*
CT-P	Broad septate hyphae with acute angle branching	Grayish green colour colonies	*Aspergillus*

AA-C: *Acacia auriculiformis*(control); AS-C: *Alstonia scholaris* (control); AS-P: *Alstonia scholaris* (Polluted); CF-C: *Cassia fistula* (Control); CS-P: *Cassia siamea* (Polluted); CT-P: *Chukrasia tabularis* (Polluted)



AA-C : *Acacia auriculiformis* (control); AS-C : *Alstonia scholaris* (control); *Alstonia scholaris* (Polluted); CF-C : *Cassia fistula* (Control); CS-P : *Cassia siamea* (Polluted); CT-P : *Chukrasia tabularis* (Polluted)

Fig. 4 : Microscopic Examination of isolated pure fungal cultures from control and polluted locations



Treatments : 1 : *Acacia auriculiformis,* 2 : *Alstonia scholaris,* 3 : *Chukrasia tabularis,* 4 : *Cassia fistula,* 5 : *Cassia siamea,* 6 : *Dalbergia sissoo,* 7 : *Heterophragma adenophyllum,* 8 : *Putranjiva roxburghii*; Location : 1 : Polluted; 2 : Control

Fig. 5 : Variation in phenol and Ascorbic acid (ABA) content of selected roadside tree species growing at two different locations in Ludhiana city

2016; Bharti *et al*., 2012 and Li *et al*., 2018). These genera include opportunistic and pathogenic species, suggesting that pollution can create niches for harmful microbes while reducing populations of more beneficial ones.

Secondary metabolite production also provided insights into plant responses to pollution. Consistent with previous studies (Chandawat *et al*., 2014 and Alhesnawi *et al*., 2018), trees at polluted sites exhibited higher levels of total phenols and ascorbic acid. This increase is likely a defensive response to elevated oxidative stress resulting from pollution, reflecting the plants' attempts to mitigate environmental stressors through biochemical means.

These findings have significant implications for urban ecosystem management. The altered microbial dynamics and increased secondary metabolite production underscore the importance of understanding how air quality affects both plant health and microbial communities. The presence of metal-tolerant Enterobacter at polluted sites suggests a potential role in bioremediation, utilizing metal pollutants for growth. This insight could guide strategies for pollution management through targeted microbial interventions.

Moreover, the study highlights the need for incorporating these insights into urban green space design. By selecting tree species with high resilience to pollution and beneficial microbial interactions, urban planners can enhance both environmental quality and aesthetic value. Effective green infrastructure, including parks, green belts and green walls, can improve air quality and support plant health.

Ultimately, understanding the interactions between plants, microbes and pollutants provides a foundation for developing sustainable urban environments. These insights are crucial for advancing strategies that integrate ecological and environmental considerations into urban planning and management practices, aiming to create resilient and healthy urban ecosystems.

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Mysore J. Agric. Sci., **58 (4) : 77-88 (2024)**

Accumulation and Decomposition of Litter in Different Agroforestry Systems under Semiarid Condition

A. Kokila, C. Nagarajaiah and D. C. Hanumanthappa
Department of Forestry and Environmental Science, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : kokila95.anbalagan@gmail.com

Authors Contribution

A. Kokila : Conceptualization, investigation and draft preparation;

C. Nagarajaiah & D. C. Hanumanthappa : Conceptualization, framed research proposal, supervision and draft correction;

Corresponding Author :
A. Kokila

Received : July 2024
Accepted : August 2024

Abstract

Agroforestry integrates woody perennials with crops and/or animals, fostering ecological and economic interactions. This study examined litter accumulation and decomposition in seven agroforestry systems such as Teak (*Tectona grandis*), Mahogany (*Swietenia mahagoni*), Malabar Neem (*Melia dubia*) Pongam (*Pongamia pinnata)*, Mango (*Mangifera indica),* Cashew *(Anacardium occidentale)* and Jamun (*Syzygium cumini).* at GKVK, Bengaluru, India, over one year. Litter was collected monthly using traps and analyzed for decomposition rates using litter bags. Results indicated that most of the tree species follow an unimodal pattern of litterfall and have peak litterfall during the months of late rainy and dry seasons. The litter production was significantly higher in *S. mahagoni* and lower in *P. pinnata*. Among the tree species, litter from *P. pinnata* was found to decompose faster with a low half-life period. Litter from *S. mahagoni* and *S. cumini* observed slow rate of decomposition where small portions of litter remained undecomposed. Seasonal fluctuations influenced decomposition, with higher rates in June-August. The study underscores the importance of species selection in agroforestry for effective nutrient cycling and soil fertility.

Keywords : Agroforestry systems, Litter accumulation, Decomposition

Agroforestry is a collective name for a land-use system and technology whereby woody perennials are deliberately used on the same land management unit as crops and/or animals in some form of spatial arrangement or temporal sequence. In an agroforestry system there are both ecological and economical interactions between the various components. It is recommended as a sustainable land use practice for augmentation of biomass production which delimits the opportunities of deforestation, declining soil fertility, occur of droughts and illegitimate use of dangerous chemicals (Nair, 1984 and Kang & Wilson, 1987). It can be an attractive choice for environmental, social and economic development because it improves the environmental quality generating additional income to the farmers (Radhakrishnan & Varadharajan, 2016 and Arya *et al*., 2017).

Litter fall from upper storey trees in agroforestry systems plays a crucial role in maintaining the input-output system of nutrient, the rate at which decomposes controlling the nutrient cycling and the overall improvement (Murovhi *et al*., 2012 and Singh *et al*., 2019). Especially in the tropics where most of the recycling nutrient depends on the amount of litter on the forest floor. Litter production in any ecosystem depends on climatic condition of the ecosystem, the forest type, species composition, the age of the forest and plantation and method of conversion of the original forest to the plantation. Litter cover acts as a protective layer for improving the soil's physical properties like retaining soil moisture, buffering against soil temperature and compaction change and soil conservation from erosion or leaching (Mo *et al.,* 2003 and Bargali *et al.,* 2015). It also provides habitats and substrates for soil fauna and flora (Ruf *et al*., 2006).

The decomposition of litter is an important part of nutrient cycling in forests. The rates at which litter falls and subsequently decay thus in understanding the productivity and nutrient budgeting of these ecosystems (Shivakumar *et al.*, 2014**)**. Decomposition plays an important role in maintaining soil carbon and nutrient pools as well as fertility in a forest ecosystem. The rate of decomposition and nutrient release varies with a number of factors, including rainfall, humidity, temperature, soil moisture, edaphic factors and including the nature of the plant material (Singh *et al*., 1999) (Pandey *et al*., 2006). Meanwhile, their chemical constituents also play a significant role in the amount of nutrient addition through leaf litter decomposition varies from species to species (Mahmood *et al*., 2011). Foliar litter occupies a major fraction of the litter in forest ecosystems and maybe totally decomposed within a year in subtropical and tropical areas. It is thus of importance to evaluate the pattern of litter accumulation, decomposition and its influence on the different agroforestry systems.

MATERIAL AND METHODS

Experiment Site

The experiment was conducted in Agroforestry plot under the maintenance of AICRP (All India Coordinated Research Project) on Agroforestry located in Gandhi Krishi Vignana Kendra (GKVK), the main campus of the University of Agricultural Sciences, Bengaluru, Karnataka. Geographically, the site is located at 12° 58' N latitude, 77°35' E longitude having an altitude of 930 m above MSL. It is located in Eastern Dry Agro-climatic Zone (Zone-V) of Karnataka.

Climatic Conditions

GKVK has a tropical climate with distinct wet and dry seasons. The average annual rainfall of the station is 920 mm. The major portion of it is received during April to November with two peaks in September (196 mm) and October (164.7 mm). The mean maximum air temperature ranges from 26.3 to 33.8p C. The mean monthly relative humidity ranges from 76 per cent in March to 90 per cent in August. Maximum bright sunshine hours are recorded in February (9.6 hr) and lowest in July (4.4 hr) and the mean wind speed is maximum during June (12.2 km/hr) and the minimum in October (5.4 km/hr). The open pan evaporation is directly related to the maximum and minimum temperature of the month and follows the same trend as that of maximum temperature and is maximum during March (7.5 mm per day) and April month (7.4 mm per day).

Experiment Details

The experiment was conducted in the Agro-forestry field unit of AICRP on Agroforestry at GKVK, Bangalore. Here, seven different agroforestry systems *viz.,* Teak (*Tectona grandis*), *Meliadubia*, *Pongamiapinnata*, Mahogany (*Swietenia mahagoni*), Cashew *(Anacardium occidentale)*, Mango (*Mangifera indica) and* Jamun (*Syzygium cumini)* were studied with different intercrops consisting either a cereal or a pulse crop (Table 1). The experiment was carried out for one year (June 2022 to May 2023). Samples were collected at monthly intervals.

Quantification of Litters

Leaf litters of each tree species were collected from agroforestry systems in an area of 1m×1 m using litter traps (Sundarapandian and Swamy, 1999). With three litter traps for each tree species, totally 21 litter traps were established (plate 1). The litters were collected at monthly interval. The collected leaf litters were washed, oven dried and then weighed. The recorded weight was added to quantify the accumulation of litters during the study period.

Litter Decomposition Pattern

The standard litterbag technique was employed for characterising litter decomposition rates (Pinos *et al*., 2017). Twenty grams of leaf litter samples were

TABLE 1

Details of tree species and intercrops in different agroforestry systems (2022-23)

Tree species	Field crop	Year of planting	Spacing
Teak (*Tectonagrandis*)	Fodder Sorghum (*Sorghum bicolor*)	2010	8 m x 3 m
Melia (*Meliadubia*)	Finger millet (*Eleusine coracana*)	2010	8 m x 5 m
Pongamia (*Pongamiapinnata*)	Cowpea (*Vigna unguiculata*)	2017	5 m x 5 m
Mahogany (*Swietenia mahagoni*)	Cowpea (*Vigna unguiculata*)	2010	10 m × 5 m
Cashew (*Anacardium occidenatle*)	Sunnhemp (*Crotalaria juncea*)	2007	10 m x 10 m
Mango (*Mangifera indica*)	Sunnhemp (*Crotalaria juncea*)	2007	10 m x 10 m
Jamun (*Syzygium cumini*)	Sunnhemp (*Crotalaria juncea*)	2007	10 m x 10 m

Plate 1 : Litter traps for litter accumulation study

Plate 2 : Litter bags for litter decomposition study

packed into mesh bags (dimensions: 20x20 cm: 2 mm mesh size) and were sealed. A total of 36 bags were buried in the soil sub-surface of each tree species. At monthly intervals, three bags from each tree species were retrieved from the soil and analysed in the laboratory. The bags were gently rinsed with water to remove the soil and other extraneous materials. The residual litter mass removed from the bags were oven dried at 80°C and weighed to estimate the decomposition rate (plate 2).

Rate of Decomposition Pattern

The litter decomposition rate was compared using litter decay rates, estimated with the commonly used first-order negative exponential decay model (Olson, 1963),

$$X_t = X_0 e^{-kt} ; k = - \ln(X_t - X_0)/ t$$

Where X_0 and X_t are initial and final litter masses, respectively and t is a time interval.

Statistical Analysis

The experimental data obtained during the course of investigation were subjected to statistical analysis by applying the technique of analysis of variance (ANOVA) appropriate to the design to test the significance of the overall differences among the treatments. All statistical analyses were carried out using SPSS 16.0 software.

TABLE 2

Litter accumulation (kg/ha) from different agroforestry systems (2022-23)

Months	Tree species							
	T. grandis +Fodder Sorghum	*M. dubia*+ finger millet	*P. pinnata* +cowpea	*S. mahagoni* +cowpea	*A. occidentale* + Sunnhemp	*M. indica* + Sunnhemp	*S. cumini* + Sunnhemp	Mean
June	37.25	63.25	75.68	691.60	554.22	223.81	391.53	291.05 [g]
July	83.82	120.00	65.69	684.40	642.09	289.23	512.53	342.54 [g]
August	82.68	190.00	75.68	640.00	735.76	665.34	646.20	433.67 [f]
September	114.15	298.01	79.68	719.40	1201.50	554.25	827.65	542.09 [e]
October	357.24	746.49	86.98	898.65	1305.99	727.53	978.68	728.79 [d]
November	735.10	951.50	112.45	936.20	1285.00	967.38	1492.60	925.75 [c]
December	919.30	1044.25	124.38	1077.10	1250.00	2047.50	1709.15	1167.38 [a]
January	320.80	1231.26	152.75	1432.20	1060.00	1718.40	1927.78	1120.46 [b]
February	204.09	958.50	182.28	1917.60	936.60	886.44	1075.17	880.1 [c]
March	50.69	613.25	146.74	2017.20	696.21	670.62	951.92	735.23 [d]
April	3.42	230.00	108.61	1156.90	612.94	288.67	937.27	476.83 [f]
May	1.11	77.51	94.54	955.30	706.90	398.28	820.92	436.37 [f]
Total	2909.66	6524.02	1305.46	13126.55	10987.21	9437.45	12271.39	
Mean	242.47 [f]	543.69 [e]	108.79 [g]	1093.88 [a]	915.60 [c]	786.45 [d]	1022.62 [b]	

	Months	Species
S.Em±	4.722	6.183
CD (P=0.05)	13.196	17.277

Note : Alphabets in superscript indicate the significance level

RESULTS AND DISCUSSION

Litter Accumulation of Tree Species

The mean litter biomass varied from 108.79 kg/ha to1093.88 kg/ha on the floor of different agro forestry systems where the seasonal pattern of litter biomass was similar (Table 2). The litterfall is in the order; *S. mahagoni* (13126.55 kg/ha) >*S. cumini* (12271.39 kg/ha) >*A. occidenatle* (10987.21 kg/ha) > *M. indica* (9437.45 kg/ha) >*M. dubia* (6524.02 kg/ha) >*T. grandis* (2909.66 kg/ha) >*P. pinnata* (1305.46 kg /ha). Mean monthly litter was found to be higher in *S. mahagoni* (1093.88 kg/ha) followed by *S. cumini* (1022.62 kg/ha) *and A. occidenatle* (915.60 kg/ha). Lower accumulation has been recorded in *P. pinnata* (108.79 kg/ha) and *T. grandis* (242.47 kg/ha). litter accumulation was higher during the months of low rain and dry seasons.

In *T. grandis*, the overall litter accumulation during the study period was 2909.66 kg/ha. Being deciduous, teak undergoes litterfall in specific seasons, notably in November (735.10 kg/ha) and December (919.30 kg/ha). These months contribute 25.26 per cent and 31.59 per cent, respectively, to the total litter accumulation, showcasing a distinct unimodal litterfall pattern (Fig. 1). The least amount of litterfall was recorded in April (3.42 kg/ha) and May (1.11 kg/ha). The data showed that the seasonal dynamics of teak litterfall, emphasizing pronounced peaks in late autumn and minimal during the months of summer. The similar litter fall pattern was by reported by Ojo *et al.* (2010). The cumulative litter input had slow increase during rainy months followed by rapid increase in winter and then again slower down during the summer (Jha, 2010).

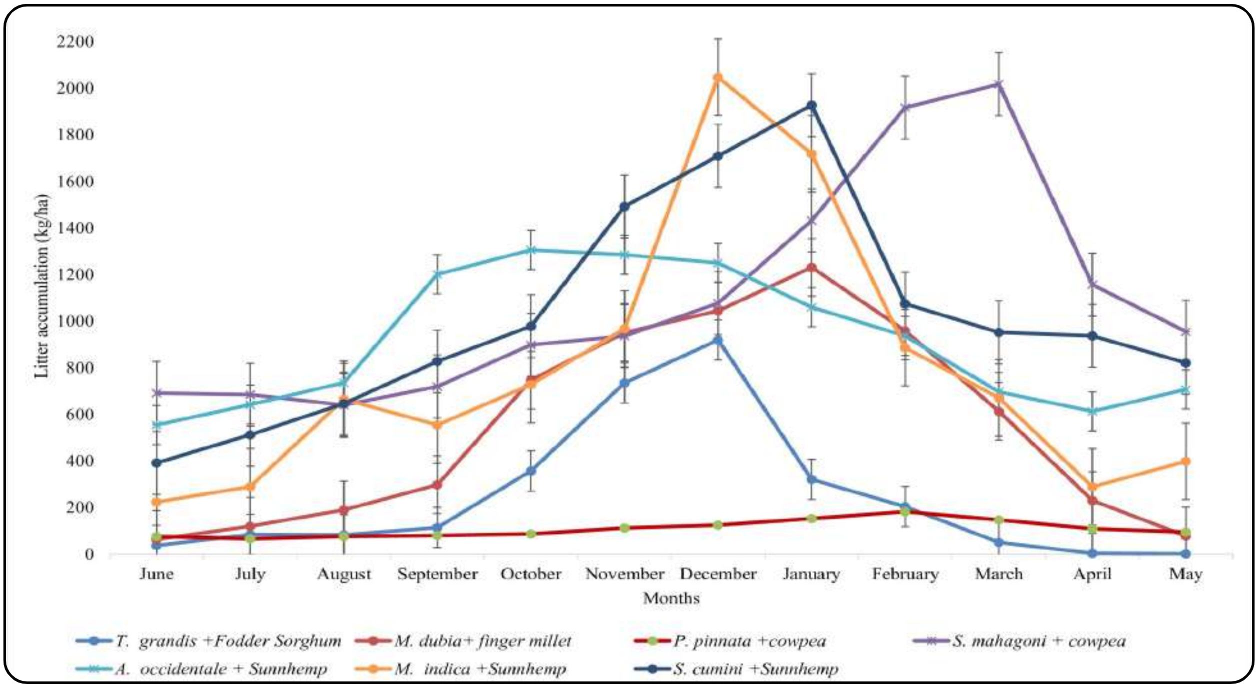

Fig. 1 : Monthly litter accumulation pattern in different agroforestry systems during the study period

M. dubia is also a deciduous tree species having unimodal pattern of litter accumulation. The overall litter accumulation during the study period was 6524.02 kg/ha. The peak of litterfall occurred in the winter months of December (1044.25 kg/ha) and January (1231.26 kg/ha), contributing 16.0 per cent and 18.87 per cent to the overall litter production, respectively. Minimal litter fall was observed during May (77.51 kg/ha) and June (63.25 per cent). As this is a deciduous forest, 100per cent leaf fall occurs each year (Chopra *et al.,* 2023).

In *P. pinnata,* the mean monthly litter was 108.79 kg/ha which is lower compared to other tree species, because of the differences in the age of the tree species. The total litter accumulation during the study period was 1305.46 kg/ha.*P. pinnata*is an evergreen tree species which produces litter throughout the year. It was found that the peak in litterfall was observed during December to March which falls under the winter season. The minimum litterfall was recorded during the summer and rainy season (May to October). Shivakumar *et al*. (2014) studied litter production in *P. pinnata* based agroforestry system which was also observed to have a similar pattern. Litterfall patterns in the majority of Pongamia showed an unimodal distribution, characterized by a clear peak occurring either at the onset or towards the conclusion of the dry period (Cintron and Lugo, 1990).

In *S. mahagoni,* the litterfall followed a unimodal pattern and a distinct peak was noticed during March (2017.20kg/ha). Lower litter production was observed during the months of the rainy season (June to September). Being evergreen, there was a continuous litterfall was noticed during the study period. The mean litter accumulation observed throughout the study period was 1093.88 kg/ha, while the total litter accumulation reached 13126.55 kg/ha.The litterfall from *S. mahagoni* was recorded as 8.3 Mg/ha/yr (Ono *et al.,* 2006) and 3201.65 g/m^2 (Bindu *et al.,* 2014) primarily consisting of leaf litter, with occasional small quantities of bark and small branches falling consistently throughout the year.

In *A. occidenatle,* the total litter production was recorded to be 10987.21 kg/ha during the study period and the mean litterfall was 915.60 kg/ha. As an evergreen tree, litter accumulation was observed consistently throughout the year. The highest litter accumulation occurred in October (1305.99 kg/ha) and November (1285.00 kg/ha), while the lowest accumulation was comparatively recorded in June (554.22 kg/ha). Distinct peaks were observed in November and *A.occidentale* did not register quantifiable amount of reproductive parts in the detritus (Isaac and Nair, 2006).

M. indica exhibited a litter production of 9437.45 kg/ha, with an average litterfall of 786.45 kg/ha. Notably, the highest accumulation occurred in January (2047.50 kg/ha), while the lowest was observed during the early rainy season. Due to its evergreen nature, litter accumulation persisted throughout the entire year. Murovhi *et al.* (2012) observed mean leaf litter production during the 2 year study period, mango produced 6.3 t /ha while seasonal leaf litter production was in late autumn and winter.

In *S. cumini,* the highest amount of litter accumulated in December (1709.15kg/ha) and January (1927.78 kg/ha) and the lowest in June and July (143.21 kg/ha). The overall and mean litter accumulation during the study period was 1221.39 kg/ha and 1022.6 kg/ha respectively. It was observed to have an unimodal pattern of litterfall and accumulated throughout the year because of its evergreen nature. Fontes *et al.* (2014) observed that leaves always represented the largest fraction of litterfall for all cocoa agroforests (mean of 78.1%).

From the study, it was found that peak litter fall of the tree species observed, coincided to the beginning of dry period (December-February). This may be due to water or temperature stress which will activate the synthesis of abscissic acid in the foliage (Kumar and Deepu, 1992). The unimodal litter fall pattern is most common for tropical species (George & Kumar, 1998 and Jamaludheen & Kumar, 1999). The differential accumulation of floor litter biomass among the different agroforestry systems was mainly due to species characteristics followed by annual environmental changes (Tangjang, 2015). Moreover, after spring season or with the onset rainy season, phenological observations do reveal that is a period of newleaf development and expansion for most evergreen species in the area (Singh *et al.,* 2019). So accumulation of floor litter mass during rainy season was less compared with other seasons (Silva *et al.*, 2011; Arunachalam *et al.*, 1998 and Sundarapandian & Swamy, 1999).

Among the various parts of plant that constitute litter leaf tissue accounts for more than 70 per cent of aboveground litter in forests and the rest is composed of stems, small twigs and propagative structures (Robertson and Paul, 1999). In the present study although the segregated litter data is not given, leaf litter is in above mentioned range. The amount and pattern of litterfall varied with the species. It is primarily due to evergreen or deciduous nature of the trees. Deciduous trees, which shed their leaves seasonally, typically exhibit a pronounced peak in litterfall, often occurring in the autumn or winter months. This seasonal shedding is a strategy for conserving water during colder or drier periods and results in a substantial accumulation of leaf litter on the forest floor during these times. Although evergreen trees do shed leaves, the process is more gradual and thus, the contribution to litterfall is more evenly distributed across the seasons. Studies have shown that litter contribution varied with the species, growth, age, tree density, canopy characteristics and seasons (Bhardwaj *et al*., 2001 and Butenschoen *et al.,* 2014). Understanding the patterns and drivers of litterfall is essential for managing forest ecosystems and ensuring their long-term sustainability. The interactions between litterfall and other ecological processes highlight the intricate balance within forest ecosystems, where even small changes in one component can have cascading effects on the entire system.

Litter Decomposition of Tree Species

Litter decomposition was expressed as a dry mass remaining at the end of each month during the study period (Table 3 and Fig. 2). The mean values provide an overall measure of the average litter mass remaining un-decomposed for each species over the entire period.

TABLE 3

Litter mass (g) remained un-decomposed at monthly intervals (2022-23)

Months	Tree species						
	T. grandis +Fodder Sorghum	*M. dubia*+ finger millet	*P. pinnata* +cowpea	*S. mahagoni* +cowpea	*A. occidentale* + Sunnhemp	*M. indica* + Sunnhemp	*S. cumini* + Sunnhemp
June	17.28	17.82	18.40	19.75	18.80	18.20	17.53
July	16.12	16.73	16.80	17.90	16.80	18.20	16.24
August	16.23	14.37	14.40	16.73	14.40	17.20	15.20
September	14.12	13.62	12.20	15.64	13.80	15.80	14.13
October	11.87	12.58	11.80	14.69	12.40	11.80	12.84
November	8.72	9.23	9.60	12.54	11.60	11.40	10.25
December	7.12	7.49	8.20	11.92	10.40	9.20	9.16
January	5.46	6.15	6.20	10.74	9.20	6.80	8.84
February	3.21	4.08	5.20	9.87	7.60	5.60	7.25
March	1.28	3.86	3.60	8.25	6.80	3.60	5.92
April	0.65	2.67	1.80	6.21	5.40	2.20	5.32
May	0.65	1.26	0.80	4.23	3.80	1.80	3.26
Mean	8.56	9.16	9.08	12.37	10.92	10.15	10.50
			Months			Species	
S.Em±			0.062			0.047	
CD (P=0.05)			0.173			0.132	

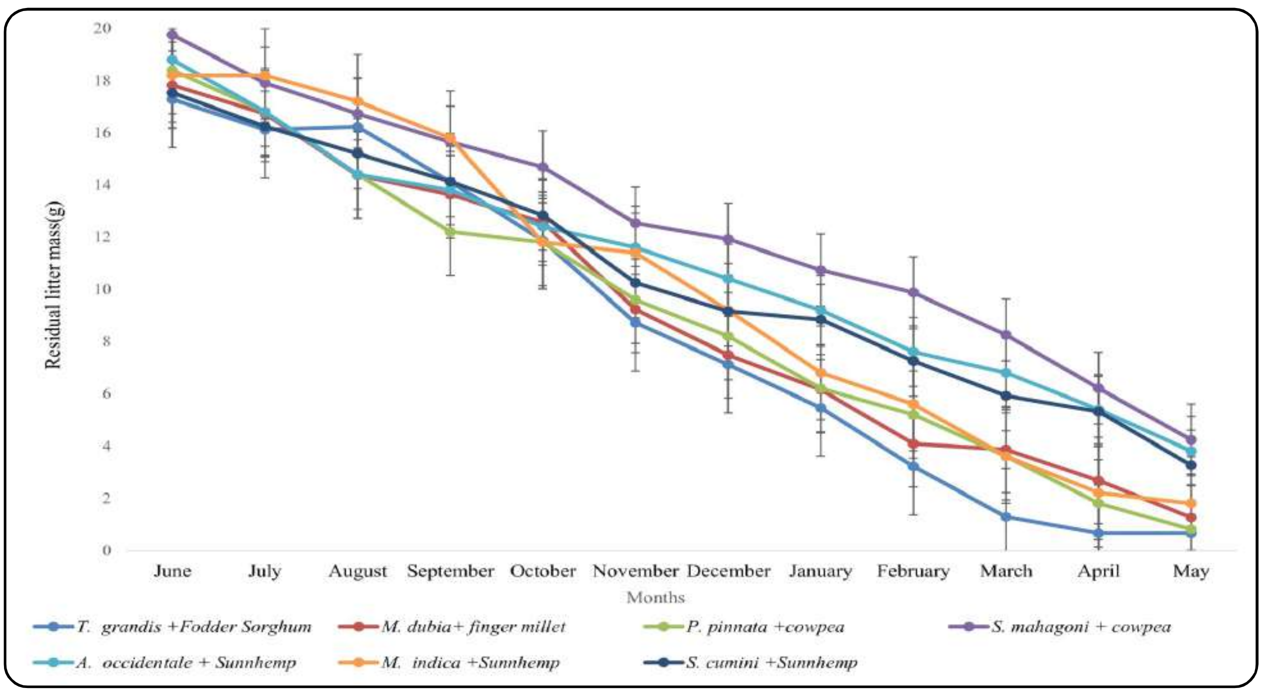

Fig. 2 : Monthly residual litter mass of different agroforestry tree species

Residual litter mass declined exponentially with time for all tree species studied. In *T. grandis* and *A. occidenatle,* nearly 50 per cent of the leaf litter was found decomposed during the first six months of the study while, 40 per cent of *M. dubia, P. pinnata* and *M. indica*; 36 per cent of *S. mahagoni*; 27 per cent of *S. cumini* was decomposed.

There is variability in the litter masses among the different tree species across the months. *S. mahagoni* consistently has higher litter masses compared to other species, indicating slower decomposition for this species. *T. grandis, M. dubia* and *P. pinnata* also show relatively faster decomposition. Litter masses fluctuate throughout the months, suggesting potential seasonal influences on decomposition rates.

T. grandis exhibits moderate litter masses throughout the year, with a mean value of 8.56 grams. There is variability in litter masses across months, suggesting that decomposition rates may be influenced by seasonal factors. *M. dubia* shows relatively consistent and slightly lower litter masses compared to some other species. The mean litter mass for *M. dubia* is 9.16 grams. The consistent litter mass may be indicative of a steady decomposition rate, influenced by factors such as litter quality or microbial activity.

P. pinnata has a moderate litter mass throughout the year, with a mean value of 9.08 grams. *S. mahagoni* consistently maintains higher litter masses undecompesd compared to other species, with a mean value of 12.37 grams. The consistently high litter masses suggest slower decomposition rates for *S. mahagoni*. This species may have leaves with compounds that decompose more slowly or may be less favorable to microbial decomposition.

A. occidentale exhibits variable litter masses, with a mean value of 10.92 grams. The species shows fluctuating patterns, and factors such as litter quality, microbial communities and environmental conditions may contribute to these variations. *M. indica* maintains moderate to high litter masses, with a mean value of 10.15 grams. *S. cumini* generally has lower litter masses compared to other species, with a mean value of 10.50 grams.The lower litter masses may indicate faster decomposition or a lower input of litter from this species.

There is significant variability in the litter decomposition rates among different tree species across the months (Table 4 and Fig. 3). Decomposition rates are given in units of k months^{-1}, representing the proportion of litter decomposed per month.The mean values provide an overall measure of the average decomposition rate for each species over the entire period. *P. pinnata* has the highest mean decomposition

TABLE 4

Litter decomposition rate (k months^{-1}) in different agroforestry systems (2022-23)

Months	Tree species						
	T. grandis +Fodder Sorghum	*M. dubia*+ finger millet	*P. pinnata* +cowpea	*S. mahagoni* +cowpea	*A. occidentale* + Sunnhemp	*M. indica* + Sunnhemp	*S. cumini* + Sunnhemp
June	0.329	0.185	0.470	0.223	0.182	0.385	0.227
July	0.315	0.581	0.582	0.372	0.582	0.508	0.294
August	0.443	0.574	0.574	0.346	0.574	0.523	0.343
September	0.443	0.456	0.514	0.296	0.456	0.412	0.359
October	0.419	0.400	0.421	0.294	0.406	0.354	0.421
November	0.371	0.351	0.390	0.278	0.355	0.328	0.359
December	0.365	0.326	0.353	0.287	0.323	0.325	0.340

Continued....

Table 4 Continued....

Months	Tree species						
	T. grandis +Fodder Sorghum	*M. dubia*+ finger millet	*P. pinnata* +cowpea	*S. mahagoni* +cowpea	*A. occidentale* + Sunnhemp	*M. indica* + Sunnhemp	*S. cumini* + Sunnhemp
January	0.335	0.295	0.328	0.261	0.297	0.298	0.323
February	0.313	0.283	0.299	0.247	0.280	0.268	0.296
March	0.293	0.264	0.280	0.232	0.258	0.255	0.280
April	0.269	0.247	0.264	0.224	0.244	0.240	0.262
May	0.247	0.232	0.246	0.212	0.232	0.224	0.242
Mean	0.345	0.350	0.393	0.273	0.349	0.343	0.312
			Months			Species	
S.Em±			0.002			0.002	
CD (P=0.05)			0.006			0.004	

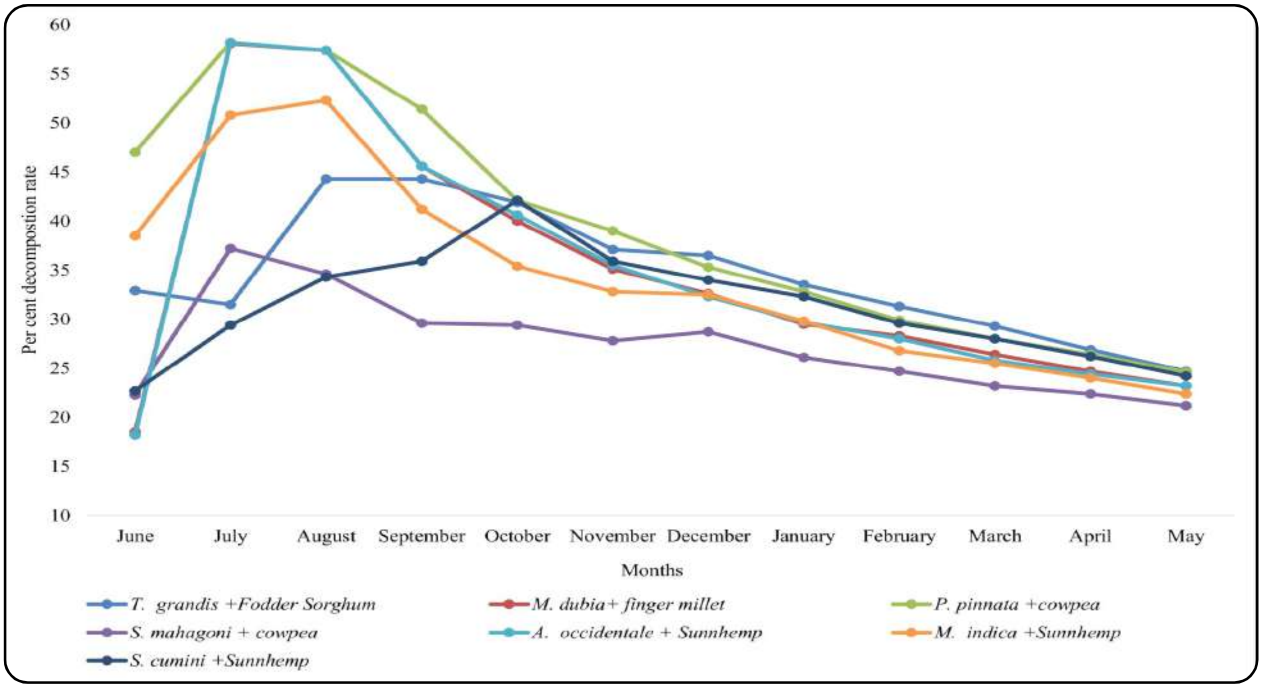

Fig. 3 : Monthly leaf litter decomposition rate across different agroforestry systems

rate, followed by *M. dubia* and *A. occidentale*. *S. mahagoni* has the lowest mean decomposition rate among the species.

T. grandis showed varying decomposition rates, with a mean of 0.345 and it fluctuate, with higher values in June and August. *M. dubia* showed a relatively consistent decomposition rate, with a mean of 0.350 and higher rates were observed in July and August. *P. pinnata* showed variability, with a mean decomposition rate of 0.393. Higher rates are observed in June and July. *S. mahagoni* showed a mean decomposition rate of 0.273, with lower rates compared to other species. Consistent patterns are observed. *A. occidentale* showed variability, with a mean decomposition rate of 0.349. Higher rates are observed in June and August. *M. indica* showed a mean decomposition rate of 0.343, with consistent patterns across the months. *S. cumini* showed a mean decomposition rate of 0.312, with relatively lower rates compared to other species.

Decomposition rates vary seasonally, with some species showing higher rates during certain months. Higher rates during June to August are observed for several species, while rates may decrease during the fall and winter. The different tree species contribute to litter decomposition at varying rates, influencing nutrient cycling and soil health in agroforestry systems. Higher decomposition rates may lead to faster nutrient turnover and potentially influence the availability of nutrients in the soil.

Similar observations were also noticed by Manlay *et al.* (2004). The high rate of decomposition in rainy season was attributed to the optimum moisture, rainfall and microbial population (Sarjubala and Yadava, 2007). Seasonal variations in litter masses suggest that environmental factors, including temperature and humidity, significantly influence decomposition rates. Slower decomposition in some species, especially during summer, may have implications for nutrient cycling and soil health.

The litter decomposition rate was high in initial stages and then it declined gradually due to the influence of environmental factors, litter contents and soil organisms (Das & Mondal, 2016). Also, higher mass loss at the initial stages was due to the decomposition of water-soluble components and relatively slower mass losses at the later stages was due to the presence of recalcitrant constituents such as lignin, cellulose etc., in the residual litter mass along with poor climatic conditions (Hasanuzzaman and Hossain 2014).

The study highlights the critical role of tree litter in agroforestry systems for nutrient cycling and soil health. Significant variability was observed in both litter accumulation and decomposition rates among different tree species, underscoring the influence of species characteristics and seasonal factors. *S. mahagoni* and *S. cumini* were identified as major contributors to litter biomass, while *P. pinnata* and *T. grandis* had lower accumulations. Decomposition rates were highest in *P. pinnata* and lowest in *S. mahagoni*, with seasonal peaks during the summer months. These findings emphasize the importance of selecting appropriate tree species in agroforestry practices to enhance nutrient turnover and soil fertility. By understanding litter dynamics, agroforestry systems can be optimized for sustainable land management, ensuring ecological balance and economic benefits for farmers.

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Mysore J. Agric. Sci., 58 (4) : 89-99 (2024)

Identifying Promising Cowpea (*Vigna unguiculata* L. Walp) Genotypes for Grain yield and its Component Traits through Direct and Indirect Selection Suitable for *Rabi* Conditions

T. Lakshmi Pathy[1], A. Mohan Rao[2], S. Ramesh[3], K. Madhusudan[4], N. Nagaraju[5], S. R. Anand[6], N. Akshay Rahul[7], V. Prashantha[8], J. Ashwini Jain[9]

[1,3,7&8]Department of Genetics and Plant Breeding, [2,6&9]AICRN on Potential Crops, [4]National Seed Project, [5]Department of Plant Pathology, GKVK, UAS, Bangalore - 560 065

e-Mail : pathy4u76@gmail.com

Authors Contribution

T. Lakshmi Pathy : Conceptualization, designing of the research work and data collection;

A. Mohan Rao and S. Ramesh : Supervision, conceptualization;

K. Madhusudan and N. Nagaraju : Critical feedback, helped to shape the research

S. R. Anand : Field experiment supervision and critical feedback;

N. Akshay Rahul : Data recording, tabulation of result;

V. Prashantha and J. Ashwini Jain : Draft prepration

Corresponding Author :
T. Lakshmi Pathy

Received : September 2024
Accepted : October 2024

Abstract

Identification of cowpea genotypes suited to unconventional *rabi* season, forms the prerequisite to initiate breeding programs for such conditions. To achieve this, a minicore set of 172 accessions (163 germplasm and nine checks) were evaluated in alpha design in *rabi* 2022. The genotypes were evaluated for nine quantitative yield and its attributing traits *viz.,* days to fifty *per cent* flowering (DFF), pod length (cm) (PL), pod width (cm) (PW), seeds per pod (SP), pods cluster^{-1} (PC), average pod weight (g) (APWT), pods plant^{-1} (PP), hundred seed weight (g) (HSW) and grain yield plant^{-1} (g) (GYP). Among the traits, largest variation was observed for PP, followed by GYP and the least for PW. Trait specific accessions were identified based on adjusted means of genotypes. Accessions promising for multiple traits were also identified. The accessions 144 (IC202779) and 362 (EC107163) were identified to be promising for three traits each *viz.,* PW, HSW, APWT and SP, PP, GYP, respectively. Indirect selection was exercised by deploying six selection indices considering all traits except GYP, which were then compared against direct selection (DS) for GYP, through relative selection efficiency (RSE). Consequently, Base Linear Phenotypic Selection Index (BLPSI) proved to be better in selecting promising genotypes for GYP, with higher RSE of 64.89 per cent against DS. However, DS had highest coincidence index with rank sum method, suggesting higher number of common genotypes between them.The genotypes 362 (EC107163) and 390 (EC738131) were selected by five and four out of six indices respectively, highlighting their superiority over others. These selected genotypes, after further evaluations during *rabi*, would serve as potential cultivar options and as parents for developing elite genotypes upon hybridisation and selection.

Keywords : *Rabi* cowpea, Direct selection, Indirect selection, Selection indices, Relative selection efficiency

Grain legumes form an important source of protein besides possessing considerable amount of carbohydrate and other micronutrients. Cowpea (*Vigna unguiculata* L. Walp) is one such food legume which is native to Central Africa (Harlan, 1971), however predominantly cultivated in arid and semi-arid tracts of the world. Highest production of cowpea is in Nigeria, accounting for nearly half of the Africa's production (FAO, 2019). In India, it is cultivated in 3.9 million hectares (Giridhar *et al.,* 2020; Pushpa *et al.,* 2023), majorly in states of Rajasthan, Karnataka, Kerala, Tamil Nadu, Maharashtra and Gujarat. However, cowpea is less preferred by the farmers over other legume crops primarily owing to its reduced yield potential especially in intensive farming systems (Poornima *et al.,* 2023).

In tropical India, cowpea is primarily grown as main crop in *kharif* or as rice fallow crop during late *kharif.* Cowpea being a tropical crop, enjoys ample sunshine, during (late) *kharif* and produce luxuriant vegetative growth before translating that to grain yield. In contrast, rabi conditions are characterised by low temperatures, increased photoperiods and low rainfall. Since the selection programs were oriented towards identifying superior genotypes suitable for *kharif* cultivation, the chosen genotypes may not exhibit similar performance during *rabi* season (Padulosil, 1997). Moreover, fallow crop or intercrop sown as part of cropping system in rabi could be able to harness the residual moisture effectively in the field, providing more returns to farmers. Hence, it becomes quintessential to breed for and identify genotypes suitable specifically for *rabi* season. To achieve this, available germplasm needs to be screened under *rabi* conditions to identify best yielding accessions, which may serve as a cultivar option or parents for developing better genotypes suitable for *rabi* season.

Selection of genotypes in variable population based on single target trait, may not lead to desirable genetic gain, especially for complex and less heritable traits like grain yield, which is often governed by large number of genes and highly influenced by environment. Under this premise, selection based on less complex traits like yield components, would enable us to identify genotypes promising for a single trait or a combination of traits. Thus, multi-trait selection facilitated through the use of multivariate selection indices aids in selection of superior genotypes for majority of traits *vis*-à-*vis* grain yield. Such selected trait specific accessions can serve as genetic stocks and putative parental lines for improving target trait, when complemented with another trait specific accession. Direct selection refers to selection of genotypes based on grain yield, whereas indirect selection emphasises selection for component traits except grain yield. Considering all the above constraints, the study is framed to address objectives *viz.,* to identify promising trait specific accessions suitable for *rabi* season from among cowpea mini core set, to construct and compare the efficiency of muti-trait selection indices against direct selection and to identify genotypes superior for multiple traits through selection indices.

Material and Methods

A set of 172 genotypes were selected from coreset of cowpea available with ICAR-NBPGR, New Delhi, and All India Coordinated Network Project (AICRN) on Potential crops, University of Agricultural Sciences, GKVK, Bengaluru, based on the principle of constructing mini core set with maximum representativeness and minimum redundancy, which was further validated (data not shown). This set comprised 163 germplasm accessions and nine checks (C1 to C9), where C1 (GC-3), C2 (DC-15), C3 (PL-3), C4 (PL-4) and C5 (RC-101) are the standards recommended by ICAR-NBPGR, whereas C6 (KBC-2), C7 (KBC-9), C8 (KBC-11) and C9 (PGCP-6) were developed at University of Agricultural sciences, Bangalore. These 172 genotypes were evaluated during late *rabi* 2022 for grain yield and its attributing traits, wherein the experiment was laid out in alpha design, with two replications. Sowing was taken up on 15th December 2021. Each genotype was sown in paired rows per replication with 45 cm between rows of same genotype and 90 cm between different genotypes. All the recommended agronomic and plant protection measures were followed to maintain healthy and productive crop.

Data was recorded on nine quantitative traits *viz.,* days to fifty per cent flowering (DFF), pod length (cm) (PL), pod width (cm) (PW), seeds pod^{-1} (SP), pods cluster^{-1} (PC), average pod weight (g) (APWT), pods plant^{-1}(PP), hundred seed weight (g) (HSW), grain yieldplant^{-1} (g) (GYP). Mean daily temperature during crop growth phase in rabi 2022 crop was recorded as 22.13°C. In each genotype, five random plants per replication were chosen for recording data on the above-mentioned traits. Data collected was analysed in R studio (R core team, 2021) with the package *agricolae*, using the function *PBIB. test* and adjusted means were calculated with variance component (VC) model. Based on the adjusted means, trait specific accessions for each the traits were identified. Genotypes which expressed lower mean values than trait grand mean minus twice of standard deviations (<GM+2σ) for flowering and higher values for other traits (>GM+2σ) are identified as superior accession (s) for each of the traits (Kirankumar *et al.,* 2023).

Multi-trait selection was performed to select accessions superior across all the traits except for GYP. Six multi trait selection criteria *viz.,* LPSI (linear phenotypic selection index) (Smith (1936); Hazel and Lush (1942); Hazel (1943)), BLPSI (Base linear phenotypic selection index) (Williams 1962), ESIM (Eigen selection index method) (Ceron-Rojas *et al*., 2008), rank sum (RS), FAI (factor analysis and ideotype-design) index (Rocha *et al*., 2018), MGIDI (Mean Genotype and ideotype distance index) (Olivoto *et al*., 2022) were deployed to select best genotypes for eight traits *viz.,* DFF, PL, PW, SP, PC, APWT, PP and HSW. Comparison of selection indices is based on relative selection efficiency (RSE) computed as selection differential (SD) for GYP in each of selection indices against SD obtained by selecting genotypes through direct selection (DS) on GYP. Selection differential is computed as difference between selected genotypes and total population and expressed as units of trait mean.

$$\text{SD} = \text{Mean of selected genotypes} - \text{Mean of all genotypes}$$

$$\text{RSE} = \frac{\text{SD obtained for GYP from indirect selection criteria}}{\text{SD obtained for GYP from direct selection}}$$

Among selection criteria mentioned above, four are weight free indices and the rest are weight based, where the breeder needs to assign weights to individual traits. In this case, equal weightage was given to eight traits subjected to analysis *viz.,* DFF, PL, PW, SP, PC, APWT, PP and HSW for LPSI, BLPSI, ESIM and MGIDI. Detailed description of LPSI, BLPSI and ESIM selection indices is provided in Ceron-Rojas and Crossa (2018) and explanation on FAI and MGIDI is provided by Rocha *et al.,* 2018 and Olivoto *et al.,* 2022, respectively. In rank sum (RS) method, ranks were assigned to the accessions for each of the traits (Pathy *et al.,* 2022), which were summed across traits, and further ranks were computed based on summed ranks. For DFF, ranks were given in ascending order, while it was *vice-versa* for other traits. FAI, MGIDI and ESIM are based on principal component analysis (PCA) and the number of principal components, having eigen value of more than one, were selected for further analysis. Analysis for LPSI, BLPSI and ESIM were performed in RindselR (Alvarado *et al*., 2018), ranksum was computed in MS Excel, while FAI and MGIDI were calculated through 'metan' package in R. Coincidence index (CI) was estimated according to Hamblin and Zimmermann (1986) given as:

$$CI = \frac{A - C}{M - C} \times 100$$

where CI is coincidence index, A is number of common selected genotypes in different methods; C is the number of expected genotypes selected by chance and M is the number of selected genotypes according to the selection intensity.

RESULTS AND DISCUSSION

Phenotypic data on nine quantitative traits were subjected to analysis of variance (ANOVA) and results manifested significant differences among genotypes for all the traits at 1 per cent level of significance (Table 1). These differences could be exploited by plant breeders to exercise selection for each of the traits and identify best ones. The adjusted means for each of the genotypes were taken for computing grand mean (GM) and these are indicated in Table 2. The mean DFF was 65.17 days, which is way higher as compared to *kharif* season. This can be expected in legumes owing to their higher photo and thermo sensitivity. A wide range of variation was observed for all the traits, highlighting substantial genetic diversity among the accessions constituting reduced representative core set. Standardised range is an unitless measure which compares variation across

TABLE 1

Analysis of Variance for nine quantitative traits among 172 cowpea genotypes constituting reduced representative core set

Source of variation	Degrees of freedom	DFF		PL		PW		SP		APWT		PP		PC		HSW		GYP	
		MSS	p value	MSS	p value	MSS	p value	MSS	p value	MSS	p value	MSS	p value	MSS	p value	MSS	p value	MSS	p value
Replication	1	3.98	0.26	4.20	0.25	0.03	0.18	1.41	0.09	0.14	0.09	4.97	0.09	0.51	0.08	0.14	0.24	32.38	0.02
Genotypes	171	40.56	<0.001	22.47	<0.001	0.04	<0.001	10.80	<0.001	0.82	<0.001	281.07	<0.001	0.29	<0.01	31.05	<0.001	31.05	<0.001
Block/rep	84	4.10	0.11	4.11	0.12	0.01	0.77	0.48	0.57	0.05	0.42	1.54	0.74	0.13	0.84	0.11	0.28	5.30	0.72
Residual	87	3.15		3.18		0.02		0.50		0.05		21.77		0.17		0.09		6.01	

DFF: Days to fifty per cent flowering, PL: Pod length (cm), PW: Pod width (cm), SP: Seeds pod^{-1}, APWT: Average pod weight (g), PP: Pod plant^{-1}, PC: Pods cluster^{-1}, HSW: Hundred seed weight (g), GYP: Grain yield plant^{-1}, MSS: Mean sum of squares, rep: replication.

TABLE 2

Descriptive statistics for nine quantitative traits among 172 cowpea genotypes constituting reduced representative core set

Statistic	DFF	PL	PW	SP	APWT	PP	PC	HSW	GYP
Grand mean	65.17	15.21	0.69	13.61	1.77	21.75	2.19	11.41	24.49
Coefficient of variation	2.72	11.71	17.78	5.18	12.41	6.12	18.63	2.69	10.10
Range	80-47.89	28.5-7.0	1.0-0.4	19-7	3.60-0.62	72.78-2.04	3.50-1.25	25.51-3.67	60.66-2.08
Standardised range	0.49	1.41	0.86	0.92	1.68	3.25	1.02	1.91	2.39

DFF: Days to fifty per cent flowering, PL: Pod length (cm), PW: Pod width (cm), SP: Seeds pod^{-1}, APWT: Average pod weight (g), PP: Pod plant^{-1}, PC: Pods cluster^{-1}, HSW: Hundred seed weight (g), GYP: Grain yield plant^{-1}

the traits. Accordingly, PP had highest variation followed by GYP, while the least was observed for DFF. Highest variation in PP during rabi might be because of significant flower drop in a few accessions, which are not adapted to the conditions. These differences would reflect in the trait GYP as well because of high correlation between these two traits.

Owing to high variations in these traits, it is imperative to select accessions promising for each of the traits. Therefore, trait specific accessions were identified considering grand mean and standard deviation as criteria and the accessions identified for each of traits is listed in Table 3. Consequently, 4, 4, 4, 7, 3, 5, 6, 6 and 9 trait-specific accessions were identified for DFF, PL, PW, SP, PC, APWT, PP, HSW and GYP, respectively (Table 3). These are the genotypes that are superior for each of traits considered in the study. Broadly, these promising accessions for each of the traits can serve as potential parents for trait specific breeding program. For instance, 524 (IC263015) was early flowering accession identified, which has high probability of throwing out superior early flowering transgressants, when combined with any of the other three trait specific accessions for DFF *viz.,* 102 (EC723684), 355 (EC738083), 399 (EC738260). This is rendered possible since the latter are exotic collections originating from different geographical regions thus possessing distinct set of genes regulating DFF, which could associate in segregating progeny to isolate and identify transgressants for early flowering. Such quantitative traitspecific germplasm accessions have been identified from core/mini-core collection in cowpea (Cobbinah, *et al.,* 2011). dolichos bean (Vaijayanthi *et al.,* 2016), common bean (Zeven *et al.* 1999), chickpea (Meena *et al.,* 2010; Parameshwarappa *et al.,* 2012; Meena and Kumar 2014) and groundnut (Upadhyaya *et al*. 2003).

Among trait specific genotypes selected, those superior for more than one trait were identified (Table 4). Consequently, three accessions *viz.,* 87 (EC244057), 143 (IC202774), 261 (IC400103) were promising for two traits and two *viz.,* 144 (IC202779) and 362 (EC107163) were promising for

TABLE 3

Promising trait specific accessions identified from among 172 cowpea genotypes constituting reduced representative core set

DFF	PL	PW	SP	APWT	PP	PC	HSW	GYP
102(EC723684)	307(IC-20658)	8(EC5269)	78(EC243943)	87(EC244057)	120(EC528420)	147(IC202791)	19(EC99573)	70(EC240983)
355(EC738083)	372(EC724239)	144(IC202779)	165(IC338865)	362(EC107163)	143(IC202774)	254(IC383461)	41(EC149457)	87(EC244057)
399(EC738260)	407(IC626138)	289(IC546525)	173(IC397942)	C2(DC-15)	144(IC202779)	264(IC413324)	143(IC202774)	98(EC244116)
524(IC263015)	518(EC724805)	505(EC725102)	242(IC548860)		171(IC361790)	312(IC-53351)	144(IC202779)	134(IC68786)
			249(IC372720)		225(IC278035)	362(EC107163)	256(IC397405)	238(IC334368)
			285(IC536609)		261(IC400103)	378(EC724745)	519(EC244046)	261(IC400103)
			300(NR-18-75)		371(EC724160)			274(IC426816)
								342(EC472282)
								362(EC107163)

DFF: Days to fifty per cent flowering, PL: Pod length (cm), PW: Pod width (cm), SP: Seeds pod^{-1}, APWT: Average pod weight (g), PP: Pod plant^{-1}, PC: Pods cluster^{-1}, HSW: Hundred seed weight (g), GYP: Grain yield plant^{-1}

TABLE 4

Accessions identified promising for more than one trait among 172 cowpea genotypes constituting reduced representative core set evaluated during *rabi* season

Accessions	Number of traits for which accession is promising	Traits for which accession is promising
87 (EC244057)	2	SP, GYP
143 (IC202774)	2	APWT, HSW
144 (IC202779)	3	PW, HSW, APWT
261 (IC400103)	2	APWT, GYP
362 (EC107163)	3	SP, PP, GYP

DFF : Days to fifty per cent flowering, PL: Pod length (cm), PW: Pod width (cm), SP: Seeds pod^{-1}, APWT: Average pod weight (g), PP : Pod plant^{-1}, PC: Pods cluster^{-1}, HSW: Hundred seed weight (g), GYP: Grain yield plant^{-1}

three traits. Majority of the accessions, thus identified, were superior for traits which are highly correlated. For example, 144 (IC202779) was promising for PW, HSW and APWT and 261 (IC400103) for APWT and GYP. However, 362 (EC107163) was identified to be superior for SP, PP and GYP, where SP and PP are not correlated in general. This accession tends to possess superior genes for two distinct component traits for GYP and could serve as putative parent for improvement of GYP, when combined with complementary trait specific accessions like 144 (IC202779) or 143 (IC202774). Since these latter accessions are indigenous collections, the genetic diversity existing between them and 362 (EC107163) can be tapped to recover superior transgressants for GYP.

Six different selection criteria *viz.,* RS, FAI, MGIDI, SHI, BLPSI and ESIM were deployed to identify best accessions based on multiple yield component traits DFF, PL, PW, SP, PC, APWT, PP and HSW. These traits formed the basis for selecting genotypes through indirect selection. Whereas, trait specific genotypes for GYP were the basis for direct selection. Selection intensity was fixed at 5 per cent and selection differential and RSE were estimated for each of the indices. GYP mean of accessions selected directly was 52.17 g and this is taken as standard to compare the indices (Fig. 1). The highest mean was

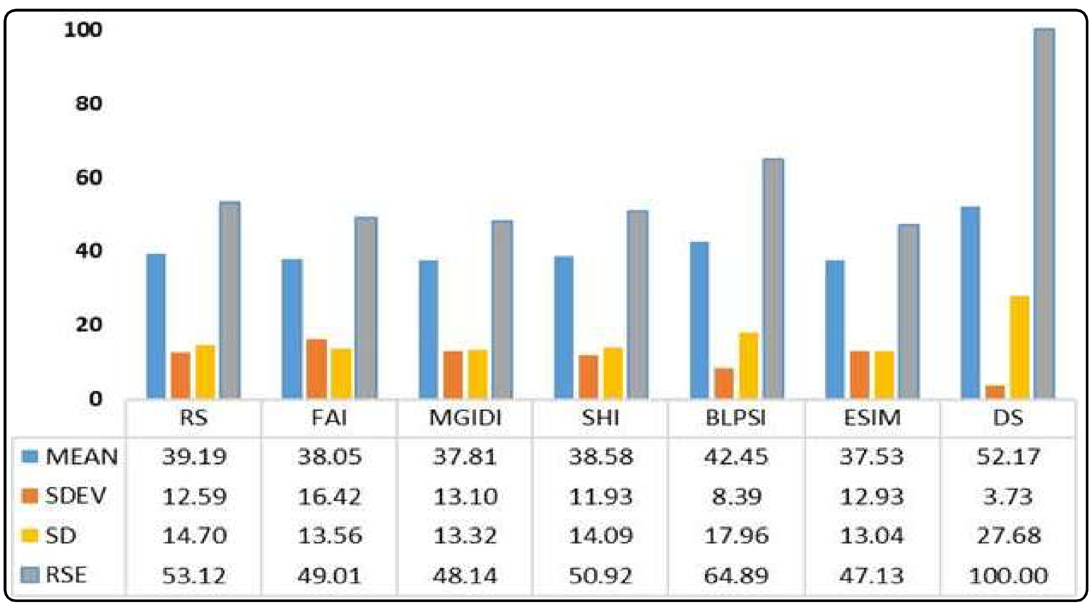

Fig. 1 : Comparative statistics of six indirect selection indices and direct selection (DS) for GYP

observed in BLPSI followed by RS and the least in ESIM. Similar trend was observed for SD and RSE. The RSE of BLPSI was 64.89 per cent of DS, while ESIM, FAI and MGIDI had less than 50 per cent RSE. Standard deviations among selected accessions in each of the indices revealed that direct selection had lowest deviations followed by BLPSI, while large deviations were observed in FAI. Large means and low standard deviations of BLPSI suggests that selection of accessions targeted higher GYP values with little deviations around mean. Larger standard deviations imply selection of genotypes with inconsistent GYP, pulling down the mean values. Similar results were obtained in the previous studies on chickpea (Talekar *et al.,* 2023).

FAI and MGIDI are based on the principle of factor analysis, which assumes the presence of underlying factors that contribute to the correlation between observed traits. Index scores based on FAI were derived from varimax rotation of factor loadings, whereas genotypes are selected based on distance between ideotype and genotypes in MGIDI. Based on the principal component analysis (PCA), three PCs were selected with eigen value of more than one, which explained a cumulative variation of more than 65 per cent (Fig. 2). As seen from the Table 5, PW, APWT, PP and HSW had higher loadings in factor 1, PL and SP for factor 2 and DFF and PC for factor 3. PC and SP had the highest communalities (Table 5), where DFF recorded lowest, with a mean communality of 65.13 per cent. This suggests that the factors explained 80 per cent of the variation in PC and SP, whereasonly 42 per cent of variation in DFF was explained by these common factors, implying that DFF is least correlated with the other traits studied. FAI is a weight free index, where the factor scores are used as weight to derive the scores for genotypes. In contrast, weights have to assigned for traits in MGIDI, to construct the ideotype, to select the genotypes closer to ideotype based on the scores. Among the selected accessions, 390 and 50 had smallest contributions for factor 1, inferring the superiority of these accessions for PW, APWT, PP and HSW. Similarly, for PL and SP (factor 2), 362 and C2 were identified to be the best among selected ones. However, some of the accessions *viz.,* 192, 354 and C2 selected through MGIDI indirect selection had lower GYP, resulting in reduced SD upon selection.

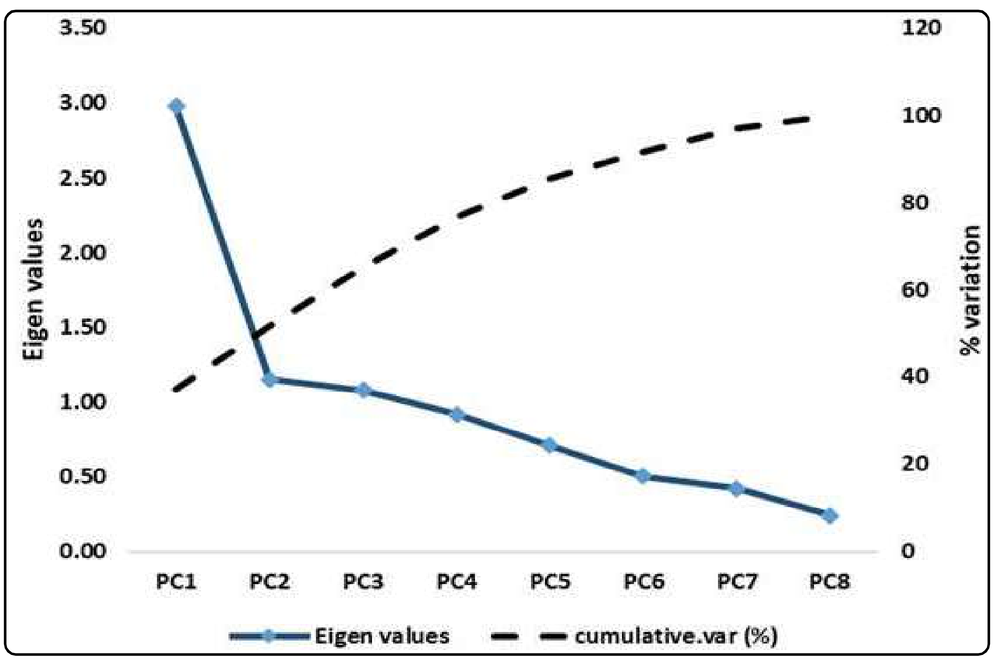

Fig. 2 : Extracted principal components (PCs) along with eigen values and cumulative variation explained

TABLE 5

Rotated factor loadings for traits and communalities extracted from factor analysis

Trait	FA1	FA2	FA3	Communalities	Assigned factor
DFF	-0.26	0.22	0.55	0.42	FA3
PL	-0.53	0.6	-0.07	0.64	FA2
PW	-0.66	0.36	0.1	0.58	FA1
PC	0.1	-0.11	0.88	0.8	FA3
SP	0.12	0.88	0.07	0.8	FA2
APWT	-0.69	0.52	0.12	0.77	FA1
PP	0.67	0.13	0.2	0.46	FA1
HSW	-0.86	0.07	0.07	0.74	FA1

DFF: Days to fifty per cent flowering, PL: Pod length (cm), PW: Pod width (cm), SP: Seeds pod^{-1}, APWT: Average pod weight (g), PP: Pod plant^{-1}, PC: Pods cluster^{-1}, HSW: Hundred seed weight (g), GYP: Grain yieldplant^{-1}; FA1, FA2 and FA3 are factors extracted through PCA

Different indices employed in the study varied in the selection of genotypes and to compare the indices consistent with each other, coincidence index (CI) was estimated (Table 6). Accordingly, CI matrix resulted in identifying SHI and BLPSI, as highly consistent with value of 0.88, wherein eight out nine selected accessions were jointly selected by both of them. Least CI (0.06) was observed among SHI and RS, FAI, MGIDI and also BLPSI and RS, FAI, MGIDI. This highlights the diversity among the employed indices in selecting accessions. Higher values of CI were observed between weight-based indices (SHI and BLPSI) and between Factor analysis-based indices *viz.,* FAI and MGIDI. High CI among such indices directs the researcher to use any of those indices, if not others, to select best genotypes to avoid redundancy. RS recorded highest CI with DS, highlighting the efficiency of the former in selecting the best ones. This could possibly due to the fact that ranking of genotypes were directly based on phenotypic values, which contribute to the yield ultimately (Pathy *et al.,* 2022 and Vinu *et al.,* 2024).

TABLE 6

Matrix of Coincidence index (CI) among evaluated selection indices

	FAI	MGIDI	SHI	BLPSI	ESIM	DS
RS	0.53	0.41	0.06	0.06	0.30	0.41
FAI		0.65	0.06	0.06	0.18	0.30
MGIDI			0.06	0.06	0.06	0.18
SHI				0.88	0.18	0.18
BLPSI					0.18	0.30
ESIM						0.18

RS: Rank sum, FAI: Factor analysis index, MGIDI: Mean Genotype Ideotype Distance Index, SHI: Smith Hazel Index, BLPSI: Best linear Phenotypic selection index, ESIM: Eigen selection index method, DS: Direct selection

Fixed selection intensity of 5 per cent resulted in identification of nine genotypes per index, making a total of 54 selections across six indices. As discussed with respect to CI, certain genotypes were selected by more than one index, thereby downsizing 54 selections to 28 unique genotypes. Frequency of these 28 genotypes being selected by more than one index is depicted in the graph (Fig. 3). Eight of these 28 genotypes (indicated by * in the graph) were identified as GYP trait specific accessions based on DS. The accession 362 (EC107163) was selected by highest number of five different indices, whereas 11 accessions were selected by only one of the indices. This genotype was also selected through DS.

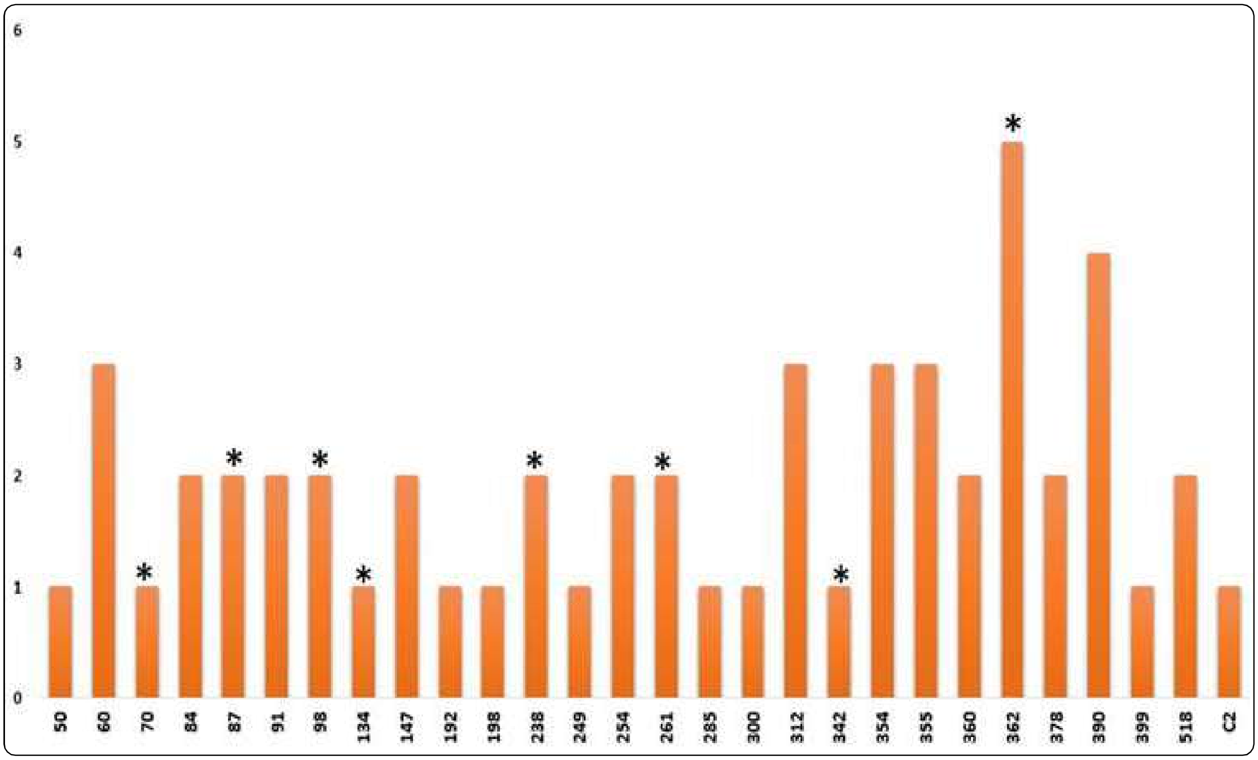

Fig. 3 : Frequency of promising cowpea accessions identified through indirect selection six different selection indices

Accession number	Accession	Accession number	Accession	Accession number	Accession	Accession number	Accession
50	EC240665	134	IC68786	261	IC400103	360	EC-738122
60	EC240841	147	IC202791	285	IC536609	362	EC107163
70	EC240983	192	IC560918	300	NR-18-75	378	EC724745
84	EC244025	198	IC590841	312	IC-53351	390	EC738131
87	EC244057	238	IC334368	342	EC472282	399	EC738260
91	EC244065	249	IC372720	354	EC-724805	518	EC724805
98	EC244116	254	IC383461	355	EC-738083	C2	DC-15

*Indicates trait specific accessions for GYP through direct selection

Another genotype 390 (EC738131) follows 362, being selected by four indices, but was not a part of GYP trait specific accessions.

A total of 172 genotypes (163 germplasm accessions and nine checks) were evaluated for nine agronomic traits in *rabi* 2022 and promising accessions for each of the traits were identified. Genotype 362 (EC107163) found to be promising for three traits *viz.,* SP, PP, GYP. Selection indices deployed as indirect selection for all the component traits except yield, proved BLPSI as best index for selecting genotypes for GYP based on its relative selection efficiency. Accessions selected through BLPSI also had low standard deviations for GYP. Five selection indices included the accession 362 in their selection, which was also selected through DS. This accession could offer potential parental source for future breeding programs.

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Household Attributes and Agro Diversity Across Different Land Holdings : A Case Study from Sihphir Village in Mizoram, India

R. Lalchungnungi[1], A. Nongtri[2], N. Lyngdoh[3] and K. Upadhyaya[4]
[1&2]Department of Environmental Science, [3]Biodiversity Research Centre, [4]Department of Forestry, Mizoram University, School of Earth Sciences and Natural Resources Management, Aizawl, Mizoram - 796 004
e-Mail : lyngdoh@gmail.com

Authors Contribution

R. Lalchungnungi : Investigation and draft preparation;

A. Nongtri : Data analysis and manuscript preparation;

N. Lyngdoh : Conceptualization, framed research proposal and supervision;

K. Upadhyaya : Conceptualization and manuscript correction

Corresponding Author :
N. Lyngdoh

Received : August 2024
Accepted : September 2024

Abstract

Land holding is a strong driver of household attribute, crop diversity and farm management. Present study explores its influence in Sihphir village, Aizawl district of Mizoram by considering three land holding categories *viz.* marginal land holding (MLH; < 1ha), small land holding (SLH; 1-2ha) and semi medium land holding (SMLH; 2-4ha). Household attributes and farm management were surveyed using a questionnaire on thirty households, while for farm diversity by laying plots in 15 farms under each category. Agriculture is the main occupation across land holding with education skewed to the lower levels among marginal land holders. The percentage of household members involved in agriculture and land allocated for agriculture decreased with larger land holdings. Piggery is the main livestock reared by all land holders with average number of pigs per household ranging from 1.96 ± 1.95 in MLH to 2.46 ± 1.97 in SLH. Total household income increased with land holding, but there was large variation in income from agriculture and livestock within each category with co-efficient of variation values above 50 per cent. A total of 55 food plant species were reported in all farms out of which 28 were trees and 27 herbs. The survey reports 17 species primarily used as source of fruits, 11 as a vegetable and 2 as spices. Tree density was highest in farms of the SLH category. *Cleodendrum infortunatum*is the most common species in all farms. Tree diversity and dominance indices across farms in various categories of land holding differed marginally in contrast to herbaceous crop species which showed the highest diversity in SMLH. Among the herbaceous crops, *Brassica nigra* had highest density in all categories. The management practices followed by different land holders did not vary significantly except for the tendency of saving seeds for the next season.

Keywords : Household income, Livestock, Agro diversity, Species richness

In rural societies, land is a prominent production factor and provides socio-economic and political stability to a household. Land holding has a multi-dimensional role providing food and nutritional security, income as well as future security against accidents and misfortunes. Agricultural land is vital for three out of four of the poorest billion individuals in the world, which depend on it and related activities for their subsistence (Anonymous, FAO, 2016). There are ample evidences to relate land holding with household income (Pramanik, 2022), education levels (Sharma *et al*., 2012), nutrition (Pritchard *et al.,* 2016) and overall food security (Joshi & Joshi, 2016 and Nkomoki *et al*., 2019). Such relationships are particularly strong in societies where land distribution is highly biased to those sitting in higher echelon and prevailing customs prevent any break in the ownership cycle.

Size of land holding is a significant factor in controlling farm characteristic, input and management, whose effects resonate back to overall household attributes. Francesco *et al.* (2021) in a detailed analysis on studies made across 42 countries found positive correlation between agricultural diversity and the farm area. According to the earlier arguments given by Bhatta *et al.* (2016) and Makate *et al.* (2016), there is very less scope for crop diversification if land holding is small. On the contrary, Aheibam and Singh (2017) argued that farmers with low land holding are forced to diversify their crop resources to reduce risks and stabilize income. Larger landholding, in most contexts provides liberty to invest on capital intensive technologies (Sahu & Das, 2015 and Hurakadli & Gaddi, 2023), high input crop and farm management practices such as use of high yielding varieties, external fertilizers, freedom to test new technologies and crop combinations (Adjimoti *et al*., 2017).

Drawing from the above evidences, there appears to be marked differences in many household and farm attributes that can surface from land holding status within the farming community. According to a data paper on Global and Inequality by Bauluz *et al*. (2020), South East Asia is a region that shows one of the highest levels of inequality in land distribution with the top ten per cent of land owners capturing up to 75 per cent of agricultural land and the bottom 50 per cent owning less than two per cent. Treading along the insights of previous reports, this paper explores household attributes, agrodiversity and farm management practices across landholders in a village of Mizoram in north east India. Mizoram is a hilly state which shares its borders with neighboring states of Assam, Manipur, Tripura and internationally with Myanmar and Bangladesh. Mizo is an agrarian society with no hierarchical class distinction in social status and participation in the community life. Agriculture is the main occupation of people with an average landholding of 1.26ha (Anonymous, Statistical Handbook of Mizoram, 2022). However, there are limited marketing opportunities for agricultural produce because of the hilly terrain and poor road infrastructure. Given the above features and challenges in the state, the objective of the study is to investigate whether size of land holding can significantly influence the diversity of crops grown on a farm, farm management practices followed and the contribution of farm income to the total income of farmers. The results are expected to offer insights into the general characteristics of a typical Mizo household, specifically to understand influence of these attributes are influenced by the size of land holding.

METHODOLOGY

Study Site

The study area is in Sihphir village, 14 km north of Aizawl, the capital of Mizoram, which lies along 23.82 °N latitudes and 92.74 °E longitudes. As far as it is known the village came into existence in 1890s. The village is a densely populated permanent community with around 2000 households. The people in Sihphir mainly live in concrete buildings and some in assam-type houses. Most families own farmlands, but the size greatly vary from a few acres to tens of acres. Farmers generally follow a multi-cropping systems and farm produce include mustard, broccoli, cabbage, crowder pea/leaf, pumpkin, chilli, arum, tomato, pigeon pea, snake gourd, bitter gourd, bitter nut, bitter bean, orange, jackfruit, Macedonia, cucumber, betel leaf, etc and also many of them cultivated betel-nut palm.

Sihphir village experiences a mild subtropical climate characterized by warm summers with temperatures ranging from 25 to 30 °C (77 to 86 °F) and mild winters rarely dropping below 10 °C (50 °F). The village receives abundant rainfall during the monsoon season from June to September, averaging between 2500 and 3000 millimeters (98 to 118 inches) annually. This climate is favourable which supports diverse agricultural activities, including the cultivation of crops such as rice, maize, vegetables and fruits.

Sampling and Data Collection

Household Attributes

The information about land holding and ownership was obtained from village council. Land was categorized into marginal land holding (MLH; < 1ha), small land holding (SLH; 1-2ha) and semi medium land holding (SMLH; 2-4ha). Due to low sample size, larger land holding was not considered for the study. The entire village was divided into three blocks and within each block, ten households under each land holding category were randomly selected. Survey pertaining to different household attributes which included respondent information, household member details, income sources, livestock asset, etc. were obtained using a structured questionnaire supplemented by semi structured interview for a total of thirty households under each category. Information on adoption of key management farm practices was obtained from all sampling units using a dichotomous questionnaire. The data from questionnaires were compiled and analyzed using MS Excel 2010.

Agrobiodiversity Survey

To study crop diversity 15 households were randomly selected from the list of 30 households from each category. Crop diversity was studied in the month of February 2023 by laying 10 plots of 10m x 10m for trees, within which 5 sub plots of 1m x 1m in each plot were laid for herbs. All trees and herbs under respective plots were identified and enumerated. Girth of trees was measured at breast height. The field data was analyzed for number of species and quantitative analysis of density per ha calculated. Crop diversity was calculated using Shannon and Wiener Index (1963) and the index of dominance of the plant community was calculated by Simpsons Index (1949).

RESULTS AND DISCUSSION

Farming is the predominant occupation among all landholder categories with 96.67 per cent in marginal and small land holding and 90 per cent in semi medium land holding. Average family size was highest in the SMLH category (6.00 ± 2.31) and lowest in MLH (4.96 ± 1.80) with highest male-female ratio in the SMLH category and lowest in MLH (2.33 and 1.75, respectively). The education of respondents is skewed to the lower education level among the MLH group with not more than ten per cent studied beyond high school while SLH and SMLH categories had more than 30 per cent (Fig. 1).

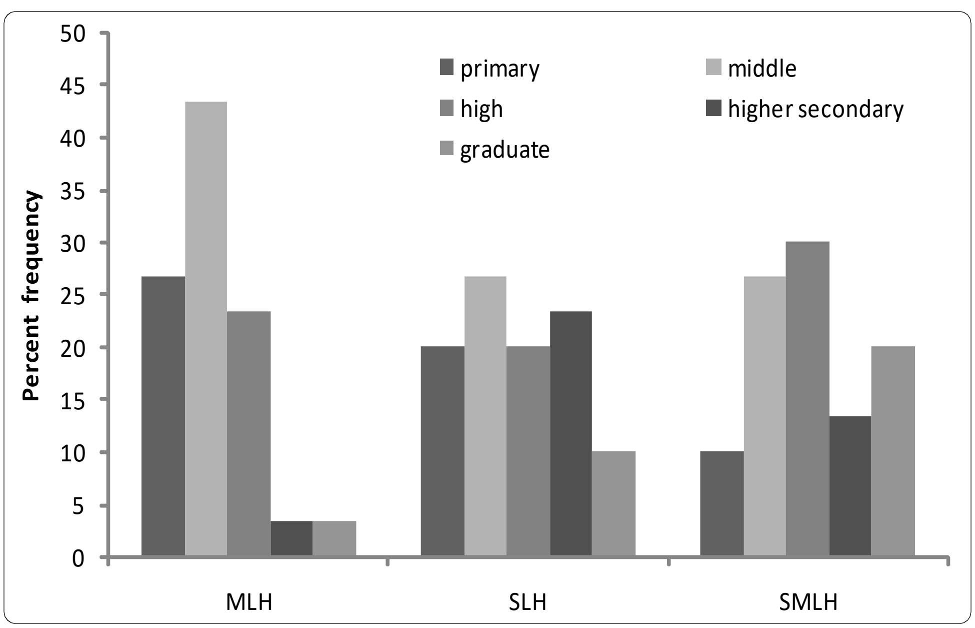

Fig. 1: Education level of respondents across different land holding status at Sihphir Village, Mizoram
(MLH: Marginal Land Holding; SLH: Small Land Holding; SMLH: Semi Medium Land Holding)

Although the primary occupation of the residents was farming, only 42.28 per cent of the households members in MLH, 35.88 per cent in SLH and 35.59 per cent in SMLH category are involved in crop cultivation.

The average land holding of farmers was 0.67 ha, 1.50 ha and 2.96 ha in MLH, SLH and SMLH, respectively. In all categories owners allocated more than one fourth of their land for crop cultivation with figures decreasing in cases where entire land was used from MLH to SMLH (Fig. 2).

Poultry, pig and cattle are the types of livestock reared by the villagers the majority being pig (70 per cent and above) in the three categories. A very small percentage reared cattle, highest being in SLH (26.66

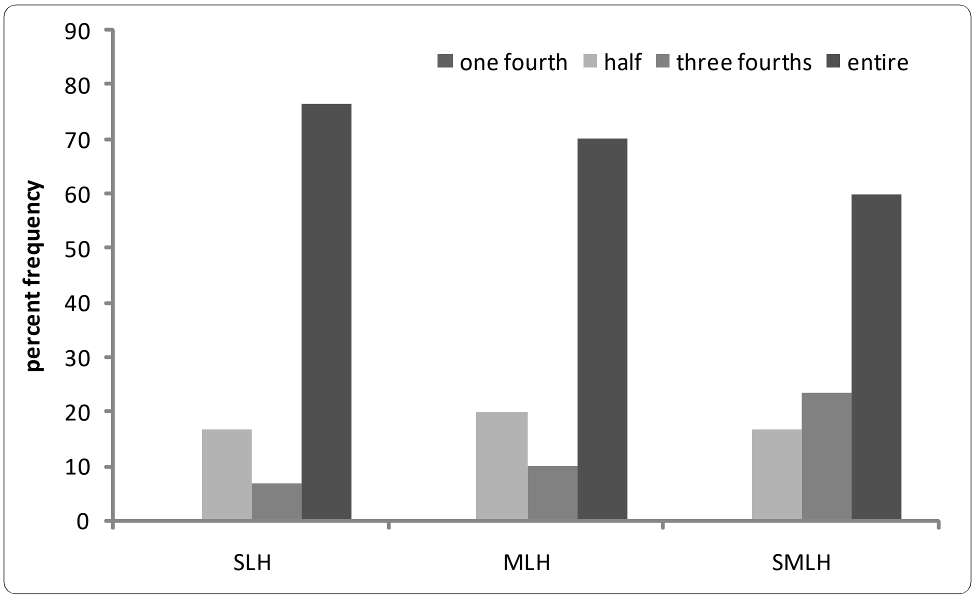

Fig. 2 : Percentage of household allocating land to agriculture across different land holding status at Sihphir Village, Mizoram (MLH: Marginal Land Holding; SLH: Small Land Holding; SMLH: Semi Medium Land Holding)

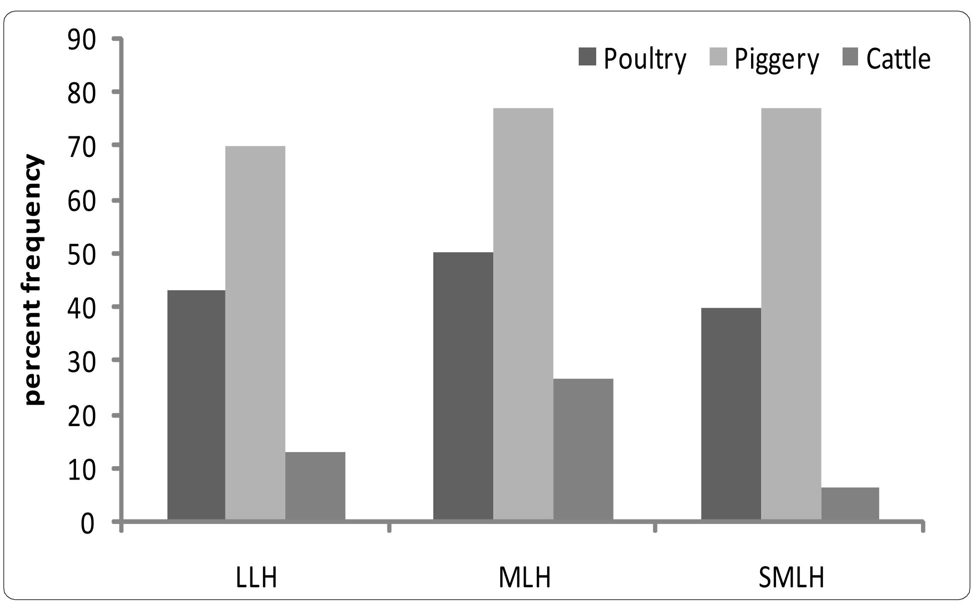

Fig. 3 : Percentage of household rearing different kinds of animals across different land holding status at Sihphir Village, Mizoram (MLH: Marginal Land Holding; SLH: Small Land Holding; SMLH: Semi Medium Land Holding)

per cent; Fig. 3). The average number of pigs per household was highest in SLH (2.46 ± 1.97) and least in MLH (1.96 ± 1.95).

There was an increase in average total household income with larger land holding. The contribution of income from crop to the total income also followed increasing trend with larger land holding yielding more income (Table 1). However, when income from livestock and crops were added together, their contribution to the total income was found highest in SLH (65.46 per cent), followed by SMLH (59.83 per cent) and MLH (54.27 per cent), with income from piggery contributing as high as 19.35 per cent in SLH category. Income contribution from cattle was not reported in any category. Overall there was large variation in income from crop cultivation and livestock within each category. The coefficient of variation for income from crop cultivation and livestock of MLH was 58.88 per cent, 70.28 per cent in SLH and 67.16 per cent in SMLH.

A total of 55 food plant species were reported in all farms, out of which 28 were trees and 27 herbs. Out of the 28 tree species, 17 were a source of fruit and the rest for vegetable while 11 herbaceous plants were used as a vegetable, 2 as fruit and rest for spice. The number of herb species recorded in farms ranged from 16 to 20 and that of tree species from 17 to 21 (Table 2).

Tree density was highest in farms of the SLH category (110 individuals/ha) and least in SMLH. Among tree species, *Cleodendron infortunatum,* a

TABLE 1

Annual income (in rupees) from different sources of household across different land holding status at Sihphir Village, Mizoram

Category	Crop	Piggery	Poultry	Crop and livestock	Service	Business	Others	Total income
Marginal land holding	138401 (33.70)	68723 (15.66)	11640 (2.65)	218764 (54.27)	28772 (6.55)	57658 (13.14)	133592 (30.44)	438787
Small land holding	178026 (40.66)	94592 (19.35)	35215 (7.23)	307834 (65.46)	42733 (8.74)	4716 (0.96)	133555 (27.32)	488840
Semi Marginal land holding	249241 (43.41)	70431 (11.85)	8490 (1.42)	325815 (59.83)	89040 (14.98)	109060 (18.35)	70198 (18.35)	594113

*Figures in parenthesis indicate percentage

TABLE 2

Diversity of tree and herb species in farms of different land holders at Sihphir Village, Mizoram

	Species number	Density per ha	Shannon Index	Simpson Index
Tree species				
Marginal land holding	17	90.00	1.03	0.14
Small land holding	21	110.67	1.11	0.1
Semi Marginal land holding	19	55.33	1.14	0.08
Herb species				
Marginal land holding	16	60826.67	0.72	0.31
Small land holding	20	52400.00	0.75	0.29
Semi Marginal land holding	17	69066.67	0.9	0.21

small tree is commonly found in farms across categories. In the MLH, species with high density were *Clerodendrum infortunatum*, *Psidium guajava* and *Dysoxylum excelsum,* while it was *C.infortunatum, P. guyjava* and *Areca catechu* in SLH and *A. catechu, P. guajava* and *Clerodendrum infortunatum* in the SMLH (Table 3).

Tree diversity and dominance indices across farms in various categories of land holding differed marginally (Table 2). Density of herbaceous species was highest

TABLE 3

Density of tree species per hectare in farms of different land holders at Sihphir Village, Mizoram

Species name	Common name	MLH	SLH	SMLH
Acacia pennata	Climbing acacia	2.67	-	0.667
Areca catechu	Supari	4	-	8
Arengapinata	Sugar palm	-	1.33	-
Artocarpus heterophyllus	Kathal	3.33	-	2.667
Artocarpus lacucha	Lakooch	-		0.667
Averrhoa carambola	Star fruit	1.33	-	-
Carica papaya	Papaya	-	0.67	0.667
Castanopsis tribuloides	Chestnut	-	-	0.667
Citrus aurantifolia	Kagzinebu	-	-	5.333
Citrus medica	Bara nimbu	2	4.67	-
Citrus sinensis	Musambi	-	0.667	2
Clerodendrum infortunatum	Hill glory bower	19.33	22.67	7.333
Cocos nucifera	Coconut palm	-	-	1.333
Coffea arabica	Coffee	3.33	-	-
Dendrocalamus longispathus	Rupohithekera	6	-	-
Dysoxylum excelsum	Indian white cedar	11.33	9.33	0.667
Garcinia spp	Rupohithekera	-	1.333	-
Macadamia	Thingsemim	-	2	-
Mangifera indica	Am	4	3.33	5.333
Musa ornata	Ornamental banana	3.33	1.33	2.667
Musa acuminata	Kella	-	-	2
Ostodes paniculata	Panicled bone tree	-	0.67	-
Parkia timoriana	Tree bean	10	8.67	2.667
Persea americana	Avocado	3.33	4	1.333
Phyllanthus emblica	Amla	3.33	4	2.667
Psidium guajava	Guava	9.33	10.67	7.333
Tamarindus indica	Imli	-	0.67	2
Trachycarpus martianus	Martius fan palm	2.67	-	-
Trevesia palmata	Snowflake tree	-	4	-
Zanthoxylum budrunga	Indian prickly ash	2	2	1.333
Leucaena leucocephala	Lead tree	-	2	0.667

in farms of Semi Marginal land holders (69066.67 per ha), followed by Marginal and small land holders (60826.67 per ha and 52400 per ha, respectively; (Table 2). There were also marked differences in the species diversity between farms of SMLH and those of SLH and MLH (Table 2). In the case of herbaceous species, *Phasoelus vulgaris* had highest density in all categories followed by *Solanum nigrum* in MLH, *Brassica nigra* in SLH and SMLH category(Table 4).

A survey on the conventional methods of farm management reveals that more than 90 per cent of the farmers in the study site use inorganic fertilizers (Table 5). The percentage of farmers having access to

TABLE 4

Density of herb species per hectare in farms of different land holders at Sihphir Village, Mizoram

Species name	Common name	MLH	SLH	SMLH
Acmella oleracea	Toothache plant	2893.33	2973.33	1160
Acmella paniculata	Panicled spot flower	-	-	4160
Ageratum conyzoides	Goat weed	2760	-	2133.33
Amaranthus viridis	Slender amaranth	840	-	5573.33
Amomum dealbatum	Java Cardamon	253.33	-	-
Brassica olearacea var. *capitata*	Cabbage	1920	1600	-
Brassica olearacea var. *italica*	Brocolli	3093.33	6480	5546.67
Brassica nigra	Mustard	33000	26480	28840
Capsicum frutescens	Chilli	-	13.333	-
Coriandrum sativum	Dhania	-	3693.33	3720
Cucurbita maxima	Pumpkin	2333.33	-	1173.33
Fragaria ananassa	Strawberrry	346.67	-	-
Glycine max	Soybean	626.67	40	-
Lablab purpureus	Hycinth bean	280	200	-
Luffa aegyptica	Sponge gourd	-	93.33	-
Lycopersicon esculentum	Tomato	133.33	-	53.33
Mentha arvensis	Pudina	640	-	-
Momordica charantia	Bitter gourd	-	266.667	213.33
Mormodica cochinchinensis	Spiny bitter cucumber	-	120	200
Ocimum americanum	Wild Basil	-	93.33	-
Phaseolus vulgaris	French Bean	3653.33	3586.667	6373.33
Piper sarmentosum	Betel leaf	-	120	-
Prunus virginiana	Bitter berry	-	40	66.67
Raphanus sativum	Mula	-	3466.66	3693.33
Selenicereus undatus	Dragon fruit	93.33	-	493.33
Solanum arthiopicum	Bitter tomato	-	40	-
Solanum nigrum	Black nightshade	7960	2693.33	2346.67
Trichosanthes anguina	Snake gourd	-	253.333	-

TABLE 5

Farm management activities (in percentage adoption) across households with different land holdings at Sihphir Village, Mizoram

Management Practices	MLH	SLH	SMLH
Inorganic fertilizer	90.00	96.60	100.00
Sprinkler system	16.77	16.77	10.00
Fencing	70.00	20.00	23.00
Purchase plant seed	23.00	33.30	63.00
Household using manures	6.60	0.00	0.00

sprinklers in their farms was also higher among the low and medium land holding category (Table 5). Farmers in the MLH and SLH tend to save seeds for the next seasons while SMLH farmers mostly purchased fresh seed (Table 5). In all the categories, small percentage of the farmers plant trees and use of animal-based manures was negligible.

The state of Mizoram lies in the southern tip of the north eastern region of India. The state is still considered to be remote in term of accessibility by road and railway construction is currently under way. Like many other north eastern state agriculture is the main occupation of rural households. Ninety per cent of the households was agricultural irrespective of the land holding, much higher than the overall state figure of 74.4 per cent (Anonymous, Statistical Handbook of Mizoram, 2022). Further, overall average land holding of farmers in the study area across categories was higher (1.61ha) than the overall district figure of 1.02ha (Anonymous, Statistical Handbook of Mizoram, 2022). The average land holding size in the marginal category is at par with state figure (0.67 ha as against 0.60 ha) while they were higher in the small and semi medium category (1.50 ha as against 1.28 ha and 2.96 ha as against 2.29 ha, respectively; Anonymous, Statistical hand book of Mizorzm, 2022). The figures under small and semi medium category are comparable with national averages of 1.41 ha and 2.70 ha (GOI, 2018). The state of Mizoram is under developed in terms of industrial establishment, tourism and service sector. Therefore, farming remains a dominant activity. Over 75 per cent of households in MLH category allocate their entire land towards farming, 70 per cent in the SLH and 60 per cent in the SMLH category. However, farming is not the only source of income. Evidence of income diversification can be observed that in more than 95 per cent of the all households less than 75 per cent of the members were involved in farming. This is further supported by the reasonably high percent income from other sources such as from government and private service, business and daily wage (50.14 per cent in MLH, 37.02 per cent in SLH and 45.15 per cent in SMLH). Off farm income is seen as a reliable strategy of averting risk or to cope with weather shocks among rural households (Pramanik, 2022), especially among the marginal land holders where production levels are subsistent and marketing channels are constrained. High coefficient of variation figures of total household income from agriculture and live stock within each category further implies large differences in usage pattern of land resource. We assume that there is a general lack of awareness among farmers of the various strategies to increase farm income through cultivation of valuable crops, farm diversification such as cattle rearing, integrated management and adopting proven technologies.

Although crop income increased with larger land holding, the income from piggery and poultry when added changed the pattern. The SLH farmers reared more pigs and poultry and obtained highest income from these two sources (Table 1). Piggery is a highly remunerative business in the state because of its huge demand. Pork contributes 71 per cent of total meat consumed in the state (Kumaresan *et al.*, 2006). In addition, low cost of production (fed with kitchen waste and locally available plants), less land area required and minimum labour makes it one of the alternative livelihood options for many households. The income generated from piggery is higher than that reported from Dhemaji and Karbi Anglong districts of Assam which ranged between Rs.27701-34300 per annum (Janmoni *et al.*, 2017).

North East India farms are characterized by diverse crop species that have supported the traditional lifestyle of the community and blends with the landscape architecture. Compared to the many reports on overall plant species diversity of home garden in Mizoram that reveal high trees, shrub and herb richness (Sahoo & Pebam, 2015; Sahoo & Jeeceelee, 2015 and Barbhuiya *et al*., 2016) information on agro diversity which is directly linked to farmer food security and livelihood opportunities is absent. Drawing comparison to a study by Pandey *et al*. (2022) on the diversity of food system of Garo tribes of Meghalaya, we find that the crop diversity in the present study was much higher, 39 against 55, respectively. The crops categories included vegetable, fruits, spices and medicinal plants which indicate a diverse food basket for the households. While there was no marked differences in tree diversity across farm sizes, MLH and SLH farms had higher herbaceous diversity. Smaller landholders have a tendency to diversify their produce to meet nutritional needs (Malapit *et al*., 2015), avert risk and stabilize farm income (Aheibam & Singh, 2017) and also lesser land holding makes intensive cropping for commercial purpose non profitable (Adjimoti *et al.,* 2017). Herb and tree density in farms are seen to be inversely related. For instance, in farms of SMLH low tree density is compensated by high herb density and *vice versa* in the farms of SLH. *B. nigra* is found to be commonly and extensively grown in farms representing more than 50 per cent of crop cover in farms across all categories. Mustard is an obvious choice because of its tolerance to drought during the winter and offers good income to the farmers. Other crops include French beans, cabbage, coriander, brocolli. Sihphir village is recognized as one of the few pockets of Mizoram where commercial cultivation of vegetable crops is practiced (Singh *et al*, 2013) and since it is located close to the capital city, the produce is marketed easily.

Our approach to the present study was land holding size transforms into many household and farm attributes. Besides household attributes such as household members, level of education and family income (Fig. 1 and Table 1), differences in farm attributes were also observed. For instance, plantation tree species such as *A. catechu* and *C. sinensis* dominate farms of SLH and SMLH which were commercial and required crop management practices, whereas in MLH *P. timoriana* and *D. procera*, which were naturally found and required less attention, dominated the farms. *C. infortunatum*, a small tree species of 4-8 feet, was abundant in all farms. Leaves of the species is used as a vegetable and renowned against hypertension across different tribes of the north east India (Kalita *et al*., 2014) and reported to have many pharmacological properties (Lalrinpuia, 2018). The study reported the use of inorganic fertilizer by almost all households, perhaps because of the unavailability of animal manure due to the low livestock population, especially that of cattle (Fig. 3). Mizoram reported a dramatic increase in use of fertilizer between 2020-21 and 2021-22. Urea consumed in the state was 1113.69Mt in 2020-21 which shot to 8392Mt in 2021-22 (Anonymous, Statistical Handbook Mizoram 2022). Fencing was more common among households with MLH, presumably an apprehension against encroachment.

In many contexts, land is a measure of wealth that has overriding influence on many aspects of household, on and off farm activities. Although the opportunities for education, income generation, purchasing power, and crop choices can be witnessed among higher land holders, we failed to see this advantage being transformed in way of crop production, diversity and farm management practices. This is perhaps because all farmers irrespective of their land holding size continue to practice traditional multi cropping system with very low adoption rate of modern technologies. There is no large scale cultivation of high value crops even among the high land holders, the reason being limited marketing avenues and weak supply channels. The income from agriculture is less than 5 per cent of the Gross Development Product (Anonymous, Statistical Handbook Mizoram 2022). There is large scope for diversification of farm produce by way of diverting certain percentage of land area to high value crops and adoption of technologies for higher benefits and livelihood enhancement. Another promising enterprise is integration of livestock for commercial milk production and to promote use of organic manure in farms. Most importantly, there is a great need for the state to improve transportation infrastructure to facilitate marketing of produce.

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Mysore J. Agric. Sci., 58 (4) : 111-122 (2024)

Farmers Vulnerability to Climate Change in Telangana State - A Critical Analysis

Marepally Udaya Sindhu, Y. N. Shivalingaiah, B. Shivanna, R. Vinay Kumar,
H. K. Pankaja and T. L. Mohan Kumar
Department of Agricultural Extension, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : marepallysindhu@gmail.com

Authors Contribution

Marepally Udaya Sindhu : conceptualization, draft preparation, investigation, and data analysis;

Y. N. Shivalingaiah : Conceptualization, guidance and draft correction;

B. Shivanna & R. Vinay Kumar : Conceptualization and guidance;

H. K. Pankaja & T. L. Mohan Kumar : Data curation, guidance and draft correction

Corresponding Author :
Marepally Udaya Sindhu

Received : July 2024
Accepted : September 2024

Abstract

Vulnerability in the context of climate change refers to the degree to which a system is susceptible and unable to cope with adverse climate effects. Farmers' vulnerability to climate change is a critical issue, especially in countries like India, where a substantial portion of the population relies on agriculture for their livelihood. In India, the excessive pressure on natural resources, coupled with inadequate coping mechanisms, has aggravated this vulnerability. The study was conducted in two districts of Telangana state to analyse the vulnerability level of farmers to climate change. A total of 240 farmers were selected by using simple random sampling technique from twenty four villages from two districts. Personal interview method was used to collect data and appropriate statistical tools were applied to analyse the data. The findings revealed that nearly half (45.00 %) of the farmers belonged to moderately vulnerable category followed by severe (31.67 %) and least (25.84 %) vulnerable level category. The major problems related with adaptative capacity of farmers to climate change was limited access to information regarding long-term climate change, insufficient awareness about suitable adaptation measures (climate resilient crop varieties, soil-moisture conservation techniques etc.), inadequate transportation facilities, challenging to engage in fieldwork due to extreme temperatures, absence of credit or loans from banking institutions. Provision of incentives and support for increased use of green manure, promotion of awareness and providing support for the adoption of organic farming technologies, crop diversification were some of the major suggestions given by farmers to overcome adverse effects of climate change.

Keywords : Climate change, Vulnerability, Challenges

Climate change and its variability have become significant concerns for Indian agriculture in recent years. Global climate change projections indicate an increase in extreme events such as heat waves, cold waves and flooding, along with higher atmospheric carbon dioxide and ground-level ozone concentrations. Additionally, a rise in sea levels is expected to inundate coastal areas, among other impacts (Raghavan *et al.,* 2020).

Developing countries like India are particularly vulnerable to climate change, facing large-scale climate variability and heightened risks. India's susceptibility is exacerbated by its agrarian economy, expansive coastal areas and regions like the Himalayas. Climate change poses significant trade-offs with economic growth and social development. With 2.4 per cent of the world's surface area, India supports around 17.5 per cent of the global population, housing 30 per cent of the world's poor and significant proportions of the global population lacking electricity, clean cooking resources and safe drinking water (Anonymous, 2015). India has a diverse ecology and some regions have evolved and adapted practices over time to tackle vagaries. Judicious use of some of these practices has the potential to mitigate the effects of climate change. Proper management and implementation of practices that have resulted in an increased agri-produce in unfavourable conditions can also be used to adapt to climate change (D. V. Srinivas Reddy *et al.,* 2023).

Vulnerability in the context of climate change refers to the degree to which a system is susceptible to and unable to cope with adverse climate effects. It is a function of the exposure to climatic hazards, the sensitivity of the system to these hazards and the adaptive capacity of the system (IPCC, 2007a). In India, the excessive pressure on natural resources, coupled with inadequate coping mechanisms, has exacerbated this vulnerability.

Studying farmer's vulnerability is essential for several reasons. Firstly, it provides insights into the specific climatic risks faced by different agricultural regions, helping to tailor adaptive measures effectively. Secondly, it aids in understanding the socio-economic factors that influence farmer's capacity to adapt, such as access to resources, knowledge and technology. Thirdly, it supports the development of policies and programs that enhance the resilience of the agricultural sector, ensuring food security and economic stability. In summary, understanding and addressing the vulnerability of farmers to climate change is imperative for sustaining agricultural productivity and ensuring the livelihoods of millions in India.

To cope with climate change and enhance agricultural resilience, planned approaches in agricultural practices and development are essential. India's diverse ecology has led to the evolution and adaptation of various practices over time, which can effectively address climate variability. The judicious application of these practices has the potential to mitigate the impacts of climate change.

Climate-resilient crops and crop varieties, designed to withstand biotic and abiotic stresses, play a crucial role in maintaining or increasing crop yields under extreme weather conditions. These crops offer a viable solution to counter diminishing yields caused by droughts, higher average temperatures and other climatic challenges (Maricelis Acevedo *et al.,* 2020).

The collaboration among farmers, extension professionals, and scientists is pivotal in managing crises induced by climate change. Active interaction among them is necessary to accelerate agricultural development in concerned areas. However, research in this area has been primarily focused on investigating farmer's adjustment patterns and simultaneously study the crisis-mitigating strategies of government organizations and research systems.

Methodology

Ex-post facto research design was adopted for the study. The study was conducted in the Northen Zone of Telangana. Bodhan and Armoor taluks from Nizamabad district, Boath and Ichoda from Adilabad district were selected purposively for the study. The district and taluks with higher degree of climate change were purposively selected for the study. Villages from each of the taluks were selected randomly and the list of the villages from each of the *taluks* so selected was collected from the Revenue Department and then the six villages from each of the *taluk* were selected randomly for the study. In each of the village, 10 farmers were selected Thus, totally 60 farmers from each Taluk and totally 240 respondents constituted sample for the study.

The independent variables selected for the study were age, education, land holding, experience in farming, annual income, social participation, mass media exposure, farm mechanisation, extension participation, extension contact, credit orientation, risk orientation, management orientation, innovative ness, risk orientation, scientific orientation cosmopoliteness, deferred gratification and knowledge about climate smart technologies.

The scale for assessing the vulnerability level of farmers to climate change was developed and standardized consisting of 89 statements was administered on the respondents along with five point continum representing 'Strongly Agree (SA)', 'Agree (A)', 'Undecided (UD)', 'Disagree (D)' and

'Strongly Disagree (SDA)' with weightage of 5, 4, 3, 2 and 1, respectively. The statements were carefully formed by consulting subject matter specialists of University of Agricultural Sciences, Bangalore along with review of related literature. The statements were subjected to thorough scrutiny and editing to avoid ambiguity of meaning, eliminate duplication of ideas and to achieve clarity and specificity of question. The vulnerability score of a respondent was worked out by adding the scores obtained by him/her on all final statements considered for the measurement.

Results and Discussion

Overall Comparison of Farmers Based on Vulnerability Level to Climate Change

Table 1, indicates the comparison of farmers based on vulnerability level to climate change. The data revealed that among farmers of Nizamabad district, slightly less than half (49.16%) of the farmers belonged to moderate vulnerability level, followed by slightly more than one-fourth (26.67%) were under severely vulnerable level and nearly one-fourth (24.17%) belonged to least vulnerable level category. Among farmers of Adilabad district, the trend observed was that 40.83 per cent of them were under moderate vulnerability level category followed by severely vulnerable level (36.67%) and least vulnerable level category (22.50%). In the case of overall farmers, more than two-fifth (45.00%) of the farmers were categorized under moderate vulnerability level followed by severely vulnerable level (31.67%) and least vulnerable level category (23.33%). The trends reveal that while many farmers are moderately vulnerable to climate change, a significant portion, especially in Adilabad, faces severe risks. The results are inline with results of Shankar (2019) where majority of the respondents were under medium level of vulneralibility followed by severe and low vulnerable category. This situation underscores the need for targeted interventions, such as improving access to resources, enhancing adaptive capacity and promoting sustainable practices to reduce vulnerability levels across both districts. Understanding these dynamics is crucial for developing effective agricultural policies and climate resilience strategies tailored to the specific needs of each community.

Classification of Farmers based on Exposure, Sensitivity, Attitude, Egalitarianism

In the study area data collected on different dimensions of vulnerability level such as exposure, sensitivity, attitude and egalitarianism were analyzed separately for all farmers to know the extent of exposure, sensitivity attitude and egalitarianism. The farmers were grouped and presented in the Table 2. The data in the table reveals that, two-fifth (45.00%) of the farmers were fall in medium level of exposure to climate change (rainfall and temperature) followed by 30 per cent were in low level exposure and one-fourth (25.00%) of them belongs to high exposure category among farmers of Nizamabad district, whereas in Adilabad, slightly less than half

Table 1

Comparison of farmers based on vulnerability level to climate change

(n=240)

Vulnerability level of farmers to climate change	Farmers of Nizamabad district (n_1=120)		Farmers of Adilabad district (n_2=120)		Overall farmers (n=240)	
	Number	Percentage	Number	Percentage	Number	Percentage
Least vulnerable (< 2.94)	29	24.17	27	22.50	56	23.33
Moderately vulnerable (2.94 -4.26)	59	49.16	49	40.83	108	45.00
Severely vulnerable (>4.26)	32	26.67	44	36.67	76	31.67

TABLE 2

Classification of farmers based on exposure, sensitivity, attitude, egalitarianism

(n=240)

Indicators	Classification	Farmers of Nizamabad district (n_1=120)		Farmers of Adilabad district (n_2=120)		Overall farmers (n=240)	
		Number	Percentage	Number	Percentage	Number	Percentage
Exposure	Less exposure (<2.54)	36	30.00	33	27.50	69	28.75
	Moderate exposure (2.54-3.82)	54	45.00	59	49.17	113	47.08
	High exposure (>3.82)	30	25.00	28	23.33	58	24.17
Sensitivity	Less sensitive (<2.49)	17	14.17	16	13.33	33	13.75
	Moderately sensitive (<2.49-3.77)	61	50.83	57	47.50	118	49.17
	Highly sensitive (>3.77)	42	35.00	47	39.17	89	37.08
Attitude	Unfavourable (<2.53)	37	30.83	42	35.00	79	32.92
	favourable (2.53-3.79)	49	40.84	56	46.67	105	43.75
	Most favourable (>3.79)	34	28.33	22	18.33	56	23.33
Egalitarianism	Poor (<2.50)	43	35.83	48	40.00	91	37.92
	Good (2.50-3.78)	51	42.50	53	44.17	104	43.33
	Better (>3.78)	26	21.67	19	15.83	45	18.75

(49.17%) of the farmers were fall in medium level of exposure to climate change (rainfall and temperature) followed by 27.50 per cent were in low level exposure and 23.33 per cent of them belongs to high exposure category.

Overall results with respect to exposure revealed that less than half (47.08%) of the farmers were fall in medium level of exposure to climate change (rainfall and temperature) followed by 28.75 per cent were in low level exposure and slightly less than one-fourth (24.75%) of them belongs to high exposure category. The high proportion of farmers with medium to high exposure to climate change (rainfall and temperature) indicates the need for targeted adaptation strategies to help them cope with the changing climatic conditions. Interventions should focus on improving farmer's access to weather information, early warning systems and climate-smart agricultural practices to enhance their preparedness and resilience.

With respect to sensitivity, half (50.83%) of the farmers were moderately sensitive to climate change and 35.00 per cent of them were highly sensitive to climate change followed category of low level of sensitivity with 14.17 per cent among farmers of Nizamabad district, whereas in Adilabad, less than half (47.50%) of farmers were moderately sensitive to climate change and 39.17 per cent of them were highly sensitive to climate change followed category of low level of sensitivity with 13.33 per cent.

Overall results with respect to sensitivity revealed that slightly less than half (49.17%) of farmers were moderately sensitive to climate change and 37.05 per cent of them were highly sensitive to climate change followed category of low level of sensitivity with 13.75 per cent. The significant share of farmers with moderate to high sensitivity to climate change underscores the vulnerability of the agricultural sector in the study area. Efforts should be made to strengthen the adaptive capacity of farmers, particularly those highly sensitive, through capacity building, access to resources and the promotion of diversified livelihood options.

With respect to attitude, two-fifth (40.84%) of the farmers were under favourable attitude, followed by unfavorable attitude (30.83%) and most favourable attitude (28.33%) among the farmers of Nizamabad district, whereas in Adilabad, 46.67 per cent of farmers were under favourable, followed by unfavorable attitude (35.00%) and most favourable attitude (18.33%). Overall results with respect to attitude revealed that, 43.75 per cent of farmers were under favourable attitude, followed by unfavorable attitude (32.92%) and most favourable attitude (23.33%). The prevalence of favorable and unfavorable attitudes towards climate change among farmers suggests the need for targeted awareness campaigns and educational programs. Improving farmer's understanding of climate change impacts and the importance of adaptation measures could foster more favorable attitudes and encourage proactive engagement in climate-resilient practices.

With respect to egalitarianism, more than two-fifth (42.50%) of the farmers belongs to good level of egalitarianism followed by poor (35.83%) and better level (21.67%) egalitarianism category among the farmers of Nizamabad district, whereas in Adilabad, more than two- fifth (44.17%) of the farmers belongs to good level of egalitarianism followed by poor (40.00%) and better level (15.83%) egalitarianism category. Overall results with respect to egalitarianism, more than two-fifth (43.33%) of the farmers belongs to good level of egalitarianism followed by poor (37.92%) and better level (18.75%) egalitarianism category. The relatively low levels of egalitarianism among farmers, with a significant proportion in the poor and better categories, indicate the need to address socio economic disparities and promote inclusive climate change adaptation strategies. Interventions should aim to enhance equitable access to resources, information and decision-making processes, ensuring that all farmers, regardless of their socioeconomic status, can benefit from climate change adaptation efforts. The findings are inline with results of Chetri (2017), where majority of the respondents were under medium exposure, moderately sensitive category, favourable attitude and good to poor egalitarianism category.

The findings highlight the multidimensional nature of vulnerability to climate change among farmers in the study area. Addressing these vulnerabilities will require a comprehensive approach that combines targeted interventions, capacity building and the promotion of inclusive and equitable climate change adaptation strategies. By addressing the identified vulnerabilities, policymakers and stakeholders can enhance the resilience of the agricultural sector and improve the livelihoods of farmers in the face of a changing climate.

Association of Independent Variables with Vulnerability of Farmers to Climate Change

The chi-square test was used to find out the association between profile characteristics and overall vulnerability of farmers to climate change among farmers of Nizamabad district. It was observed from the data in the Table 3 that, the variables such as age, social participation, economic motivation and

TABLE 3

Comparison of association of independent variables with vulnerability level of farmer

(n=240)

Independent variables	Farmers of Nizamabad district (n_1=120)	Farmers of Adilabad district (n_2=120)	Overall farmers (n=240)
Age	9.658 **	10.896 **	12.698 **
Education	11.12 *	12.49 *	11.236 *
Family size	0.569 NS	0.428 NS	0.496 NS
Land holding	1.596 NS	2.263 NS	2.168 NS

Continued....

TABLE 3 Continued....

Independent variables	Farmers of Nizamabad district (n_1=120)	Farmers of Adilabad district (n_2=120)	Overall farmers (n=240)
Experience in farming	8.021 *	7.085 *	7.862 *
Annual income	8.263 *	8.120 *	8.189 *
Social participation	8.467 **	8.866 **	8.662 *
Mass media exposure	7.369 *	7.985 *	7.729 *
Extension contact	8.109 *	7.863 *	8.000 *
Extension participation	8.010 *	8.197 *	8.000 *
Farm mechanisation	3.259 NS	2.968 NS	3.189 NS
Innovativeness	7.210 *	7.928 *	7.762 *
Risk orientation	8.061 *	8.163 *	8.102 *
Scientific orientation	7.296 *	7.000 *	7.169 *
Economic motivation	14.329 **	13.728 **	13.926 **
Management orientation	7.320 *	7.892 *	7.518 *
Credit orientation	8.169 *	8.012 *	8.129 *
Cosmopoliteness	7.139 *	7.368 *	7.261 *
Deferred gratification	1.635 NS	2.356 NS	1.539 NS
Knowledge about climate smart technologies	26.367 **	25.936 **	26.296 **

NS- Non-Significant, *- Significant at 5 per cent level, **- Significant at 1 per cent level

knowledge about climate smart technologies at 1 per cent level of significance. The other variables such as education, farming experience, family income, mass media exposure, innovativeness, extension participation, social participation, extension contact, cosmopoliteness, credit orientation, management orientation, risk orientation, scientific orientation at 5 per cent level of significance and family size, land holding, farm mechanisation and deferred gratification had non-significant association with vulnerability of farmers to climate change. The chi-square test was used to find out the association between profile characteristics and overall vulnerability of farmers to climate change among farmers of Adilabad district.

It was observed from the data in the Table 3 that, the variables such as age, social participation, economic motivation and knowledge about climate smart technologies at 1 per cent level of significance. The other variables such as education, farming experience, family income, mass media exposure, innovative ness, extension participation, social participation, extension contact, cosmopoliteness, credit orientation, management orientation, risk orientation, scientific orientation at 5 per cent level of significance and family size, land holding, farm mechanisation and deferred gratification had non-significant association with vulnerability of farmers to climate change. With respect to overall farmers, same trend of association of variables with vulnerability was found.

Age and Vulnerability Level of Farmers to Climate Change

The study revealed that age is positively and significantly associated with the vulnerability of farmers to climate change. This association can be attributed to several factors. Younger farmers often lack the extensive experience needed to manage climate-related challenges effectively, which increases their vulnerability. Additionally, those with lower educational levels may struggle to understand the impacts of climate variability, making them more susceptible to adverse effects. Farmers who have not built strong community networks may find it difficult to access resources and support during climate crises. Moreover, some older farmers might resist adopting new technologies or practices, further heightening their vulnerability to climate impacts. Economic constraints also play a significant role, as farmers with limited financial resources may struggle to invest in necessary adaptations, leaving them exposed to climate risks. A reliance on traditional farming methods without considering climate change can increase vulnerability to extreme weather events.

Environmental degradation resulting from unsustainable practices further contributes to this issue. Social isolation can prevent farmers from receiving timely support or knowledge about coping strategies, while older farmers may face physical limitations that hinder their ability to implement necessary changes, ultimately increasing their vulnerability to climate change impacts.

Education and Vulnerability Level of Farmers to Climate Change

Education plays a crucial role in shaping farmer's vulnerability to climate change. Studies have shown that education is significantly associated with the vulnerability of farmers, highlighting the importance of knowledge acquisition and critical thinking skills. Farmers with lower levels of education may struggle to understand climate variability and the associated risks, leading to increased susceptibility to adverse effects. Additionally, less educated farmers may have limited access to new technologies and practices, which can further heighten their vulnerability. With out the ability to plan and organize effectively, these farmers are less equipped to identify challenges and opportunities, ultimately impacting their overall farm management. Consequently, a lower level of education often correlates with a higher vulnerability to climate change, as it limits farmer's capacity to adapt and respond to shifting agricultural conditions.

Mass media and Vulnerability Level of Farmers to Climate Change

Mass media plays a crucial role in raising awareness, increasing knowledge and influencing the vulnerability of farmers to climate change. Research has shown that exposure to mass media is significantly associated with farmer's vulnerability, as those with higher levels of media exposure gain important insights into the risks associated with climate change and the need for sustainable practices. Additionally, increased awareness can lead to complacency if farmers do not have the resources or support to implement new technologies, thereby heightening their vulnerability. The study also revealed that extension participation and contact are positively and significantly associated with farmer's vulnerability to climate change. More frequent interactions with extension personnel and participation in activities like field days and trainings can help farmers understand adaptation strategies, but those who are less engaged may struggle to access this vital information. This limited contact can leave farmers ill-equipped to respond effectively to climate challenges, ultimately increasing their vulnerability and jeopardizing their agricultural sustainability.

Social Participation, Cosmopoliteness and Vulnerability Level of Farmers to Climate Change

Both social participation and cosmopoliteness were found to have a significant impact on the vulnerability of farmers to climate change. Social participation fosters community engagement, but those lacking involvement in local organizations may miss out on critical knowledge sharing and resource access, increasing their vulnerability during climate-related challenges. Without strong community ties, farmers may struggle to adapt effectively to changing conditions. Similarly, cosmopoliteness, or openness to external ideas, can help farmers learn about broader agricultural trends, but farmers who are isolated from these influences may fall behind in adopting necessary practices, further heightening their vulnerability. Additionally, limited social connections can result in a lack of support during difficult times, leaving farmers without essential resources or assistance.

Credit Orientation, Management Orientation Risk Orientation and Vulnerability Level of Farmers to Climate Change

Furthermore, credit orientation, management orientation and risk orientation significantly influence farmer's vulnerability to climate change. Farmers with low credit orientation may find it challenging to secure funding for new technologies, limiting their ability to invest in climate-resilient strategies. Similarly, a lack of risk orientation can prevent farmers from experimenting with innovative practices, making them less resilient in the face of climate variability. Without effective management, farmers may fail to assess operational challenges and respond strategically, increasing their susceptibility to climate impacts. Additionally, farmers who lack access to credit may miss out on vital training and support services that equip them to adapt their practices. Overall, insufficient social participation, cosmopoliteness and orientations towards credit, management and risk contribute significantly to the vulnerability of farmers in the face of climate change.

Scientific Orientation and Vulnerability Level of Farmers to Climate Change

The study revealed that scientific orientation is positively and significantly associated with the vulnerability of farmers to climate change. Farmers lacking a strong scientific orientation may struggle to understand climate-related challenges, making them more susceptible to adverse impacts. Without the ability to adopt innovative practices, these farmers are less equipped to navigate changing conditions, increasing their vulnerability. Limited access to education and information further compounds this issue, preventing farmers from making informed decisions that support sustainable farming and effective resource management.

Moreover, insufficient participation in social networks and extension programs can lead to isolation, reducing opportunities for collaboration and knowledge sharing, which are vital for resilience. Farmers who do not diversify their practices are more reliant on single crops or methods, heightening their vulnerability to climate variability. Additionally, without adequate training and support from extension services, farmers may fail to implement necessary climate-smart practices. Ultimately, a limited scientific mindset can lead to stagnant thinking and a failure to critically evaluate existing methods, resulting in practices that do not promote biodiversity or ecological balance, which are essential for long-term sustainability in the face of climate change.

Knowledge about Climate Smart Technologies and Vulnerability Level of Farmers to Climate Change

Knowledge about climate-smart technologies is positively and significantly associated with vulnerability of farmers to climate change because farmers who lack understanding of these technologies may be ill-equipped to implement effective strategies to combat climate change. Without this knowledge, farmers are more likely to rely on traditional practices that may not be resilient to shifting climatic conditions, increasing their susceptibility to adverse impacts. Additionally, limited awareness of innovative techniques can lead to poor decision-making, resulting in reduced crop yields and heightened vulnerability. Furthermore, farmers without access to information about climate-smart options may miss out on opportunities for adaptation, leaving them unable to respond effectively to climate-related challenges and further exacerbating their vulnerability.

Challenges in Adaptation Experienced by Farmers Due to Climate Change

The data projected in the Table 4 reveals that one of the major challenges expressed by farmers of Nizamabad district was to insufficient awareness about suitable adaptation measures was ranked first with mean score of 2.53 as most important challenge, followed by shortage of labour availability with mean score of 2.49 (Rank II) and limited access to information regarding long-term climate change and lack of timely availability of inputs such as seeds, pest control chemicals and fertilizers were with mean score of 2.48 (Rank III), reduced market prices for agricultural produce and inadequate processing units capacity within the village were with mean score of

TABLE 4

Challenges expressed by farmers for adaptation in response to climate change

(n=240)

Challenges	Farmers of Nizamabad district (n_2=120)		Farmers of Adilabad district (n_2=120)		Overall Farmers (n=240)	
	Mean score	Rank	Mean score	Rank	Mean score	Rank
Challenging to engage in fieldwork due to extreme temperatures.	2.44	VII	2.43	VI	2.43	VII
Increased expenses for agricultural inputs.	2.42	XII	2.43	VI	2.42	IX
Lack of timely availability of inputs such as seeds, pest control. chemicals, and fertilizers	2.48	III	2.48	III	2.48	III
Reduced market prices for agricultural produce.	2.40	XIV	2.44	V	2.42	IX
Shortage of labour availability.	2.49	II	2.40	IX	2.45	IV
Elevated labour wage rates.	2.46	V	2.40	IX	2.43	VII
Inconsistent supply of reliable electricity.	2.38	XVI	2.40	IX	2.39	XVI
Limited access to information regarding long-term climate change.	2.48	III	2.48	III	2.45	IV
Absence of irrigation facilities	2.43	IX	2.37	XII	2.42	IX
Insufficient awareness about suitable adaptation measures.	2.53	I	2.52	II	2.51	I
Absence of credit or loans from banking institutions.	2.43	IX	2.46	IV	2.44	VI
Inadequate storage capacity within the village	2.44	VII	2.36	XIII	2.40	XV
Inadequate processing units capacity within the village	2.40	XIV	2.42	VII	2.41	XIII
Limited understanding of a. Processing b. Gradingc. Storage	2.43	XI	2.30	XV	2.39	XVI
Considerable distance of the regulated market from the village.	2.45	VI	2.33	XIV	2.39	XVI
Inadequate transportation facilities.	2.48	III	2.54	I	2.51	I

2.40 (Rank XIV each) and inconsistent supply of reliable electricity was with mean score of 2.38 (XVI) respectively, whereas among farmers of Adilabad, inadequate transportation facilities was ranked first with mean score of 2.54 followed by insufficient awareness about adaptation strategies with mean score of 2.52 (Rank II) and limited access to information regarding long-term climate change and lack of timely availability of inputs such as seeds, pest control chemicals and fertilizers were with mean score of 2.48 (Rank III). With respect of overall farmers, inadequate transportation facilities and insufficient awareness about suitable adaptation measures was ranked first with mean score of 2.51, followed by limited access to information regarding long-term climate change, shortage of labour availability and lack of timely availability of inputs such as seeds, pest control chemicals, and fertilizers were with mean score of 2.45 (Rank III) and Inadequate storage capacity within the village with mean score of 2.40 (Rank XV) and considerable distance of the regulated market from the village, irregular electricity, limited understanding of processing, grading and storing weres with mean score of 2.39 (Rank XVI) respectively. The probable reasons for the difficulties faced by farmers include small-scale farming with low per capita land availability, low income and a lack of cosmopolitan influence. These factors make it highly challenging for them to adapt suitable technologies in their fields. This aligns with the findings of Banafar and Chandrakar (2016), who identified major socio-economic constraints in pigeon pea production, such as the unavailability of improved and high-yielding variety seeds, cattle grazing issues, lack of irrigation, insufficient knowledge of agricultural practices, poor economic conditions of small farmers and problems with insect pests and diseases. Similarly, Muhammad *et al.* (2015), reported that limited water availability, high levels of poverty and a weak local government role in providing proper infrastructure exacerbate farmer's sensitivity to climate-related risks. They highlighted constraints such as a lack of resources, limited information, insufficient finances and inadequate institutional support, which all limit the adaptive capacity of farm households. Chinwendu *et al.* (2017), found that inadequate education, limited access to resources (including land, labour supply and traditional knowledge/information), poor local institutional capacity and services and gender disparities are key factors shaping vulnerability.

Expectations of Farmers to Overcome the Adverse Effects of Climate Change

The data projected in the Table 5 reveals that one of the major expectations expressed by farmers of Nizamabad district was to provide subsidies or compensation for crops to offset cultivation costs due to weather aberrations and incentives and support for increased use of green manure and raising awareness regarding appropriate measures for adapting to climate change were ranked first with mean score of 2.94 as most important suggestion, followed by Farmers should receive early alerts about environmental changes with mean score of 2.44 (Rank IV), whereas among farmers of Adilabad, provide subsidies or compensation for crops to offset cultivation costs due to weather aberrations was ranked first with mean score of 2.52 followed by raising farmer's awareness regarding appropriate

TABLE 5

Expectations of farmers to overcome adverse effects of climate change

(n=240)

Expectations	Farmers of Nizamabad district (n_2=120)		Farmers of Adilabad district (n_2=120)		Overall Farmers (n=240)	
	Mean score	Rank	Mean score	Rank	Mean score	Rank
Farmers should receive early alerts about environmental changes.	2.44	IV	2.48	II	2.46	IV
Raise farmers' awareness regarding appropriate measures for adapting to climate change.	2.49	I	2.48	II	2.48	II
The development department must ensure timely supply of production inputs to villages.	2.43	V	2.43	VIII	2.43	VI
Provide subsidies or compensation for crops to offset cultivation costs due to weather anomalies.	2.49	I	2.52	I	2.50	I
Extend insurance coverage to encompass all crops.	2.39	IX	2.44	VII	2.42	X
Offer financial assistance for enriching soil nutrients.	2.41	VII	2.43	VIII	2.42	X
Provide incentives and support for increased use of green manure.	2.49	I	2.46	V	2.48	II
Establish a support price for all crop produce based on cultivation costs.	2.39	IX	2.46	V	2.43	VI
Promote awareness and provide support for the adoption of organic farming technologies.	2.41	VII	2.47	IV	2.44	V
Increase the number of drip/sprinkler irrigation facilities to cover a larger number of farm families.	2.43	V	2.43	VIII	2.43	VI

measures for adapting to climate change and receiving early alerts were with mean score of 2.48 (Rank II) and promote awareness and provide support for the adoption of organic farming technologies with mean score of 2.47 (Rank IV). With respect of overall farmers, provide subsidies or compensation for crops to offset cultivation costs due to weather aberrations was ranked first with mean score of 2.50, followed by incentives and support for increased use of green manure and raising awareness regarding appropriate technologies were with mean score of 2.48 (Rank II) and receiving early alerts about environmental changes was with mean score of 2.46 (Rank IV). Based on the extensive experience of farmers, several key suggestions have been identified to address the challenges posed by climate change. Government and development departments must consider these suggestions to meet farmer's needs and reduce vulnerability caused by climate change. The present study aligns with Deepa and Shiyani (2016) highlight the need for unique strategies in dryland areas like Kutch that consider their uncertain dynamics. Strategies such as rainwater harvesting, livestock development and techniques to enhance dryland agriculture can help overcome many constraints. Implementing policies to promote efficient irrigation systems is essential. Water management strategies should include deepening wells, properly utilizing water supply systems, constructing check-dams and focusing on integrated watershed management and rainwater harvesting. Strengthening insurance coverage (crop, livestock, etc.) and micro-financing facilities is also crucial. Investments in dryland agriculture should include addressing climate change. The results were also supported by the findings of Pooja *et al.* (2022) where various adaptation techniques like awarness about fertilizer management, crop diversification etc., lead to increase in livelihood and income of farmers.

Climate change and agriculture are globally interrelated, with climate change affecting agriculture through shifts in temperature, rainfall, climate extremes, pests, diseases, atmospheric carbon dioxide, ozone concentrations and sea levels. India is particularly vulnerable due to its large population dependent on agriculture. Ensuring food and nutritional security amidst climate change is crucial for India. Climate change poses a significant threat to millions of livelihoods in India, making timely and relevant information vital for farmers to adapt their practices. Providing weather trends and best management practices helps farmers make informed decisions about crop choices, sales and inputs. Crop diversification was also found to be essential not only for achieving higher yields and returns but also for maintaining soil health and providing other benefits (Siddique *et al.,* 2012). Understanding farmer's vulnerability and adaptation strategies is essential for developing effective measures to manage farms and implement agri-environmental policies. The findings revealed that nearly half (45.00%) of the farmers belonged to moderately vulnerable category followed by severe (31.67%) and least (25.84%), vulnerable level category. The chi-square test was used to find out the association between profile characteristics and overall vulnerability of farmers to climate change among farmers of Adilabad district. It was observed from the data that, the variables such as age, social participation, economic motivation and knowledge about climate smart technologies at 1 per cent level of significance with overall vulnerability of farmers. The other variables such as education, farming experience, family income, mass media exposure, innovativeness, extension participation, social participation, extension contact, cosmopoliteness, credit orientation, management orientation, risk orientation, scientific orientation at 5 per cent level of significance.

Bridging the gap in addressing the vulnerability of farmers to climate change requires a strategic and multifaceted approach. Conducting surveys and field studies can identify specific areas of vulnerability, such as water scarcity, pest outbreaks, soil degradation and crop failure. Customized extension strategies are essential, involving mass media campaigns, workshops and seminars to raise awareness about climate change and adaptive measures. Sharing success stories and organizing motivational sessions with experts can build confidence among farmers.

Collaboration with government agencies, NGOs and private organizations can provide resources like drought-resistant seeds, efficient irrigation systems, and climate-smart technologies at subsidized rates. Community resource centers can offer continuous support and information.

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Effect of Seed Priming on Seed Quality in Parental Lines of Hybrid Maize (*Zea mays* L.) MAH 15 - 84

Mallikarjun Sherakhane[1], Parashivamurthy[2], Basave Gowda[3], H. C. Lohithaswa[4] and G. Keshavareddy[5]
[1,2&3]Department of Seed Science and Technology, [4]Department of Genetics and Plant Breeding, [5]Department of Entomology, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : mssherakhane@gmail.com

Authors Contribution

Mallikarjun Sherakhane : Conceptualization, data analysis, investigation and manuscript preparation;

Parashivamurthy : Conceptualization, editing manuscript and supervision;

Basave Gowda ; H. C. Lohithaswa & G. Keshavareddy : Draft prepration, methodology, guidance and interpretation

Corresponding Author :
Mallikarjun Sherakhane

Received : June 2024
Accepted : August 2024

Abstract

The laboratory experiment was conducted to standardize the seed priming techniques for enhancement of seed yield and quality in parental lines of hybrid maize (*Zea mays* L.) MAH 15-84 at Department of Seed Science and Technology, CoA, UAS, GKVK, Bengaluru during 2022. The seeds of both male (MAI-19-20) and female (MAI-19-117) parents were primed with KNO_3 and $ZnSO_4$ at 0.5 and 1 per cent, gibberellic acid (GA_3) and salicylic acid (SA) at 50 and 100 ppm and hydroprimed for 12 and 24 h and unprimed seeds were used as control. The results revealed that, among treatments, seeds of male and female parents primed with 50 ppm GA_3 for 12 h (T_9) recorded highest seed germination (99.33 and 99.00%), root length (29.70 and 27.33 cm), shoot length (25.26 and 26.02 cm), seedling dry weight (93.31 and 92.33 mg), SVI-I (5459 and 5282), SVI-II (9268 and 9141), total dehydrogenase activity (2.456 and 2.348 at A_{480} nm) and least electrical conductivity (0.262 and 0.228 dSm^{-1}), less duration for radicle emergence (70.93 and 69.07 h) and T_{50} value (3.08 and 3.24 days) respectively, which was followed by seeds primed with 1 per cent $ZnSO_4$ for 12 h (T_7) compared to control (89.33 and 90.67%, 20.40 and 20.42 cm, 18.09 and 18.01 cm, 78.41 and 82.00 mg, 3438 and 3484, 7004 and 7435, 0.974 and 0.724 at A_{480} nm 0.610 and 0.650 dSm^{-1}, 80.83 and 82.27 h and 5.04 and 4.78 days respectively). Thus, seed priming with 50 ppm GA_3 for 12 h and 1 per cent $ZnSO_4$ for 12 h found to be the best treatments to enhance the seed quality of hybrid maize compared to other priming treatments and control. Hence, these two treatments could be utilised for commercial exploitation of maize hybrid seed production to get better seed yield.

Keywords : Maize hybrid, Seed priming, KNO_3, $ZnSO_4$, GA_3, Salicylic acid, Hydropriming

Maize, scientifically known as *Zea mays* L. belonging to the Poaceae family is having a chromosome number with 2n=20. It holds a significant stature among cereal crops globally, closely trailing rice and wheat in both production and consumption. It is originated in Central America and hailed as the 'Miracle crop' or the 'Queen of cereals' for its remarkable genetic yield potential. It is one of the most versatile emerging crops having wider adaptability due to its C_4 plant status making it a linchpin in sustainable agricultural practices (Kumar and Jhariya, 2013). With approximately 9.9 per cent protein, 4 per cent oil and 70 per cent starch, maize serves as a vital source of nutrients including vitamins A and E, riboflavin and nicotinic acid addressing the dietary requirements of a growing population (Gami *et al.,* 2018). Beyond its role as a staple food crop, maize exhibits versatility across various domains, including feed, fodder, industrial raw materials and biofuel production. This diverse range of applications has led to its designation as a '4F crop' (Food, Feed, Fuel and Fodder).

Globally, maize stands out as a leading cereal crop, cultivated on an area of 201 million hectares with a production of 1162 million tonnes and productivity of 5.75 tonnes per hectare (Anonymous, 2021). In India, maize ranks third position among cereals with the production of 33.73 million tonnes from an area of 9.95 million hectares with productivity of 3.38 t / hectare. Andhra Pradesh, Karnataka, Maharashtra, Rajasthan and Bihar together account for about 2/3rd of the total maize production in India (Anonymous, 2022). Among all states, Karnataka holds first place in maize production with 1.68 million hectares of area. This is about 17.0 per cent of India's total area under cultivation, producing around 5.18 million tonnes which is 16.45 per cent of all India production with a yield of 3092 kg / hectare (Anonymous, 2020).

Seed Priming

The recent surge in maize production and utilization has garnered significant national and international interest from researchers. This emphasis aims to tackle issues such as poor genetic potential, low seed yield and inadequate adaptation to diverse agro-ecologies, particularly focusing on improving the performance of certain varieties (Deepak and Vasudevan, 2023). To suffice the utmost requirement of breeders, development of high-yielding maize hybrids necessitates access to top-quality seeds. Among the array of seed enhancement technologies available, seed priming stands out as a notable approach (Subedi & Ma, 2005 and Dutta, 2018).

Seed priming involves controlled hydration to enhance pre-germinative metabolism without initiating radicle emergence. It encompasses alterations in water content, regulation of the cell cycle, ultrastructural changes, management of oxidative stress and mobilization of reserves. Imbibition triggers protein synthesis and respiratory activities utilizing existing mRNA, thus kickstarting germination processes. Known for its cost-effectiveness and efficacy, seed priming ensures uniform emergence, enhances growth and stress resistance, improves nutrient and water efficiency and suppresses weeds, leading to synchronization of flowering and enhancement of seed yield and quality (Raj and Raj, 2019). Diverse seed-priming techniques have been established, including hydro-priming, osmo-priming, nutrient priming, chemical priming, bio-priming and priming with plant growth regulators, extracts, nanoparticles and physical agents (Dawood, 2018).

Halo-priming, involving the immersion of seeds in solutions of inorganic salts such as zinc sulphate, sodium chloride, potassium nitrate and calcium chloride which promotes uniform germination and enhances crop performance, even under challenging conditions like temperature extremes and oxygen deprivation (Raj and Raj, 2019). Optimal levels of potassium nitrate notably enhance the seed quality parameters *viz.,* germination time and emergence in parental plants of maize facilitating synchronized flowering (Krishna *et al.,* 2019 and Karmore & Tomar, 2015). Hormopriming with gibberellic acid (GA_3) optimizes seedling growth and development, enhancing vegetative and reproductive traits by regulating crucial physiological processes across diverse crop species (Pawar and Laware, 2018). Additionally, salicylic acid (SA) as a silicon source effectively mitigates abiotic and biotic stresses, maintaining plant water balance, photosynthetic activity, leaf erectness and xylem vessel structure under high transpiration rates. It notably enhances germination percentage, shoot and root length as well as relative water content in salt-stressed maize (Ullah *et al.,* 2023). Critical factors in hydropriming include the duration of seed soaking, water volume and priming temperature. Taylor *et al.* (1998) noted that water freely enters the seed during hydropriming, contributing to increased final germination percentage and vigour in maize seeds (Dezfuli *et al.,* 2008).

Optimizing seed priming conditions, including the choice of priming agent and treatment duration, is pivotal for achieving the desired response. Given the variability among crop species, determining the most effective treatment often requires experimentation.

This study aims to standardize priming treatments, considering factors such as soaking duration and temperature to investigate their effects on seed quality in parental lines of hybrid maize (*Zea mays* L.) MAH 15-84.

Material and Methods

Freshly harvested seeds of MAI-19-117 (female parent) and MAI-19-20 (male parent) of single cross hybrid maize MAH 15-84 were obtained from Zonal Agricultural Research Station (ZARS), UAS, GKVK, Bengaluru. The laboratory experiments were carried out at the Department of Seed Science and Technology, GKVK and Seed Technology Research Unit, NSP, UAS, GKVK, Bengaluru, during June-July 2022. The seed material was dried to maintain safe moisture level (< 9-10%) and graded to uniform size by using 18/64" round perforated sieves.

Table 1
Treatment details of the experiment

Priming material used	Concentration	Duration (h)
Control (Unprimed)	Nil	Nil
Hydro priming	Nil	12 & 24
Priming with KNO_3	0.5 % & 1%	12 & 24
Priming with $ZnSO_4$	0.5 % & 1%	12 & 24
Priming with GA_3	@ 50 & 100 ppm	12 & 24
Priming with Salicylic Acid (SA)	@ 50 & 100 ppm	12 & 24

Preparation of Priming Solutions

KNO_3 (0.5% and 1%) : 5.06 and 10.11 grams crystalline solid form of KNO_3 was added to a small volume of distilled water in two separate one-liter volumetric flasks, stirred until it gets dissolved completely in water and made the volume to one-liter each with distilled water to get 0.5 and 1 per cent KNO_3 respectively.

$ZnSO_4$ (0.5% and 1%) : 2.88 and 5.76 grams of colorless crystalline solid form of $ZnSO_4$ was added to100 ml of distilled water in two separate, cleaned and dried one-liter volumetric flask, stirred until it gets dissolved completely in water and made the volume to one-liter each with distilled water and allow to cool to room temperature to get 0.5 and 1 per cent $ZnSO_4$ respectively.

Table 2
Treatment combinations of the experiment

T_1 : Seed Priming with 0.5 % KNO_3 for 12 h
T_2 : Seed Priming with 0.5 % KNO_3 for 24 h
T_3 : Seed Priming with 1 % KNO_3 for 12 h
T_4 : Seed Priming with 1 % KNO_3 for 24 h
T_5 : Seed Priming with 0.5 % $ZnSO_4$ for 12 h
T_6 : Seed Priming with 0.5 % $ZnSO_4$ for 24 h
T_7 : Seed Priming with 1 % $ZnSO_4$ for 12 h
T_8 : Seed Priming with 1 % $ZnSO_4$ for 24 h
T_9 : Seed Priming with 50 ppm GA_3 for 12 h
T_{10} : Seed Priming with 50 ppm GA_3 for 24 h
T_{11} : Seed Priming with 100 ppm GA_3 for 12 h
T_{12} : Seed Priming with 100 ppm GA_3 for 24 h
T_{13} : Seed Priming with 50 ppm Salicylic Acid for 12 h
T_{14} : Seed Priming with 50 ppm Salicylic Acid for 24 h
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h
T_{17} : Hydropriming for 12 h
T_{18} : Hydropriming for 24 h
T_{19} : Control

GA_3 and Salicylic Acid (50 and 100 ppm) : 50 mg and 100 mg each of GA_3 and Salicylic Acid was added to two separate one-liter volumetric flasks by adding small quantity of ethanol prior to dilution with distilled water. Then distilled water was added to make the volume 1 liter to get 50 and 100 ppm GA_3 and Salicylic Acid solution respectively.

Procedure of Seed Priming : Seeds of both male (MAI-19-20) and female (MAI-19-117) parental lines of hybrid maize MAH 15-84 were subjected to respective priming treatments for 12 h and 24 h specific durations during experimentation by utilising solutions prepared as mentioned above. After priming, the seeds were removed from the solutions, rinsed in distilled water and redried to its original moisture content under shade at room temperature. The unprimed seeds were used as control.

Seed Quality Testing : Seed quality parameters *viz.,* seed germination (%), radicle emergence (h), T_{50} value (days), seedling length (cm), seedling dry weight (mg), seedling vigour index I & II, electrical conductivity (dSm^{-1}) and total dehydrogenase activity (A_{480} nm) were determined for primed seeds along with unprimed control as per the methods prescribed by ISTA (2021) at the Department of Seed Science and Technology, GKVK and Seed Technology Research Unit, NSP, UAS, GKVK, Bengaluru.

Data Analysis : The experimental data on seed priming treatments were subjected to completely randomized design (CRD) statistical analysis as suggested by Gomez and Gomez (1984). Critical difference (CD) values were computed at 1 per cent level wherever 'F' test was significant.

Results and Discussion

In the present investigation, effect of different seed priming technique for standardization showed that the seeds primed with gibberellic acid (GA_3) and zinc sulphate ($ZnSO_4$) with different concentration and durations performed better as compared to other treatments and control through initial improvement in seed quality attributes *viz.,* seed germination (%), radicle emergence (h), T_{50} value (days), seedling length (cm), seedling dry weight (mg), vigour indices, electrical conductivity (dSm^{-1}) and total dehydrogenase activity (at A_{480}nm) and are presented in Table 3-6, Fig. 1-3 and discussed in the following paragraph.

Table 3

Influence of different seed priming treatments on seed germination, radicle emergence and T_{50} value in parental lines of maize hybrid MAH 15-84

Treatments	Seed germination (%)		Radicle emergence (h)		T_{50} value (Days)	
	Male	Female	Male	Female	Male	Female
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	92.00	93.33	78.27	79.10	4.26	4.49
T_2 : Seed Priming with 0.5 % KNO_3 for 24 h	93.00	94.00	76.37	75.37	3.92	3.65
T_3 : Seed Priming with 1 % KNO_3 for 12 h	93.33	93.67	76.10	76.67	3.66	3.60
T_4 : Seed Priming with 1 % KNO_3 for 24 h	94.00	95.33	75.33	75.57	3.51	3.43
T_5 : Seed Priming with 0.5 % $ZnSO_4$ for 12	92.33	93.67	77.73	78.13	3.92	3.83
T_6 : Seed Priming with 0.5 % $ZnSO_4$ for 24 h	93.67	94.67	76.47	76.53	4.01	3.83
T_7 : Seed Priming with 1 % $ZnSO_4$ for 12 h	98.00	98.33	72.07	70.30	3.38	3.40
T_8 : Seed Priming with 1 % $ZnSO_4$ for 24 h	94.00	95.33	73.03	74.50	3.47	3.54
T_9 : Seed Priming with 50 ppm GA_3 for 12 h	99.33	99.00	70.93	69.07	3.08	3.24
T_{10} : Seed Priming with 50 ppm GA_3 for 24 h	95.00	96.67	73.63	73.70	3.63	3.84
T_{11} : Seed Priming with 100 ppm GA_3 for 12 h	96.00	96.33	72.50	72.67	3.63	3.74
T_{12} : Seed Priming with 100 ppm GA_3 for 24 h	94.67	95.33	72.97	73.03	3.92	3.90
T_{13} : Seed Priming with 50 ppm Salicylic Acid for 12 h	93.00	93.67	76.83	76.63	4.14	4.02
T_{14} : Seed Priming with 50 ppm Salicylic Acid for 24 h	95.00	94.00	74.83	74.57	4.00	3.82
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h	94.00	95.33	76.13	76.47	4.20	4.18
T_{16} : Seed Priming with 100 ppm Salicylic Acid for 24 h	95.33	96.00	73.00	73.10	4.08	3.68
T_{17} : Hydropriming for 12 h	92.00	91.67	75.57	75.50	4.14	4.21

Continued....

TABLE 3 Continued....

Treatments	Seed germination (%)		Radicle emergence (h)		T_{50} value (Days)	
	Male	Female	Male	Female	Male	Female
T_{18} : Hydropriming for 24 h	92.33	93.00	76.37	75.90	3.95	4.25
T_{19} : Control	89.33	90.67	80.83	82.27	5.04	4.78
Mean	94.02	94.74	75.21	76.14	3.82	3.96
S. Em ±	0.91	0.95	0.39	0.37	0.16	0.14
CD (P=0.01)	2.61	2.71	1.12	1.06	0.45	0.38
CV (%)	1.69	1.74	1.90	1.85	2.04	2.41

TABLE 4

Influence of different seed priming treatments on root length and shoot length in parental lines of maize hybrid MAH 15-84

Treatments	Root length (cm)		Shoot length (cm)	
	Male	Female	Male	Female
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	21.74	21.56	19.11	18.47
T_2 : Seed Priming with 0.5 % KNO_3 for 24 h	22.77	22.27	19.80	19.13
T_3 : Seed Priming with 1 % KNO_3 for 12 h	23.56	24.08	20.47	19.18
T_4 : Seed Priming with 1 % KNO_3 for 24 h	22.14	22.66	20.72	20.20
T_5 : Seed Priming with 0.5 % $ZnSO_4$ for 12	22.42	21.69	19.60	18.40
T_6 : Seed Priming with 0.5 % $ZnSO_4$ for 24 h	23.96	25.10	20.65	19.93
T_7 : Seed Priming with 1 % $ZnSO_4$ for 12 h	27.62	26.63	23.44	24.86
T_8 : Seed Priming with 1 % $ZnSO_4$ for 24 h	23.09	23.88	21.71	20.93
T_9 : Seed Priming with 50 ppm GA_3 for 12 h	29.70	27.33	25.26	26.02
T_{10} : Seed Priming with 50 ppm GA_3 for 24 h	26.24	24.34	22.35	21.69
T_{11} : Seed Priming with 100 ppm GA_3 for 12 h	26.68	25.97	23.27	23.80
T_{12} : Seed Priming with 100 ppm GA_3 for 24 h	25.27	24.01	22.76	22.14
T_{13} : Seed Priming with 50 ppm Salicylic Acid for 12 h	23.62	23.83	20.84	19.00
T_{14} : Seed Priming with 50 ppm Salicylic Acid for 24 h	24.23	23.95	21.19	20.80
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h	26.28	24.52	22.15	21.42
T_{16} : Seed Priming with 100 ppm Salicylic Acid for 24 h	25.48	25.28	22.84	22.68
T_{17} : Hydropriming for 12 h	25.20	24.15	22.26	20.71
T_{18} : Hydropriming for 24 h	24.35	25.30	21.07	20.43
T_{19} : Control	20.40	20.42	18.09	18.01
Mean	24.52	24.06	21.48	20.94
S. Em ±	0.50	0.47	0.39	0.25
CD (P=0.01)	1.43	1.35	1.11	0.72
CV (%)	3.54	3.40	3.14	2.09

TABLE 5

Influence of different seed priming treatments on mean seedling length and seedling dry weight in parental lines of maize hybrid MAH 15-84

Treatments	Mean seedling length (cm)		Seedling dry weight (mg)	
	Male	Female	Male	Female
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	21.74	21.56	19.11	18.47
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	40.85	40.03	80.97	83.99
T_2 : Seed Priming with 0.5 % KNO_3 for 24 h	42.57	41.40	81.60	83.80
T_3 : Seed Priming with 1 % KNO_3 for 12 h	44.03	43.26	84.15	85.57
T_4 : Seed Priming with 1 % KNO_3 for 24 h	42.86	42.86	82.83	83.77
T_5 : Seed Priming with 0.5 % $ZnSO_4$ for 12	42.02	40.09	80.98	84.41
T_6 : Seed Priming with 0.5 % $ZnSO_4$ for 24 h	44.61	45.03	84.20	84.79
T_7 : Seed Priming with 1 % $ZnSO_4$ for 12 h	51.06	51.49	91.53	90.71
T_8 : Seed Priming with 1 % $ZnSO_4$ for 24 h	44.80	44.81	84.80	89.58
T_9 : Seed Priming with 50 ppm GA_3 for 12 h	54.96	53.35	93.31	92.33
T_{10} : Seed Priming with 50 ppm GA_3 for 24 h	48.59	46.03	89.13	89.32
T_{11} : Seed Priming with 100 ppm GA_3 for 12 h	49.95	49.77	89.17	89.60
T_{12} : Seed Priming with 100 ppm GA_3 for 24 h	48.03	46.15	88.40	90.35
T_{13} : Seed Priming with 50 ppm Salicylic Acid for 12 h	44.46	42.83	83.40	85.70
T_{14} : Seed Priming with 50 ppm Salicylic Acid for 24 h	45.42	44.75	85.54	87.55
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h	48.43	45.94	88.07	88.53
T_{16} : Seed Priming with 100 ppm Salicylic Acid for 24 h	48.32	47.96	89.13	89.63
T_{17} : Hydropriming for 12 h	47.46	44.86	88.70	88.03
T_{18} : Hydropriming for 24 h	45.42	45.73	85.03	87.57
T_{19} : Control	38.49	38.43	78.41	82.00
Mean	46.00	45.00	85.78	87.22
S. Em ±	1.87	0.79	0.43	0.41
CD (P=0.01)	5.37	2.27	1.24	1.18
CV (%)	3.22	3.05	1.34	1.12

TABLE 6

Influence of different seed priming treatments on seedling vigour index (SVI) I and II in parental lines of maize hybrid MAH 15-84

Treatments	Vigour index-I		Vigour index-II	
	Male	Female	Male	Female
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	21.74	21.56	19.11	18.47
T_1 : Seed Priming with 0.5 % KNO_3 for 12 h	3758	3736	7449	7839
T_2 : Seed Priming with 0.5 % KNO_3 for 24 h	3959	3892	7589	7877
T_3 : Seed Priming with 1 % KNO_3 for 12 h	4109	4052	7854	8015
T_4 : Seed Priming with 1 % KNO_3 for 24 h	4029	4086	7786	7986
T_5 : Seed Priming with 0.5 % $ZnSO_4$ for 12	3880	3755	7477	7907
T_6 : Seed Priming with 0.5 % $ZnSO_4$ for 24 h	4179	4263	7887	8027
T_7 : Seed Priming with 1 % $ZnSO_4$ for 12 h	5009	5063	8970	8920
T_8 : Seed Priming with 1 % $ZnSO_4$ for 24 h	4211	4272	7971	8540

Continued....

Table 6 Continued....

Treatments	Vigour index-I		Vigour index-II	
	Male	Female	Male	Female
T_9 : Seed Priming with 50 ppm GA_3 for 12 h	5459	5282	9268	9141
T_{10} : Seed Priming with 50 ppm GA_3 for 24 h	4606	4450	8467	8635
T_{11} : Seed Priming with 100 ppm GA_3 for 12 h	4795	4794	8560	8631
T_{12} : Seed Priming with 100 ppm GA_3 for 24 h	4547	4399	8369	8613
T_{13} : Seed Priming with 50 ppm Salicylic Acid for 12 h	4135	4012	7756	8028
T_{14} : Seed Priming with 50 ppm Salicylic Acid for 24 h	4315	4207	8126	8230
T_{15} : Seed Priming with 100 ppm Salicylic Acid for 12 h	4552	4379	8279	8440
T_{16} : Seed Priming with 100 ppm Salicylic Acid for 24 h	4616	4604	8497	8604
T_{17} : Hydropriming for 12 h	4534	4131	8160	8070
T_{18} : Hydropriming for 24 h	4194	4253	7851	8144
T_{19} : Control	3438	3484	7004	7435
Mean	4332	4269	8070	8267
S. Em ±	56.94	100.24	122.80	107.73
CD (P=0.01)	163.03	286.97	351.58	308.42
CV (%)	2.28	4.07	2.63	2.27

SVI- I= Germination (%) × Mean seedling length (cm); SVI- II = Germination (%) × Seedling dry weight (mg)

$$\text{Per cent increase (\%)} = \frac{\text{Highest value - Lowest value}}{\text{Lowest value}} \times 100$$

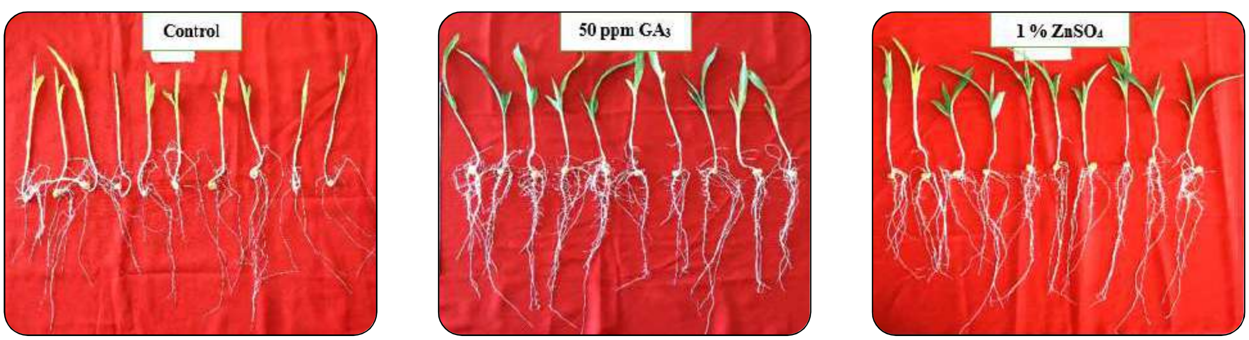
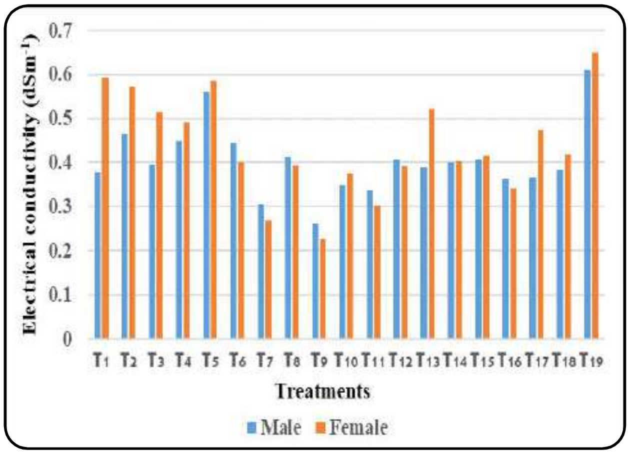


Fig. 1 : Seedling length of male parental line primed with 50 ppm GA_3 (12 h) and 1 % $ZnSO_4$ (12 h) in comparison to control in maize hybrid (MAH 15-84)

Fig. 2 : Seedling length of female parental line primed with 50 ppm GA_3 (12 h) and 1 % $ZnSO_4$ (12 h) in comparison to control in maize hybrid (MAH 15-84)



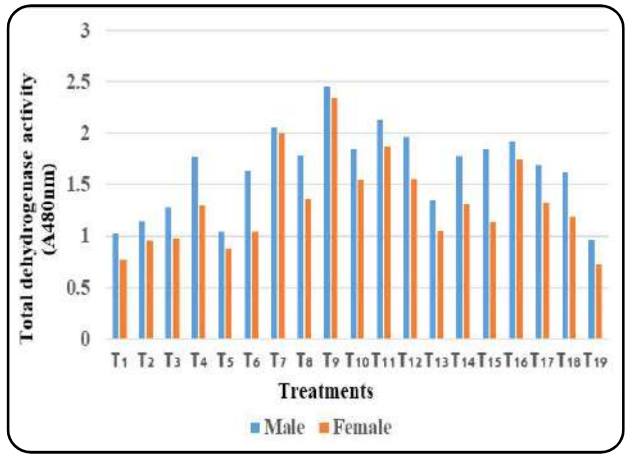


Fig. 3 : Influence of different seed priming treatments on electrical conductivity and total dehydrogenase activity in parental lines of maize hybrid MAH 15-84

Treatments : [T_1: Seed Priming with 0.5 % KNO_3 for 12 h, T_2: Seed Priming with 0.5 % KNO_3 for 24 h, T_3: Seed Priming with 1 % KNO_3 for 12 h, T_4: Seed Priming with 1 % KNO_3 for 24 h, T_5: Seed Priming with 0.5 % $ZnSO_4$ for 12 h, T_6: Seed Priming with 0.5 % $ZnSO_4$ for 24 h, T_7: Seed Priming with 1 % $ZnSO_4$ for 12 h, T_8: Seed Priming with 1 % $ZnSO_4$ for 24 h, T_9: Seed Priming with 50 ppm GA_3 for 12 h, T_{10}: Seed Priming with 50 ppm GA_3 for 24 h, T_{11}: Seed Priming with 100 ppm GA_3 for 12 h, T_{12}: Seed Priming with 100 ppm GA_3 for 24 h, T_{13}: Seed Priming with 50 ppm Salicylic Acid for 12 h, T_{14}: Seed Priming with 50 ppm Salicylic Acid for 24 h, T_{15}: Seed Priming with 100 ppm Salicylic Acid for 12 h, T_{16}: Seed Priming with 100 ppm Salicylic Acid for 24 h, T_{17}: Hydropriming for 12 h, T_{18}: Hydropriming for 24 h, T_{19}: Control]

Seed Germination (%)

Significant variations were observed among the parental lines of maize hybrid MAH 15-84 in response to different seed priming treatments concerning seed germination percentage (Table 3). The germination percentages ranged from 89.33 per cent to 99.33 per cent for male parental lines and from 90.67 per cent to 99.00 per cent for female parental lines, with mean values of 94.02 per cent and 94.74 per cent respectively. However, seeds of male and female parents primed with 50 ppm GA_3 for 12 h (T_9) recorded highest seed germination (99.33 and 99.00%) which was followed by seeds primed with 1 per cent $ZnSO_4$ for 12 h (T_7: 98.00 and 98.33%) compared to control (T_{19}: 89.33 and 90.67%) which showed lowest germination percentage respectively. Treatment T_9 increased germination by 11 and 9 per cent, while T_7 increased it by 10 and 8 per cent over the control for male and female parents respectively.

This highlights the effectiveness of GA_3 and $ZnSO_4$ seed priming treatments in enhancing seed germination performance compared to untreated seeds. This enhancement in seed germination can be attributed to the heightened activity of enzymes such as amylase, protease and lipase which are pivotal in breaking down macromolecules for embryo growth and development, consequently leading to increased seedling emergence. Similar findings were reported by Hidayat *et al.* (2008) and Manjunatha *et al.* (2018) in maize genotypes. Kumari *et al.* (2017) also reported the positive impact of GA_3 on maize germination, further supporting our findings and emphasizing the significance of seed priming techniques in optimizing seedling establishment and crop productivity.

Radicle Emergence (h)

Seeds of male and female parents of maize hybrid MAH 15-84 exhibited significant differences in response to diverse seed priming treatments concerning radicle emergence. It ranged from 70.93 and 69.07 to 80.83 and 82.27 with a mean of 75.21 and 76.14 hours for male and female parents respectively (Table 3). Remarkably, the treatment T_9 (50 ppm GA_3 for 12 h) resulted in the shortest time for radicle emergence (70.93 and 69.07 h) which was followed by seeds primed with 1 per cent $ZnSO_4$ for 12 h (T_7: 72.07 and 70.30 h) compared to the control

(T_{19}: 80.83 and 82.27 h) which took longest time for radicle emergence in male and female parents respectively. Treatment T_9 decreased time taken for radicle emergence by 14 and 19 per cent, while T_7 decreased it by 12 and 17 per cent over the control for male and female parents, respectively.

GA_3 and $ZnSO_4$ seed priming treatments accelerate radicle emergence in maize by stimulating the enzymatic breakdown of stored reserves like starch and proteins facilitating rapid embryo growth and enhancing cell elongation by regulating gibberellin, auxin and cytokinin signalling pathways, ultimately leading to quicker and more efficient germination leading to enhanced seedling establishment. Similar results were reported by Farooq *et al.* (2010) for GA_3 in rice and by Shakirova *et al.* (2018) for $ZnSO_4$ in maize.

T_{50} Value (Days)

Significant differences were noted among the parental lines of maize hybrid MAH 15-84 subjected to various seed priming treatments with respect to T_{50} value. It ranged from 3.08 to 5.04 days for male parental lines and from 3.24 to 4.78 days for female parental lines, with mean durations of 3.82 and 3.96 days respectively (Table 3). However, seeds of male and female parents primed with 50 ppm GA_3 for 12 h (T_9) recorded lowest T_{50} value (3.08 and 3.40 days), which was followed by seeds primed with 1 per cent $ZnSO_4$ for 12 h (T_7: 3.38 and 3.40 days). In contrast, the control (T_{19}) showed higher T_{50} values, with durations of 5.04 and 4.78 days for male and female parents respectively. Treatment T_9 decreased T_{50} value by 64 and 48 per cent, while T_7 decreased it by 45 and 36 per cent over the control for male and female parents, respectively.

This is due to stimulative activity of pivotal enzymes, notably amylase and protease, involved in seed metabolism by breaking down of complex starches and proteins into readily available forms, thus energizing the germination process. By accelerating the hydrolysis of these reserves, GA_3 and $ZnSO_4$ hasten the metabolic processes necessary for germination leading to a quicker attainment of the T_{50} value. Similar findings were reported by Wang *et al.* (2015) and Rajput *et al.* (2018) in maize.

Root and Shoot length (cm)

Significant variations in root and shoot length were observed among treatments (Table 4 and Fig. 1 & 2). The most notable enhancements were observed in treatment T_9 (50 ppm GA_3 for 12 h) resulting in the highest root length (29.70 and 27.33 cm) and shoot length (25.26 and 26.02 cm) followed by treatment T_7-1 per cent $ZnSO_4$ for 12 h exhibited considerable root length (27.62 and 26.63 cm) and shoot length (23.44 and 24.86 cm) for seeds of male and female parental lines respectively. Additionally, treatment T_{16} - 100 ppm salicylic acid for 24 h and T_{11} - 100 ppm GA_3 for 12 h demonstrated substantial root length measuring 25.48 and 25.28 cm and 26.68 and 25.97 cm shoot length of 22.84 and 22.68 cm and 23.27 and 23.80 cm for seeds of male and female parental lines respectively. In contrast, the control (T_{19}) exhibited the lowest root length (20.40 and 20.42 cm) and shoot length (18.09 and 18.01 cm) compared to all other seed priming treatments. Treatment T_9 increased root length by 44 and 34 per cent and shoot length by 40 and 44 per cent, while T_7 increased it by 35 and 30 per cent and 30 and 38 per cent over the control for male and female parents respectively.

The improvements in root and shoot length were facilitated by GA_3, which stimulated cellular growth through the promotion of cell elongation and division by activating α-amylase. Mean while, $ZnSO_4$ contributed to hormonal balance by synthesizing auxins and enhancing enzyme activity involved in essential processes like protein, nucleic acid and chlorophyll synthesis. These combined effects played a crucial role in enhancing root and shoot development. Similar findings were reported by Krishna *et al.* (2023) and Soumya *et al.* (2021) in maize.

Mean Seedling Length (cm)

Significant variations were evident in mean seedling length across the treatments (Table 5 and Fig. 1 & 2). It ranged from 38.49 to 54.96 cm for male parental lines and from 38.43 to 53.35 cm for female parental lines, with mean of 46.00 and 45.00 cm respectively. The most notable enhancements were observed in treatment T_9 (50 ppm GA_3 for 12 h), resulting in the highest mean seedling length (54.96 and 53.35 cm) followed by treatment T_7-1 per cent $ZnSO_4$ for 12 h (51.06 and 51.49 cm) exhibited considerable improvements compared to the control (T_{19}: 38.49 and 38.43 cm) for seeds of male and female parental lines respectively. Treatment T_9 increased mean seedling length by 43 and 39 per cent, while T_7 increased it by 33 and 34 per cent over the control for male and female parents, respectively.

GA_3 stimulates the synthesis of enzymes responsible for loosening and expanding cell walls, promoting elongation in roots and shoots. In parallel, $ZnSO_4$ enhances photosynthetic efficiency and supports root and shoot system development. These synergistic effects culminate in superior growth and development of maize seedlings. Similar findings were reported by Wang *et al.* (2019) and Menaka *et al.* (2019) in maize.

Seedling Dry Weight (mg)

Significant variations were noted in mean seedling dry weight among the treatments, as indicated in Table 5. It ranged from 78.41 to 93.31 mg for male parental lines and from 82.00 to 92.33 mg for female parental lines, with mean values of 85.78 mg and 87.22 mg respectively. Highest seedling dry weight was recorded in the treatment T_9 (93.31 and 92.33 mg) followed by T_7 (91.53 and 90.71 mg). Additionally, treatments T_{16} (100 ppm salicylic acid for 24 h) and T_{11} (100 ppm GA_3 for 12 h) demonstrated substantial seedling dry weights measuring 89.53 and 89.63 mg, and 89.17 and 89.60 mg for seeds of male and female parental lines respectively. In contrast, the control (T_{19}) exhibited the lowest seedling dry weight, measuring 78.41 and 82.00 mg compared to all other seed priming treatments. Treatment T_9 increased seedling dry weight by 19 and 13 per cent, while T_7 increased it by 17 and 11 per cent over the control for male and female parents, respectively.

GA_3 promotes cell elongation and division, salicylic acid induces stress tolerance *via.,* stimulation of gibberellic and auxin signalling pathways and $ZnSO_4$ enhances nutrient uptake resulting in robust seedling growth and biomass accumulation. This aligns with findings of Adhikari and Subedi (2022), Shatpathy *et al.* (2018) and Soumya *et al.* (2021) in maize.

Seedling Vigour Indices

The study on seed priming treatments revealed significant differences in seedling vigour index I and II among the treatments (Table 6). The results showed that, T_9 (50 ppm GA_3 for 12 h) recorded highest vigour index I (5459 and 5282) and vigour index II (9268 and 9141) which was followed by T_7 (5009 and 5063; 8970 and 8920) for seeds of male and female parental lines respectively. Additionally, treatments T_{16} (100 ppm salicylic acid for 24 h) and T_{11} (100 ppm GA_3 for 12 h) demonstrated substantial vigour index I and II measuring (4616 & 4604 and 8497 & 8604) and (4795 & 4794 and 8560 & 8631) respectively. In contrast, the control (T_{19}) exhibited the lowest vigour index I and II measuring 3438 and 3484; 7004 and 7435 respectively compared to all other seed priming treatments. Treatment T_9 increased vigour index I by 59 and 52 per cent and vigour index II by 32 and 23 per cent meanwhile, T_7 increased vigour index I by 46 and 45 per cent and vigour index II by 28 and 20 per cent over the control for male and female parents, respectively.

The results highlight the efficacy of diverse seed priming treatments in enhancing seedling vigour compared to the untreated control. GA_3 and salicylic acid accelerates and standardizes germination, enhances seedling growth through increased metabolic activity, while $ZnSO_4$ promotes hormonal balance and nutrient uptake augmenting stress resistance against drought and diseases. Similar findings were reported by Khan *et al.,* 2015; Li *et al.,* 2020 and Sastry & Divakara*,* 2011 in maize.

Electrical Conductivity (dSm^{-1})

The parental lines exhibited significant variation on electrical conductivity of seed leachate for different seed priming treatments (Fig. 3). It ranged from 0.262 to 0.610 dSm^{-1} for male parental lines and from 0.228 to 0.650 dSm^{-1} for female parental lines, with mean values of 0.406 and 0.440 dSm^{-1}, respectively. The results revealed that seeds of male and female parental lines primed with 50 ppm GA_3 for 12 h (T_9) recorded significantly lower electrical conductivity of seed leachate (0.262 and 0.228 dSm^{-1}) followed by the treatment 1 per cent $ZnSO_4$ for 12 h (T_7: 0.305 and 0.269 dSm^{-1}) whereas, the control (T_{19}) recorded highest (0.610 and 0.650 dSm^{-1}) electrical conductivity respectively.

The reduction in the value of electrical conductivity of seed leachate was due to critical maintains of structural integrity and cell membrane permeability, hormonal regulation and genetic factors. The results were in accordance with the findings of Kiran and Channakeshava (2017) and Omar *et al.* (2022) in maize.

Total Dehydrogenase Activity (A_{480} nm)

Seeds of male and female parents of maize hybrid MAH 15-84 exhibited significant differences in response to diverse seed priming treatments concerning total dehydrogenase activity (Fig. 3). It ranged from 0.971 & 0.724 to 2.456 & 2.348 with a mean of 1.646 & 1.321 $A_{480\ nm}$ for male and female parents respectively. The treatment T_9 showed highest total dehydrogenase activity (2.456 and 2.348 $A_{480\ nm}$) which was followed by T_7 (2.061 and 2.005 $A_{480\ nm}$) whereas, the control (T_{19}) recorded the lowest (0.971 and 0.724 $A_{480\ nm}$) for male and female parental lines respectively.

The results indicated that GA_3 and $ZnSO_4$ as seed priming agents boosts seed germination and early seedling growth by activating genes linked to cell elongation and by stimulating dehydrogenase enzymes crucial for cellular respiration and energy metabolism, ultimately elevating total dehydrogenase activity. Similar findings were reported by Wang *et al.,* 2019 and Wu *et al.,* 2017.

The experiment demonstrated significant improvements in seed quality parameters in parental lines of maize hybrid MAH 15-84 through seed priming with various methods, concentrations and durations compared to the control. Priming with GA_3 and $ZnSO_4$ effectively enhanced seedling growth and vigour by promoting mechanisms such as cell elongation, stress tolerance and nutrient uptake. T_9 (50 ppm GA_3 for 12 h) and T_7 (1% $ZnSO_4$ for 12 h) emerged as optimal priming treatments which enhances overall seed quality and suitable for commercial exploitation of maize hybrid production. These findings offer practical pathways to enhance seedling establishment, vigour and yield in commercial maize seed production.

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Mysore J. Agric. Sci., 58 (4) : 136-143 (2024)

Deciphering Genetic Variability Parameters in Partial Male Sterile and Virescence Lines of Finger Millet [*Eleusine coracana* (L.) Gaertn.]

J. Meenakshi[1], T. E. Nagaraja[2], M. V. C. Gowda[3], Sujatha Bhat[4], S. Gazala Parveen[5], Chetana[6] and D. N. Vinutha[7]
[1&6]Department of Genetics and Plant Breeding, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
[2,3,4,5&7]ICAR-AICRP on Small Millets, UAS, GKVK, Bengaluru - 560 065
e-Mail : meena05kshi@gmail.com

Authors Contribution

J. Meenakshi :
Conceptualization, curation data analysis and draft writing;

T. E. Nagaraja &
M. V. C. Gowda :
Conceptualization, design and draft editing;

Sujatha Bhat :
Experimental design and conceptualization;

S. Gazala Parveen;
Chetana &
D. N. Vinutha :
Data analysis, manuscript editing and curation

Corresponding Author :
J. Meenakshi

Received : May 2024
Accepted : July 2024

Abstract

Finger millet is an important cereal owing to its nutritive qualities. It is highly self-pollinated, allotetraploid crop with extremely small-sized flower makes hybridization a bottleneck to exploit the variability. Partial male sterile and virescence lines are of greater importance in finger millet breeding since, it facilitates easy identification of true F_1s in seedling stage with the help of virescence maker. Selection of appropriate parents is key to success of hybridization and crop improvement. In this back drop the present study was conducted during *kharif*, 2021 and *kharif*, 2022 utilizing twenty-three finger millet lines comprising 11 partial male sterile, six partial male sterile with virescence marker and six virescent lines to unravel the genetic variability parameters. Analysis of variance indicated the selection of experimental material was appropriate. High phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) was observed for number of productive tillers, grain yield per plant, ear head weight and threshing percentage in both seasons. The line 20-12 was earliest flowering, 3-3-1 had long finger length and highest productive tillers and the virescent line vir early had highest yield per plant. Days to fifty per cent flowering showed low PCV and GCV in both the seasons. High heritability and high GAM were observed for traits like peduncle length, ear length, finger length, finger width, finger number, productive tillers, test weight, grain yield per plant and ear head weight in *kharif,* 2021 and traits *viz.,* finger number, grain yield per plant and threshing percentage in *kharif*, 2022. These results suggest that the trait expression is less influenced by the environment and selection would be effective. Partial male sterile and virescence lines have substantial amount of variability and most of the traits under study exhibit high heritability and genetic advance and could be exploited in crop improvement program.

Keywords : Finger millet, Partial male sterility, PCV, GCV, Heritability, Genetic advance

Finger millet, colloquially known as ragi in South India is consumed by habitants of arid and semi-arid countries of Asia and Africa. It is scientifically termed as *Eleusine coracana*, belongs to order poales, family *poaceae*, sub family *Chloridoideae*. *Eleusine africana* is said to be the wild progenitor of the crop (Chennaveeraiah and Hiremath, 1974 and Hilu & De Wet, 1976) and East Africa is considered as the primary centre of origin (De wet, 1995). It is allotetraploid species with chromosome number 2n=4x=36, highly self-pollinated crop. A very large number of cereal crops *viz.*, quinoa, millets, teff, sorghum, bajra, wheat, rice and maize etc. have been cultivated since ancient times, however, due to consumer preferences, selection and domestication process crop diversity has drastically reduced in recent decades where more than 50 per cent of world dietary intake is dominated by major cereals *i.e.,* rice, maize and wheat. Continued consumption of these cereals leads to health issues like weight gain, diabetes and other coronary diseases. It is high time to bring in the other underutilized millet crops into lime light. However, finger millet has gained its importance owing to its nutritive value. The varieties in finger millet have reached yield stagnation, in order to increase yield potential release of variability is essential. The size of flowers is extremely small and polyploidy nature of finger millet turns out to be bottleneck for hybridization. However, male sterile lines could be utilized to create genetic variability and exploit heterosis in finger millet. But, studies on partial male sterility (PS lines) in finger millet are scarce, which attracts the researchers to investigate the variability present in PS lines. The usage of PS lines in hybridization had advantage since the hybrid recovery percentage is very high ranging from 29-80 per cent (Manjappa, 2017) when compared to emasculation and pollination which results in only 2-3 per cent (Gupta, 2006) of crossed seeds. The sterility in partial male sterility is due failure of pollen tube growth after pollination (Manjappa, 2017). This property of low seed set per cent makes them worthy genetic resources to be used in finger millet hybridization program. Usage of partial sterile lines helps in identification of true F_1s during seed set stage which also requires more time and space. While, usage of partial sterile line with virescence marker helps in identification of true F_1s in the seedling stage in the nursery which saves time, resources and labour. In this regard, the present research was framed to study the extent of genetic variability in partial male sterile (PS lines) and virescence lines of finger millet to assess their utility in crop improvement programmes.

Material and Methods

The PS lines (Fig. 1a) were developed by inducing mutations in a well-known finger millet variety GPU 28 by treating it with Ethyl methyl sulfonate (EMS), a chemical mutagen and virescence lines (Fig.1b) were developed by treating the finger millet variety Indaf-8 with the same chemical mutagen (Manjappa *et al.,* 2019).

Fig. 1 : (a) Panicle view of partial sterile line 28-1-2, b) Field view of virescence line

The resultant lines were utilized to study the genetic parameters *viz.*, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability h^2 (bs) and genetic advance as per cent mean (GAM). The current study was conducted at Zonal Agricultural Research Station (ZARS), ICAR-AICRP (Small millets), University of Agricultural Sciences (UAS), Bangalore located at altitude of 937m above mean sea level, latitude of 13.04 ^{0}N and longitude of 77.34^0 E. The experimental material consisted of 23 lines that included 11 partial male sterile, six partial male sterile lines with virescence marker and six virescent lines (Table 1)

Table 1

Finger millet partial sterile and virescence lines used in the present study

Partial sterile lines	Partial sterile lines with virescence marker	Virescence lines
PS1	19-5-2 (Vir PS)	Vir early
14-5 (PS1×PR202)	1-16-5 (Vir PS2)	Vir 32b
20-12 (PS1×TRV - 1)	E-13-2 (Vir PS3)	Vir 33b
23-4-1 (PS1×GE 4693)	14-5-1 (Vir PS4)	Vir 33
32-1 (PS1×Indaf 7)	21-8-4 (Vir PS5)	GE 1
34-3 (PS1×GPU 66)	21-8-4	28-1
44-3-1 (PS1× Indaf 8)		
44-1 (PS1×GE-1)		
29-8-1 (PS1×PR202)		
28-1-2 (PS1×GE4972)		
3-3-1 (VL149)		

Table 2

Mean performance of partial sterile and virescence lines evaluated for quantitative traits in *kharif*, 2021

Partial sterile / virescence line	DTFF	FLL	PL	EL	FL	FW	FN	PT	PH	TW	YLD	EW	TP
28-1	71.00	26.03	20.33	7.29	6.05	0.85	7.57	1.76	83.67	3.68	4.43	7.54	58.78
Vir early	74.00	29.50	24.92	9.14	6.35	0.90	8.65	1.07	92.70	3.38	7.09	12.91	55.70
Vir32b	76.50	29.50	26.25	9.29	6.58	0.84	8.75	1.05	93.68	3.67	6.64	8.96	74.06
Vir 33B	73.50	31.10	23.22	9.06	6.56	0.94	10.14	1.00	90.60	3.25	6.75	11.25	59.87
Vir 33	72.00	27.15	21.73	9.80	6.95	0.79	9.24	1.14	89.55	2.91	5.25	7.95	66.13
GE 1	72.00	27.05	20.44	10.03	6.83	0.81	8.27	1.26	82.59	2.81	4.74	7.34	64.97
19-5-2	71.50	24.72	15.67	6.11	4.25	0.58	7.50	1.44	70.06	3.61	1.89	2.61	76.75
1-16-5	69.00	27.73	20.36	8.03	5.63	0.62	7.19	1.44	77.53	3.46	3.83	5.75	69.51
E-13-2	72.00	27.94	18.83	6.13	4.73	0.52	8.21	1.26	71.86	3.44	1.11	3.56	30.38
14-5-1	74.50	27.47	22.17	7.81	5.72	0.67	7.86	1.40	74.49	3.10	1.69	3.62	49.44
21-8-4	75.50	27.25	25.08	9.78	6.79	0.69	8.70	1.00	82.85	3.22	2.08	4.50	46.21
21-8-4(gn)	75.50	29.78	26.57	10.01	6.91	0.74	8.14	1.00	86.28	3.08	2.66	4.94	53.49
3-3-1	63.00	30.12	25.53	12.39	8.67	0.50	6.80	1.47	96.31	3.85	2.59	5.05	51.32
14-5	69.00	32.02	25.74	9.21	6.36	0.48	6.95	1.26	108.21	4.06	1.48	5.17	31.88
20-12	57.50	31.74	22.69	9.55	6.48	0.57	6.06	1.64	94.50	4.08	2.00	3.61	57.43
23-4-1	71.50	36.22	30.13	10.35	8.52	0.60	5.09	1.13	106.47	4.15	2.24	4.70	48.07
32-1	70.00	33.26	24.32	8.18	6.13	0.49	7.48	1.78	98.91	5.38	2.27	5.53	42.67
34-3	71.00	31.72	22.86	8.47	6.11	0.50	7.11	1.17	86.89	4.42	1.98	4.31	45.92
44-3-1	75.50	29.94	20.58	10.23	7.02	0.63	9.19	1.39	96.28	2.89	3.45	6.94	48.52
44-1	75.50	29.93	23.31	9.33	6.68	0.66	7.99	1.06	92.61	3.47	2.88	4.51	65.18
29-8-1	68.00	32.63	22.10	10.36	8.30	0.66	6.15	1.15	89.45	3.99	2.35	4.95	47.50
28-1-2	66.00	33.00	26.08	9.65	7.00	0.57	6.20	2.10	101.50	3.94	2.05	3.85	53.25
PS-1	67.00	32.33	23.25	9.08	6.28	0.46	7.33	2.89	99.33	3.67	1.92	6.63	28.97
Mean	70.91	29.91	23.13	9.09	6.55	0.65	7.67	1.38	89.83	3.63	3.19	5.92	53.3
Max	76.50	36.22	30.13	12.39	8.67	0.94	10.14	2.89	108.21	5.38	7.09	12.91	76.75
Min	57.50	24.72	15.67	6.11	4.25	0.46	5.09	1.00	70.06	2.81	1.11	2.61	28.97
Sem	1.57	1.46	1.28	0.41	0.28	0.03	0.45	0.2	4.48	0.29	0.49	0.87	7.92
CD @5%	4.62	4.28	3.76	1.2	0.82	0.12	1.34	0.6	13.14	0.87	1.45	2.55	23.23

DTFF- days to fifty percent flowering, FLL- flag leaf length, PL- peduncle length, EL- ear length, FL- Finger length, FW- finger width, FN- finger number, PT- number of productive tillers, PH- plant height, TW- test weight, YLD- grain yield per plant, EHW- ear head weight, TP- threshing percentage that were evaluated in randomized complete block design with two replications in two seasons *i.e., kharif,* 2021 and *kharif,* 2022. Each plot consisted of 10 rows of 3m length with a spacing of 30×10cm. The observations were recorded on five random plants in each replication in both the season and their mean values were used for the statistical analysis. The data was recorded on thirteen quantitative traits *viz.,* days to 50 per cent flowering, flag leaf length (cm), peduncle length (cm), ear length (cm), finger length (cm), finger width (cm), finger number, productive tiller, plant height (cm), test weight (g), grain yield (g), ear head weight (g) and threshing percentage.

Analysis of variance (ANOVA) was done as per the procedure given by Panse and Sukhatme (1967). The method outlined by Burton and Devane (1952) was used to estimate PCV and GCV. Heritability in broad sense (h^2(bs)) as suggested by Lush (1940) and Robinson *et al*. (1949) was estimated. Genetic advance as percent of mean (GAM) was estimated as described by Johnson *et al*. (1955).

Results and Discussion

The analysis of variance revealed significant differences among the partial male sterile lines, with virescence marker and virescent lines for all the traits studied *i.e.,* days to fifty per cent flowering, flag leaf length, peduncle length, ear length, finger length, finger width, finger number, productive tiller, plant height, test weight, grain yield, ear head weight, threshing percentage in both the seasons except for ear length and test weight in *kharif,* 2022. The significant differences justify the substantial variability in the experimental material and their utilization in finger millet breeding programs. Similar results were reported by Nagaraja *et al.* (2023) in germplasm lines of finger millet, Mulualem (2022), Hema *et al*. (2022), Udamala *et al*. (2020) and Ulaganathan & Nirmalakumari, (2015) in finger millet germplasm lines.

The mean, minimum and maximum values for all the traits among the 23 lines is presented in the Table 2 and 3. The estimates of GCV, PCV, h^2 (bs) and GAM for all the traits is summarized in Table 4, Fig. 2a and 2b. All the partial sterile lines used in the study flowered from 57.50 days (20-12) to 76.50 days (Vir 32b) with mean of 70.91 days, their finger length varied from 4.25 cm (19-5-2) to 8.67cm (3-3-1) with a mean of 6.55 cm, number of productive tillers ranged from 1 (21-8-4) to 2.89 (PS-1) with a mean of 1.38 and the grain yield per plant ranged from 1.11g (E-13-2) to 7.09g (vir early) with a mean of 3.19g in *kharif,* 2021 (Table 2). Similarly, days to 50 per cent flowering varied from 61.25 (20-12) to 75.75 (Vir 33) with a mean of 70.32 days, finger length varied from 5.6 cm (19-5-2) to 10.13cm (vir 33b) with a mean of 7.74cm, number of productive tillers ranged from 1.2 (28-1) to 3.70 (3-3-1) with a mean of 2.57 and the grain yield per plant ranged from 1.41g (PS1) to 15.71g (vir early) with a mean of 5.99g in *kharif*, 2022 (Table 3). Since PS1 was first partial sterile line developed (Manjappa *et al.,* 2019), the performance of all the sterile lines were compared with PS1. Lines that had better performance than PS1 with respect to various traits like, days to fifty per cent flowering (20-12, 3-3-1), flag leaf length (23-4-1, 32-1), ear length (3-3-1, 23-4-1), finger length (3-3-1, 23-4-1), finger number (21-8-4, 21-8-4gn), test weight (32-1, 20-12) and grain yield (4-3-1, 20-12) were identified and these lines can be used as parental lines for hybridization.

The GCV for all the traits was lesser than PCV, signifying that environmental effect is associated with the expression of the traits studied but, the difference between estimates of GCV and PCV was low for most of the traits which suggests that even though the environmental effect is present, it is negligible (Table 4). Similar results were reported by Udamala *et al.* (2020) in finger millet. High PCV and GCV was observed for number of productive tillers, grain yield per plant, ear head weight and threshing per cent in both the seasons, while days to 50 per cent flowering showed low PCV and GCV in both the seasons (Table 4).

High magnitude of PCV and GCV indicated sufficient amount of variation present for these characters and offers ample scope for selection and crop improvement. The results were in consonance with

TABLE 3

Mean performance of partial sterile and virescence lines evaluated for quantitative traits in *kharif*, 2022

Partial sterile / virescence line	DTFF	FLL	PL	EL	FL	FW	FN	PT	PH	TW	YLD	EW	TP
28-1	73.50	25.45	19.65	7.35	6.30	0.82	7.60	1.20	85.40	3.77	4.50	7.20	62.28
Vir early	75.50	28.80	19.50	7.20	6.25	1.12	8.60	2.20	99.30	3.41	15.72	19.78	77.97
Vir 32b	74.00	33.70	23.90	8.00	6.90	1.07	9.80	1.50	98.00	3.53	12.78	16.96	75.42
Vir 33B	75.00	27.70	20.00	7.80	6.73	1.00	10.13	1.70	95.78	3.64	11.61	15.11	76.94
Vir 33	75.75	31.60	25.00	7.35	6.50	1.09	9.90	1.70	95.00	3.76	11.38	14.68	77.82
GE 1	75.50	22.20	18.50	8.85	7.70	1.16	9.20	2.20	88.60	3.74	13.89	17.29	80.36
19-5-2	63.00	24.40	17.30	6.50	5.40	0.87	5.60	3.30	75.00	3.59	1.63	4.15	40.01
1-16-5	67.25	29.50	19.40	7.40	5.90	0.93	6.70	3.50	84.60	3.57	3.74	7.04	52.50
E-13-2	71.50	24.60	19.00	7.45	6.50	0.98	7.10	2.00	85.20	3.54	3.94	7.76	49.22
14-5-1	75.50	22.90	16.90	7.20	5.95	0.94	7.20	2.70	72.00	3.94	2.99	5.80	48.30
21-8-4	75.50	26.10	18.20	9.15	7.31	0.96	8.40	2.20	93.50	3.17	4.74	8.63	52.17
21-8-4(gn)	75.50	26.20	18.80	8.05	7.25	0.94	8.60	2.10	82.60	3.26	3.75	7.46	48.05
3-3-1	64.75	28.60	19.30	8.30	7.30	1.02	6.80	3.70	96.20	3.61	3.95	7.55	52.41
14-5	69.00	30.30	24.30	8.40	6.85	1.00	7.20	3.00	102.00	4.18	3.18	7.36	41.12
20-12	61.25	27.40	21.90	8.85	7.35	0.93	6.90	3.10	99.70	4.20	7.43	10.72	68.45
23-4-1	63.00	34.40	27.00	10.05	8.97	0.93	6.50	3.00	114.80	4.06	4.88	8.23	59.46
32-1	66.50	30.80	22.20	7.15	6.25	1.00	7.30	2.70	96.90	3.89	4.23	6.96	57.44
34-3	67.25	28.50	21.30	7.30	6.30	1.00	7.30	2.50	98.10	3.68	4.84	8.27	58.72
44-3-1	75.75	27.20	18.50	9.10	7.95	0.93	9.50	2.50	87.40	3.89	3.82	8.13	47.07
44-1	75.25	26.80	20.00	8.15	6.75	0.94	7.40	3.20	93.60	4.07	4.67	9.30	49.94
29-8-1	63.50	31.30	20.90	9.70	8.04	0.98	7.10	3.20	97.50	4.06	4.37	6.95	64.56
28-1-2	66.00	23.90	18.00	8.10	6.45	0.96	6.60	3.30	95.20	4.06	4.48	7.74	55.11
PS-1	67.50	29.80	23.40	6.92	6.00	0.98	6.40	2.70	99.30	3.85	1.42	5.44	26.57
Mean	70.32	27.91	20.56	8.01	6.82	0.98	7.74	2.57	92.85	3.76	5.99	9.5	57.47
Max	75.75	34.4	27	10.05	8.97	1.16	10.13	3.70	114.8	4.2	15.72	19.77	80.36
Min	61.25	22.20	16.90	6.50	5.40	0.82	5.6	1.20	72.00	3.17	1.42	4.14	26.57
Sem	1.11	1.47	1.64	0.5	0.46	0.04	0.56	0.42	5.56	0.23	1.97	2.46	6.51
CD @5%	3.27	5.88	4.82	1.47	1.36	0.12	1.64	1.35	16.31	0.69	5.79	7.21	19.11

DTFF- days to fifty percent flowering, FLL- flag leaf length, PL- peduncle length, EL- ear length, FL- Finger length, FW- finger width, FN- finger number, PT- number of productive tillers, PH- plant height, TW- test weight, YLD- grain yield per plant, EHW- ear head weight, TP- threshing percentage

TABLE 4

Estimates of genetic variability parameters for quantitative traits evaluated in partial sterile and virescence lines of finger millet

Trait	Mean		GCV		PCV		h^2 (bs)		GAM	
	K-21	K-22	K-21	K-22	K-21	K-22	K-21	K-22	K-21	K-22
DTFF	70.91	70.32	5.95	7.21	6.73	7.55	78.17	91.17	10.84	14.14
FLL	29.91	27.91	7.77	10.41	10.40	12.82	55.89	65.96	11.97	17.42
PL	23.13	20.56	12.07	10.14	14.40	15.15	70.24	44.54	20.83	13.94
EL	9.09	8.01	14.79	9.68	16.10	13.13	84.32	54.32	27.98	14.69
FL	6.55	6.82	15.05	9.98	16.23	13.86	85.99	51.80	28.76	14.79
FW	0.65	0.98	21.05	6.53	22.70	8.83	85.97	54.67	40.21	9.94
FN	7.67	7.74	14.19	10.28	16.53	17.97	73.74	67.29	25.11	24.92
PT	1.38	2.57	27.77	19.44	34.89	31.97	63.35	36.96	45.53	24.34
PH	89.83	92.85	10.28	8.04	12.47	11.67	68.00	47.39	17.47	11.40
TW	3.63	3.76	13.74	4.11	17.99	9.76	58.36	17.72	21.63	3.56
YLD	3.19	5.99	53.62	59.07	57.98	75.21	85.54	61.69	102.17	95.58
EHW	5.92	9.50	39.95	35.91	45.05	51.29	78.64	49.04	72.98	51.81
TP	53.30	57.47	19.17	21.44	28.45	26.77	45.42	64.14	26.62	35.37

DTFF- days to fifty percent flowering, FLL- flag leaf length, PL- peduncle length, EL- ear length, FL- Finger length, FW- finger width, FN- finger number, PT- number of productive tillers, PH- plant height, TW- test weight, YLD- grain yield per plant, EHW- ear head weight, TP- threshing percentage, GCV-genotypic co-efficient of variation, PCV- Phenotypic co-efficient of variation, h_2 (bs)-heritability broad sense, GAM- genetic advance as percent mean, K- *kharif*.

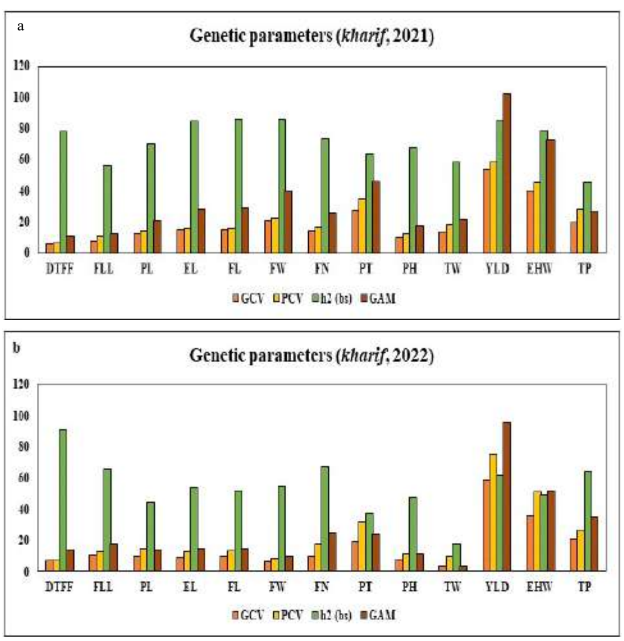

Fig. 2 : Histogram representation of mean, GCV-genotypic co-efficient of variation, PCV-Phenotypic co-efficient of variation, h_2-heritability broad sense, GAM-genetic advance as percent mean of 13 quantitative traits: a) *kharif,* 2021, b) *kharif*, 2022

that of Hema *et al*. (2022), Shashibhushan *et al*. (2022) and Bhavsar *et al.* (2020) in finger millet. Contrastingly, the traits like ear length, finger length, finger width and plant height depicted low GCV with moderate PCV in *kharif,* 2022 suggesting selection would not be effective. Rest of the traits recorded moderate PCV and GCV in *kharif*, 2021 and *kharif,* 2022. High PCV and moderate GCV was noticed for number of productive tillers (Table 4), narrow difference between PCV and GCV was observed for all the traits except number of productive tillers and ear head weight that implies a significant portion of the variability in these traits is attributed to genetic factors, as the influence of the environment is minimal. Similar results were reported by Jyothsna *et al.* (2016) and Anuradha *et al*. (2017) in finger millet. Similar studies have been carried by Singh *et al.* (2013) in rice male sterile lines for flower morphological traits.

Heritability is the heritable portion of phenotypic variance, it is a good index of transmission of characters from parents to offspring (Falconer, 1964). Johnson *et al.* (1955), proffered that heritability and genetic advance together were more valuable for predicting superior individuals compared to relying on information from heritability and genetic advance alone. For selection to be effective, a trait with high heritability should ideally be associated with a considerable genetic advance. High heritability and high GAM were observed for traits like peduncle length, ear length, finger length, finger width, finger number productive tillers, test weight, grain yield per plant and ear head weight in *kharif,* 2021 and traits *viz.,* finger number, grain yield per plant and threshing per cent in *kharif,* 2022. The results are in accordance with studies conducted by Mahanthesha *et al*. (2017). Likewise, Ezeaku *et al*., 2015 also carried out heritability studies in sterile lines and maintainer lines of pearl millet for agronomic traits.

Further, days to 50 per cent flowering, plant height exhibited high heritability coupled with moderate GAM in *kharif,* 2021 (Table 4, Fig. 2a) and days to 50 per cent flowering, flag leaf length, ear length, finger length, finger width and finger number showed high heritability with moderate GAM in *kharif,* 2022 indicating that selection will be effective for these traits. Test weight showed low heritability coupled with low GAM in *kharif,* 2022 which can be due to influence of environment and selection would not be appropriate (Table 4, Fig. 2b). Since, most of the traits showed high heritability and GAM suggests that the variability in these lines could be exploited in breeding and hybridization program. These PS lines are derived from different genetic backgrounds and possess greater levels of genetic variability for different traits as evident in the study and have potential to be used as parents in crossing program in finger millet.

Acknowledgement : The senior author gratefully acknowledges Council of Scientific and Industrial Research (CSIR), New Delhi, India for providing Junior Research Fellowship (JRF) vide No. 09/ 0271(15958)/2022-EMR-I dated 07-11-2022 for pursuing Ph.D. degree program at University of Agricultural Sciences, Bangalore, India.

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Mysore J. Agric. Sci., 58 (4) : 144-165 (2024)

Effect of Sowing Windows on Growth and Yield Parameters of Small Millets and their Varieties during Late *Kharif*

Mohod Aishwarya Anilrao[1], T. S. Sukanya[2], M. N. Thimmegowda[3], M. R. Anand[4], R. Krishnamurthy[5] and G. Anand Manegar[6]

[1]Dept. of Agronomy; [6]Dept. of Animal Science, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
[2]AICRP on Small Millets, [3]AICRP on Agrometeorology, [4]AICRP on Arid Legumes,
[5]AICRP on STCR, UAS, GKVK, Bengaluru - 560 065
e-Mail : tssukanya@gmail.com

Authors Contribution

Mohod Aishwarya Anilrao : Investigation, data collection, investigation, data analysis and draft preparation;

T. S. Sukanya : Conceptualization, draft correction and supervision;

M. N. Thimmegowda :
M. R. Anand :
R. Krishnamurthy &
G. Anand Manegar :
Supervision, data curation and manuscript correction

Corresponding Author :
T. S. Sukanya

Received : July 2024
Accepted : August 2024

Abstract

A field trial was conducted during the *kharif* seasons of 2021 and 2022, at UAS, GKVK, Bengaluru, Karnataka. The aim of the study was to investigate the agronomic performance of two varieties each in foxtail millet, proso millet and little millet across three sowing windows *viz*., second fortnight of august (W_1), first fortnight of september (W_2) and second fortnight of september (W_3). There were 18 treatment combinations with three replications each, tested in RCBD with factorial design concept. In the study, significant variations were observed among the sowing windows and millet varieties with respect to plant height, leaf area, dry matter production, productive tillers, days to 50 per cent flowering and maturity, ear head length, ear head weight and yield. Foxtail millet consistently displayed higher values in several parameters, with genotype DHFt-109-3 showing superior performance in terms of ear head weight and ear head length. Proso millet demonstrated the early maturation, while little millet showed relatively late performance across different sowing windows. The first sowing window (W_1) consistently recorded the highest grain and straw yields across millet crops, followed by subsequent sowing windows W_2 and W_3. The findings highlight the importance of sowing small millet crops in late *kharif* to optimize agronomic practices in aberrant weather condition. Additionally, the findings emphasize the importance of selecting suitable varieties that exhibit robust performance across different sowing windows, contributing to sustainable agriculture practices in the face of climate variability.

Keywords : Aberrant weather, Small millets, Sowing windows, Varieties, Yield

Millets, often referred to as 'nutri-cereals,' are small-grain cereal crops packed with essential nutrients such as protein, dietary fibre, vitamins and minerals (Sukanya *et al*., 2023). These nutrient-rich grains play a crucial role in traditional diets, providing a staple food source in many cultures. Additionally, millets are increasingly being incorporated into modern food products, including probiotics and popped snacks, due to their health benefits and versatility (Nithyashree & Vijayalaxmi, 2022 and Yadagouda & Ravindra, 2022). Their high nutritional value makes them an excellent choice for promoting food security and improving dietary quality, especially in regions facing nutritional deficiencies.

Seven major small millets, including finger millet, foxtail millet, kodo millet, little millet, barnyard millet, proso millet and brown top millet are the most dependable food crops for resource-poor dryland farmers due to their resilience to climate change and sustainable production (Sukanya and Narayanan, 2023).

Increasing the area under cultivation, growing high yielding varieties and enhancing crop management are potential strategies for boosting small millet production. While new, improved varieties are continuously being released, there is a significant gap in information regarding the late sowing windows for these varieties in Karnataka. Prioritizing suitable agronomic techniques is essential for achieving vigorous root growth, vegetative progress and ultimately, a prominent yield (Sukanya and Narayanan, 2023). Selecting suitable cultivars and determining the optimal sowing time are not only essential for maximizing yield potential and yield-contributing factors (Honnaiah *et al*., 2021; Kumar *et al.,* 2021; Salmankhan *et al*., 2021; Jadipujari *et al*., 2023 and Pannase *et al*., 2024) but also for minimizing risk of crop failures and cost reduction (Soler *et al.,* 2008). Additionally, evaluating varietal performance under different sowing windows and adapting management practices in the context of climate change are vital. This includes adjusting sowing dates to align with predicted weather patterns and potential changes in precipitation levels. With this background, current study was undertaken with an aim to identify optimum sowing window in late *kharif* for the three small millets - foxtail millet, proso millet and little millet and their varieties for Bangalore region.

Material and Methods

The field trial was conducted during late *kharif* 2021 and 2022, between August second fortnight to November second fortnight, September first fortnight to December first fortnight and September second fortnight to December second fortnight, at the Zonal Agriculture Research Station (ZARS), University of Agricultural Sciences, GKVK, Bengaluru (13° 4' 44.688" N, 77° 34' 16.5684" E; elevation 930 m), Karnataka, India. The soil of experimental site was red sandy clay loam in texture. The soil was slightly acidic in reaction (pH 5.95), low electrical conductivity (0.22 dS/m) and low organic carbon content (0.36%). The soil was low in available nitrogen (249.7 kg/ha), high in available phosphorus (71.80 kg/ha) and medium in available potassium (180.40 kg/ha). During both experimental periods, the site received higher than normal rainfall.

The experiment consisted of 18 treatments with three sowing windows (W_1: August 2nd fortnight, W_2: September 1st fortnight and W_3: September 2nd fortnight), three crops (C_1: Foxtail millet, C_2: Proso millet and C_3: Little millet) and two varieties in each crop (V_1: GPUF 3, GPUP 28 and GPUL6; V_2: DHFt 109-3, GPUP 21 and DHLM 36-3). Seeds were sown at a spacing of 30 cm x 10 cm and plot measured 14.7 sq. m., with a net plot area of 9.3 sq.m. Normal post-sowing agronomic practices recommended for this region to raise a healthy crop were followed.

Growth and yield attributes were recorded at 30, 60 DAS and at harvest. The grain and straw yield obtained from each net plot area was converted to kg/ha. The data recorded on various parameters were subjected to Fisher's method of analysis of variance and interpretation of the data was made as given in the F-test was P = 0.05. Whenever, the F-test was significant for comparison amongst the treatments, an appropriate value of critical differences (CD) was worked out. Otherwise, against CD values abbreviation 'NS' (Non-significant) is indicated.

Results and Discussion

The data on various growth and yield attributing parameters of the three small millets evaluated in three sowing windows were collected across the *kharif* seasons of 2021 and 2022 and pooled data is presented in the Tables 1, 2, 3, 4 and 5.

Plant Height (cm)

Plant height at harvest was significantly influenced by different sowing windows, crops and their varieties. The data pooled over two years are presented in Table 1.

Data indicated that the crop sown during second fortnight of august recorded significantly higher plant

Table 1

Plant height (cm) and leaf area (cm²/ hill) at harvest of small millets as influenced by sowing windows and varieties at harvest

Treatment*	Plant height (cm)			Leaf area (cm²/hill)		
	2021	2022	Pooled	2021	2022	Pooled
Sowing Window (W)						
W_1	93.2	95.3	94.2	645.8	689.8	667.8
W_2	87.7	90.8	89.3	538.9	574.0	556.4
W_3	83.6	86.0	84.8	468.8	498.9	483.8
S.Em ±	1.97	2.17	2.07	7.13	8.61	6.14
CD at 5%	5.65	6.24	5.94	20.49	24.74	17.65
Crops (C)						
C_1	94.6	96.8	95.7	681.2	721.5	701.4
C_2	82.0	84.7	83.3	545.9	583.8	564.9
C_3	88.0	90.5	89.2	426.4	457.3	441.8
S.Em ±	1.97	2.17	2.07	7.13	8.61	6.14
CD at 5%	5.65	6.24	5.94	20.49	24.74	17.65
Varieties (V)						
V_1	87.0	89.7	88.4	530.2	569.9	550.0
V_2	89.3	91.6	90.5	572.1	605.2	588.7
S.Em ±	1.60	1.77	1.69	5.82	7.03	5.01
CD at 5%	4.61	5.09	4.85	16.73	20.20	14.41
Sowing Window (W) x Crops (C)						
W_1C_1	100.0	100.8	100.4	768.3	827.8	798.0
W_1C_2	87.4	89.6	88.5	639.6	672.9	656.3
W_1C_3	92.0	95.4	93.7	529.4	568.7	549.0
W_2C_1	94.6	97.5	96.0	692.8	719.3	706.1
W_2C_2	80.6	85.2	82.9	526.3	574.6	550.5
W_2C_3	88.1	89.8	88.9	397.5	428.0	412.8
W_3C_1	89.1	92.2	90.6	582.4	617.5	600.0
W_3C_2	77.9	79.4	78.7	471.7	504.0	487.8
W_3C_3	83.7	86.4	85.1	352.3	375.2	363.7
S.Em ±	3.40	3.76	3.58	12.35	14.91	10.63
CD at 5%	9.78	10.81	10.29	35.49	42.86	30.56
Sowing Window (W) x Varieties (V)						
W_1V_1	92.1	94.9	93.5	639.4	676.0	657.7
W_1V_2	94.3	95.7	95.0	652.2	703.5	677.9
W_2V_1	87.0	90.3	88.6	519.3	558.6	539.0
W_2V_2	88.5	91.3	89.9	558.5	589.3	573.9

Continued....

Table 1 Continued....

Treatment*	Plant height (cm)			Leaf area (cm^2/hill)		
	2021	2022	Pooled	2021	2022	Pooled
W_3V_1	82.1	84.0	83.0	419.1	447.5	433.3
W_3V_2	85.1	87.9	86.5	518.5	550.3	534.4
S.Em ±	2.78	3.07	2.92	10.08	12.18	8.68
CD at 5%	7.99	8.82	8.40	28.97	34.99	24.95
Sowing Window (W) x Crops (C) x Varieties (V)						
$W_1C_1V_1$	98.7	100.1	99.4	760.7	824.1	792.4
$W_1C_1V_2$	101.3	101.5	101.4	775.9	831.4	803.7
$W_1C_2V_1$	84.9	87.3	86.1	608.9	653.8	631.3
$W_1C_2V_2$	89.9	91.9	90.9	670.4	692.0	681.2
$W_1C_3V_1$	92.6	97.2	94.9	586.9	632.7	609.8
$W_1C_3V_2$	91.5	93.7	92.6	471.8	504.6	488.2
$W_2C_1V_1$	92.1	95.2	93.7	636.0	673.6	654.8
$W_2C_1V_2$	97.0	99.7	98.4	749.7	765.0	757.4
$W_2C_2V_1$	80.4	85.1	82.7	507.2	563.7	535.5
$W_2C_2V_2$	80.8	85.2	83.0	545.5	585.5	565.5
$W_2C_3V_1$	88.4	90.6	89.5	414.6	438.5	426.6
$W_2C_3V_2$	87.8	88.9	88.3	380.4	417.5	399.0
$W_3C_1V_1$	83.5	86.3	84.9	453.2	485.8	469.5
$W_3C_1V_2$	94.6	98.0	96.3	711.7	749.1	730.4
$W_3C_2V_1$	77.2	78.2	77.7	446.4	469.5	457.9
$W_3C_2V_2$	78.6	80.6	79.6	497.0	538.4	517.7
$W_3C_3V_1$	85.5	87.6	86.5	357.7	387.0	372.4
$W_3C_3V_2$	82.0	85.2	83.6	346.8	363.4	355.1
S.Em ±	4.81	5.32	5.07	17.46	21.09	15.04
CD at 5%	13.84	15.28	14.56	50.18	60.61	43.22

*Treatments : Window : W_1: August 2nd fortnight; W_2: September 1st fortnight; W_3: September 2nd fortnight; Crop: C_1: Foxtail millet; C_2: Proso millet; C_3: Little millet; Variety: V_1: GPUF 3 /GPUP 28 / GPUL6; V_2: DHFt 109-3/ GPUP 21 / DHLM 36-3

height (94.2cm) at harvest followed by the crop sown at first fortnight of September (89.3cm). Among the different small millets, higher plant height was recorded in foxtail millet (95.7cm) followed by little millet (89.2cm). Among varieties, DHFt-109-3 of foxtail millet, GPUP 21 of proso millet and GPUL 6 of little millet were significantly superior over GPUF 3 of foxtail millet, GPUP 28 of proso millet and DHLM 36-3 of little millet at harvest.

The significant interaction was found between sowing windows and crops at harvest. Sowing of foxtail millet during second fortnight of August has recorded significantly higher plant height (100.4cm) followed by sowing of foxtail millet during first fortnight of september (96cm). The interaction between sowing windows and varieties was found significant in which second fortnight of august and variety V_2 (DHFt 109-3, GPUP 21 and GPUL 6) has recorded significantly higher plant height (95 cm), which was followed by second fortnight of august and variety V_1 (GPUF 3, GPUP 28 and DHLM 36-3) significantly lower plant height was observed with second fortnight of september and variety V_1 (83cm).

The significant interaction was found between crop and variety. Among different combinations DHFt-109-3 of foxtail millet has recorded significantly higher plant height (98.7 cm) which was followed by GPUF 3 variety of foxtail millet (92.6cm). Significantly lower plant height was recorded in GPUP 28 of proso millet (82.2cm).

Overall interaction between sowing windows, crops and varieties found significant in all growth stages of crop. Sowing of foxtail millet variety DHFt 109-3 during second fortnight of august (101.4cm) has recorded significantly higher plant height which was on par with foxtail millet variety GPUF 3 sown in second fortnight of august (99.4cm).

Increased plant height in first sowing window might be due to favorable climatic conditions during the early stages of growth, such as adequate sunlight, rainfall and temperature which attribute to crop growth at different stages and resulted in maximum plant height. These results are in accordance with the findings of Pandiselvi *et al*. (2010) in finger millet and Gavit *et al*. (2017) in proso millet and crop sown during second fortnight of august had advantage in terms of having more time to establish their root systems and undergo early growth stages. The results are in conformity with Kiranmai *et al.* (2021) in small millets. The lower plant height was recorded with second fortnight of september sown crop. This might be due to unfavorable climatic conditions which limit the plant growth. The present findings corroborate with that of Girase *et al*. (2016) in summer pearl millet. Variations in plant height in different varieties was attributed to variations in their genetic inheritance. Short duration varieties typically have a shorter growth cycle, reach maturity more quickly than long-duration varieties. Combined effect of sowing of DHFt 109-3 variety of foxtail millet resulted in taller plants due to favourable weather conditions. These results corroborate with the findings of Rurinda *et al*. (2014) who reported significant increase in the yield of maize, finger millet and sorghum crops with early sowing.

Leaf Area (cm^2/hill)

Leaf area was significantly influenced by different sowing windows, crops and their varieties. The pooled data of two years are presented in Table 1. Crop sown during second fortnight of august showed significantly higher leaf area (667.8cm^2/hill) at harvest. It is followed by first fortnight of september (556.4cm^2/hill) and significantly lower leaf area was observed in crop sown on september second fortnight (483.8cm^2/hill). Among the crops, foxtail millet (701.4 cm^2/hill) has recorded higher leaf area followed by proso millet (564.9 cm^2/hill) and little millet (441.8 cm^2/ hill) at harvest. Varieties V_2 (DHFt 109-3 of foxtail millet, GPUP-21 of proso millet and GPUL 6 of little millet) (588.68 cm^2/hill) have recorded higher leaf area which was followed by V_1 (GPUF 3 of foxtail, GPUP 28 of proso millet and DHLM-36-3 of little millet) (550.02 cm^2/hill) at harvest.

There was significant interaction between sowing window and crop with respect to leaf area at harvest in which sowing of foxtail millet during second fortnight of august has recorded significantly higher leaf area (798.03cm^2/ hill) followed by foxtail millet sown during first fortnight of september (706.08cm^2/ hill).

There was significant interaction found between sowing windows and varieties among which, the combination of V_2(DHFt 109-3 of foxtail millet, GPUP 21 of proso millet and GPUL 6 of little millet) variety sown during second fortnight of august (677.85 cm^2/hill) has recorded significantly higher leaf area which was on par with variety V_1 (GPUF 3 foxtail millet, GPUP 28 of proso millet and DHLM 36-3 of little millet) sown during second fortnight of august (657.70cm^2/hill) and significantly lower leaf area was recorded in V_1 (GPUF 3 foxtail millet, GPUP 28 of proso millet and DHLM-36-3 of little millet) variety of little millet sown during second fortnight of september (433.26cm^2/hill).

There was significant interaction among crops and their varieties, among different combinations foxtail millet variety DHFt 109-3 has recorded significantly higher leaf area (763.82cm^2/hill) which was followed by variety GPUF 3 of foxtail millet (638.89cm^2/hill) and significantly lower leaf area was recorded in little millet variety DHLM 36-3 (414.10cm^2/hill).

There was significant interaction between all three factors, the combination of DHFt 109-3 variety of foxtail millet sown during second fortnight of august (803.68 cm^2/hill) recorded significantly higher leaf area (792.39cm^2/hill) which was on par with sowing of GPUF 3 of foxtail millet sown during second fortnight of august.

The higher leaf area observed in crops sown during the second fortnight of August may be due to favorable temperatures that promote rapid tissue multiplication and increased growth substances, including auxins. These findings are consistent with those of Bashir *et al.* (2015). Early sowing resulted in a greater number of larger leaves due to optimal weather conditions. In contrast, late sowing can lead to a mismatch between the crop's photoperiod requirements and the actual photoperiod, resulting in lower leaf area in crops sown during the second fortnight of September.

Foxtail millet demonstrated wider adaptability as a C_4 crop with low water requirements. Varieties such as DHFt-109-3 of foxtail millet, GPUP 21 of proso millet and GPUL 6 of little millet exhibited vigorous growth, resulting in higher leaf area per hill. The interaction effect of sowing in the second fortnight of August and the three small millet varieties had a synergistic impact on leaf area. Combining short-duration varieties with sowing in the second fortnight of August resulted in better crop growth and higher leaf area. Himasree *et al.* (2018) in foxtail millet, Srikanya *et al.* (2020) in foxtail millet and Sukanya *et al.* (2022) in kodo millet also observed similar findings.

Dry Matter Production (g/hill)

Dry matter production at harvest was significantly influenced by different sowing windows, crops and their varieties at harvest. The pooled data of two years are presented in Table 2.

Table 2

Total dry matter production (g/hill) and number of productive tillers/hills of small millets as influenced by sowing windows and varieties at harvest

Treatment*	Total Dry matter (g/hill)			No. of Productive tillers/hill		
	2021	2022	Pooled	2021	2022	Pooled
Sowing Window (W)						
W_1	22.0	22.2	22.1	3.76	3.97	3.87
W_2	20.7	20.4	20.6	3.14	3.35	3.24
W_3	18.9	19.0	19.0	2.66	2.91	2.78
S.Em ±	0.42	0.38	0.38	0.05	0.05	0.05
CD at 5%	1.20	1.10	1.10	0.13	0.14	0.14
Crops (C)						
C_1	22.3	23.0	22.7	2.55	2.70	2.62
C_2	20.7	20.2	20.5	3.17	3.41	3.29
C_3	18.6	18.4	18.5	3.84	4.12	3.98
S.Em ±	0.42	0.38	0.38	0.05	0.05	0.05
CD at 5%	1.20	1.10	1.10	0.13	0.14	0.14
Varieties (V)						
V_1	20.3	20.2	20.3	3.17	3.39	3.28

Continued....

Table 2 Continued....

Treatment*	Total Dry matter (g/hill)			No. of Productive tillers/hill		
	2021	2022	Pooled	2021	2022	Pooled
V_2	20.8	21.8	21.2	3.20	3.42	3.31
S.Em ±	0.34	0.31	0.31	0.04	0.04	0.04
CD at 5%	0.98	0.90	0.90	NS	NS	NS
Sowing Window (W) x Crops (C)						
W_1C_1	24.0	25.9	25.0	3.19	3.27	3.23
W_1C_2	21.6	20.7	21.2	3.61	3.87	3.74
W_1C_3	20.3	19.9	20.1	4.50	4.76	4.63
W_2C_1	22.3	22.5	22.4	2.36	2.65	2.51
W_2C_2	20.6	20.2	20.4	3.20	3.34	3.27
W_2C_3	19.3	18.4	18.8	3.84	4.06	3.95
W_3C_1	20.6	20.7	20.6	2.11	2.17	2.14
W_3C_2	19.9	19.7	19.8	2.69	3.02	2.86
W_3C_3	16.3	16.8	16.5	3.18	3.54	3.36
S.Em ±	0.73	0.66	0.66	0.08	0.08	0.08
CD at 5%	2.08	1.90	1.91	0.23	0.24	0.24
Sowing Window (W) x Varieties (V)						
W_1V_1	22.0	22.2	22.1	3.72	3.87	3.80
W_1V_2	22.0	22.1	22.0	3.80	4.06	3.93
W_2V_1	20.4	19.8	20.1	3.14	3.30	3.22
W_2V_2	21.1	21.0	21.0	3.13	3.40	3.26
W_3V_1	18.7	18.6	18.6	2.58	2.81	2.70
W_3V_2	19.2	19.5	19.3	2.74	3.00	2.87
S.Em ±	0.59	0.54	0.54	0.06	0.07	0.07
CD at 5%	1.70	1.55	1.56	0.19	0.20	0.19
Crops (C) x Varieties (V)						
C_1V_1	21.4	21.6	21.5	2.39	2.51	2.45
C_1V_2	23.2	24.5	23.9	2.72	2.88	2.80
C_2V_1	20.5	20.1	20.3	2.99	3.32	3.16
C_2V_2	20.9	20.3	20.6	3.34	3.50	3.42
C_3V_1	19.1	19.0	19.0	4.21	4.44	4.33
C_3V_2	18.1	17.8	17.9	3.47	3.79	3.63
S.Em ±	0.59	0.54	0.54	0.06	0.07	0.07
CD at 5%	1.70	1.55	1.56	0.19	0.20	0.19
Sowing Window (W) x Crops (C) x Varieties (V)						
$W_1C_1V_1$	23.7	25.2	24.4	2.92	2.98	2.95
$W_1C_1V_2$	24.4	26.5	25.5	3.46	3.56	3.51
$W_1C_2V_1$	21.4	20.7	21.0	3.50	3.76	3.63

Continued....

TABLE 2 Continued....

Treatment*	Total Dry matter (g/hill)			No. of Productive tillers/hill		
	2021	2022	Pooled	2021	2022	Pooled
$W_1C_2V_2$	21.9	20.7	21.3	3.71	3.98	3.85
$W_1C_3V_1$	20.9	20.8	20.8	4.75	4.87	4.81
$W_1C_3V_2$	19.6	19.1	19.4	4.25	4.65	4.45
$W_2C_1V_1$	21.4	20.4	20.9	2.31	2.54	2.42
$W_2C_1V_2$	23.2	24.7	23.9	2.42	2.76	2.59
$W_2C_2V_1$	20.5	20.1	20.3	3.02	3.31	3.17
$W_2C_2V_2$	20.8	20.4	20.6	3.38	3.36	3.37
$W_2C_3V_1$	19.2	18.9	19.1	4.07	4.34	4.21
$W_2C_3V_2$	19.4	17.9	18.6	3.61	3.78	3.70
$W_3C_1V_1$	19.1	19.1	19.1	1.94	2.00	1.97
$W_3C_1V_2$	22.1	22.3	22.2	2.28	2.33	2.31
$W_3C_2V_1$	19.7	19.5	19.6	2.46	2.89	2.67
$W_3C_2V_2$	20.1	19.8	20.0	2.93	3.15	3.04
$W_3C_3V_1$	17.3	17.2	17.2	3.82	4.12	3.97
$W_3C_3V_2$	15.3	16.3	15.8	2.54	2.95	2.75
S.Em ±	1.03	0.94	0.94	0.11	0.12	0.12
CD at 5%	2.95	2.69	2.70	0.32	0.34	0.33

*Treatments : Window : W_1: August 2nd fortnight; W_2: September 1st fortnight; W_3: September 2nd fortnight, Crop : C_1: Foxtail millet; C_2: Proso millet; C_3: Little millet, Variety: V_1: GPUF 3 /GPUP 28 / GPUL6; V_2: DHFt 109-3/ GPUP 21 / DHLM 36-3

Significantly higher dry matter production was found in the second fortnight of august sowing (22.07g/hill) followed by sowing during first fortnight of september (20.56g/hill). Among different crops, foxtail millet has recorded significantly higher dry matter content (22.67g/hill) which was followed by proso millet (20.45g/hill). Whereas, in varieties, V_2 (DHFt 109-3 of foxtail millet, GPUP-21 of proso millet and GPUL 6 of little millet) has recorded significantly higher dry matter content per hill compared to V (GPUF 3 foxtail millet, GPUP 28 of proso millet and DHLM-36-3 of little millet) at all the growth stages.

There was significant interaction between sowing window and crop at harvest in which, foxtail millet sown during second fortnight of August (24.95g/hill) has recorded significantly higher dry matter production which was on par with the sowing of proso millet during second fortnight of august (21.16g/hill).

There was significant interaction found between sowing windows and varieties among which, the combination of V_2 (DHFt 109-3 of foxtail millet, GPUP-21 of proso millet and GPUL 6 of little millet) variety sown during second fortnight of august has recorded significantly higher dry matter production (22.03 g/hill) which was on par with variety V_1 (GPUF 3 of foxtail millet, GPUP 28 of proso millet and DHLM-36-3 of little millet) sown during second fortnight of august (22.10g/hill).

A significant interaction between crops and their varieties was noticed and among different combinations, foxtail millet variety DHFt 109-3 (23.86 g/hill) has recorded significantly higher values (21.48g/hill) for dry matter production which was found on par with foxtail millet GPUF 3.

There was significant interaction between all three factors at harvest. The combination of foxtail millet variety DHFt 109-3 sown during second fortnight of august has recorded significantly higher dry matter production per hill (25.47g/hill) and found on par with sowing of foxtail millet variety GPUF 3 (24.44g/hill) on second fortnight of august.

The higher dry matter production was obtained when the crops were sown during second fortnight of August. It may be attributed to the maximum length of growing period was availed for early sowings which resulted in better vegetative growth with maximum dry matter accumulation. These results are similar with the findings of Shinde *et al.* (2003) and Patel *et al.* (2017). In latter sown windows, crops may face shorter growing season and cooler as they approach maturity. Among crops, foxtail millet has recorded higher dry matter because of higher leaf surface area which resulted in increased photosynthesis which is further contributing to higher dry matter production compared to proso millet and little millet. Varieties of DHFt 109-3 of foxtail millet, GPUP 21 of proso millet and GPUL 6 of little millet produced maximum dry matter accumulation might be due to genetic potential of these varieties. These findings are in accordance with results of Dixit *et al.* (2005) and Agarwal *et al.* (2005) in fodder sorghum. The interaction effect of foxtail millet variety sown during second fortnight of August resulted in higher dry matter production due to the ability to produce more photosynthates and partitioning of dry matter from sources to sink.

Productive Tillers Per Hill

The pooled data of two years are given in Table 2. Data indicated that the crop sown during second fortnight of august recorded significantly maximum productive tillers (3.87) followed by the crop sown at first fortnight of september (3.2). Significantly lower productive tillers were recorded in second fortnight of september sown crops(2.8). Among the small millets, significantly higher number of productive tillers was recorded in little millet (3.98) followed by proso millet (3.29) and lower number of productive tillers were observed in foxtail millet (2.6).

There was a significant interaction found between sowing windows and crops. Among different combinations, the sowing of little millet during second fortnight of august recorded significantly higher number of productive tillers (4.63) followed by sowing of little millet during first fortnight of september (3.95).

The interaction effect between sowing windows and varieties was found significant in which the second fortnight of august sowing and V_2 (DHFt 109-3 of foxtail millet, GPUP 21 of proso millet and GPUL 6 of little millet) has recorded significantly higher productive tillers (3.93) whereas significantly the lowest number of productive tillers was observed with second fortnight of September sowing and V_1 (GPUF 3 of foxtail millet, GPUP 28 of proso millet and DHLM-36-3 of little millet) (2.70).

The significant interaction between crop(foxtail millet, proso millet and little millet) and variety was observed. Among different combinations, GPUL 6 variety of little millet has recorded significantly maximum productive tillers (4.33). Significantly lower productive tillers were recorded in variety GPUF 3 of foxtail millet (2.45).

Overall interaction between sowing windows, crops and varieties found significant with respect to productive tillers. The combination of sowing of little millet genotype GPUL 6 during second fortnight of august (4.81) has recorded significantly higher number of productive tillers and significantly lower productive tillers was observed with combination sowing of GPUF 3 variety of foxtail millet during second fortnight of September (1.97) which was followed by sowing of DHFt 109-3 variety of foxtail millet during second fortnight of september (2.31).

Significantly higher numbers of productive tillers were found with the second fortnight of August sowing, irrespective of the crops or varieties tested. The next highest was found with the first fortnight of September sowing. This is likely because crops sown earlier benefited from favorable micro-climatic conditions, such as temperature, during critical growth stages. This led to better overall crop growth and more productive tillers. Similar results were observed in pearl millet (Andhale *et al.*, 2003) and castor (Patel *et al.*, 2005). Late sowing has resulted in a reduced number of tillers being produced. It could be because plants have a shorter growing season and so there is less time for tiller initiation and development. As a result, the overall tiller density may be lower, leading to decrease in the potential number of heads or grains produced per unit area. These results agree with the findings of Saikishore *et al.* (2020) in browntop millet, Srikanya *et al.* (2020) in foxtail milet, Kiranmai *et al.* (2021) in proso millet, little millet and foxtail millet and Lokesh *et al.* (2023) in foxtail millet. Varieties DHF 109-3, GPUP 21 and GPUL 6 produced the highest number of productive tillers, likely due to their genetic potential under the given climatic conditions. These results are consistent with the findings of Rana *et al.* (2013) and Satpal *et al.* (2016) in forage sorghum.

Days to 50 per cent Flowering and Days to Maturity

The data on 50 per cent flowering and days to maturity was significantly influenced by sowing windows, crops and their varieties at harvest. The data pooled over two years are presented in Table 3.

TABLE 3

Days to 50% flowering and days to maturity of small millets as influenced by sowing windows and varieties

Treatment*	Days to 50% flowering			Days to maturity		
	2021	2022	Pooled	2021	2022	Pooled
Sowing Window (W)						
W_1	53.79	54.53	54.2	86.2	86.8	86.50
W_2	49.17	49.85	49.5	81.0	81.6	81.34
W_3	42.70	43.26	43.0	76.4	76.9	76.7
S.Em ±	0.83	0.84	0.83	1.41	1.41	1.41
CD at 5%	2.37	2.43	2.40	4.05	4.04	4.05
Crops (C)						
C_1	49.1	49.7	49.4	83.1	83.8	83.5
C_2	44.5	45.1	44.8	74.7	75.2	74.9
C_3	52.1	52.8	52.4	85.8	86.4	86.1
S.Em ±	0.83	0.84	0.83	1.41	1.41	1.41
CD at 5%	2.37	2.43	2.40	4.05	4.04	4.05
Varieties (V)						
V_1	48.8	49.4	49.1	82.2	82.8	82.5
V_2	48.3	49.0	48.7	80.2	80.7	80.5
S.Em ±	0.67	0.69	0.68	1.15	1.15	1.15
CD at 5%	NS	NS	NS	NS	NS	NS
Sowing Window (W) x Crops (C)						
W_1C_1	54.1	54.8	54.4	87.8	88.6	88.2
W_1C_2	50.2	50.9	50.6	80.7	81.3	81.0
W_1C_3	57.1	57.8	57.4	90.0	90.5	90.2
W_2C_1	49.4	50.1	49.7	82.5	83.2	82.8

Continued....

Table 3 Continued....

Treatment*	Days to 50% flowering			Days to maturity		
	2021	2022	Pooled	2021	2022	Pooled
W_2C_2	45.7	46.3	46.0	74.8	75.3	75.9
W_2C_3	52.4	53.1	52.8	85.8	86.4	86.1
W_3C_1	43.7	44.3	44.0	79.1	79.7	79.4
W_3C_2	37.6	38.0	37.8	68.5	68.8	68.6
W_3C_3	46.8	47.4	47.1	81.7	82.2	82.0
S.Em ±	1.43	1.46	1.45	2.44	2.44	2.44
CD at 5%	4.11	4.20	4.16	7.02	7.00	7.01
Sowing Window (W) x Varieties (V)						
W_1V_1	53.9	54.6	54.3	86.7	87.4	87.1
W_1V_2	53.7	54.4	54.0	85.7	86.2	85.9
W_2V_1	49.3	50.0	49.6	81.6	82.2	81.9
W_2V_2	49.0	49.7	49.3	80.5	81.0	80.7
W_3V_1	43.1	43.7	43.4	78.3	78.8	78.6
W_3V_2	42.3	42.8	42.6	74.5	75.0	74.8
S.Em ±	1.17	1.19	1.18	2.00	1.99	1.99
CD at 5%	3.36	3.43	3.39	5.73	5.72	5.72
Crops (C) x Varieties (V)						
C_1V_1	49.1	49.8	49.4	84.7	85.5	85.1
C_1V_2	49.0	49.7	49.4	81.6	82.2	81.9
C_2V_1	45.1	45.7	45.4	75.4	75.9	75.7
C_2V_2	43.9	44.5	44.2	73.9	74.5	74.2
C_3V_1	52.1	52.8	52.4	85.2	85.6	85.4
C_3V_2	52.1	52.8	52.5	86.5	87.2	86.8
S.Em ±	1.17	1.19	1.18	2.00	1.99	1.99
CD at 5%	3.36	3.43	3.39	5.73	5.72	5.72
Sowing Window (W) x Crops (C) x Varieties (V)						
$W_1C_1V_1$	53.9	54.6	54.2	88.8	90.0	89.4
$W_1C_1V_2$	54.2	55.0	54.6	86.8	87.3	87.0
$W_1C_2V_1$	51.0	51.7	51.3	80.6	81.0	80.8
$W_1C_2V_2$	49.5	50.2	49.9	80.9	81.7	81.3
$W_1C_3V_1$	56.9	57.6	57.3	89.3	89.7	89.5
$W_1C_3V_2$	57.2	58.1	57.6	90.6	91.4	91.0
$W_2C_1V_1$	49.2	49.9	49.5	84.9	85.7	85.3
$W_2C_1V_2$	49.6	50.3	50.0	80.0	80.7	80.3
$W_2C_2V_1$	46.6	47.2	46.9	73.3	73.9	73.6
$W_2C_2V_2$	44.8	45.4	45.1	76.4	76.8	76.6
$W_2C_3V_1$	52.2	52.9	52.6	86.5	87.2	86.8

Continued....

TABLE 3 Continued....

Treatment*	Days to 50% flowering			Days to maturity		
	2021	2022	Pooled	2021	2022	Pooled
$W_2C_3V_2$	52.6	53.4	53.0	85.2	85.6	85.4
$W_3C_1V_1$	44.2	44.8	44.5	80.3	80.8	80.6
$W_3C_1V_2$	43.3	43.9	43.6	77.9	78.5	78.2
$W_3C_2V_1$	37.9	38.3	38.1	72.4	72.7	72.6
$W_3C_2V_2$	37.3	37.8	37.5	64.5	65.0	64.8
$W_3C_3V_1$	46.3	46.9	46.6	81.1	81.5	81.3
$W_3C_3V_2$	47.2	47.9	47.5	82.3	83.0	82.6
S.Em ±	2.02	2.07	2.05	3.46	3.45	3.45
CD at 5%	5.82	5.94	5.88	9.93	9.91	9.91

*Treatments : Window: W_1: August 2nd fortnight; W_2: September 1st fortnight; W_3: September 2nd fortnight; Crop : C_1: Foxtail millet; C_2: Proso millet; C_3: Little millet; Variety: V_1: GPUF 3 /GPUP 28 / GPUL6; V_2: DHFt 109-3/ GPUP 21 / DHLM 36-3

Data indicated that the crop sown during second fortnight of August recorded significantly more number of days to reach 50 per cent flowering and maturity (54.2 and 86.5 days) followed by the crop sown at first fortnight of september (49.5 and 81.3 days). Significantly lower number of days to 50 per cent flowering and maturity was recorded in crop sown during second fortnight of september (42.9 and 76.7 days). Among the small millets, significantly more number of days to reach 50 per cent flowering and maturity was recorded in little millet (52.4 and 86.1 days) followed by foxtail millet (49.4 and 83.5 days). Significantly lower number of days to 50 per cent flowering and days to maturity was observed in proso millet (45.1 and 74.9 days). Varieties were found to be non-significant with respect to flowering and maturity.

There was a significant interaction found between sowing windows and crops. Among different combinations, the sowing of little millet during second fortnight of August has recorded significantly more days to 50 per cent flowering and maturity (57.45 and 90.25 days) followed by sowing of foxtail millet during second fortnight of August (54.43 and 88.21 days).

The interaction between sowing windows and varieties was found significant in which second fortnight of August and V_1 (GPUF 3 of foxtail millet, GPUP 28 of proso millet and DHLM 36-3 of little millet) has recorded significantly more days to 50 per cent flowering and maturity (54.27 and 87.06 days) which was on par with second fortnight of August and V_2 (DHFt 109-3 of foxtail millet, GPUP 21 of proso millet and GPUL 6 of little millet) (54.05 and 85.94 days) and significantly lesser days to 50 per cent flowering and maturity was observed with second fortnight of september and V_2 (DHFt 109-3 of foxtail millet, GPUP 21 of proso millet and GPUL 6 of little millet) (42.57 and 74.76 days).

There was significant interaction between crop and variety. Among different combinations, little millet variety DHLM 36-3 of (52.45 and 86.81days) has recorded significantly maximum number of days to reach 50 per cent flowering and maturity which was on par with variety GPUL 6 of little millet (49.43 and 85.09 days).

The combination of sowing little millet variety DHLM 36-3 during second fortnight of August has recorded significantly higher number of days to reach 50 per cent flowering and maturity (57.6 and 90.9 days) which was on par with the combination of sowing little millet variety GPUL 6 during second fortnight of august (57.3 and 89.5 days) and significantly lower number of days to 50 per cent flowering and maturity was observed with combination sowing of proso millet variety GPUP 21 during second fortnight of September (37.5 and 64.7 days).

Late sowing can significantly affect the number of days required to reach 50 per cent flowering in crops. The timing of flowering is a crucial stage in plant growth and development, as it marks the beginning of reproductive processes and subsequent grain formation. The number of days taken to 50 per cent flowering and maturity decreased significantly with each day's delay in sowing during the experiment. This reduction is likely due to the exposure of late-sown crops to lower temperatures, which forces the crop into the reproductive phase without sufficient vegetative growth. These findings are consistent with those of Kiranmai *et al.* (2021) in proso millet, foxtail millet, little millet.

Crops sown in the second fortnight of August exhibited significantly more number of days to maturity compared to those planted later. This is likely because crops sown earlier received less solar radiation and lower temperatures during growth, resulting in a prolonged vegetative phase and extended days to maturity. These observations align with the results of Patel *et al.* (2005) and Ramanjaneyulu *et al.* (2013) both in castor. Furthermore, as the sowing window progresses, crops mature early due to cold stress, which can negatively impact grain filling and maturity, leading to reduced grain yield and quality. These results are supported by Parvin *et al.* (2013) in amaranth and Kiranmai *et al.* (2021) in proso millet, little millet and foxtail millet. Differences among varieties in days to maturity were non-significant, likely due to the genetic makeup of the crops and their varieties.

Ear Head Length (cm) and Ear Head Weight (g)

The data on ear head length and ear head weight was significantly influenced by sowing windows, crops and their variety. The data pooled over two years are presented in Table 4.

Table 4

Ear head length, ear head weight and test weight of small millets as influenced by sowing windows and varieties

Treatment*	Ear head length (cm)			Ear head weight (g)			Test weight (g)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Sowing Window (W)									
W_1	18.82	19.51	19.17	5.68	5.85	5.76	2.87	2.88	2.87
W_2	17.36	18.02	17.69	5.09	5.25	5.17	2.83	2.85	2.84
W_3	13.44	13.95	13.69	4.79	4.94	4.86	2.77	2.79	2.78
S.Em ±	0.29	0.23	0.26	0.07	0.07	0.07	0.04	0.04	0.04
CD at 5%	0.84	0.65	0.74	0.20	0.21	0.20	NS	NS	NS
Crops (C)									
C_1	19.14	19.83	19.49	8.30	8.56	8.43	3.20	3.22	3.21
C_2	17.93	18.62	18.28	5.18	5.34	5.26	2.79	2.81	2.80
C_3	12.54	13.02	12.78	2.07	2.14	2.11	2.47	2.49	2.48
S.Em ±	0.29	0.23	0.26	0.07	0.07	0.07	0.04	0.04	0.04
CD at 5%	0.84	0.65	0.74	0.20	0.21	0.20	0.12	0.13	0.12
Varieties (V)									
V_1	15.27	15.83	15.55	5.00	5.16	5.08	2.76	2.77	2.76

Continued....

Table 4 Continued....

Treatment*	Ear head length (cm)			Ear head weight (g)			Test weight (g)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
V_2	17.81	18.48	18.15	5.36	5.53	5.45	2.89	2.91	2.90
S.Em ±	0.24	0.18	0.21	0.06	0.06	0.06	0.03	0.04	0.04
CD at 5%	0.68	0.53	0.61	0.16	0.17	0.17	NS	NS	NS
Sowing Window (W) x Crops (C)									
W_1C_1	23.43	24.25	23.84	8.91	9.19	9.05	3.28	3.30	3.29
W_1C_2	18.94	19.66	19.30	5.91	6.10	6.01	2.84	2.82	2.83
W_1C_3	14.09	14.63	14.36	2.20	2.27	2.23	2.49	2.51	2.50
W_2C_1	21.82	22.65	22.23	8.17	8.43	8.30	3.21	3.23	3.22
W_2C_2	17.67	18.35	18.01	5.01	5.17	5.09	2.80	2.83	2.81
W_2C_3	12.58	13.06	12.82	2.08	2.14	2.11	2.47	2.49	2.48
W_3C_1	12.15	12.61	12.38	7.82	8.06	7.94	3.12	3.13	3.12
W_3C_2	17.19	17.84	17.52	4.61	4.75	4.68	2.74	2.77	2.76
W_3C_3	10.97	11.38	11.17	1.94	2.00	1.97	2.45	2.46	2.46
S.Em ±	0.50	0.39	0.45	0.12	0.12	0.12	0.07	0.08	0.07
CD at 5%	1.45	1.13	1.29	0.35	0.36	0.35	0.21	0.22	0.21
Sowing Window (W) x Varieties (V)									
W_1V_1	18.61	19.27	18.94	5.61	5.78	5.69	2.79	2.80	2.79
W_1V_2	19.03	19.75	19.39	5.74	5.92	5.83	2.94	2.95	2.95
W_2V_1	16.92	17.57	17.25	4.80	4.95	4.88	2.76	2.78	2.77
W_2V_2	17.79	18.47	18.13	5.37	5.54	5.46	2.89	2.92	2.91
W_3V_1	10.27	10.66	10.47	4.60	4.74	4.67	2.72	2.73	2.72
W_3V_2	16.60	17.23	16.92	4.98	5.13	5.06	2.82	2.85	2.83
S.Em ±	0.41	0.32	0.37	0.10	0.10	0.10	0.06	0.06	0.06
CD at 5%	1.18	0.92	1.05	0.29	0.29	0.29	0.17	0.18	0.17
Crops (C) x Varieties (V)									
C_1V_1	15.13	15.65	15.39	8.21	8.46	8.33	3.09	3.11	3.10
C_1V_2	23.14	24.02	23.58	8.39	8.65	8.52	3.31	3.33	3.32
C_2V_1	17.73	18.41	18.07	4.70	4.84	4.77	2.68	2.69	2.69
C_2V_2	18.14	18.82	18.48	5.66	5.84	5.75	2.90	2.92	2.91
C_3V_1	12.94	13.44	13.19	2.11	2.17	2.14	2.49	2.50	2.50
C_3V_2	12.14	12.61	12.38	2.04	2.10	2.07	2.45	2.47	2.46
S.Em ±	0.41	0.32	0.37	0.10	0.10	0.10	0.06	0.06	0.06
CD at 5%	1.18	0.92	1.05	0.29	0.29	0.29	0.17	0.18	0.17
Sowing Window (W) x Crops (C) x Varieties (V)									
$W_1C_1V_1$	22.71	23.43	23.07	8.82	9.09	8.96	3.15	3.16	3.16
$W_1C_1V_2$	24.15	25.07	24.61	9.00	9.28	9.14	3.41	3.43	3.42

Continued....

TABLE 4 Continued....

Treatment*	Ear head length (cm)			Ear head weight (g)			Test weight (g)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
$W_1C_2V_1$	18.54	19.25	18.89	5.73	5.90	5.82	2.72	2.70	2.71
$W_1C_2V_2$	19.34	20.07	19.71	6.10	6.29	6.20	2.95	2.94	2.94
$W_1C_3V_1$	14.57	15.13	14.85	2.27	2.34	2.31	2.50	2.52	2.51
$W_1C_3V_2$	13.60	14.12	13.86	2.12	2.19	2.16	2.47	2.49	2.48
$W_2C_1V_1$	20.29	21.05	20.67	8.02	8.27	8.14	3.10	3.12	3.11
$W_2C_1V_2$	23.35	24.24	23.80	8.32	8.59	8.46	3.32	3.35	3.33
$W_2C_2V_1$	17.38	18.05	17.71	4.31	4.45	4.38	2.68	2.70	2.69
$W_2C_2V_2$	17.97	18.66	18.31	5.72	5.89	5.80	2.91	2.95	2.93
$W_2C_3V_1$	13.11	13.61	13.36	2.08	2.14	2.11	2.49	2.51	2.50
$W_2C_3V_2$	12.04	12.51	12.28	2.08	2.15	2.11	2.45	2.47	2.46
$W_3C_1V_1$	18.92	19.75	19.19	7.78	8.02	7.90	3.03	3.04	3.04
$W_3C_1V_2$	21.92	22.75	22.34	7.85	8.09	7.97	3.21	3.22	3.21
$W_3C_2V_1$	17.28	17.94	17.61	4.06	4.18	4.12	2.65	2.67	2.66
$W_3C_2V_2$	17.10	17.74	17.42	5.16	5.32	5.24	2.83	2.88	2.85
$W_3C_3V_1$	11.14	11.57	11.36	1.96	2.03	1.99	2.48	2.47	2.48
$W_3C_3V_2$	10.79	11.19	10.99	1.92	1.98	1.95	2.42	2.45	2.43
S.Em ±	0.71	0.55	0.63	0.17	0.18	0.17	0.10	0.11	0.11
CD at 5%	2.05	1.59	1.82	0.49	0.51	0.50	0.29	0.31	0.30

*Treatments : Window: W_1: August 2nd fortnight; W_2: September 1st fortnight; W_3: September 2nd fortnight; Crop : C_1: Foxtail millet; C_2: Proso millet; C_3: Little millet; Variety: V_1: GPUF 3 /GPUP 28 / GPUL6; V_2: DHFt 109-3/ GPUP 21 / DHLM 36-3

Significantly higher ear head length and ear head weight was found in crop sown during second fortnight of August (19.17cm and 5.76g) followed by sowing during first fortnight of september (17.69cm and 5.17g). significantly the least ear head length was observed in september second fortnight of September (13.69 cm and 4.86g). Among different crops, foxtail millet has recorded significantly higher ear head length (19.49) and ear head weight (8.43g) which was followed by proso millet (18.28cm and 5.26g).

There was significant interaction between sowing window and crop in which sowing of foxtail millet during second fortnight of August has recorded significantly higher ear head length (23.84cm) and ear head weight (9.05g) which was followed by sowing of foxtail millet during first fortnight of september (22.23cm and 8.30g) and significantly lower ear head length and ear head weight was recorded in little millet which was sown during second fortnight of september (11.17cm and 1.97g).

There was significant interaction found between sowing windows and varieties among which combination of V_2 (DHFt 109-3 of foxtail millet, GPUP-21 of proso millet and GPUL 6 of little millet) sown during second fortnight of August has recorded significantly higher ear head length (19.39cm) and ear head weight (5.83g) which was on par with V_1 (GPUF 3 of foxtail millet, GPUP 28 of proso millet and DHLM 36-3 of little millet) sown during second fortnight of august (18.94cm and 5.69g).

There was significant interaction between crops and their varieties, among different combinations DHFt 109-3 variety of foxtail millet has recorded significantly higher ear head length (23.58cm) and weight (8.52g).

There was significant interaction between all three factors in ear head length and ear head weight. The combination of foxtail millet variety DHFt 109-3 sown during second fortnight of august has recorded significantly higher ear head length (24.61cm) and ear head weight (9.14g) which was on par with sowing of foxtail millet variety GPUF 3 during second fortnight of august (23.07cm and 8.96g).

Significant variations in ear head length and ear head weight were found, the highest in the earliest (W_1) sowing window followed by W_2 and W_3. This is likely due to increased photosynthetic surface resulting in increased production of photosynthates and thereby increased translocation of photosynthates from source to sink. These results are in conformity with Govindan *et al.* (2002) in castor, Kamara *et al.* (2009) in corn and Terefe *et al.* (2015) in castor. Foxtail millet showed better resilience as compared to proso millet and little millet due to its wider adaptability which attributes to higher ear head length and ear head weight. Similar variations in yield attributes were noticed by Chandrappa (1993) in small millets. Variations in yield attributes in different varieties may be attributed to variations in their genetic traits.

Test Weight (g)

Test weight was not significantly influenced by sowing windows and varieties. However, it was significantly influenced by crops (Table 4). Among different crops, foxtail millet has recorded significantly higher test weight (3.21g) which was followed by proso millet (2.80g) and significantly lower test weight was recorded in little millet (2.48g).

There was significant interaction found between sowing window and crop in which sowing of foxtail millet during second fortnight of August has recorded significantly higher test weight (3.29g) which was on par with sowing of foxtail millet during first fortnight of september (3.22g).

Interaction effect between sowing window and variety was found significant. Combination of V_2 (DHFt 109-3 of foxtail millet, GPUP 21 of proso millet and GPUL 6 of little millet) variety sown during second fortnight of August has recorded significantly higher test weight (2.95g) which was on par with V_2 (DHFt 109-3 of foxtail millet, GPUP-21 of proso millet and GPUL 6 of little millet) variety sown during first fortnight of september and V_2 (DHFt 109-3 of foxtail millet, GPUP-21 of proso millet and GPUL 6 of little millet) variety sown during second fortnight of September (2.91g). Lower test weight was recorded in V_1 variety sown during second fortnight of september (2.72g).

The interaction effect between crops and their varieties was significant, among different combinations variety DHFt 109-3 of foxtail millet has recorded significantly higher test weight (3.32g) which was on par with variety GPUF 3 of foxtail millet (3.10g) and significantly lower test weight was recorded in variety DHLM 36-3 of little millet (2.46g).

Overall interaction between all three factors was found significant with respect to test weight. The combination of variety DHFt 109-3 variety of foxtail millet sown during second fortnight of August has recorded significantly higher test weight (3.42g) which was on par with sowing of variety GPUF 3 of foxtail millet during second fortnight of August (3.16g). Significantly lower test weight was observed with combination of little millet variety DHLM 36-3 of sown during second fortnight of september (2.43g) which was on par with combination of variety GPUL 6 of little millet sown during second fortnight of september.

Test weight is a measure of the weight of a specified volume of grain and is often used as an indicator of grain quality. Foxtail millet has the highest test weight because of its genetics. These results are in line with Srikanya *et al*. (2020) and Lokesh *et al.* (2023) in foxtail millet. Among interactions combination of millets along with sowing in second fortnight of September (W_3) has recorded the lowest test weight. This is likely due to late sowing does which might have prevented the full growth and development cycle resulting in incomplete grain filling and reduced test weight.

Grain Yield, Straw Yield and Harvest Index

The data on grain and straw yield was significantly influenced by sowing windows, crops and their varieties. The data pooled over two years are presented in Table 5.

Data indicated that the crop sown during second fortnight of August recorded significantly higher grain yield and straw yield (1994kg/ha and 3115kg/ha, respectively) followed by the crop sown at first fortnight of september (1740 kg/ha and 2807 kg/ha, respectively). Significantly lower grain yield and straw yield was recorded in crops sown during second fortnight of september (1562kg/ha and 2538kg/ha, respectively). Among the different small millets, significantly higher grain yield and straw yield was recorded in foxtail millet (2090 kg/ha and 3327 kg/ha, respectively) followed by proso millet (1715 kg/ha and 2699kg/ha, respectively).

There was a significant interaction found between sowing windows and crops. Among different combinations, sowing of foxtail millet during second fortnight of August (2402 kg/ha and 3729 kg/ha) has recorded significantly higher grain yield and straw yield followed by sowing of foxtail millet during first fortnight of September (2050 kg/ha and 3289 kg/ha).

TABLE 5

Grain yield, Straw yield and Harvest index of small millets as influenced by sowing windows and varieties

Treatment*	Grain yield (kg/ha)			Straw yield (kg/ha)			Harvest index		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Sowing Window (W)									
W_1	1943	2044	1994	3052	3177	3115	0.38	0.39	0.39
W_2	1696	1784	1740	2703	2912	2807	0.38	0.38	0.38
W_3	1524	1601	1562	2432	2644	2538	0.36	0.37	0.37
S.Em ±	50.7	53.47	52.09	73.24	70.84	66.14	0.01	0.01	0.01
CD at 5%	145.73	153.68	149.70	210.49	203.60	190.08	NS	NS	NS
Crops (C)									
C_1	2037	2144	2090	3250	3404	3327	0.38	0.39	0.38
C_2	1672	1757	1715	2621	2777	2699	0.37	0.39	0.38
C_3	1455	1528	1491	2317	2552	2434	0.37	0.37	0.37
S.Em ±	50.7	53.47	52.09	73.24	70.84	66.14	0.01	0.01	0.01
CD at 5%	145.73	153.68	149.70	210.49	203.60	190.08	NS	NS	NS
Varieties (V)									
V_1	1656	1741	1698	2598	2781	2690	0.38	0.38	0.38
V_2	1786	1878	1832	2860	3041	2950	0.37	0.38	0.38
S.Em ±	41.4	43.66	42.53	59.8	57.84	54.00	0.01	0.01	0.01
CD at 5%	118.99	125.48	122.23	171.87	166.24	155.20	NS	NS	NS
Sowing Window (W) x Crops (C)									
W_1C_1	2340	2464	2402	3666	3793	3729	0.39	0.39	0.39
W_1C_2	1845	1941	1893	2769	2849	2809	0.39	0.41	0.40
W_1C_3	1644	1728	1686	2720	2891	2806	0.36	0.37	0.37

Continued....

Table 5 Continued....

Treatment*	Grain yield (kg/ha)			Straw yield (kg/ha)			Harvest index		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
W_2C_1	1997	2103	2050	3201	3377	3289	0.38	0.38	0.38
W_2C_2	1669	1754	1711	2717	2877	2797	0.37	0.38	0.38
W_2C_3	1424	1494	1459	2191	2481	2336	0.38	0.38	0.38
W_3C_1	1772	1864	1818	2882	3041	2962	0.37	0.38	0.38
W_3C_2	1501	1577	1539	2376	2606	2491	0.36	0.37	0.36
W_3C_3	1298	1361	1330	2039	2285	2162	0.36	0.37	0.37
S.Em ±	87.82	92.61	90.22	126.86	122.70	114.55	0.02	0.02	0.02
CD at 5%	252.41	266.18	259.28	364.58	352.65	329.22	NS	NS	NS
Sowing Window (W) x Varieties (V)									
W_1V_1	1920	2021	1971	2955	3062	3009	0.39	0.40	0.39
W_1V_2	1966	2068	2017	3148	3293	3220	0.37	0.38	0.38
W_2V_1	1610	1692	1651	2587	2777	2682	0.38	0.38	0.38
W_2V_2	1783	1875	1829	2819	3047	2933	0.38	0.38	0.38
W_3V_1	1437	1509	1473	2253	2505	2379	0.36	0.37	0.37
W_3V_2	1611	1692	1651	2612	2783	2697	0.36	0.38	0.37
S.Em ±	71.71	75.62	73.66	103.58	100.19	93.53	0.01	0.01	0.01
CD at 5%	206.09	217.33	211.71	297.68	287.93	268.81	NS	NS	NS
Crops (C) x Varieties (V)									
C_1V_1	1862	1959	1911	2951	3147	3049	0.38	0.38	0.38
C_1V_2	2211	2328	2269	3549	3661	3605	0.38	0.39	0.38
C_2V_1	1603	1685	1644	2460	2593	2526	0.37	0.39	0.38
C_2V_2	1741	1830	1785	2782	2961	2872	0.37	0.38	0.38
C_3V_1	1503	1578	1540	2385	2604	2494	0.37	0.38	0.37
C_3V_2	1408	1477	1442	2248	2501	2374	0.37	0.37	0.37
S.Em ±	71.71	75.62	73.66	103.58	100.18	93.53	0.01	0.01	0.01
CD at 5%	206.09	217.33	211.71	297.68	287.93	268.81	NS	NS	NS
Sowing Window (W) x Crops (C) x Varieties (V)									
$W_1C_1V_1$	2256	2376	2316	3574	3703	3639	0.39	0.39	0.39
$W_1C_1V_2$	2424	2552	2488	3757	3882	3820	0.39	0.39	0.39
$W_1C_2V_1$	1753	1843	1798	2430	2488	2459	0.41	0.43	0.42
$W_1C_2V_2$	1938	2039	1988	3108	3210	3159	0.37	0.39	0.38
$W_1C_3V_1$	1753	1843	1798	2861	2996	2928	0.37	0.38	0.37
$W_1C_3V_2$	1535	1612	1573	2580	2786	2683	0.36	0.37	0.36
$W_2C_1V_1$	1798	1891	1844	2883	3076	2980	0.38	0.38	0.38
$W_2C_1V_2$	2197	2314	2256	3519	3679	3599	0.39	0.39	0.39
$W_2C_2V_1$	1597	1678	1638	2668	2756	2712	0.36	0.38	0.37

Continued....

TABLE 5 Continued....

Treatment*	Grain yield (kg/ha)			Straw yield (kg/ha)			Harvest index		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
$W_2C_2V_2$	1740	1830	1785	2766	2999	2882	0.38	0.38	0.38
$W_2C_3V_1$	1436	1507	1471	2210	2498	2354	0.38	0.38	0.38
$W_2C_3V_2$	1412	1481	1446	2171	2464	2318	0.39	0.38	0.38
$W_3C_1V_1$	1533	1611	1572	2394	2661	2527	0.38	0.38	0.38
$W_3C_1V_2$	2011	2117	2064	3370	3422	3396	0.36	0.38	0.37
$W_3C_2V_1$	1458	1534	1496	2281	2535	2408	0.35	0.36	0.36
$W_3C_2V_2$	1544	1621	1582	2471	2676	2574	0.36	0.38	0.37
$W_3C_3V_1$	1320	1384	1352	2084	2318	2201	0.36	0.37	0.37
$W_3C_3V_2$	1277	1339	1308	1993	2251	2122	0.36	0.37	0.37
S.Em ±	124.2	130.98	127.59	179.4	173.53	162.00	0.02	0.02	0.02
CD at 5%	356.96	376.43	366.68	515.6	498.72	465.59	NS	NS	NS

*Treatments:Window: W_1: August 2nd fortnight; W_2: September 1st fortnight; W_3: September 2nd fortnight Crop: C_1: Foxtail millet; C_2: Proso millet; C_3: Little milletVariety: V_1: GPUF 3 /GPUP 28 / GPUL6; V_2: DHFt 109-3/ GPUP 21 / DHLM 36-3

The interaction between sowing windows and varieties was found significant in which, the second fortnight of August and V_2 (DHFt 109-3 of foxtail millet, GPUP-21 of proso millet and GPUL 6 of little millet) has recorded significantly higher grain yield and straw yield (2017 and 3220kg/ha, respectively) and was on par with second fortnight of august and V_1 (GPUF 3 of foxtail millet, GPUP 28 of proso millet and DHLM 36-3 of little millet) (1971 kg/ha and 3009 kg/ha, respectively).

There was significant interaction between crop and variety. Among different combinations, variety DHFt-109-3 of foxtail millet has recorded significantly higher grain yield and straw yield (2269 kg/ha and 3605 kg/ha respectively).

Overall interaction between sowing windows, crops and varieties was found significant with respect to grain and straw yield. The combination of sowing genotype DHFt 109-3 of foxtail millet during second fortnight of August has recorded significantly higher grain yield and straw yield (2488kg/ha and 3820kg/ha, respectively) and was found on par with variety GPUF 3 of foxtail millet sown during second fortnight of August (2316kg/ha and 3639kg/ha, respectively) and significantly lower grain yield and straw yield was observed with combination sowing little millet variety DHLM 36-3 during second fortnight of September (1308kg/ha and 2122kg/ha, respectively). However, harvest index was found to be non-significant with respect to sowing windows, crops and varieties.

Grain and straw yields were highest when the crop was sown in the second fortnight of August (W_1). This is attributed to the favorable microclimate, with higher absorption of photosynthetically active radiation (PAR) and improved light use efficiency (LUE), leading to increased photosynthetic rates and yield attributes. Delayed sowing resulted in lower yields due to unfavorable conditions. These findings are supported by Siddig *et al.* (2013) in Pearl millet, Kiranmai *et al.* (2021) in foxtail millet, little millet and proso millet and Sukanya *et al*., (2022) in proso millet and kodo millet who noted similar yield declines in small millets with delayed sowing. Crops sown in the second fortnight of september likely faced colder conditions and shorter growing seasons, negatively impacting yield. The limited time for crops to complete their life cycle before adverse weather further reduced yields, as noted by Maurya *et al.* (2016) in pearl millet, Nandini and Shridhara (2019) in foxtail millet, Saikishore *et al.* (2020) in brown top, Dimple *et al.* (2022) in proso millet and Lokesh *et al.* (2023) in foxtail millet. The lowest yields from the third sowing window (W_3) were possibly due to biotic and abiotic stresses such as moisture stress and higher temperatures.

Among the crops, foxtail millet recorded the highest grain and straw yields, followed by proso millet and little millet. These differences can be attributed to factors like leaf area index (LAI), panicle weight and test weight, which depend on the genetic potential and adaptability of varieties to current climatic conditions, as noted by Vikramarjun (2019). The interaction between sowing windows, millet crops and varieties was significant for yield.

The outcomes of present study showed that the growth and yield were influenced by sowing windows, crops and their varieties. The combination of varieties of all the three small millets *i.e.,* variety DHFt 109-3 of foxtail millet, variety GPUP 21 of proso millet and variety GPUL-6 of little millet sown during second fortnight of August has recorded higher growth, grain yield (2488 kg/ha, 1988kg/ha and 1798kg/ha, respectively) and yield attributing components like ear head length (24.61, 19.71 and 14.85cm, respectively) and ear head weight (9.14, 6.20 and 2.31g respectively).

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Mysore J. Agric. Sci., 58 (4) : 166-174 (2024)

Effect of Bio-stimulants on Growth and Yield of Potato (*Solanum tuberosum* L.)

Mohammad A. Nasim[1], A. P. Mallikarjuna Gowda[2], K. N. Srinivasappa[3], A. Vidya[4], B. Manjunath[5], J. Venkategowda[6] and P. Veeranagappa[7]

[1,2,3&4]Department of Horticulture, [5]AICRP on pigeon pea, Zonal Agricultural Research Station, UAS, GKVK, Bengaluru - 560 065, [6&7]ICAR-KVK, Hadonahalli, Bengaluru Rural District,
e-Mail : nasimayobi17@gmail.com

Authors Contribution

A. Mohammad Nasim : Conceptualization, design, data analysis and manuscript preparation;

A. P. Mallikarjuna Gowda : Conceptualization, design, supervision and Draft editing;

K. N. Srinivasappa :
A. Vidya :
B. Manjunath :
J. Venkategowda &
P. Veeranagappa :
Manuscript editing and overall guidance

Corresponding Author :
A. Mohammad Nasim

Received : August 2024
Accepted : September 2024

Abstract

The research was carried out at Zonal Agricultural Research Station, UAS, GKVK, Bengaluru during *Rabi* season of 2022 - 23 to evaluate the effect of bio-stimulants for growth and yield potency in potato. An experiment was conducted by adopting randomized complete block design (RCBD) with nine treatments and replicated thrice. The treatments comprised of soil application of humic acid, amino acid, sea weed extract and microbial consortia based bio-stimulants. Maximum plant height (74.04 cm), number of branches (7.73), plant spread (2460.73 cm^2), number of leaves (66.87 $plant^{-1}$), leaf area (3216.80 cm^2), leaf area index (3.57), number of tubers (8.47 $plant^{-1}$), tuber length (8.13 cm), tuber girth (15.19 cm) and tuber yield (28.61 t ha^{-1}) were recorded with treatment comprising of whole tubers + RDF + Humic acid at 2 ml L^{-1}, which was *on par* with the treatment combination of cut tubers + RDF + Humic acid at 2 ml L^{-1} for plant height (71.87 cm), number of branches (7.00), plant spread (2367.13 cm^2), number of leaves (64.53 $plant^{-1}$), leaf area (2848.37 cm^2), leaf area index (3.16), number of tubers (6.87 $plant^{-1}$), tuber length (7.20 cm), tuber girth (14.94 cm) and tuber yield (26.87 t ha^{-1}). Whereas, control (RDF + Whole tuber) registered minimum plant height (59.47 cm), number of branches (5.67), plant spread (2020.20 cm^2), number of leaves (50.87 $plant^{-1}$), leaf area (1812.23 cm^2), leaf area index (2.01) number of tubers (5.53 $plant^{-1}$), tuber length (5.87 cm), tuber girth (11.12 cm) and tuber yield (21.47 t ha^{-1}).

Keywords : Growth and yield of potato, RDF, Bio-stimulants

The potato (*Solanum tuberosum*) is tuberous crop, belongs to Solanaceous family originated from Andes region of South America is an important staple food crop with high nutritional value and adaptability has evolved into a cornerstone of global agriculture and nutrition. It has fourth position after wheat, rice and maize in terms of human consumption. Potato has a rich nutritional profile with rich source of vitamins, including vitamin C and vitamin B6, minerals such as potassium and magnesium and dietary fibre. These nutrients contribute to its role in addressing dietary deficiencies and supporting overall health. Furthermore, the potato's culinary versatility has cemented its place in diverse cuisines worldwide from boiled to mashed and baked to fried preparations, enabling it to meet the dietary preferences and needs of various cultures (Reddy *et al*., 2018).

Economically, the potato is vital, particularly in developing regions where it serves as a staple food and a significant source of income for millions of smallholder farmers. Its relatively short growing cycle and high yield potential make it an attractive crop for farmers seeking to maximize productivity and food security. The economic benefits of potato farming extend beyond the farm gate influencing local markets, trade and food industries (Devaux *et al*., 2014)

However, the cultivation of potatoes is not without challenges. The crop is susceptible to a range of insect pests and diseases. Modern agricultural practices have mitigated some risks, yet climate change poses new threats by altering growing conditions and exacerbating pest pressures. Sustainable farming practices and technological innovations are essential to overcoming these challenges and ensuring the continued productivity of potato crops (Haverkort *et al*., 2009).

One promising approach to enhancing potato cultivation involves the use of bio-stimulants. Bio-stimulants are substances or microorganisms that when applied to plants, seeds or soil, enhance natural processes to improve nutrient uptake, stress tolerance, yield and overall quality. They represent a sustainable and environmentally friendly alternative to traditional chemical inputs. In potato farming, bio-stimulants can play a crucial role in addressing some of the most pressing challenges such as improving resistance to diseases, enhancing drought tolerance, promoting more efficient nutrient use and thereby increasing yield (Du Jardin, 2015).

This research paper seeks to provide a comprehensive exploration of the potato's multidimensional significance with a particular focus on the potential of bio-stimulants to revolutionize potato cultivation.

Material and Methods

The field experiment was conducted at Zonal Agriculture Research Station, University of Agricultural Sciences, GKVK, Bengaluru during *Rabi* season of 2022-23. The experiment having nine treatments set up in RCBD design with three replications. The treatments involved soil application of bio-stimulants *viz*., T_1-Whole tubers + RDF (Control), T_2- Whole tubers + RDF + Humic acid at 2 ml L^{-1}, T_3-Whole tubers + Amino acid at 3 ml L^{-1}, T_4-Whole tubers + RDF + Sea weed extract at 2 ml L^{-1}, T_5-Whole tubers + RDF + Arka microbial consortium at 10 ml L^{-1}, T_6- Cut tubers + RDF + Humic acid at 2 ml L^{-1}, T_7- Cut tubers + RDF + Amino acid at 3 ml L^{-1}, T_8- Cut tubers + RDF + Sea weed extract at 2 ml L^{-1}, T_9- Cut tubers + RDF + Arka microbial consortium at 10 ml L^{-1}. The whole and cut tubers of potato variety Kufri Himalini was planted in lines at 45 cm row to row and 20 cm plant to plant spacing. Soil was provided with 125: 100: 125 kg N:P:K ha^{-1} and 25 t ha^{-1} FYM before planting. The various bio-stimulants *viz*., Humic acid, Amino acid, Sea weed extract and Arka microbial consortia were applied to the crop at 30 and 60 days afters planting at the rate of 1500 litre per hectare as soil application. The growth parameters were recorded at 45 and 75 days after planting and at harvest.

Results and Discussion

Plant Growth

Plant height was significantly differed with the soil application of various bio-stimulants (Table 1). At 45 and 75 days after planting, whole tubers + RDF + Humic at 2 ml L^{-1} registered taller plants (50.67 and 64.67 cm, respectively), which was *on par* with cut tubers + RDF + humic acid at 2 ml L^{-1} (46.80 and 60.93 cm, respectively) and whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (45.20 and 58.87 cm, respectively) and followed by cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (44.53 and 56.73 cm, respectively). While, control (Whole tubers + RDF) registered shorter plants (37.73 and 50.87 cm, respectively). Whereas, at harvest, the treatment comprising of whole tubers + RDF + Humic acid at 2 ml L^{-1} resulted in maximum plant height (74.04 cm), which was at *par* with all the treatments except whole and cut tubers + RDF + Microbial consortia at 10 ml L^{-1} (65.93 and 65.00 cm, respectively) and control (59.47 cm).

Among different bio-stimulants, highest number of branches per plant (6.07) was found with whole tubers + RDF + Humic acid at 2 ml L^{-1} which was *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (5.93), whole tuber + RDF + Sea weed extract at 2 ml L^{-1} (5.60), whole tubers + RDF + Amino acid at 3 ml L^{-1} (5.47) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (5.40) at 45 DAP. The lesser number of branches per plant was observed with control (4.07). While, at 75 DAP, significantly higher number of branches per plant was observed with whole tubers +

TABLE 1
Effect of bio-stimulants on plant height of potato

Treatments	Plant height (cm)		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	37.7 c	50.87 c	59.47 c
T_2 - Whole tubers + RDF + Humic acid	50.6 a	64.67 a	74.04 a
T_3 - Whole tubers + RDF + Amino acid	42.3 bc	56.73 bc	67.44 abc
T_4 - Whole tubers + RDF + Sea weed extract	45.2 ab	58.87 ab	69.55 ab
T_5 - Whole tubers + RDF + Microbial consortia	42.0 bc	54.87 bc	65.93 bc
T_6 - Cut tubers + RDF + Humic acid	46.8 ab	60.93 ab	71.87 ab
T_7 - Cut tubers + RDF + Amino acid	42.0 bc	55.40 bc	67.38 abc
T_8 - Cut tubers + RDF + Sea weed extract	44.5 b	56.73 bc	68.67 ab
T_9 - Cut tubers + RDF + Microbial consortia	41.8 bc	55.20 bc	65.00 bc
S Em±	1.83	2.14	2.52
CD at 5%	5.49	6.42	7.54

Note : DAP - Days After Planting

RDF + Humic acid at 2 ml L^{-1} (6.87), which was at *par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (6.53), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (6.20) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (6.13) and followed by whole tubers + RDF + Amino acid at 3 ml L^{-1} (6.00). Control registered minimum number of branches per plant 5.33. Among the treatments, significantly highest number of haulms were noticed at harvest with whole tubers + RDF + Humic acid at 2 ml L^{-1} (7.73), which was *at par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (7.00) and followed by whole tubers + RDF + Sea weed extract at 2 ml L-1 (6.80). Whereas, the lowest number of branches (5.67) were observed in control (Table 2).

TABLE 2
Effect of bio-stimulants on number of branches per plant in potato

Treatments	No. of haulms ($plant^{-1}$)		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	4.00 c	5.33 c	5.67 c
T_2 - Whole tubers + RDF + Humic acid	6.07 a	6.87 a	7.73 a
T_3 - Whole tubers + RDF + Amino acid	5.47 ab	6.00 bc	6.60 b
T_4 - Whole tubers + RDF + Sea weed extract	5.60 ab	6.20 abc	6.80 b
T_5 - Whole tubers + RDF + Microbial consortia	5.20 b	5.80 bc	6.40 bc
T_6 - Cut tubers + RDF + Humic acid	5.93 ab	6.53 ab	7.00 ab
T_7 - Cut tubers + RDF + Amino acid	5.33 ab	5.93 bc	6.40 bc
T_8 - Cut tubers + RDF + Sea weed extract	5.40 ab	6.13 abc	6.60 b
T_9 - Cut tubers + RDF + Microbial consortia	5.20 b	5.73 bc	6.13 bc
S Em±	0.22	0.26	0.26
CD at 5%	0.67	0.77	0.78

Note : DAP- Days After Planting

The plant spread was significantly differed at 45 DAP, wherein maximum plant spread was generated with whole tubers + RDF + Humic acid at 2 ml L^{-1} (1540.53 cm^2) and statistically *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (1447.13 cm^2), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (1404.33 cm^2), which was followed by whole tubers + RDF + Amino acid at 3 ml L^{-1} (1293.47 cm^2). Whereas, the least plant spread was observed in control (1122.00 cm^2). At 75 DAP, whole tubers + RDF + Humic acid at 2 ml L^{-1} recorded maximum plant spread (2036.47 cm^2) and found *at par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (1962.20 cm^2), whole tuber + RDF + Sea weed extract at 2 ml L^{-1} (1920.07 cm^2) and cut tuber + RDF + Sea weed extract at 2 ml L^{-1} (1830.93 cm^2) followed by whole tubers + RDF + Amino acid at 3 ml L^{-1} (1780.07 cm^2). Whereas, lower plant spread was obtained in control (1616.93 cm^2). At harvest, the greater spreading of plant was noticed with whole tubers + RDF + Humic acid at 2 ml L^{-1} (2460.73 cm^2), which was *at par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (2367.13 cm^2) followed by whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (2253.13cm^2) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (2233.13 cm^2). The control produced lower plant spread of 2020.20 cm^2 (Table 3).

More number of leaves per plant at 45 DAP was produced with treatment comprising of whole tubers + RDF + Humic acid at 2 ml L^{-1} (47.27) and was *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (42.67) and whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (41.87) followed by cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (40.73). Similarly, highest number of leaves per plant at 75 DAP was noticed with whole tubers + RDF + Humic acid at 2 ml L^{-1} (58.73), which was *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (56.13), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (54.80) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (53.33) and followed by whole tubers + RDF + Amino acid at 3 ml L^{-1} (51.73). Whereas, control produced lowest number of leaves per plant (45.27). More number of leaves at harvest were produced with the treatment comprised of whole tubers + RDF + Humic acid at 2 ml L^{-1} (66.87), which was *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (64.53), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (64.13), cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (60.47) and cut tuber + RDF + Amino acid at 3 ml L^{-1} (59.73). Whereas, lesser number of leaves per plant (50.87) was registered with control (Table 4).

TABLE 3

Plant spread as influenced by bio-stimulants in potato

Treatments	Plant spread (cm^2)		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	1122.00 ^{d}	1616.93 ^{c}	2020.20 ^{c}
T_2 - Whole tubers + RDF + Humic acid	1540.53 ^{a}	2036.47 ^{a}	2460.73 ^{a}
T_3 - Whole tubers + RDF + Amino acid	1293.47 ^{bc}	1780.07 ^{abc}	2177.33 ^{bc}
T_4 - Whole tubers + RDF + Sea weed extract	1404.33 ^{ab}	1920.07 ^{ab}	2253.13 ^{abc}
T_5 - Whole tubers + RDF + Microbial consortia	1229.00 ^{cd}	1761.27 ^{bc}	2101.80 ^{c}
T_6 - Cut tubers + RDF + Humic acid	1447.13 ^{ab}	1962.20 ^{ab}	2367.13 ^{ab}
T_7 - Cut tubers + RDF + Amino acid	1233.00 ^{cd}	1718.87 ^{bc}	2057.20 ^{c}
T_8 - Cut tubers + RDF + Sea weed extract	1238.53 ^{cd}	1830.93 ^{abc}	2233.13 ^{abc}
T_9 - Cut tubers + RDF + Microbial consortia	1211.60 ^{cd}	1696.40 ^{bc}	2093.20 ^{c}
S Em±	48.89	82.21	76.53
CD at 5%	146.56	246.47	229.45

Note : DAP- Days After Planting

TABLE 4

Effect of bio-stimulants on number of leaves per plant in potato

Treatments	No. of leaves (plant^{-1})		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	1122.00 ^{d}	1616.93 ^{c}	2020.20 ^{c}
T_1 - Whole tubers + RDF (Control)	34.73 ^{c}	45.27 ^{d}	50.87 ^{c}
T_2 - Whole tubers + RDF + Humic acid	47.27 ^{a}	58.73 ^{a}	66.87 ^{a}
T_3 - Whole tubers + RDF + Amino acid	39.40 ^{bc}	51.73 ^{bcd}	59.40 ^{b}
T_4 - Whole tubers + RDF + Sea weed extract	41.87 ^{ab}	54.80 ^{abc}	64.13 ^{ab}
T_5 - Whole tubers + RDF + Microbial consortia	38.33 ^{bc}	50.80 ^{bcd}	58.60 ^{bc}
T_6 - Cut tubers + RDF + Humic acid	42.67 ^{ab}	56.13 ^{ab}	64.53 ^{ab}
T_7 - Cut tubers + RDF + Amino acid	39.00 ^{bc}	49.87 ^{bcd}	59.73 ^{ab}
T_8 - Cut tubers + RDF + Sea weed extract	40.73 ^{bc}	53.33 ^{abc}	60.47 ^{ab}
T_9 - Cut tubers + RDF + Microbial consortia	37.53 ^{bc}	48.67 ^{cd}	57.27 ^{bc}
S Em±	1.84	2.19	2.46
CD at 5%	5.51	6.57	7.38

Note : DAP - Days After Planting

At 45 and 75 DAP, maximum leaf area per plant was obtained with whole tubers + RDF + Humic acid at 2 ml L^{-1} (1989.37 and 2752.74 cm^2, respectively), which was followed by cut tubers + RDF + Humic acid at 2 ml L^{-1} (1659.37 and 2352.77 cm^2, respectively), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (1591.70 and 2303.71 cm^2, respectively) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (1530.31 and 2154.54 cm^2, respectively). The lesser leaf area per plant was observed with control (1027.70 and 1447.73 cm^2, respectively). The treatment involving whole tubers + RDF + Humic acid at 2 ml L^{-1} resulted in significantly highest leaf area per plant at harvest (3216.80 cm^2), which was found *at par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (2848.37 cm^2), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (2808.31 cm^2) followed by cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (2527.72 cm^2). While, the control exhibited the lesser leaf area of 1812.23 cm^2 per plant (Table 5).

TABLE 5

Effect of bio-stimulants on leaf area in potato

Treatments	Leaf area (cm^2)		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	1027.70 ^{e}	1447.73 ^{e}	1812.23 ^{d}
T_2 - Whole tubers + RDF + Humic acid	1989.37 ^{a}	2752.74 ^{a}	3216.80 ^{a}
T_3 - Whole tubers + RDF + Amino acid	1461.73 ^{bcd}	1955.07 ^{cd}	2420.01 ^{bc}
T_4 - Whole tubers + RDF + Sea weed extract	1591.70 ^{bc}	2303.71 ^{b}	2808.31 ^{ab}
T_5 - Whole tubers + RDF + Microbial consortia	1312.19 ^{cde}	1829.40 ^{cd}	2368.70 ^{bc}
T_6 - Cut tubers + RDF + Humic acid	1659.37 ^{b}	2352.77 ^{b}	2848.37 ^{ab}
T_7 - Cut tubers + RDF + Amino acid	1371.45 ^{bcd}	1957.07 ^{cd}	2533.38 ^{bc}
T_8 - Cut tubers + RDF + Sea weed extract	1530.31 ^{bcd}	2154.54 ^{bc}	2527.72 ^{bc}
T_9 - Cut tubers + RDF + Microbial consortia	1295.55 ^{de}	1780.85 ^{de}	2179.77 ^{cd}
S Em±	87.71	104.31	159.36
CD at 5%	262.96	312.72	477.75

Note : DAP- Days After Planting

The treatment combination of whole tubers + RDF + Humic acid at 2 ml L^{-1} resulted in the maximum leaf area index (2.21 and 3.06) followed by cut tubers + RDF + Humic acid at 2ml L^{-1} (1.84 and 2.61), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (1.77 and 2.56) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (1.70 and 2.39). Whereas, control registered lesser leaf area index of 1.14 and 1.61, respectively at 45 and 75 days after planting. At harvest, treatment comprising of whole tubers + RDF + Humic acid at 2 ml L^{-1} obtained maximum leaf area index (3.57), which was found *at par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (3.16) and whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (3.12) followed by cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (2.81). The control produced lesser leaf area index of 2.01 (Table 6).

An increased in growth attributes of potato *viz*., plant height, number of branches, plant spread, number of leaves, leaf area and leaf area index can likely be attributed to the balanced use of nutrients provided through RDF and bio-stimulants. These treatments may have created optimal conditions for root growth and proliferation, enhancing nutrient absorption from the soil. Consequently, this improved nutrient uptake would have facilitated proper cell division and heightened meristematic activity, ultimately leading to better plant height. The enhanced plant growth attributes might have attributed to the impact of humic acid, which supplies carbon and other essential nutrient minerals that serve as energy sources for nitrogen-fixing bacteria. This boosts bacterial activity and improves their biological functions and ultimately stimulating plant growth (Abdel Mawgaud *et al*., 2007).

Bio-stimulants helps to enhance the growth attributes through different mechanisms and in turn yielded increased number of haulms in potato. Application of humic substances lead to an increase in production of hormones, stimulating plant growth and resulted in more numbers of shoots (EL-Komy *et al*., 2021). Seaweed extract contains different growth regulators *viz*., auxins, cytokinins and gibberellins. They induce cell division and elongation, leading to increased plant spread and growth of potato plants (Khan *et al*., 2009).

The works of Farouk (2015); Arafa and EL-Howeity (2017); Wadas and Dziugiel (2019); Man-Hong *et al*. (2020) in potato; Magalhaes *et al*. (2016); Abah *et al*. (2017); Hammad *et al*. (2024) in cassava; Abuzeed *et al*. (2018) in taro; Sharanya *et al*. (2022) in cowhage and Ayobi *et al*. (2022) in okra are in line with the above findings.

TABLE 6

Effect of bio-stimulants on leaf area index (LAI) in potato

Treatments	Leaf area index (LAI)		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	1.14 ^{e}	1.61 ^{e}	2.01 ^{d}
T_2 - Whole tubers + RDF + Humic acid	2.21 ^{a}	3.06 ^{a}	3.57 ^{a}
T_3 - Whole tubers + RDF + Amino acid	1.62 ^{bcd}	2.17 ^{cd}	2.69 ^{bc}
T_4 - Whole tubers + RDF + Sea weed extract	1.77 ^{bc}	2.56 ^{b}	3.12 ^{ab}
T_5 - Whole tubers + RDF + Microbial consortia	1.46 ^{cde}	2.03 ^{cd}	2.63 ^{bc}
T_6 - Cut tubers + RDF + Humic acid	1.84 ^{b}	2.61 ^{b}	3.16 ^{ab}
T_7 - Cut tubers + RDF + Amino acid	1.52 ^{cd}	2.17 ^{cd}	2.81 ^{bc}
T_8 - Cut tubers + RDF + Sea weed extract	1.70 ^{bcd}	2.39 ^{bc}	2.81 ^{bc}
T_9 - Cut tubers + RDF + Microbial consortia	1.44 ^{de}	1.98 ^{de}	2.42 ^{cd}
S.Em±	0.10	0.12	0.18
CD at 5%	1.14 ^{e}	1.61 ^{e}	2.01 ^{d}

Note : DAP- Days After Planting

Yield

Significantly more tubers per plant was produced with whole tubers + RDF + Humic acid at 2 ml L^{-1} (8.47) followed by cut tubers + RDF + Humic acid at 2 ml L^{-1} (6.87) and whole tubers + RDF + sea weed extract at 2 ml L^{-1} (6.07). The less number of tubers (5.53) were produced with control (Table 7).

Among different treatments, whole tuber + RDF + Humic acid at 2 ml L^{-1} recorded significantly highest tuber length (8.13 cm), which was statistically *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (7.20 cm) followed by whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (6.60 cm) and whole tubers + RDF + Amino acid at 3 ml L^{-1} (6.53 cm). The shorter tuber length (5.87 cm) was noticed in the control (Table 7).

With respect to tuber girth, whole tubers + RDF + Humic acid 2 ml L^{-1} produced the larger size of tuber (15.19 cm) which was statistically *on par* with all other treatments except control 11.12 cm (Table 7).

The highest tuber yield ha^{-1} was registered with whole tuber + RDF + Humic acid at 2 ml L^{-1} (28.61 t ha^{-1}) which was *on par* with cut tubers RDF + Humic acid at 2 ml L^{-1} (26.87 t ha^{-1}) and whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (24.47 t ha^{-1}) followed by whole tubers + RDF + Amino acid at 3 ml L^{-1} (23.99 t ha^{-1}). Whereas, control produced lowest tuber yield of 21.47 t ha^{-1} (Table 7).

The humic acid significantly increased tuber length and girth in potatoes through several mechanisms. It enhances soil structure and water retention, chelates nutrients for improved availability, stimulates root growth and influences plant hormones like auxins and cytokinins, which are vital for cell division and tuber development. Overall, these effects create an optimal growing environment for tuber development (Khan *et al*. 2009). Bio-stimulants improve potato yield attributes by enhancing nutrient availability, promoting root growth, increasing stress tolerance, optimizing hormonal balance, elevating photo synthesis and improving overall soil health. These factors collectively support robust plant growth and development, upgrading maximum yield of potato tuber at harvest (Canellas *et al*., 2015).

The results are in accordance with the work of Seyedbagheri (2010), Selim *et al*., (2010), Siddagangaiah and Raveesha (2014), Canellas *et al*. (2015), Garai *et al*. (2021) in potato; Duan *et al*. (2024) in sweet potatoes; Sharanya *et al*. (2022) in cowhage and Ayobi *et al*. (2021) in okra.

TABLE 7

Effect of bio-stimulants on number of tubers per plant, tuber length, tuber girth and tuber yield (t ha^{-1}) in potato

Treatments	Number of tubers	Tuber length (cm)	Tuber girth (cm)	Tuber yieldt ha^{-1}
T_1 - Whole tubers + RDF (Control)	5.53 ^{c}	5.87 ^{b}	11.12 ^{b}	21.47 ^{c}
T_2 - Whole tubers + RDF + Humic acid	8.47 ^{a}	8.13 ^{a}	15.19 ^{a}	28.61 ^{a}
T_3 - Whole tubers + RDF + Amino acid	6.07 ^{bc}	6.53 ^{b}	14.63 ^{a}	23.99 ^{bc}
T_4 - Whole tubers + RDF + Sea weed extract	6.47 ^{bc}	6.60 ^{b}	14.89 ^{a}	24.47 ^{abc}
T_5 - Whole tubers + RDF + Microbial consortia	5.87 ^{bc}	6.27 ^{b}	14.60 ^{a}	23.88 ^{bc}
T_6 - Cut tubers + RDF + Humic acid	6.87 ^{b}	7.20 ^{ab}	14.94 ^{a}	26.87 ^{ab}
T_7 - Cut tubers + RDF + Amino acid	5.87 ^{bc}	6.27 ^{b}	14.30 ^{a}	22.83 ^{bc}
T_8 - Cut tubers + RDF + Sea weed extract	6.00 ^{bc}	6.33 ^{b}	14.51 ^{a}	22.65 ^{bc}
T_9 - Cut tubers + RDF + Microbial consortia	5.67 ^{c}	6.20 ^{b}	14.26 ^{a}	22.33 ^{bc}
S Em±	0.32	0.40	0.70	1.39
CD at 5%	0.97	1.21	2.11	4.18

The present investigation revealed that, whole tubers + RDF + Soil application of humic acid at 2 ml L^{-1} resulted in better growth and tuber yield in potato.

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Mysore J. Agric. Sci., 58 (4) : 175-184 (2024)

Assessing the Impact of Elite Indigenous *Azospirillum* Strains on Growth of Wheat (*Triticum aestivum* L.) Across Varied Nitrogen Regimes

M. K. Murali and Vithal Navi
Department of Agricultural Microbiology, College of Agriculture, UAS, Dharwad - 580 005
e-Mail : muralimk0907@gmail.com

Authors Contribution

M. K. Murali :
Conceptualization, designing of the research work, data collection, execution of field and lab experiments;

Vithal Navi :
Analysis of data, interpretation and Preparation of manuscript

Corresponding Author :
M. K. Murali

Received : August 2024
Accepted : September 2024

Abstract

The growth and productivity of wheat is mainly dependent on the availability of major essential plant nutrients. Of the major essential nutrients, nitrogen occupies a prime place and plays an important role in plant metabolism ultimately reflecting on crop production. In view of increasing cost and scarcity of nitrogenous fertilizers, exploring alternative approaches to supply crucial essential nutrients has become imperative. The use of plant growth-promoting rhizobacteria (PGPR), capable of performing biological nitorgen fixation and growth hormone production enhances growth and improves quality. Among PGPR members, genus *Azospirillum* are well known and commonly used bacteria in agriculture. A total of four native selected *Azospirillum* isolates *viz.,* UASDAZO-13, UASDAZO-21, UASDAZO-29 and UASDAZO-46 along with reference strain (ACD-15) were inoculated and evaluated on wheat growth at different nitrogen levels. Inoculation of efficient *Azospirillum* isolates along with a reference strain on wheat significantly increased seed germination, plant height, number of tillers and root parameters like root diameter, volume and surface area over uninoculated control (UIC). It was found that superior growth was observed in UASDAZO-29 inoculated with 75 per cent N application as per RDF.

Keywords : Wheat, *Azospirillum*, PGPR, Nitrogen levels

Wheat (*Triticum aestivum* L.) is one of the principal cereal crops grown worldwide and one of the important staple food of nearly 2.5 billion of world population. Among the major cereals grown in India, wheat stands second next to rice in area and production and stands first in productivity. In India, farmers annually apply considerable amount of nitrogen (N) fertilizers to ensure a higher crop yield. However, inorganic nitrogen fertilizer is a non-renewable source and its overuse is detrimental to the air, surface and groundwater environment and consequently, human health. Therefore, alternate methods are essential to reduce the need for inorganic nitrogen fertilizer while still meeting the nitrogen requirements of crops. The advancement of research involving microbiology in agriculture has intensified the use of plant growth-promoting bacteria (PGPB), capable of performing biological fixation of the atmospheric nitrogen (N), reducing the necessity of N fertilization in cereals and leguminous crops. Among PGPR members, genus *Azospirillum* are well known and commonly used bacteria in agriculture. *Azospirillum* is a diazotrophic bacteria that play a valuable role in the rhizosphere of many plants, fixes atmospheric nitrogen and converts it into plant-available form (Rehman *et al*., 2017). Nitrogen fixation, plant growth-promoting hormones production and consequently improving the water and nutrients uptake, increasing the insoluble-phosphates solubility, siderophores and vitamins production, synergistic relationship with other useful soil bacteria, nitrite production *etc.,* are some of the beneficial characteristics of this bacterium that ultimately enhances the efficiency and yield of crops (Zarea, 2017).

Inoculation of wheat seeds with *Azospirillum* spp. has been widely applied to boost crop growth and yields on different soils (Ahemad and Kibret, 2014). Also, with respect to method of application, both foliar and in-furrow bacterial applications were as effective as standard seed inoculation in providing wheat with nitrogen (Fukami *et al*., 2018). Thus, the use of *Azospirillum* spp. can help to bridge the gap between productivity and sustainability since inoculations based on this microorganism can improve plant growth and also reduce the use of nitrogen fertilizers which generate savings and greater profitability.

Material and Methods

A total of four native efficient *Azospirillum* isolates (UASDAZO-13, UASDAZO-21, UASDAZO-29 and UASDAZO-46) along with reference strain were inoculated and evaluated on wheat growth at different nitrogen levels. *Azospirillum* strain *i.e.,* ACD-15 (reference strain) collected from the Institute of Organic Farming, UAS, Dharwad, India. Efficient native *Azospirillum* isolates were isolated from different regions of Dharwad district following enrichment culture technique adopted by Dobereiner and Day (1976) in N-free malate semi-solid medium.

To study the effect of selected efficient native *Azospirillum* isolates on plant growth of wheat and its evaluation at different nitrogen levels, pot trials were conducted under greenhouse condition at the Department of Agricultural Microbiology, University of Agricultural Sciences, Dharwad.

For greenhouse studies, wheat (Variety: C-306) was cultivated in black soil using a Factorial Randomized Complete Block Design. The experiment involved 24 treatments with 3 replications. Seeds were bio-primed (Prasad *et al.,* 2020) and the nutrient application rate was set at 120 kg N, 60 kg P_2O_5 and 60 kg K_2O per hectare. The experiment consisted of inoculation of UASDAZO-13 (I_1), UASDAZO-21 (I_2), UASDAZO-29 (I_3), UASDAZO-46 (I_4) along with a reference strain, ACD-15 (I_5) and uninoculated control (I_6) treatments at four nitrogen levels *viz.,* 100% (N_1), 75% (N_2), 50% (N_3) and 0% (N_4). The observations related to this experiment like plant height, number of tillers per plant, root parameters and plant dry biomass were recorded at 60 DAS, respectively. Straw and grain yield of wheat was recorded at harvest. For root parameters, whea troots collected from pot with different treatments were washed with distilled water. After washing, roots were scanned under WinRHIZO scanner (Regents Instruments, Quebec, Canada) at 60 DAS. Nitrogen content of shoot and root was estimated by modified micro kjeldhal method as given by Jackson (1967).

The *Azospirillum* inoculation efficiency (AIE) value was computed using the following formula :

$$\text{AIE (\%)} = \frac{\text{(Total biomass of inoculated plant) - (Total biomass of uninoculated plant)}}{\text{Total biomass of inoculated plant}} \times 100$$

Nitrogen uptake enhancement (NUEN) due to inoculation of *Azospirillum* was enumerated using the formula :

$$\text{NUEN (\%)} = \frac{\text{(Total N content of inoculated plant) - (Total N content of uninoculated plant)}}{\text{Total N content of inoculated plant}} \times 100$$

Statistical Analysis

The statistical analysis was done by using WASP :2.0 (Web Agri Stat Package 2) statistical tool and means were separated by Duncan's Multiple Range Test (DMRT).

Results and Discussion

Effect of Efficient Indigenous *Azospirillum* Strains on Height and Tillers of Wheat under different Nitrogen Levels

The plant height and number of tillers per plant were recorded at 60 DAS and tabulated in Table 1. Among the different doses of N fertilization, inoculation of all the isolates and reference strain produced maximum height of plant at 75% N. Among the

TABLE 1

Influence of selected native *Azospirillum* isolates on plant height and number of tillers at different nitrogen levels in wheat

Treatments *Azospirillum* isolates inoculation (I)	Plant height (cm) 60 DAS					Number of tillers/plant 60 DAS				
	N_1	N_2	N_3	N_4	Mean of I	N_1	N_2	N_3	N_4	Mean of I
UASDAZO-13 (I_1)	67.29 $^{c-f}$	69.88 $^{a-d}$	66.2 $^{e-g}$	62.5 ^{h}	66.47	4.11 ^{ab}	4.22 ^{ab}	3.88 $^{a-c}$	3.22 $^{b-d}$	3.86
UASDAZO-21 (I_2)	66.37 $^{e-g}$	71.49 ^{ab}	68.33 $^{b-e}$	61.71 ^{h}	66.97	4.22 ^{ab}	4.33 ^{ab}	4 $^{a-c}$	3.55 $^{a-d}$	4.03
UASDAZO-29 (I_3)	67.91 $^{c-e}$	72.82 ^{a}	71.29 ^{ab}	61.83 ^{h}	68.46	4.22 ^{ab}	4.44 ^{a}	4.11 ^{ab}	3.56 $^{a-d}$	4.08
UASDAZO-46 (I_4)	66.62 $^{d-f}$	69.14 $^{b-e}$	63.13 ^{gh}	61.54 ^{h}	65.11	4 $^{a-c}$	4.11 ^{ab}	3.78 $^{a-c}$	3.33 $^{a-d}$	3.80
ACD-15 (I_5)	70.49 $^{a-c}$	71.55 ^{ab}	68.5 $^{b-e}$	63.25 ^{gh}	68.21	4.11 ^{ab}	4.22 ^{ab}	4.11 ^{ab}	3.55 $^{a-d}$	4.00
UIC (I_6)	65.94 $^{e-g}$	64.41 $^{f-h}$	61.32 ^{h}	55.92 ^{i}	61.90	3.77 $^{a-c}$	3.44 $^{a-d}$	2.89 ^{cd}	2.44 ^{d}	3.14
Mean of N	67.44	69.88	66.46	61.13		4.07	4.13	3.79	3.28	

	S. Em (±)	C.D. (P = 0.01)	S. Em (±)	C.D. (P = 0.01)
Inoculation (I)	0.515	1.952	0.097	0.369
Nitrogen level (N)	0.420	1.594	0.079	0.301
Interaction (I × N)	1.029	3.905	0.195	0.738

Note : Means followed by same letters did not differ significantly. S. Em;Applicable to Duncan's Multiple Range Test
· Nitrogen level 1 (N_1) - 100% N as per RDF
· Nitrogen level 2 (N_2) - 75% N as per RDF
· Nitrogen level 3 (N_3) - 50% N as per RDF
· Nitrogen level 4 (N_4) - 0% N as per RDF

different treatments, inoculation of *Azospirillum* isolates at 75% N and 50% N *i.e.,* I_3N_2 (72.82cm), I_5N_2 (71.55 cm), I_2N_2 (71.49 cm) and I_3N_3 (71.29 cm) produced significantly higher plant height which was significantly more than height of plant at 100% N alone *i.e.,* I_6N_1 (65.94 cm). Similarly, inoculation of *Azospirillum* isolates at 75% N *i.e.,* I_3N_2 (4.44) produced more number of tillers which was significantly more than that of number of tillers per plant at 100% N alone (3.77). In the absence of N fertilization (0% N), all the inoculants significantly produced more number of tillers per plant which was more than that of uninoculated control (Plate 1 and Plate 2).

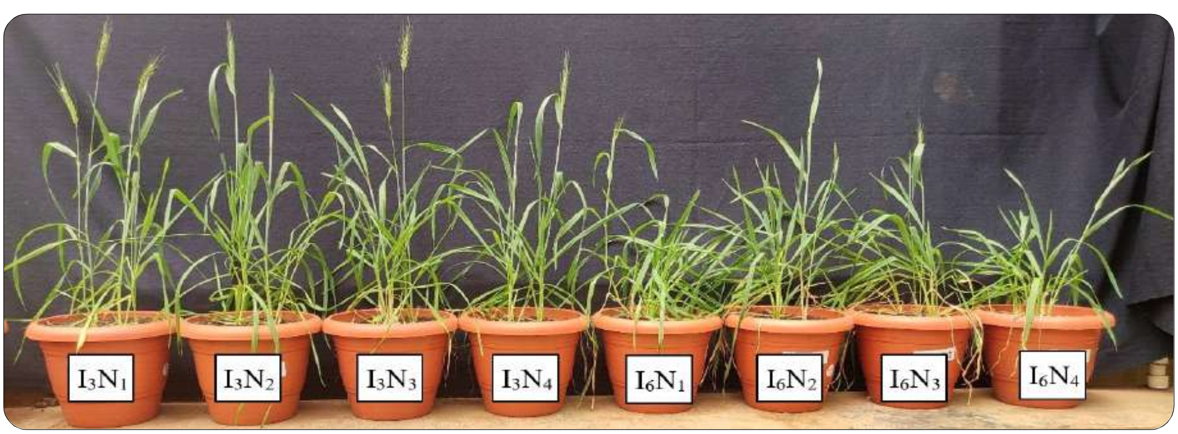

Plate 1 : Influence of efficient *Azospirillum* isolate UASDAZO-29 (I_3) on growth of wheat under different nitrogen levels at 60 DAS

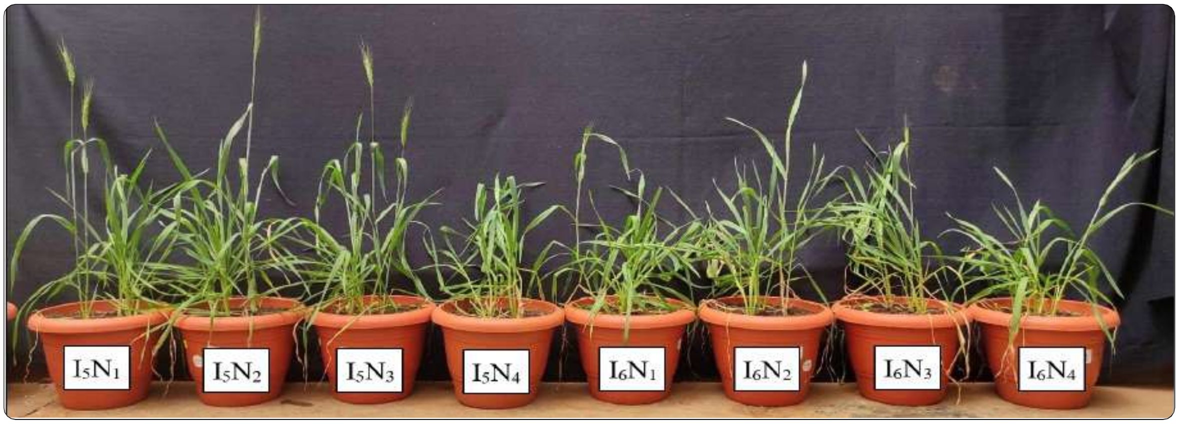

Plate 2 : Influence of *Azospirillum* isolate ACD-15 (reference; I_5) on growth of wheat under different nitrogen levels at 60 DAS

Early growth enhancement of *Azospirillum*-inoculated wheat was also observed in field-grown wheat (Karimi *et al.,* 2018). The number of tillers per m² in forages was positively influenced by N rates and by inoculation of *Azospirillum*. The increases obtained are attributed to the inclusion of additional nitrogen from both mineral source and biological fixation by bacteria through BNF, since the availability of N to the plant is fundamental for the survival and appearance of new tillers. (Benin *et al.*, 2012).

Effect of Efficient Indigenous *Azospirillum* Strains on Root Parameters of Wheat under different Nitrogen Levels

The root parameters *viz.,* average diameter, surface area of root and root volume was recorded by root analysis at 60 DAS and presented in Table 2. Among the different doses of N fertilization, inoculation of all the isolates and reference strain showed higher average root diameter, root surface area and root volume at 75% N except at uninoculated treatment where 100% N showed higher average root diameter. Among the different treatments, inoculation of *Azospirillum* isolates at 75% N *i.e.,* I_3N_2 (0.52 mm), I_5N_2 (0.52 mm), showed higher average root diameter which was more than average root diameter of all other treatments. Inoculation of *Azospirillum* isolates at 75% N *i.e.,* I_3N_2 (201.1 cm^2), I_2N_2 (198.9 cm^2), I_5N_2 (195.6 cm^2) and I_4N_2 (193.2 cm^2) showed higher root surface area which was more than root surface area of all other treatments. Similarly, inoculation of *Azospirillum* isolates at 75% N *i.e.,* I_3N_2 (2.10 cm^3), I_2N_2 (2.06 cm^3), I_5N_2 (2.02 cm^3) showed higher root volume which was more than root volume of all other treatments.

Plants being inoculated with *Azospirillum* are characterized by changes in root growth and morphology, such as enhancement of root elongation, root dry weight, promotion of root hair growth and root branching (El Sayed *et al.,* 2015), therefore occupying an enhanced soil volume. Dobbelaere *et al.* (2002) assessed the inoculation effect of *Azospirillum brasilense* on growth of spring wheat. They observed that inoculated plants resulted in better germination, early development and flowering and increased dry weight of both the root system and the upper plant parts as well as the N-uptake efficiency of plants.

Effect of Efficient Indigenous *Azospirillum* Strains on Plant Dry Biomass of Wheat under different Nitrogen Levels

The plant dry biomass *viz.,* shoot and root dry biomass was recorded at 60 DAS. The data pertaining to plant dry biomass are tabulated in Table 3.

Among the different doses of N fertilization, inoculation of all the isolates and reference strain showed higher plant dry biomass at 75% N except at uninoculated treatment where 100% N showed higher plant dry biomass. Among the different isolates and reference strain, inoculation of *Azospirillum* isolate

TABLE 2

Influence of selected native *Azospirillum* isolates on root diameter, root volume and root surface area of wheat at different nitrogen levels

Treatments	Root parameters at 60 DAS														
Azospirillum isolates inoculation (I)	Average Diameter (mm)					Surface Area (cm^2)					Root Volume (cm^3)				
	N_1	N_2	N_3	N_4	Mean of I	N_1	N_2	N_3	N_4	Mean of I	N_1	N_2	N_3	N_4	Mean of I
UASDAZO -13 (I_1)	0.45 ^{fg}	0.47 $^{d-f}$	0.46 $^{e-g}$	0.41 ^{ij}	0.44	173.3 $^{h-k}$	187.2 $^{c-f}$	175.5 $^{g-j}$	158.6 ^{lm}	173.6	1.92 ^{cd}	1.96 $^{b-d}$	1.93 $^{b-d}$	1.68 ^{h}	1.87
UASDAZO -21 (I_2)	0.49 $^{b-d}$	0.51 ^{ab}	0.51 ^{ab}	0.46 $^{e-g}$	0.49	181.9 $^{e-h}$	198.9 ^{ab}	184 $^{d-g}$	160.4 ^{lm}	181.3	1.86 $^{d-f}$	2.06 ^{ab}	1.97 $^{b-d}$	1.74 $^{f-h}$	1.91
UASDAZO -29 (I_3)	0.5 $^{a-c}$	0.52 ^{a}	0.51 ^{ab}	0.46 $^{e-g}$	0.50	184.5 $^{d-g}$	201.1 ^{a}	190.2 $^{b-e}$	167.4 $^{j-l}$	185.8	1.93 $^{b-d}$	2.10 ^{a}	1.98 $^{a-d}$	1.75 $^{f-h}$	1.94
UASDAZO -46 (I_4)	0.48 $^{c-e}$	0.49 $^{b-d}$	0.47 $^{d-f}$	0.44 ^{gh}	0.47	178.9 $^{f-i}$	193.2 $^{a-d}$	184.7 $^{d-g}$	159.8 ^{lm}	179.2	1.85 $^{d-g}$	1.93 $^{b-d}$	1.88 ^{de}	1.67 ^{h}	1.83
ACD-15 (I_5)	0.50 $^{a-c}$	0.52 ^{a}	0.51 ^{ab}	0.45 ^{fg}	0.49	183.4 $^{d-g}$	195.6 $^{a-c}$	189.5 $^{b-e}$	164.1 ^{kl}	183.1	1.9 $^{c-e}$	2.02 $^{a-c}$	1.96 $^{b-d}$	1.73 ^{gh}	1.90
UIC (I_6)	0.45 ^{fg}	0.42 ^{hi}	0.39 ^{jk}	0.38 ^{k}	0.41	170.3 $^{i-k}$	152.7 ^{m}	127.2 ^{n}	114 ^{o}	141.1	1.78 $^{e-h}$	1.49 ^{i}	1.24 ^{j}	1.01 ^{k}	1.38
Mean of N	0.48	0.49	0.47	0.43		178.7	188.1	175.2	154.1		1.87	1.93	1.83	1.60	

	Average Diameter S. Em (±)**	Average Diameter C.D. (P = 0.01)	Surface Area S. Em (±)	Surface Area C.D. (P = 0.01)	Root Volume S. Em (±)	Root Volume C.D. (P = 0.01)
Inoculation (I)	0.004	0.014	1.584	6.007	0.020	0.075
Nitrogen level (N)	0.003	0.011	1.293	4.905	0.016	0.061
Interaction (I × N)	0.007	0.028	3.167	12.015	0.039	0.149

Note : Means followed by same letters did not differ significantly. S. Em; Applicable to Duncan's Multiple Range Test

- Nitrogen level 1 (N_1) - 100% N as per RDF
- Nitrogen level 2 (N_2) - 75% N as per RDF
- Nitrogen level 3 (N_3) - 50% N as per RDF
- Nitrogen level 4 (N_4) - 0% N as per RDF

TABLE 3

Total dry biomass of wheat as influenced by efficient native *Azospirillum* isolates at different nitrogen levels

Treatments	Plant dry biomass (g plant^{-1}) at 60 DAS														
	Shoot dry biomass					Root dry biomass					Total dry biomass				
Azospirillum isolates inoculation (I)	N_1	N_2	N_3	N_4	Mean of I	N_1	N_2	N_3	N_4	Mean of I	N_1	N_2	N_3	N_4	Mean of I
UASDAZO -13 (I_1)	2.04 ^{i}	2.1 $^{g-i}$	2.05 ^{hi}	1.75 ^{j}	1.98	0.43 $^{h-k}$	0.44 $^{g-i}$	0.43 $^{h-j}$	0.39 ^{m}	0.42	2.47 ^{ij}	2.54 $^{g-i}$	2.47 ^{ij}	2.14 ^{k}	2.40
UASDAZO -21 (I_2)	2.08 ^{hi}	2.39 ^{e}	2.33 ^{e}	2.00 ^{i}	2.20	0.43 $^{h-k}$	0.45 ^{gh}	0.44 $^{g-i}$	0.41 $^{j-l}$	0.43	2.5 $^{h-j}$	2.84 ^{d}	2.77 ^{de}	2.42 ^{j}	2.63
UASDAZO -29 (I_3)	2.58 ^{cd}	2.85 ^{a}	2.67 ^{bc}	2.09 ^{hi}	2.55	0.52 ^{d}	0.60 ^{a}	0.57 ^{b}	0.46 ^{g}	0.54	3.10 ^{c}	3.45 ^{a}	3.24 ^{b}	2.55 $^{g-i}$	3.08
UASDAZO -46 (I_4)	2.15 $^{f-h}$	2.22 ^{f}	2.19 ^{fg}	2.02 ^{i}	2.14	0.44 $^{g-i}$	0.46 ^{g}	0.45 ^{gh}	0.43 $^{h-k}$	0.44	2.59 $^{f-h}$	2.68 ^{ef}	2.63 ^{fg}	2.44 ^{ij}	2.59
ACD-15 (I_5)	2.59 ^{cd}	2.74 ^{b}	2.54 ^{d}	2.05 ^{hi}	2.48	0.48 ^{f}	0.54 ^{c}	0.5 ^{e}	0.44 $^{g-i}$	0.49	3.07 ^{c}	3.29 ^{b}	3.05 ^{c}	2.49 $^{h-j}$	2.97
UIC (I_6)	2.03 ^{i}	1.78 ^{j}	1.69 ^{jk}	1.63 ^{k}	1.78	0.42 $^{i-l}$	0.37 ^{n}	0.36 ^{n}	0.32 ^{o}	0.37	2.45 ^{ij}	2.15 ^{k}	2.06 ^{kl}	1.95 ^{l}	2.15
Mean of N	2.24	2.35	2.24	1.92		0.45	0.48	0.46	0.41		2.70	2.82	2.70	2.33	

	S. Em (±)**	C.D. (P = 0.01)	S. Em (±)	C.D. (P = 0.01)	S. Em (±)	C.D. (P = 0.01)
Inoculation (I)	0.016	0.059	0.003	0.012	0.018	0.068
Nitrogen level (N)	0.013	0.049	0.003	0.010	0.015	0.055
Interaction (I x N)	0.031	0.119	0.006	0.024	0.036	0.135

Note : Means followed by same letters did not differ significantly. S. Em; Applicable to Duncan's Multiple Range Test

- Nitrogen level 1 (N_1) - 100% N as per RDF
- Nitrogen level 2 (N_2) - 75% N as per RDF
- Nitrogen level 3 (N_3) - 50% N as per RDF
- Nitrogen level 4 (N_4) - 0% N as per RDF

at 75% N *i.e.,* I_3N_2 (2.85g) showed significantly higher shoot dry biomass which was more than shoot dry biomass of all other treatments. Similarly, inoculation of *Azospirillum* isolate at 75% N *i.e.,* I_3N_2 (0.60g) showed significantly higher root dry biomass which was more than root dry biomass of all other treatments. In the absence of N fertilization, all the inoculated isolates *i.e.,* I_3N_4 (2.55g), I_5N_4 (2.49g), I_4N_4 (2.44g), I_2N_4 (2.42g) and I_1N_4 (2.14g) recorded significantly higher total dry biomass which was more than uninoculated control (1.95g) and also recorded higher total dry biomass than 50% N alone.

Inoculation with *Azospirillum brasilense* enhanced fresh weight and dry weigh by 60 and 54 per cent respectively, in inoculated seedlings of wheat after 90h treatment. The use of nitrogen fertilizers in combination with *Azospirillum* produced significantly higher green and dry matter yields than those from inoculated or fertilized alone (Dayamani *et al.,* 2011).

Increased root, shoot and total dry matter due to the inoculation of *Azospirillum* isolates could be attributed to biological nitrogen fixation and production of plant growth promoting substances (Mohamed *et al.,* 2018).

Effect of Efficient Indigenous *Azospirillum* Strains on Nitrogen Concentration of Wheat under different Nitrogen Levels

Nitrogen (N) concentration *viz.,* shoot N concentration and root N concentration was recorded at 60 DAS. The data related to nitrogen concentration are tabulated in Table 4.

Among the different doses of N fertilization, inoculation of all the isolates and reference strain showed higher shoot and root N concentration at 75% N except at uninoculated treatment where 100% N showed higher shoot and root N concentration. Inoculation of *Azospirillum* isolates I_3N_1 (1.71%),

TABLE 4

Effect of inoculation of efficient native *Azospirillum* isolates on shoot and root N concentration in wheat

Treatments	N concentration (%) at 60 DAS									
Azospirillum isolates inoculation (I)	Shoot N %					Root N %				
	N_1	N_2	N_3	N_4	Mean of I	N_1	N_2	N_3	N_4	Mean of I
UASDAZO-13 (I_1)	1.3 $^{f-i}$	1.34 $^{e-g}$	1.27 $^{f-i}$	1.16 ^{j}	1.27	0.5 ^{hi}	0.52 ^{gh}	0.49 ^{i}	0.46 ^{j}	0.49
UASDAZO-21 (I_2)	1.37 ^{e}	1.67 ^{b}	1.58 ^{c}	1.33 $^{e-h}$	1.49	0.58 ^{ef}	0.64 ^{c}	0.6 ^{de}	0.51 $^{g-i}$	0.58
UASDAZO-29 (I_3)	1.71 ^{ab}	1.75 ^{a}	1.67 ^{b}	1.39 ^{de}	1.63	0.67 ^{b}	0.71 ^{a}	0.69 ^{ab}	0.62 ^{cd}	0.67
UASDAZO-46 (I_4)	1.34 ^{ef}	1.44 ^{d}	1.39 ^{de}	1.27 $^{f-i}$	1.36	0.53 ^{g}	0.57 ^{f}	0.58 ^{ef}	0.5 ^{hi}	0.55
ACD-15 (I_5)	1.54 ^{c}	1.71 ^{ab}	1.68 ^{b}	1.34 $^{e-g}$	1.57	0.59 ^{ef}	0.64 ^{c}	0.63 ^{c}	0.57 ^{f}	0.61
UIC (I_6)	1.25 ^{i}	1.09 ^{k}	1.06 ^{kl}	0.99 ^{l}	1.10	0.46 ^{j}	0.42 ^{k}	0.41 ^{kl}	0.39 ^{l}	0.42
Mean of N	1.42	1.50	1.44	1.25		0.56	0.58	0.57	0.51	

	S. Em (±)	C.D. (P = 0.01)	S. Em (±)	C.D. (P = 0.01)
Inoculation (I)	0.011	0.041	0.004	0.014
Nitrogen level (N)	0.009	0.034	0.003	0.012
Interaction (I x N)	0.022	0.082	0.008	0.028

Note : Means followed by same letters did not differ significantly. S. Em; Applicable to Duncan's Multiple Range Test

- Nitrogen level 1 (N_1) - 100% N as per RDF
- Nitrogen level 2 (N_2) - 75% N as per RDF
- Nitrogen level 3 (N_3) - 50% N as per RDF
- Nitrogen level 4 (N_4) - 0% N as per RDF

I_3N_2 (1.75%), I_5N_2 (1.71%) showed significantly higher shoot N concentration and inoculation of *Azospirillum* isolate at 75% N *i.e.,* I_3N_2 (0.71%) and at 50% N *i.e.,* I_3N_3 (0.69%) showed significantly higher root N concentration which was more than shoot and root N concentration of all other treatments. In the absence of N fertilization, all the inoculated isolates *i.e.,* I_3N_4 (0.62%), I_5N_4 (0.57%), I_2N_4 (0.51%), I_4N_4 (0.5%) and I_1N_4 (0.46%) recorded significantly higher root N concentration which was more than uninoculated control (0.39%) and also recorded higher root N concentration than 75% N alone *i.e.,* I_6N_2 (0.42%).

The increased per cent N content in wheat in the present investigation due to inoculation of *Azospirillum* may be attributed to increased population of free living N_2-fixer, which has then probably increased the uptake of nutrients by means of altering the root surface characters involved in nutrient uptake these findings are in line with the results of Subba rao (1993) who observed increased percent 'N' in crops due to inoculation with *Azospirillum*.

Effect of Efficient Indigenous *Azospirillum* Strains on inoculation Efficiency and Nitrogen Uptake Enhancement of Wheat under different Nitrogen Levels

The efficiency of *Azospirillum* inoculation and enhancement in nitrogen uptake due to inoculation of isolates at different doses of N fertilization was examined and results are tabulated in Table 5.

Among the different doses of N fertilization, inoculation of isolates and reference strain showed higher *Azospirillum* inoculation efficiency at 75% N except in UASDAZO-13 inoculation where 50% N with UASDAZO-13 inoculation showed higher *Azospirillum* inoculation efficiency. Among the different isolates and reference strain, inoculation of UASDAZO-29 at 75% N *i.e.,* I_3N_2 (37.67%) and at 50% N *i.e.,* I_3N_3 (36.46%) showed significantly higher *Azospirillum* inoculation efficiency compared to other treatments.

Also, inoculation of isolates and reference strain showed higher nitrogen uptake enhancementat 75%

TABLE 5

***Azospirillum* inoculation efficiency and Nitrogen uptake enhancement by efficient *Azospirillum* isolates at different nitrogen levels**

Treatments	*Azospirillum* inoculation efficiency (%)					Nitrogen uptake enhancement (%)				
Azospirillum isolates inoculation (I)	N_1	N_2	N_3	N_4	Mean of I	N_1	N_2	N_3	N_4	Mean of I
UASDAZO-13 (I_1)	0.6 ^{m}	15.45 ^{i}	16.76 ^{i}	8.76 ^{j}	10.37	5.43 ^{r}	18.8 ^{m}	16.67 ^{n}	14.66 ^{o}	13.89
UASDAZO-21 (I_2)	2.14 ^{l}	24.19 ^{e}	25.69 ^{d}	19.19 ^{h}	17.91	12.35 ^{p}	34.55 ^{e}	32.69 ^{f}	24.81 ^{j}	26.10
UASDAZO-29 (I_3)	20.84 ^{fg}	37.67 ^{a}	36.46 ^{a}	23.52 ^{e}	29.60	28.24 ^{h}	38.51 ^{a}	37.69 ^{b}	30.81 ^{g}	33.81
UASDAZO-46 (I_4)	5.29 ^{k}	19.89 ^{gh}	21.91 ^{f}	20.02 ^{gh}	16.44	8.96 ^{q}	24.85 ^{j}	25.1 ^{j}	22.05 ^{k}	20.24
ACD-15 (I_5)	20.14 ^{gh}	34.59 ^{b}	32.43 ^{c}	21.63 ^{f}	27.09	19.74 ^{l}	35.48 ^{d}	36.45 ^{c}	27.42 ^{i}	29.77
UIC (I_6)	0 ^{m}	0 ^{m}	0 ^{m}	0 ^{m}	0.00	0 ^{s}	0 ^{s}	0 ^{s}	0 ^{s}	0.00
Mean of N	8.15	21.89	22.29	15.28		12.45	25.36	24.77	19.96	

	S. Em (±)	C.D. (P = 0.01)	S. Em (±)	C.D. (P = 0.01)
Inoculation (I)	0.233	0.884	0.088	0.335
Nitrogen level (N)	0.190	0.721	0.072	0.273
Interaction (I X N)	0.466	1.767	0.176	0.669

Note : Means followed by same letters did not differ significantly. S. Em;Applicable to Duncan's Multiple Range Test
- Nitrogen level 1 (N_1) - 100% N as per RDF
- Nitrogen level 2 (N_2) - 75% N as per RDF
- Nitrogen level 3 (N_3) - 50% N as per RDF
- Nitrogen level 4 (N_4) - 0% N as per RDF

N except in UASDAZO-46 inoculation treatment, where 50% N (I_4N_3) showed higher nitrogen uptake enhancement compared to 75% N level.

The increased efficiency and nitrogen uptake enhancement provided by the inoculation with *Azospirillum* positively influenced wheat growth, reducing the N doses applied in top-dressing and favoring higher yields. Similar results were obtained by Nunes *et al.* (2015), where wheat yields were 7.6 per cent higher with inoculation of A. *brasilense* when compared to control, even in an area with high N availability.

Effect of Efficient Indigenous *Azospirillum* Strains on Wheat Yield under different Nitrogen Levels

The grain and straw yield were recorded at harvest and tabulated in Table 6. Among the different doses of N fertilization, inoculation of all the isolates and reference strain produced maximum grain and straw yield at 75% N. Among the different treatments, inoculation of *Azospirillum* isolates at 75% *i.e.,* I_3N_2 (8.36g plant^{-1}) produced significantly higher grain yield which was significantly more than grain yield at 100% N alone *i.e.,* I_6N_1 (6.06g plant^{-1}). Similarly, inoculation of *Azospirillum* isolates at 75% N *i.e.,* I_3N_2 (20.30 g plant^{-1}) produced more straw yield which was significantly more than that of straw yield at 100% N alone (17.68g plant^{-1}). In the absence of N fertilization (0% N), all the inoculants significantly produced more grain and straw yield which was more than that of uninoculated control.

Inoculation of *Azospirillum* with plants usually results in increase in plant's dry weight, flowering and grain production. Improvement of yield caused by these PGPR could often be attributed to an increase in root development. Developed root system allows plant to uptake water and minerals in a better way. Similar experiments also showed that inoculation of wheat with *Azospirillum* increases the productivity of wheat (Ayyaz *et al.,* 2016).

This investigation clearly showed that the selected efficient native *Azospirillum* isolates were effective

Table 6

Influence of selected native *Azospirillum* isolates on wheat yield at different nitrogen levels

Treatments *Azospirillum* isolates inoculation (I)	Grain yield (g plant^{-1})					Straw yield (g plant^{-1})				
	N_1	N_2	N_3	N_4	Mean of I	N_1	N_2	N_3	N_4	Mean of I
UASDAZO-13 (I_1)	6.15 ^{jk}	6.28 ^{ij}	6.09 ^{kl}	5.41 ^{m}	5.98	17.88 $^{h-j}$	17.08 $^{f-h}$	16.89 $^{h-j}$	15.33 ^{k}	16.80
UASDAZO-21 (I_2)	6.45 ^{gh}	6.89 ^{e}	6.63 ^{f}	5.33 ^{jk}	6.33	18.19 ^{ef}	19.38 ^{c}	19.06 ^{d}	15.95 $^{g-i}$	18.15
UASDAZO-29 (I_3)	7.49 ^{c}	8.36 ^{a}	7.96 ^{b}	5.64 ^{e}	7.36	19.75 ^{b}	20.30 ^{a}	19.81 ^{b}	16.14 ^{fg}	19.00
UASDAZO-46 (I_4)	6.32 ^{hi}	6.62 ^{f}	6.58 ^{fg}	5.35 ^{jk}	6.22	18.05 $^{f-h}$	18.37 ^{e}	18.27 ^{ef}	16.76 ^{ij}	17.86
ACD-15 (I_5)	6.83 ^{e}	7.45 ^{c}	7.19 ^{d}	5.51 ^{fg}	6.75	19.26 ^{cd}	19.92 ^{b}	19.72 ^{b}	15.92 $^{g-i}$	18.71
UIC (I_6)	6.06$^{l\ m}$	5.54 ^{n}	5.48 ^{n}	4.78 ^{o}	5.47	17.68 ^{j}	17.14 ^{kl}	17.00 ^{lm}	15.10 ^{m}	16.73
Mean of N	6.55	6.86	6.66	5.34		18.47	18.70	18.46	15.87	

	S. Em (±)	C.D. (P = 0.01)	S. Em (±)	C.D. (P = 0.01)
Inoculation (I)	0.026	0.100	0.126	0.441
Nitrogen level (N)	0.022	0.082	0.099	0.346
Interaction (I × N)	0.053	0.200	0.282	0.987

Note : Means followed by same letters did not differ significantly. S. Em; Applicable to Duncan's Multiple Range Test
· Nitrogen level 1 (N_1) - 100% N as per RDF
· Nitrogen level 2 (N_2) - 75% N as per RDF
· Nitrogen level 3 (N_3) - 50% N as per RDF
· Nitrogen level 4 (N_4) - 0% N as per RDF

in increasing growth and N content in wheat. Among the selected efficient native *Azospirillum* isolates, UASDAZO-29 was found to be efficient for the growth and productivity of wheat at different nitrogen levels. It was found that superior growth and yield was observed in UASDAZO-29 inoculated with 75% N application as per RDF which implies that 25% of N application can be reduced by replacing it with *Azospirillum* inoculation. Therefore, the best alternative is use of *Azospirillum* for inoculation as it could be used to reduce the nitrogen requirement and also growth promotion in wheat.

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Mysore J. Agric. Sci., 58 (4) : 185-196 (2024)

Floral Architecture and Potential Floral Visitors of Dragon Fruit (*Hylocereus* spp. : Fam. Cactaceae)

Nagabhushana Reddy, G. Eswarappa, K. T. Vijayakumar and K. S. Jagadish
Department of Apiculture, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : nagabhushanareddy.b1997@gmail.com

Authors Contribution

Nagabhushana Reddy : Experimentation, data processing and manuscript preparation;

G. Eswarappa & K. S. Jagadish : Conceptualization, design, editing and supervision;

K. T. Vijayakumar : Editing manuscript

Corresponding Author :
Nagabhushana Reddy

Received : July 2024
Accepted : July 2024

Abstract

The floral biology of *Hylocereus undatus* Haw. and *Hylocereus polyrhizus* Haw. in relation to floral visitors for enhancing cross pollination was studied at farmer's field, Suradenupura, Yelahanka, Bengaluru during 2021-22. Totally, 61 parameters with respect to morphology and floral biology were recorded. The flowering period initiated during 3rd week of April and required 17.75 ± 0.96 and 19 ± 2.58 days from bud initiation to flower opening in *H. undatus* and *H. polyrhizus*, respectively. Anthesis started at 19:00 hrs, reached maximum between 01:30 to 03:40 hrs and closed completely on next day between 11:30 to 12:00 hrs, while, anther dehiscence (14:00 hrs) started 5 hrs before anthesis. Pollen grains were viable (17:00 hrs) after 3 hrs of anther dehiscence, but stigma receptivity (23:00 hrs) started 9 hrs after anther dehiscence, after 6 hrs of pollen viability and 4 hrs after anthesis. Longevity of flower was 16 hrs and 30 minutes. Cessation of flowering is on 2nd week of September in *H. undatus* and 3rd week of October in *H. polyrhizus*. Sepals of un-opened flower buds secreted nectar and pollen is major floral reward for floral visitors. Heterostyly and protandry nature of flowers needs external agents for pollination. 14 floral visitors were recorded on the flowers of two dragon fruit types of which *A. mellifera* L. abundance was maximum.

Keywords : Floral architecture, Floral biology, Floral visitors

Dragon fruit, *Hylocereus undatus* (Haw.) Britton and Rose is a climbing cactus species which has received worldwide recognition as an ornamental and fruit crop. These fruits are most beautiful in the family Cactaceae, with a bright red peel studded with green scales and white or red flesh with tiny black seeds. The flesh of the fruit is juicy and very delicious in taste, so it is considered as 'King of Fruits' in Southeast Asia. Flowers are beautiful and nicknamed as 'Noble Woman' or 'Queen of the Night'. The consumption of fruits is known to bring down cholesterol levels, stabilizes the blood sugar levels, fends off colon cancer, shore up urinary function, cranks up the brain workings and improves the sharpness of the eyes. Dragon fruit is contemplated as the fruit crop for the future (Gunasena *et al*., 2006).

Dragon fruit, *Hylocerus* spp. is an exotic fruit crop belonging to the family Cactaceae, native to Central and South American rainforests. It has been well established as a new crop in various tropical countries due to its precocious yielding ability and its acceptability in the market. Dragon fruit has been introduced to India during late 1990's. In India, it is cultivated in Karnataka, Kerala, Tamil Nadu, Maharashtra, Gujarat, Orissa, West Bengal, Andhra pradesh and Andaman and Nicobar Islands in a small area of less than 400 ha (Karunakaran *et al.,* 2019). At the onset of flowering, 3-5 spherical buttons emerge from the stem margins and 2-3 of these may develop into flower buds in about 13 days. The light green cylindrical flower buds reach about 28 cm after 17 days when anthesis occurs. The flowers are large, hermaphrodite and extremely showy. They are whitish pink in some types, very fragrant, nocturnal and bell shaped. The flower opens rapidly, starting between 6.30 - 7.00 pm and opening of the flower is completed at about 10.00 pm. Around 2.00 pm the flower closes after pollination and thereafter the flower begins to wilt. The petals close completely by daybreak (Gunasena *et al*., 2006).

It is reported that light intensity and temperature may affect the anthesis. On warm cloudy days, the flower may open at about 4.00 pm, whereas, in cool temperatures the wilting of flowers may be delayed till about 1.00 am. However, flowers remain open until the next morning if flowers are not pollinated during the night by nocturnal pollinators. The development of a floral bud to a fully opened flower takes 25-35 days (Pushpakumara *et al*., 2005 and Zee *et al*., 2004).

Flower production in Sri Lanka is usually from April to November, sometimes extending till December and it occurs in four to six flushes. Flowering is induced by long days; hence it is a photoperiod responsive species. However, the effect of photoperiod is dependent on temperature and that the time from photoperiodic induction to flower appearance increases when the temperature rises beyond the optimal point (Pushpakumara *et al*., 2005). The flowers of *Hylocereus polyrhizus* (Haw.) Britton and Rose are large, white in colour with nocturnal anthesis, accompanied by strong floral emission. The extension of floral anthesis also indicated mixed pollination syndromes of nocturnal and diurnal pollinators. Self-incompatibility of the plant is evidenced by spatial segregation of the sexual organs with approach herkogamy and dry-type stigma and numerous stigma lobes positioned above the anthers creating a large area that enhances a large amount of pollen deposition (Cho *et al*., 2021).

Pollination is essential in fruit production of the dragon fruit. As the flowers open in the night, bats and hawk moths in the natural range pollinate the flowers. In many countries where the crop is grown as a new crop, pollination is poor due to the lack of natural pollinators. Hence, hand pollination has been suggested to increase fruit set. Under Srilankan conditions, honey bee *Apis cerana* F., little honey bee *Apis florea* F. and rock bee *Apis dorsata* F. effectively pollinate the dragon fruit during the early morning hours (Pushpakumara *et al*., 2005).

Material and Methods

Two types of dragon fruit *viz*., Vietnam royal white, *Hylocereus undatus* (Haw.) Britton and Rose and Vietnam royal pink, *Hylocereus polyrhizus* (Haw.) Britton and Rose were selected to study the floral biology, floral visitors and their impact on fruit yield and quality parameters during 2021-22 in a farmer's field at Suradenupura (13° 12'08''N and 77° 33'50''E), Yelahanka (Tq.), Bengaluru Urban.

Floral Biology of Dragon Fruit

Detailed observations on the number of days taken for full bud development, time of anthesis, time of anther dehiscence, pollen viability, stigma receptivity, pollen output and longevity of flowers were recorded in both *Hylocereus undatus* and *Hylocereus polyrhizus* at the experimental site.

Duration from Flower Bud Initiation to Flower Opening

Newly initiated buds (n=10) on the stem were randomly selected and were tagged. The date on which the floral buds was initiated and their sequence of opening was recorded. From this data, the total number of days taken for flower opening was computed.

Time of Anthesis

The time of flower opening (anthesis) was recorded by tagging ten randomly selected flower buds (n=10). The tagged buds were observed from 0600 hrs at different time periods of the day upto opening of flower and the time of anthesis was recorded.

Longevity of Flower

A set of ten fully matured floral buds (n=10) were serially numbered by using tags and were observed daily to record the time and day of anthesis. The opened flowers were further monitored till they closed completely. The time gap between opening of the flower and till it closed completely was considered as longevity of flower.

Time of Anther Dehiscence

Randomly selected floral buds (n=10) along with some portion of stem, were plucked from the plant and were observed for anther dehiscence in the laboratory. The sepals and petals were removed before opening of the flower and anthers were observed by using a hand lens (10 X). The dehiscence of anther was characterized by its change of colour.

Pollen Viability

Pollen grains were collected immediately from the time of dehiscence and upto complete closing of the flower. The collected pollen grains were dusted on a glass slide and one to two drops of acetocarmine solution (2%) was placed on these grains, covered with the cover slip and were left for 4-5 minutes for proper staining. Slides were examined under microscope. Deeply stained and normal looking pollen grains were considered to be viable, whereas, shrivelled, lightly stained or colourless pollen grains were counted as non-viable (Derin and Eti, 2001).

Stigma Receptivity

Randomly selected matured floral buds (n=10) from the plant were brought to laboratory before anthesis and anther dehiscence. The petals, sepals and stamens were removed before anthesis in order to expose the stigma for testing its receptivity.

A drop of hydrogen peroxide (6%) was placed on to the surface of the stigma and formation of bubbles were observed through hand lens (10 X). The bubbling from stigma was considered as mark of receptivity of stigma. The observations were recorded at hourly intervals from previous day of flower opening, till it closed completely.

Pollen Output Per Flower

The sepals and petals of fully matured five floral buds of both the varieties were removed before anther dehiscence (1400 hrs). The floral buds were covered with plastic covers. At the time of complete closing of the flower (1200 hrs), flowers were shaken for the collection of the pollen in the plastic covers. The study was conducted both in the field as well as in the laboratory. The weight difference between the cover with pollen and the empty cover was treated as pollen yield per flower. It was expressed as grams of pollen grains per flower.

Floral Architecture of Dragon Fruit

Flowers (n=10) were randomly selected from the plant and were brought to the laboratory. The floral architecture parameters such as flower length, flower width, number of sepals per flower, number of petals per flower, number of stamens per flower, length of stamens and length of carpel were recorded by dissecting individual floral parts and also by taking the cross section of the ovary. Emphasis was laid on those structures that were useful in attracting floral visitors to enhance cross pollination (Cruden, 1977; Pias & Guitian, 2001 and Griffin & Barrett, 2002).

***Apis* and Non-*Apis* Floral Visitors of Dragon Fruit**

The observations on different species of floral visitors, their abundance, composition and diversity were recorded to recognize the most efficient pollinator species during the flowering period. All the *Apis* and non-*Apis* floral visitors including crepuscular and nocturnal visitors of dragon fruit at different phases of its flowering were collected through methods suggested by Belavadi and Ganeshaiah (2013), through visual scanning and sweep net sampling technique.

Visual Counting of Floral Visitors

Ad-libitum sampling of floral visitors for a sampling time of five minutes at hourly intervals was followed. All the floral visitors including nocturnal visitors of dragon fruit flower per sampling time were counted and recorded. The observations on species of floral visitors and number of each species per sample were recorded starting from 0600 to 1800 hrs, at hourly intervals for a period of 5 min in each hour. This was done to record variations in species composition and their abundance if any, at different time intervals of the day. The crepuscular and nocturnal visitors of dragon fruit were recorded through time-lapse camera and by visual observations. The observations were repeated at different phases of flowering. Among the insect floral visitors, the most frequently visiting species and type of floral resource (nectar/pollen) they collected was recognized during these observations for drawing further interpretations on their foraging behaviour (Belavadi and Ganeshaiah, 2013).

Results and Discussion

Floral Biology of Dragon Fruit Types

A total of 61 parameters with respect to floral morphology and floral biology were recorded in dragon fruit types, *Hylocereus undatus* (white flesh) and *Hylocereus polyrhizus* (pink flesh). The observations on floral biology parameters such as time taken from bud initiation to anthesis, time of anthesis, longevity of flower, time of anther dehiscence, pollen viability and stigma receptivity were recorded at different flowering phases of dragon fruit types during 2021-22 (Table 1).

Time taken from Floral Bud Initiation to Anthesis

The initiation of spherical button type floral buds from marginal spines of the stem was recorded during 3rd week of April in both the dragon fruit types, *Hylocereus undatus* (white flesh) and *Hylocereus polyrhizus* (pink flesh). Similarly, earlier study by Pushpakumara *et al.*, (2005) revealed that the flower production of dragon fruit in Sri Lanka usually starts from April to November, it may extend upto December.

Around 17.75 ± 0.96 and 19 ± 2.58 days were required for the floral bud to open completely in *Hylocereus undatus* and *H. polyrhizus* (Table 1), respectively. Contrary to the present findings, Pushpakumara *et al.*, (2005) stated that, the three-five spherical buttons emerge from the stem margins at the onset of flowering and only two-three developed into flower buds in about 13 days at Sri Lanka.

Initiation of Anthesis and Longevity of Flowers

The flowers of *Hylocereus undatus* and *H. polyrhizus* which are nocturnal in anthesis, started opening in

Table 1

Floral biology and floral architecture of *Hylocereus undatus* (white flesh) and *H. polyrhizus* (pink flesh) dragon fruit types during 2021-22

Parameters/Observations	*Hylocereus undatus* (Mean ± SD)	*Hylocereus polyrhizus* (Mean ± SD)
Floral bud initiation	3rd week of April	3rd week of April
Days taken from floral bud initiation to flower opening	17.75±0.96	19±2.58
Initiation of anthesis	19:00 to19:30 hrs.	19:00 to19:30 hrs.
Time at which flower opens fully	01:30 hrs.	01:30 hrs.
The time in which flowers remains open fully	01:30 hrs. to 03:40 hrs.	01:30 hrs. to 03:40 hrs.
Time at which closing of flower started	03:40 hrs.	03:40 hrs.
Time at which flower closes completely	11:30 to 12:00 hrs.	11:30 to 12:00 hrs.
Longevity of flower	16 hours and 30 minutes	16 hours and 30 minutes
Time of anther dehiscence	14:00hrs. (Before anthesis)	14:00hrs. (Before anthesis)
Time at which pollens become viable	17:00hrs. (Before anthesis)	17:00hrs. (Before anthesis)
Time at which stigma become receptive viability and 4hrs after flower	23:00 hrs. (after 6hrs of pollen viability and 4hrs after flower opening)	23:00 hrs. (after 6hrs of pollen opening)
Type and symmetry of flower Zygomorphic	Hermaphrodite and Zygomorphic	Hermaphrodite and

Continued....

TABLE 1 Continued....

Parameters/Observations	*Hylocereus undatus* (Mean ± SD)	*Hylocereus polyrhizus* (Mean ± SD)
Length of fully opened flower (cm)	29.50 ± 1.83	29.55 ± 0.76
Number of basal sepals	30±2.16	30±2.94
Colour of basal sepals	Dark greenish with pink colour	Dark greenish and edges lined
Length of basal sepals (cm)	3.45±0.26	3.55±0.31
Width of basal sepals(cm)	0.88±0.26	1.16±0.36
Number of middle sepals	13±0.82	13±1.41
Colour of middle sepals	Light greenish to light yellowish pink colour	Light green and edges lined with
Length of middle sepals (cm)	9.3±1.62	9.68±1.58
Width of middle sepals(cm)	1.12±0.36	1.24±0.2
Number of transitional sepals	19.25±1.71	19.25±0.96
Colour of transitional sepals	Light yellowish to whitish	Light yellowish to whitish
Length of transitional sepals (cm)	14.75±0.92	15.18±0.96
Width of transitional sepals (cm)	1.3±0.34	1.21±0.17
Number of petals	21.75±3.30	21.75±2.63
Colour of petals	White	White
Length of petals (cm)	12.13±0.99	13.87±2.0
Width of petals (cm)	3.3±0.6	2.95±0.57
Number of stamens	1269.±96.43	1337.±184.52
Colour of stamens	Dull white	Dull white
Length of basal stamen (cm)	8.93±0.43	9.42±0.05
Length of middle stamen (cm)	8.50±0.39	9.15±0.16
Length of apical stamen (cm)	6.78±0.15	7.33±0.51
Length of pistil (cm)	24.25±2.54	25.55±0.85
Length of style (cm)	19.7±2.17	21.0±0.80
Perimeter of style (cm)	2.83±0.15	2.45±0.06
Diameter of style (cm)	0.75±0.06	0.55±0.06
Shape of the ovary	Oval	Round
Position of ovary	Epigynous(Inferior ovary)	Epigynous(Inferior ovary)
Diameter of basal part of ovary (cm)	0.93±0.1	0.91±0.09
Diameter of middle part of ovary (cm)	1.50±0.08	1.21±0.15
Diameter of apical part of ovary (cm)	0.98±0.15	0.90±0.08
Number of ovules per ovary	Numerous	Numerous
Number of stigma lobes	25.0±0.82	25.5±1.29
Length of stigma lobes (cm)	1.98±0.48	2.68±0.1
Nectar secretion	Sepals of un-opened flower bud	Sepals of un-opened flower bud
Pollen yield per flower(g)	1.95±0.26	1.98±0.17
Colour of pollen	White	White
Shape of pollen	Round	Round

Continued....

TABLE 1 Continued....

Parameters/Observations	*Hylocereus undatus* (Mean ± SD)	*Hylocereus polyrhizus* (Mean ± SD)
Nature of pollen	Sticky	Sticky
Scope for cross pollination	Heterostyly and Protandry	Heterostyly and Protandry
Length of pistil over stamens before opening of flower (cm)	3.37±1.25	2.4±0.48
Length of pistil over stamens after opening of flower (cm)	2.25±0.28	1.75±0.28
Structure of flower that attracts insect visitors for enhancing cross pollination	Cone shaped stigma lobes and petals	Cone shaped stigma lobes and petals
No. of phases of flowering per year	7 phases	8 phases
Duration of flowering within each phase	4.85±0.37 days	4.62±0.51 days
No. of days between the flowering phases	16.33±7.20 days	19.70±9.90 days
No. of days taken from bud initiation to fruit harvest	50-55 days	50-55 days
No. of days taken from flower opening to fruit harvest	30-35 days	30-35 days
Cessation of flowering	2nd week of September	3rd week of October

between 19:00 to 19:30 hrs, opened fully at 01:30 hrs and remain fully opened upto 03:40 hrs. The closing of the flower commenced at 3:40 hrs and it closed completely in between 11:30 to 12:00 hrs. Longevity of the flower in both dragon fruit types was 16 hrs and 30 minutes (Table 1). These findings are similar to that of Pushpakumara *et al*. (2005) who stated that, the flower opens rapidly in between 6.30 - 7.00 pm and its opening is completed at 10.00 pm. The flowers started closing around 2.00 am, after pollination and thereafter, the flower begins to wilt. On warm cloudy days, the flower may open at about 4.00 pm, while in cool temperatures, the wilting may be delayed till about 1.00 pm. The petals completely closed by day break.

Time of Anther Dehiscence

The extent of dehisced anthers were observed in ten flowers each of *Hylocereus undatus* and *H. polyrhizus* with the help of hand lens (10 X) at hourly intervals before opening of flower starting from 12:00 hrs both in the farmer's field and as well as Post graduate laboratory at the Department of Apiculture, UAS, GKVK, Bengaluru. All the observed flowers revealed that anthers were completely dehisced before opening of flowers by 14:00 hrs of the day (Patil *et al.,* 2024 and Gaddi *et al.,* 2024).

Floral Architecture of Dragon Fruit

The observations on floral architecture parameters *viz.,* symmetry of flower, length of fully opened flower, number of sepals per flower, length of the sepals, number of petals per flower, length of the petals, number of stamens per flower, length of stamens, number of stigma lobes, length of style, length of stigma lobes, extension of heterostyly, diameter of the ovary, position of the ovary, pollen and nectar yield and other morphometric measurements of the flowers were recorded by dissecting individual floral parts and also by taking the cross section of ovary in both dragon fruit types (Table 1).

Type, Symmetry and Length of Fully Opened Flower

The flowers are hermaphrodite, zygomorphic in symmetry and the length of fully opened flower in *Hylocereus polyrhizus* (29.55 ± 0.76 cm) was slightly greater than the length of fully opened flower of *H. undatus* (29.50 ± 1.83 cm). The variation in the length of the flower is attributed to the genetic make-up of the two types of dragon fruit.

Description of Sepals and Petals

There was no variation in the number of petals present in the flowers of *Hylocereus undatus* (21.75 ± 3.30) and *H. polyrhizus* (21.75 ± 2.63) and they were white in colour. The length of petals was more in *H. polyrhizus* (13.87 ± 2.0 cm) compared to the length of petals of *H. undatus* (12.13 ± 0.99 cm). However, width of petals was more in *Hylocereus undatus* (3.3 ± 0.6 cm) as compared to 2.95 ± 0.57 cm width in *H. polyrhizus*.

The flowers of *Hylocereus undatus* and *H. polyrhizus* consist of three types of sepals *viz.,* basal sepals (30.00 ± 2.16 and 30.00 ± 2.94), middle sepals (13.00 ± 0.82 and 13.00 ± 1.41) and transitional sepals (19.25 ± 1.71 and 19.25 ± 0.96), respectively, (Table 1). The colour of basal sepals in *Hylocereus undatus* was dark greenish and these sepals were dark green and their edges were lined with pink colour in case of *Hylocereus polyrhizus.* However, middle sepals in *Hylocereus undatus* were light greenish to light yellowish and these sepals were light green and edges lined with pink colour in case of *Hylocereus polyrhizus*. However, transitional sepals in both the types of dragon fruit were light yellowish to whitish in colour. The length of basal (3.55 ± 0.31 and 3.45 ± 0.26 cm), middle (9.68 ± 1.58 and 9.31 ± 1.62 cm) and transitional sepals (15.18 ± 0.96 and 14.74 ± 0.92 cm) were more in *Hylocereus polyrhizus* compared to *H. undatus*. The width of basal (1.16 ± 0.36 and 0.88 ± 0.26 cm) as well as middle sepal (1.24 ± 0.2 and 1.12 ± 0.36 cm) was more in *Hylocereus polyrhizus* as compared to that of *H. undatus,* with the exception of width (1.30 ± 0.34 and 1.21 ± 0.17 cm) of transition sepals.

Description of Stamens and Style

The flowers of *Hylocereus polyrhizus* (1337 ± 184.52) had more number of stamens as compared to *H. undatus* (1269 ± 96.43) and they were dull white in colour. Flower consisted of three types of stamens *viz.,* basal, middle and apical stamens in both types of dragon fruit. The length of basal (9.42 ± 0.05 and 8.93 ± 0.43 cm), middle (9.15 ± 0.16 and 8.50 ± 0.39cm) and apical (7.33 ± 0.51 and 6.78 ± 0.15 cm) stamens was more in *H. polyrhizus* than *H. undatus*.

There was variation in length, perimeter and diameter of pistil and style in the flowers of *Hylocereus undatus* and *H. polyrhizus.* The length of pistil and style in flowers of *H. polyrhizus* (25.55 ± 0.85 and 21 ± 0.80 cm) was more than that of *H. undatus* (24.25 ± 2.54 and 19.7 ± 2.17 cm) flowers. However, perimeter and diameter of style were more in the flowers of *H. undatus* (2.83 ± 0.15 and 0.75 ± 0.06 cm) as compared to that of *H. polyrhizus* (2.45 ± 0.06 and 0.55 ± 0.06 cm) flowers.

Description of Ovary and Stigma Lobes

The ovary in the flowers of *Hylocereus undatus* was oval in shape and epigynous in position, whereas in *H. polyrhizus,* ovary was round in shape and epigynous in position. The diameter of basal, middle and apical part of ovary was more in *H. undatus* (0.93 ± 0.1, 1.50 ± 0.08 and 0.98 ± 0.15 cm) as compared to that of *H. polyrhizus* (0.91 ± 0.09 cm, 1.21 ± 0.15 cm and 0.90 ± 0.08 cm) with numerous ovules per ovary. The number and length of stigma lobes in the flowers of *H. polyrhizus* (25.5 ± 1.29 and 25 ± 0.82 cm) was relatively maximum compared to that of *H. undatus* (2.68 ± 0.1 and 1.98 ± 0.48 cm) flowers.

Floral Rewards

The unopened floral bud and opened flowers offered important rewards for floral visitors. The sepals of unopened flower buds secreted the unquantifiable nectar, which attracted the floral visitors before opening of the flowers in both the types of dragon fruit (Plate 9 and 10). The laboratory studies on estimation of pollen yield revealed that the flower of *H. polyrhizus* (1.98 ± 0.17g) offered maximum yield of pollen to floral visitors as compared to 1.95 ± 0.26 g pollen in the flower of *H. undatus*. The pollen of both types of dragon fruit were characterised by white colour, round shape and sticky nature.

Scope for Cross Pollination of Flowers

The heterostyly before and after opening of flowers in *Hylocereus undatus* (3.37 ± 1.25 and 2.25 ± 0.28 cm) and in *H. polyrhizus* (2.4 ± 0.48 and 1.75 ± 0.28 cm) necessitated the biotic or abiotic agents to transfer the pollen grains from anthers to the stigma lobes for effective cross pollination of flowers. The flower structures especially cone shaped stigma lobes and petals attracted the insect floral visitors and provided enough space for the floral visitors to load the pollen on to their hind legs, during this process also effective cross pollination of the flowers was achieved.

Fruit Harvest and Cessation of Flowering

Around 50-55 days were required from bud initiation upto fruit harvest and 30-35 days were required from flower opening upto fruit harvest in both *Hylocereus undatus* and *H. polyrhizus*.The plants of *H. undatus* stopped the flower production during 2nd week of September, whereas the plants of *H. polyrhizus* stopped the flower production during 3rd week of October.

Pollen Viability and Stigma Receptivity

The observations recorded at hourly interval before anthesis (12:00-18:00 hrs) and after anthesis (19:00-12:00 hrs) on pollen viability and stigma receptivity of *Hylocereus undatus* and *H. polyrhizus* under laboratory conditions are as presented in the Table 2 and Table 3. The staining of pollen grains with acetocarmine solution (2%) and examination under the microscope revealed that pollen grains are non-viable from 14:00-16:00 hrs before opening of the flower. The pollen grains became viable

Table 2

Pollen viability and stigma receptivity of dragon fruit type, *Hylocereus undatus*

Time (hrs)	*Hylocereus undatus* (white flesh) Pollen viability	Stigma receptivity
Before anthesis		
12:00	NV	NR
13:00	NV	NR
14:00	NV	NR
15:00	NV	NR
16:00	NV	NR
17:00	V	NR
18:00	V	NR
After anthesis		
19:00	V	NR
20:00	V	NR
21:00	V	NR
22:00	V	NR
23:00	V	R
24:00	V	R
01:00	V	R
02:00	V	R
03:00	V	R
04:00	V	R
05:00	V	R
06:00	V	R
07:00	V	R
08:00	V	R
09:00	V	R
10:00	V	R
11:00	V	R
12:00	V	R

Continued....

Table 2 Continued....

Note : NV= Non-viable; V= Viable; NR=Not-receptive; R=Receptive

Table 3

Pollen viability and stigma receptivity of dragon fruit type *H. polyrhizus*

Time (hrs)	*Hylocereus undatus* (pink flesh)	
	Pollen viability	Stigma receptivity
Before anthesis		
12:00	NV	NR
12:00	NV	NR
13:00	NV	NR
14:00	NV	NR
15:00	NV	NR
16:00	NV	NR
17:00	V	NR
18:00	V	NR
After anthesis		
19:00	V	NR
20:00	V	NR
21:00	V	NR
22:00	V	NR
23:00	V	R
24:00	V	R
01:00	V	R
02:00	V	R

Continued....

Table 3 Continued....

Time (hrs)	*Hylocereus undatus* (pink flesh)	
	Pollen viability	Stigma receptivity
03:00	V	R
04:00	V	R
05:00	V	R
06:00	V	R
07:00	V	R
08:00	V	R
09:00	V	R
10:00	V	R
11:00	V	R
12:00	V	R

Note : NV= Non-viable; V= Viable; NR=Not-receptive; R=Receptive

(17:00 hrs) after anther dehiscence (14:00 hrs) and before anthesis (19:00 hrs) upto complete closing of the flower (12:00 hrs) in both types of dragon fruit. The reaction of hydrogen peroxide (6%) on stigmatic surface in the form of bubbles observed through hand lens (10x) revealed that the stigma was not receptive starting from before anthesis of flower (13:00 hrs) and upto after anthesis (22:00 hrs) in both the types of dragon fruit. The stigma became receptive after anthesis, starting from 23:00 hrs upto closing of the flowers (12:00 hrs). It is clear that the stigma became receptive four hours after flower opening and six hours after pollen attained viability (Table 2 and 3).

Phases of Flowering

There are seven phases of flowering per year (Table 4) in *Hylocereus undatus,* first phase of flowering started in the 1st week of May and ended in 2nd week of May (06-05-2022 to 10-05-2022), second phase of flowering started and ended in 4th week May (27-05-2022 to 31-05-2022), third phase of flowering started and ended in 2nd week of June (09-06-2022 to 12-06-2022), fourth phase of flowering started in started in 4th week of June and ended in 1st week of July (27-06-2021 to 01-07-2021), fifth phase of flowering started and ended in 3rd week of July (19-07-2021 to 23-07-2021), sixth phase of flowering started and ended in 1st week of August (02-08-2021 to 06-08-2021) and seventh phase of flowering started in 1st week of September and ended in 2nd week of September (04-09-2021 to 08-09-2021). The number of days of flowering in all the phases ranged from 4-5 days with a mean of 4.85 ± 0.37 days and there was 9 to 29 days gap in between the phases of flowering, with a mean of 16.33 ± 7.20 days. The number of phases of flowering and respective flowering period of *Hylocereus undatus* indicated 5 months of reproductive period from May to September and 7 months of vegetative period from October to April.

Table 4

Flowering phases of *Hylocereus undatus* at Suradenupura, Bengaluru urban during 2021-22

Flowering Phases	Hylocereus undatus		
	Flowering period	No. of days of flowering	Gap between flowering phases (Days)
1	06-05-2022 to 10-05-2022	5	
2	27-05-2022 to 31-05-2022	5	17
3	09-06-2022 to 12-06-2022	4	9
4	27-06-2021 to 01-07-2021	5	15
5	19-07-2021 to 23-07-2021	5	18
6	02-08-2021 to 06-08-2021	5	10
7	04-09-2021 to 08-09-2021	5	29
Mean ± SD	-	4.85 ± 0.37	16.33 ± 7.20

TABLE 5

Flowering phases of *Hylocereus polyrhizus* at Suradenupura, Bengaluru urban during 2021-22

Flowering Phases	Hylocereus undatus		
	Flowering period	No. of days of flowering	Gap between flowering phases (Days)
1	05-05-2022 to 08-05-2022	4	
2	26-05-2022 to 30-05-2022	5	18
3	09-06-2022 to 12-06-2022	4	10
4	27-06-2021 to 30-06-2021	4	15
5	19-07-2021 to 23-07-2021	5	19
6	02-08-2021 to 06-08-2021	5	10
7	04-09-2021 to 08-09-2021	5	29
8	15-10-2021 to 19-10-2021	5	37
Mean ± SD	-	4.62 ± 0.51	19.70 ± 9.90

There were eight phases of flowering per year (Table 5) in *Hylocereus polyrhizus,* first phase of flowering started in the 1st week of May and ended in 2nd week of May (05-05-2022 to 08-05-2022), second phase of flowering started and ended in 4th week May (26-05-2022 to 30-05-2022), third phase of flowering started and ended in 2nd week of June (09-06-2022 to 12-06-2022), fourth phase of flowering started and ended in 4th week of June (27-06-2021 to 30-06-2021), fifth phase of flowering started and ended in 3rd week of July (19-07-2021 to 23-07-2021), sixth phase of flowering started and ended in 1st week of August (02-08-2021 to 06-08-2021), seventh phase of flowering started in 1st week of September and ended in 2nd week of September (04-09-2021 to 08-09-2021) and eighth phase of flowering started and ended in 3rd week of October (15-10-2021 to 19-10-2021). The number of days of flowering in all the phases ranged from 4-5 days with a mean of 4.62 ± 0.51 days and there were 10 to 37 days gap in between the phases of flowering, with a mean of 19.70 ± 9.90 days. The number of phases of flowering and respective flowering period of *H. polyrhizus* indicated 6 months of reproductive period from May to October and 6 months of vegetative period from November to April. The gap of 9-29 days between phases of flowering in *H. undatus* and gap of 10-37 days between phases of *H. polyrhizus* flowering was recorded. The variation might be due to prevailing temperature of the experimental site and crop nutrient management between phases, either for late or early induction of the floral buds. Since it is a long day plant, it requires more sunlight and hence very few farmers in Karnataka installed artificial lighting system with 9 watts bulb in between the four poles from 1900-0400 hrs which helps to induce the floral buds in the areas where the prevailing temperature is too low.

Apis and Non-*Apis* Floral Visitors of Dragon Fruit

The diurnal and nocturnal floral visitors of *Hylocereus undatus* and *Hylocereus polyrhizus* in the farmer's field at Suradenupura, Bengaluru urban district, were recorded during different flowering phases. The diurnal floral visitors were recorded from 0600 upto1200 hrs, whereas, nocturnal floral visitors were observed from 1800 upto 0600 hrs at hourly intervals in each flowering phase (Table 6). Totally fourteen species of floral visitors which included *Apis* and non-*Apis* species were recorded at different flowering phases of *Hylocereus undatus* and *Hylocereus polyrhizus* during 2021-22, out of which seven species from Hymenoptera *viz., Apis dorsata* F., *Apis cerana* F., *Apis mellifera* L. and *Apis florea* F. belonging to Apidae were regular diurnal flower visitors. These findings are supported by the reports of Pushpakumara

TABLE 6

Floral visitors of dragon fruit types, *Hylocereus undatus* and *Hylocereus polyrhizus* during flowering period of 2021-22

Order	Family	Sl. No.	Scientific name	Visiting status	Forage collected	Foraging period (hrs)
Hymenoptera	Apidae	1	*Apis dorsata* Fab.	Regular	P+N	05:40-11:00
		2	*Apis cerana* Fab.(yellow & black strain)	Regular	P+N	06:00- 11:30
		3	*Apis florea* Fab.	Regular	P+N	08:00- 12:00
		4	*Apis mellifera* L.	Regular	P+N	06:00-11:30
	Vespidae	5	*Ropalidia marginata* P.	Occasional	N	08:00-18:00
	Formicidae	6	*Camponotus compressus* F.	Regular	N	06:00-18:00
		7	*Tapinoma melanocephalum* F.	Regular	N	06:00-18:00
Lepidoptera	Nymphalidae	8	*Tirumala* sp.	Occasional	N	07:00-08:00
Coleoptera	Chrysomelidae	9	*Colasposoma* sp.	Occasional	P	7:30-09:00
	Coccinellidae	10	*Coccinella transversalis* F.	Occasional	P	08:00-10:00
	Meloidae	11	*Mylabris pustulata* Thun.	Occasional	P	07:00-09:00
	Scarabidae	12	*Popillia schizonycha* A.	Occasional	P	07:00-09:00
	Curculionidae	13	*Myllocerus viridanus* F.	Occasional	p	07:30-10:00
	Nitidulidae	14	*Carpophilus* sp.	Regular	P	02:00-12:00

Note : P : pollen; N : nectar

et al., (2005) who stated that *Apis cerana* F., *Apis florea* F. and *Apis dorsata* F. were the most likely pollinators of *H. undatus* and *H. polyrhizus* in Bulathsinhala, Sri Lanka. Similarly, Muniz *et al.,* (2019) recorded the visitation of *A. mellifera* on *H. undatus* and *H. polyrhizus* at Northeastern Brazil. The wasp *Ropalidia marginata* P. under Fam. Vespidae was a diurnal occasional visitor, whereas *Camponotus compressus* F. and *Tapinoma melanocephalum* F. belonging to Formicidae were regular diurnal flower visitors. Muniz *et al.,* (2019) witnessed the visitation of ants and wasps on *Hylocereus undatus* and *Hylocereus polyrhizus*at Northeastern Brazil. The *Tirumala* sp. from Lepidoptera which belonged to Family Nymphalidae is an occasional and diurnal flower visitor. Six species from Coleoptera, one each belonging to Chrysomelidae (*Colasposoma* sp.), Coccinellidae (*Coccinella transversalis* F.), Meloidae (*Mylabris pustulata* Thun.), Scarabidae (*Popillia schizonycha* A.), Curculionidae (*Myllocerus viridanus* F.) were found as occasional visitors, whereas *Carpophilus* sp. from Nitidulidae was a regular nocturnal visitor (Table 6). On the contrary to the present findings on the nocturnal visitors, many earlier studies (Muniz *et al.,* 2019; Locatelli *et al.,* 1997 and Rocha *et al.,* 2019) conducted in the place of origin of this crop showed that *Pilosocereus* species was pollinated by bats and moths, but no such non-insect pollinators could be observed in the present study.

The honey bees, *Apis dorsata*, *Apis cerana*, *Apis mellifera* and *Apis florea* collected nectar from sepals of unopened flower bud (Plate 19) and pollen from fully opened flowers. Among honey bees, *Apis dorsata* (05:40-11:00 hrs) was the first visitor of the flower followed by *A. cerana* (06:00- 11:30 hrs), *A. mellifera* (06:00- 12:00 hrs) and *A. florea* (06:00-11:30 hrs), whereas, from non-*Apis* species, *Camponotus compressus* (0600-1800 hrs) and *Tapinoma melanocephalum* (0600-1800 hrs) were the first visitors which collected nectar from the sepals of unopened floral bud, followed by *Tirumala* sp. (07:00-08:00 hrs), which collected the nectar from sepals of just opened flower. However, *Mylabris* *pustulata* (07:00-09:00 hrs), *Popillia schizonycha* (07:00-09:00 hrs), *Colasposoma* sp. (7:30-09:00 hrs), *Myllocerus viridanus* (07:30-10:00 hrs) and *Coccinella transversalis* (08:00-10:00 hrs) collected the pollen from opened flower. The *Ropalidia marginata* (0800-1800 hrs) foraged on the nectar from the sepals of unopened floral bud. The *Carpophilus* sp. was the only nocturnal visitor which foraged on the pollen from 02:00-12:00 hrs (Table 6).

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Sublethal Effects of Insecticides on Mating Performance of Melon Fly, *Zeugodacus cucurbitae* (Coquillett) (Diptera: Tephritidae)

J. K. Pavana[1], K. Muralimohan[2], B. Shivanna[3], B. S. Rajendra Prasad[4], R. Vasantha Kumari[5] and C. R. Jahir Basha[6]

[1,2&3]Department of Entomology, [5]Department of Horticulture and [6]Department of Pathology, College of Agriculture, UAS, GKVK, Bengaluru - 560 065

[4]KVK, Chandurayanahalli, Kalya, Magadi Taluk, Ramanagara District - 562 120

e-Mail : entomurali@gmail.com

Authors Contribution

J. K. Pavana : Conceptualization, investigation, data analysis, manuscript prepration;

K. Muralimohan : Designing of experiment, data interpretation and supervision;

B. Shivanna; B. S. Rajendra Prasad; R. Vasantha Kumari and C. R. Jahir Basha : Designing of experiment and manuscript editing

Corresponding Author :
K. Muralimohan

Received : October 2024
Accepted : October 2024

Abstract

The melon fruit fly, *Zeugodacus cucurbitae*, is a major pest of cucurbitaceous fruits. Insecticides are commonly used to control this pest. However, environmental factors can reduce lethal doses to sublethal levels. Additionally, adult flies might only receive sublethal exposure due to limited contact during spraying. This study aimed to determine the sublethal effects of fipronil 5 SC, spinosad 45 SC and malathion 50 EC insecticides on mating and remating performance in *Z. cucurbitae*. Adults were treated with LC_{20} of insecticides through topical application and the experiment included four combinations: (1) treated female and treated male (F+M+); (2) treated female and untreated male (F+M-); (3) untreated female and treated male (F-M+); (4) untreated female and untreated male (F-M-). Fipronil treated flies exhibited significantly lower mating percentage (75%-females, 60%-males). However, mating percent in spinosad and malathion was on par with control group. Contrary to this, a significant decrease in remating percentage was noticed in all the insecticide treatments. These findings underscore the adverse effects of sublethal insecticide exposure on reproductive performance in melon fruit fly, which may alter population dynamics and the efficacy of pest management strategies.

Keywords : Melon fly, Insecticides, Sublethal effects, Mating, Remating

The melon fruit fly, *Zeugodacus cucurbitae* (Coquillett), is recognized as one of the most destructive pests affecting vegetables and fruits in temperate, tropical and subtropical regions, including areas across Asia, Africa, the Americas and Australia (Fletcher, 1987; Dhillon *et al.,* 2005 and Sapkota *et al.,* 2010). This pest has an extensive host range, infesting over 81 different plant species, but shows a particular preference for cucurbit crops such as bitter gourd (*Momordica charantia* L.), muskmelon (*Cucumis melo* L.), snap melon (*C. melo* L. var. *momordica*), snake gourd (*Trichosanthes anguina* L.), cucumber (*Cucumis sativus* L.) and ridge gourd (*Luffa acutangula* L.) (Dhillon *et al.,* 2005; Siderhurst & Jang, 2010 and Shivaramu *et al.,* 2022). Female flies oviposit their eggs deep within the fruit pulp, where the developing larvae feed on the fruit from the inside, leading to significant reductions in both market value and crop yield. In addition, this pest facilitates the entry of pathogens, which can exacerbate crop losses and increase the risk of secondary infections. The extent of damage caused by the melon fruit fly can vary widely, ranging from 30 to 100 per cent, depending on seasonal conditions and the vulnerability of the crops to infestation (Dhillon *et al.,* 2005; Amin *et al.,* 2011; Subedi *et al.,* 2021; Devaiah *et al.,* 2022 and Pradhan *et al.,* 2023). Chemical insecticides remain the primary method of controlling tephritid fruit flies globally. But, there are high chances that, flies are exposed to sublethal doses in the field condition. Because, adult flies don't feed on fruits and come in contact with fruits only during oviposition. Additionally abiotic factors such as sunlight, rainfall and temperature may reduce lethal dose of insecticides to sublethal dose over period of time (Stark *et al*., 1995). Sublethal exposure may not result in immediate mortality, but it can adversely affect the pest's behaviour, reproductive capacity and resilience to natural enemies, thereby altering population dynamics and overall pest management efficacy (Desneux *et al.,* 2007). In melon fly, copulation starts at dusk and terminates at dawn, with a mating duration of more than 10 hours (Tsubaki and Sokei, 1988). Female and male fruit flies mate multiple times, as repeated mating can increase the likelihood of successful fertilization and improve overall reproductive output (Teruya and Isobe, 1982; Kuba and Ito, 1993). Sublethal dose of insecticides may alter intricate mating dynamics, such as courtship rituals, mate choice and rematings. Therefore, this study aims to explore the sublethal effects of insecticides on the mating and remating performance of *Z. cucurbitae*, with a focus on how these effects may alter reproductive biology and impact pest management strategies. Understanding the implications of sublethal insecticide exposure on mating dynamics, is crucial for designing integrated pest management approaches that consider the ecological and evolutionary consequences of chemical use.

Material and Methods

Insect culture

Fruit fly-infested fruits were collected from bitter gourd and ridge gourd fields in GKVK campus (13° 4' 49.6" N and 77° 33' 58.8" E). The infested fruits were brought to the laboratory and placed in plastic container (29 cm diameter × 12 cm height) with a 2-3inch layer of sand to facilitate pupation. Pupae were collected from the sand using a sieve. These collected pupae were later transferred to a wooden insect cage (30 x 30 x 30 cm). Upon adult emergence, the flies were provided with a food supplement consisting of yeast hydrolysate enzymatic (a protein source from MP Biomedicals™), sugar and water. After 10-15 days, pumpkins were placed inside the cage, as an oviposition substrate. After pupation, the pupae were harvested and the F_1 adults were subsequently used in the experiments.

Insecticides

Several studies have highlighted the efficacy of spinosad, fipronil and malathion in reducing fruit infestation from *Z. cucurbitae*, thereby providing higher yields (Srinivas *et al*., 2018; Sharma & Gupta, 2019; Abhishek *et al*., 2021 and Nehra *et al.,* 2021). In this context, commonly used insecticides *viz.,* fipronil 5 SC, spinosad 45 SC and malathion 50 EC were used to study the sublethal effects on mating performance of fruit flies.

Determination of sublethal concentrations

Bioassays were conducted by topical application method. Preliminary assays were carried out in the laboratory to find the appropriate dose, giving mortality in the range of 10-90 per cent. Later, five concentrations of each insecticide were finalized and used in the experiment. 5 days old, male and female flies were treated topically with selected insecticides on the body of insect through Multipette® M4 - Multi-Dispenser Pipette (Eppendorf™). Prior to application, flies were immobilised by 3 min exposure to 4 °C and 5 µl of insecticide solution was applied on the thorax of each fly. This method was adapted from the approach reported previously (Busvine, 1980 and Hsu *et al.,* 2012) and is the preferred method of measuring toxicity in arthropods as it is efficient and accurate. After exposure, the treated adults were transferred to new plastic containers along with food supplement and mortality was recorded till 168 hours. Later, the mortality was corrected using Abbott's formula and corrected mortality was subjected to probit analysis and LC_{20} was estimated. The flies were then, treated with sublethal dose (LC_{20}) of insecticides

(Table 1) to determine the impact on mating performance.

TABLE 1

Insecticides used in the experiment

Insecticide	LC_{20} (ppm)
Fipronil 5 SC	7.62
Spinosad 45 SC	1.06
Malathion 50 EC	33.78

Treatment Groups

Here, the flies were treated with LC_{20} of the insecticides on thorax using topical application method as described above. Later, male and female flies of the same treatment were mixed in single container (mating cum oviposition chamber) for mating in different combinations as follows:

1. Treated female and treated male (F+ M+)
2. Treated female with untreated male (F+ M-)
3. Untreated female with treated male (F- M+)
4. Untreated female with untreated male (F- M-)

In each treatment, 20 flies for each sex were used and each pair of fly was considered as one replication. The untreated group (F- M-) was considered as control. The same procedure was followed for all the insecticides and observations were recorded accordingly.

Impact of Sublethal Dose of Insecticides on Mating and Remating per cent

All the containers were regularly checked and monitored every night to confirm the mating status of flies. The mating pairs in the mating chambers were collected with vials, without disturbing mating activity and were transferred to separate boxes. The mated flies remained in pairs throughout the night until sunrise of the next day. Later, mated male and female flies were marked on the thorax with the help of paint (Fig. 1). Then, the marked flies (mated) were released back into the mating chamber and were observed daily for additional mating events. If a marked fly

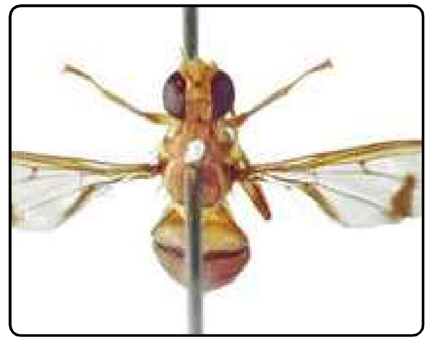

Fig. 1 : Mated fly marked on thorax with paint

(previously mated) has paired with an unmarked fly (virgin), the latter was marked with a different colour and monitored for subsequent matings. Each pair of flies were marked with a distinct paint colour to avoid misidentification. Every time a marked fly mated; it was recorded. Further, remating percentage (per cent of flies remated) was calculated based on the number of times the marked fly mated. The same procedure was followed in all the treatment groups and observation were recorded separately.

Statistical Analysis

The data was analysed and statistical significance among treatments were estimated at 5 per cent probability level using one way analysis of variance (ANOVA) followed by Tukey's as post hoc test. The data was analysed using IBM SPSS statistics ver. 27 (IBM, Armonk, NY, USA).

RESULTS AND DISCUSSION

Effect of Sublethal Dose of Insecticides on Mating (%)

Mating (%) varied significantly between treatment groups. In F+ M+ treatment group, per cent of female and male flies mated was significantly lower (75%-females, 60%-males) (F-46.13, P<0.01) in fipronil treated flies compared to control flies (100%-females, 100%-males). Whereas, in spinosad treated flies, 90 per cent of females and 60 per cent of males mated. However, no significant difference was observed in malathion (80%-females, 90%-males) (F- 46.13, P-0.14) treated flies compared to control flies (100%-females, 100%-males) (Fig. 2).

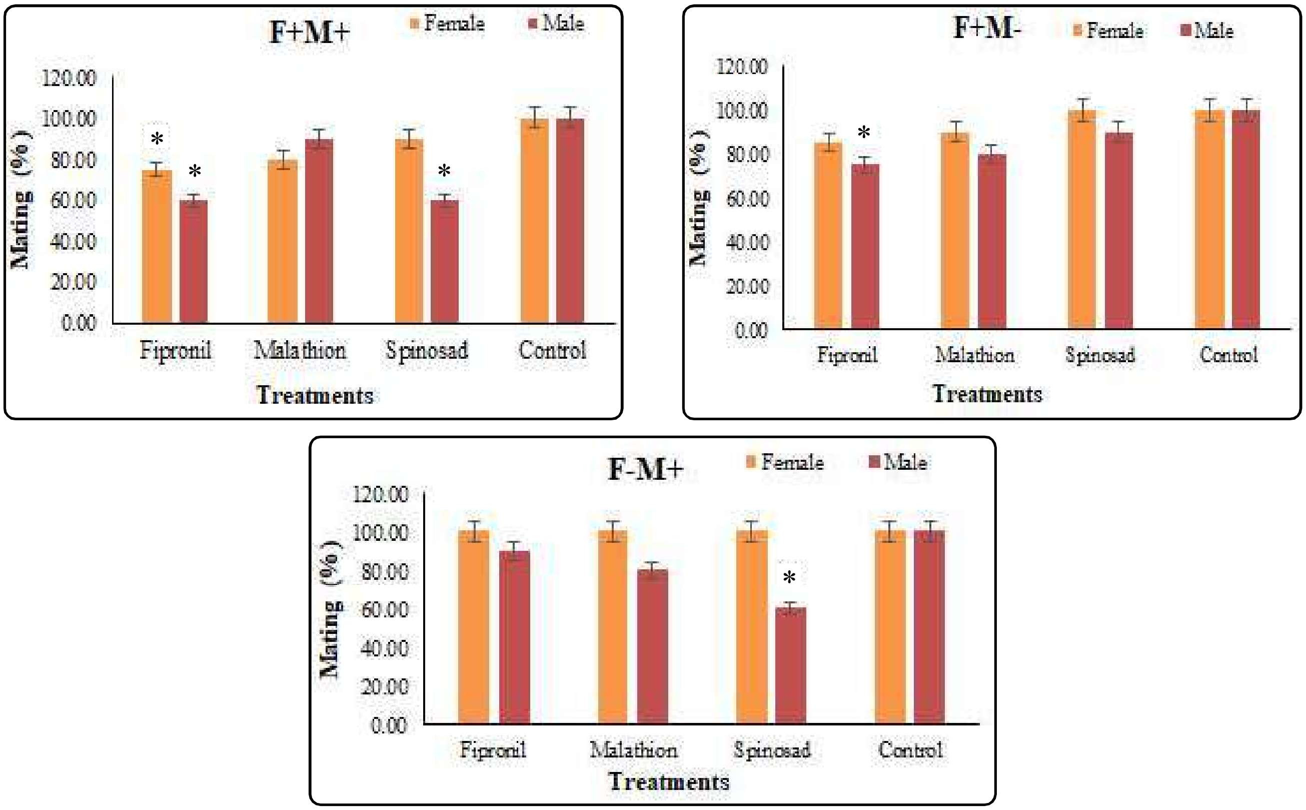

Fig. 2 : Mating (%) recorded in fipronil, spinosad and malathion treated flies (LC_{20}) in different treatment groups

In F+M- treatment group, mating (%) was significantly lower in fipronil treated males flies (75%) (F- 36.38, P<0.02), but no effect was observed on females, where 85 per cent of females mated. Whereas, mating (%) observed in, malathion (90%-females and 80%-males) and spinosad (100%-females and 90%-males) treated flies were on par with control group (100%-females and 100%-males) (Fig. 2).

In F- M+ treatment group, significantly lower mating (%) was observed in spinosad treated males (60%) (F-61.2, P<0.001), but no effect was observed on females, where 100 per cent of females mated. Whereas, no significant difference (F-61.2, P-0.9) was observed in fipronil (100%-females and 90%-males) and malathion treated flies (100%-females and 80%-males) compared to control (100%-females and 100%-males) (Fig. 2).

Overall, only fipronil treated male and female flies and spinosad treated male flies recorded lower mating (%) in F+M+ group compared to control flies.

Effect of Sublethal Dose of Insecticides on Remating (%)

Remating (%) varied significantly among treatment groups. In F+ M+ treatment group, significantly lower remating per cent was observed in fipronil (20%-females, 25%-males) and malathion (20%-females, 25%-males) (F-94.4, P<0.0001) treated flies compared to control flies (90%-females, 80%-males). Whereas, in spinosad treated flies, 30 per cent of females and 50 per cent of males mated (F-94.4, P<0.0001), which was significantly lower than control (Fig. 3).

In F+ M- treatment group, significantly lower remating (%) was observed in malathion treated flies (30%-females and 30%-males) (F- 53.9, P<0.001) followed by spinosad (60%-females and 60%-males) and fipronil (45%-females and 45%-males) treated flies compared to control group (90%-females and 80%-males) (Fig. 3).

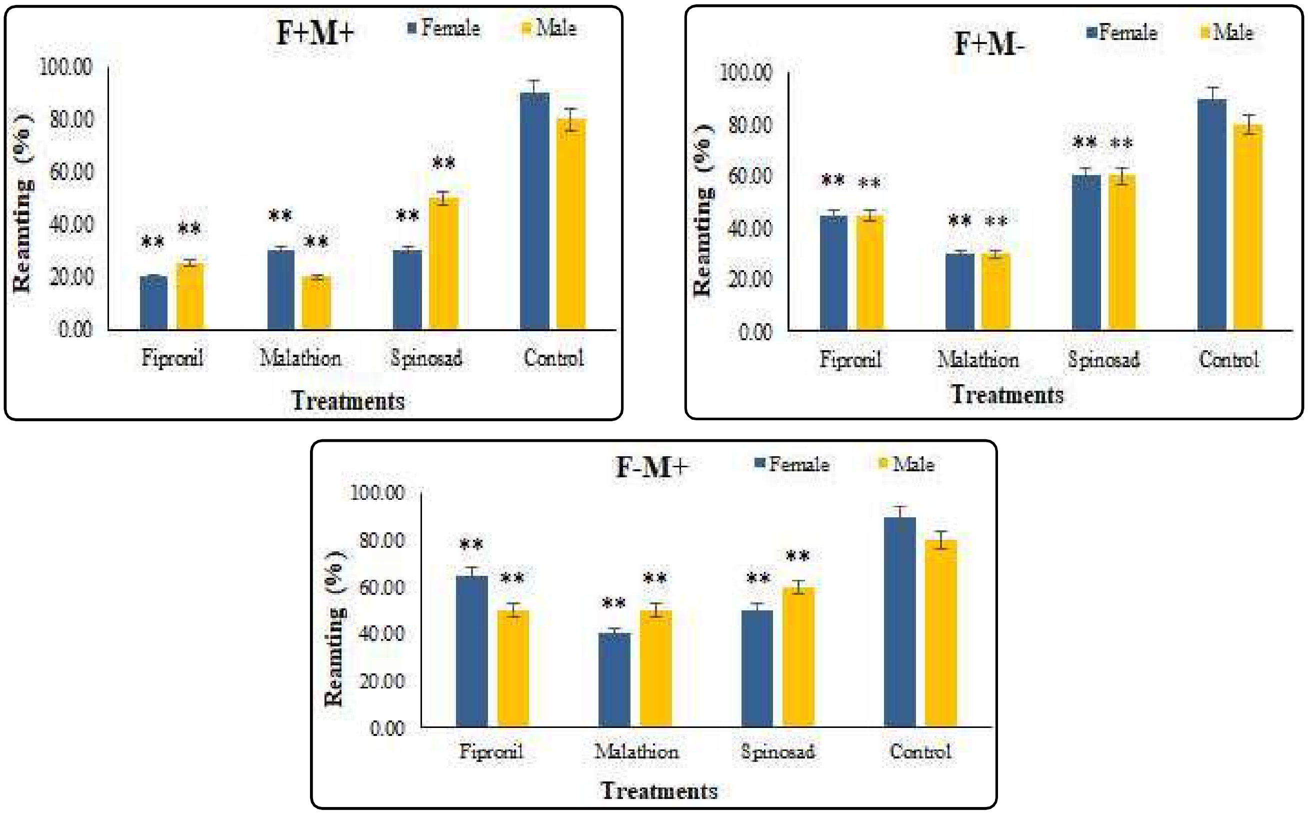

Fig. 3 : Remating (%) recorded in fipronil, spinosad and malathion treated flies (LC_{20}) in different treatment groups

In F-M+ treatment group, significantly lower remating (%) was observed in malathion treated flies (40%-females and 50%-males) (F- 36.38, P<0.001) followed by spinosad (50%-females and 60%-males) and fipronil (65%-females and 50%-males) treated flies compared to control group (90%-females and 80%-males) (Fig. 3).

Overall, remating (%) was significantly lower in flies of all the insecticidal treatment, compared to control flies.

Spinosad, fipronil and malathion insecticides are widely used for management of fruit flies. There are high chances that, flies are exposed to sublethal doses in the field condition. Because, adult flies don't feed on fruits and come in contact with fruits only during oviposition. Additionally abiotic factors such as sunlight, rainfall and temperature may reduce lethal dose of insecticides to sublethal dose over period of time (Stark *et al.*, 1995). Sublethal dose/ concentrations of insecticides may change the chemical communication system and therefore, decrease chances of reproduction in insects (De Franca *et al.,* 2017). Sublethal doses of insecticides on insects can vary by sex and species (Tejeda *et al.,* 2014 and Margus *et al.,* 2019). Thus, in the present study, sublethal effects of insecticides on both the sexes was evaluated. Sublethal doses of tested insecticides had varied effect on the mating and remating in melon fly, *Z. cucurbitae*. Fipronil treated flies recorded lower mating (%) compared to malathion and spinosad treated flies. Fipronil, a phenyl pyrazole, is a potent inhibitor of the gamma-aminobutyric acid (GABA)-gated chloride channel (Cole *et al.,* 1993). It is known to induce oxidative stress, reducing fecundity, fertility and longevity in *Spodoptera litura* (Jameel *et al.,* 2019). Fipronil interacts and binds with DNA which might be responsible for higher DNA damage and cell death (Jameel *et al.,* 2019). The oxidative stress or the DNA damage could be the one of the reasons for reduced mating observed in treated flies. In contrast, remating (%) was significantly reduced in all the treatment groups. Spinosad acts as nicotinic acetylcholine receptor (nAChR) allosteric modulators. Spinosad causes direct or indirect changes in the complex physiological mechanisms that regulate reproductive behaviour by modulation of certain genes (Gomulski *et al.,* 2012). Whereas, malathion is an organophosphate, which acts as acetyl cholinesterase inhibitor. Malathion may reduce neurophysiological responses by acting on the CNS at particular synapses between neurons. The blocking or disruption of neural signals by insecticides will thus, affect courtship behaviour (Zhang, 1987). Even though, insecticides failed to reduce mating (%), rematings were significantly inhibited in flies. Female and male fruit flies mate multiple times to enhance their reproductive fitness (Teruya & Isobe, 1982 and Kuba & Ito, 1993) and remating is crucial for maintaining genetic diversity and population resilience. Inhibiting remating in such flies would greatly limit the reproductive potential, thus inhibiting pest build up. Several studies have reported sublethal effects of various insecticides on *Z. cucurbitae* such as reduced fecundity, fertility and longevity (Rana *et al*., 2015; Nian *et al.,* 2022 and Li *et al.,* 2023).

The results suggest that, insecticides such as fipronil, malathion and spinosad significantly reduced remating in melon flies. These findings contribute to a broader understanding of how chemical control methods influence insect populations and highlight the necessity of considering sublethal effects when designing pest management programs. Further studies are necessary, to elucidate the specific physiological and molecular mechanisms underlying the observed behavioural changes.

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Effect of Micronutrients on Growth and Yield of Sweet Corn - Greengram Cropping System

K. M. Pravalika[1], S. B. Yogananda[2], P. S. Fathima[3], P. Thimmegowda[4], S. S. Prakash[5] and K. V. Shivakumar[6]

[1,2,3&4]Department of Agronomy, [5]Department of Soil Science and Agricultural Chemistry, [6]Department of Crop Physiology, College of Agriculture, V. C. Farm, Mandya - 571 405

e-Mail : kmpravalika1997@gmail.com

Authors Contribution

K. M. Pravalika : Conceptualization, data collection, investigation and manuscript preparation;

S. B. Yogananda : Conceptualization, guidance draft correction and supervision;

P. S. Fathima ;
P. Thimmegowda ;
S. S. Prakash :
K. V. Shivakumar : Conceptualization, data curation and guidance

Corresponding Author :

K. M. Pravalika

Received : September 2024

Accepted : October 2024

Abstract

An investigation on the impact of micronutrients in the sweet corn-greengram cropping system was conducted at College of Agriculture, V. C. Farm, Mandya during *kharif* 2022 and 2023 followed by *rabi* 2022 and 2023. The study comprised ten treatments with three replications which was laid out in randomized block design. The pooled data showed that the foliar spray of MM_1 @ 0.1 per cent (Micronutrients mixture - Zn, Mn, Fe, Cu and B) + Humic acid @ 0.5 per cent applied at 30 DAS significantly increased the yield attributes of sweet corn, such as number of cobs plant^{-1}, fresh cob yield and green fodder yield (1.43, 181 q ha^{-1} and 281 q ha^{-1}, respectively), as well as the growth parameters of plant height, number of leaves plant^{-1} and leaf area at harvest (213.78 cm, 10.27, 4275.07 cm^2 plant^{-1}, respectively). In contrast, greengram which is grown as a sequential crop without any treatment imposition, the residual effect of foliar spray of MM_2 @ 0.2 per cent + Humic acid @ 0.5 per cent recorded significantly higher growth parameters, such as plant height and leaf area at harvest (37.55 cm and 408.78 cm^2 plant^{-1}, respectively) and yield attributes, such as number of pods plant^{-1}, seed yield and haulm yield (29.78, 996 kg ha^{-1} and 1971 kg ha^{-1}, respectively).

Keywords : Greengram, Growth, Micronutrients mixture, Yield of sweet corn

In India, maize, a member of the *Poaceae* family and an important cereal in the world's agricultural economy, ranks third in importance among cereal crops, behind rice and wheat (Biradar *et al*., 2013 and Parameshnaik *et al*., 2024). Dent corn, sweet corn, pop corn and baby corn are the various varieties of maize that are categorised according to the endosperm of the kernels (Gurunath Raddy *et al*., 2022). Growing maize, also known as sweet corn for vegetables is a recent development aimed at diversifying the value-added and food processing industries. Maize needs a lot of soil nutrients for growth and development in order to produce higher yields, but most farmers only use fertilisers that supply the major nutrients - N, P and K, paying little attention to secondary and micronutrients, which causes them to quickly deplete and necessitate periodic or annual supplies of these nutrients. Even though secondary and micronutrient requirements are lower than those of primary nutrients, a lack of these can still restrict crop growth and productivity. Additionally, sufficient amounts of these nutrients contribute to the effectiveness of fertilisers that are applied (Ramanjineyulu *et al*., 2016). The purpose of growing greengram in succession was to preserve the fertility of the soil.

From cell development to respiration, photosynthesis, chlorophyll formation, enzyme activity, hormone synthesis, nitrogen fixation and other processes, micronutrients are actively involved in the metabolic processes of plants. In order to bring stability and sustainability to the food production process, micronutrients will be crucial in providing protection. Macro and micronutrient roles are critical to yields. Proteins and all enzymes are primarily made of nitrogen. P is an essential component of ATP and ADP, two energy carrier molecules and is involved in nearly all biochemical processes. All higher plants are known to need six micronutrients: Mn, Fe, Cu, Zn, B and Mo. Their involvement in photosynthesis, N-fixation, respiration and other biochemical pathways has been extensively documented. According to Bhangare *et al*. (2019), maize (*Zea mays* L.) crops have relatively small micronutrient requirements and the range between their deficiencies and toxicities in plants and soils is relatively narrow. In order to better understand the impact of micronutrients with recommended dose of fertilizers on sweet corn productivity, a field study was conducted.

Material and Methods

A field experiment was carried out at the College of Agriculture, V. C. Farm, Mandya, during the *kharif* and *rabi* seasons of 2022 and 2023. At an elevation of 695 meters above mean sea level, the site is situated in Karnataka's Agro Climatic Zone VI (Southern Dry Zone). The purpose of the study was to examine the impact of micronutrients on the growth and yield of a sweet corn - greengram cropping system, which consisted of ten treatments replicated three times in a randomised complete block design. The details of the treatment are: T_1 - Absolute control; T_2 - Recommended package of practices [RDF (Sweet corn - 120:60:40 NPK kg ha^{-1} and greengram - 25 : 50 : 50 NPK kg ha^{-1}), FYM @ 10 t ha^{-1} and $ZnSO_4.7H_2O$ @ 10 kg ha^{-1} was common for all treatments except absolute control]; T_3 - Foliar spray of MM_1 @ 0.1 per cent (Micronutrients mixture - Zn, Mn, Fe, Cu and B);T_4 - Foliar spray of MM_2 @ 0.2%; T_5 - Humic acid spray @ 0.5 per cent; T_6 - Biostimulant spray @ 625 ml ha^{-1}; T_7 - T_3 + Humic acid spray @ 0.5 per cent; T_8 - T_4 + Humic acid spray @ 0.5 per cent; T_9 - T_3 + Biostimulant spray @ 625 ml ha^{-1}; T_{10} - T_4 + Biostimulant spray @ 625 ml ha^{-1}. Foliar spray was done at 30 DAS.

For all treatments other than the absolute control, the recommended dose of fertilizers remained the same. In this experiment, macarena (seaweed extract) is the biostimulant used. Two weeks prior to the sweet corn sowing, FYM was applied. Greengram, on the other hand, was planted as a succession crop after the incorporation of the sweet corn stubbles and with the exception of the absolute control, the recommended dosage of fertilizers (25:50:50 NPK kg ha^{-1}) was given. The greengram variety used was KKM-3, released from ARS, Kathalagere and the sweet corn hybrid used for sowing is Sugar-75, released by Syngenta Company. Plant height (cm), leaf area (cm^2 plant^{-1}), number of cobs plant^{-1}, fresh cob yield (q ha^{-1}) and green fodder yield (q ha^{-1}) in sweet corn and plant height, leaf area (cm^2 plant^{-1}), number of pods plant^{-1}, seed yield (kg ha^{-1}) and haulm yield (kg ha^{-1}) in greengram were recorded as biometric observations and plant characteristics as indicators of crop growth and yield.

The statistical analysis of the experimental observations was conducted using Fisher's method of analysis of variance (ANOVA), as described by Gomez and Gomez (1984). The computation of critical difference (CD) values occurs when the 'F' test values are deemed significant at the five per cent significance level.

Results and Discussion

Growth Parameters of Sweet Corn and Greengram

Plant Height (cm)

The absolute control produced the shortest plant height (25.22, 67.90, 85.42 and 129.85 cm, respectively) at 30, 45, 60 DAS and at harvest in sweet corn (Table 1). The highest plant height was observed with the foliar application of MM_1 @ 0.1 per cent + Humic acid spray @ 0.5 per cent applied at 30 DAS (40.94, 132.99, 182.59 and 213.78 cm, respectively), which is significantly superior over rest of the treatments.

Taller plants with the combined foliar application of MM_1 @ 0.1 + 0.5 per cent humic acid might be

TABLE 1

Plant height (cm) of sweet corn at different growth stages as influenced by foliar application of micronutrients in sweet corn – greengram cropping system

Treatment	30 DAS			45 DAS			60 DAS			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	23.84	26.60	25.22	67.18	68.62	67.90	84.86	85.97	85.42	129.23	130.48	129.85
T_2	36.81	39.53	38.17	95.43	95.60	95.52	128.77	131.90	130.33	186.08	187.46	186.77
T_3	37.48	40.09	38.79	121.71	119.69	120.70	155.47	158.84	157.15	190.04	192.77	191.41
T_4	24.87	27.98	26.42	87.11	89.60	88.36	117.57	120.85	119.21	162.06	164.16	163.11
T_5	37.44	40.14	38.79	118.52	114.82	116.67	139.23	143.40	141.31	188.03	190.02	189.03
T_6	37.24	39.95	38.60	100.14	101.75	100.94	138.01	140.93	139.47	186.08	188.27	187.18
T_7	39.61	42.28	40.94	132.06	133.92	132.99	180.55	184.63	182.59	208.99	218.56	213.78
T_8	37.26	39.85	38.55	100.33	104.74	102.53	143.47	148.25	145.86	190.03	191.19	190.61
T_9	37.77	40.48	39.13	126.77	127.40	127.09	172.59	177.58	175.08	195.02	200.52	197.77
T_{10}	37.40	39.98	38.69	112.90	107.23	110.06	148.60	152.10	150.35	190.49	191.85	191.17
S.Em. (±)	1.59	2.30	1.33	4.73	5.25	3.35	6.83	7.02	4.74	7.57	7.66	4.88
CD @ 5%	4.71	6.84	3.94	14.05	15.61	9.96	20.30	20.87	14.08	22.50	22.76	14.50

Treatment details :

T_1 : Absolute control
T_2 : Recommended package of practices
T_3 : Foliar spray of MM_1
T_4 : Foliar spray of MM_2
T_5 : Humic acid spray @ 0.5%
T_6 : Biostimulant spray @ 625 ml ha^{-1}
T_7 : T_3 + Humic acid spray @ 0.5%
T_8 : T_4 + Humic acid spray @ 0.5%
T_9 : T_3 + Biostimulant spray @ 625 ml ha^{-1}
T_{10} : T_4 + Biostimulant spray @ 625 ml ha^{-1}

due to sufficient absorption and utilization of micronutrients, which increased nutrient uptake and the synthesis of hormones that promote growth, especially auxin. This could have led to increased growth and internode count, which in turn encouraged the development of the main shoot and increased the height of the sweet corn plant (Yogesh *et al*., 2022). Haghi *et al*. (2016) and Adarsha *et al*. (2019) reported similar observations and findings in maize. This could also be due to favourable effects on a range of biochemical processes at the cytoplasm, membrane and cell wall. Enhanced respiration and photosynthesis rates, enhanced protein synthesis and plant hormone-like activity that promotes shoot and root growth are some of these effects. These findings align with those reported by El-Shafey and El-Dein (2016), Hassan *et al*. (2019), Khan *et al*. (2019), Mahmood *et al*. (2020) and Abd-Rabboh *et al*. (2020). Taller plants were observed in the treatments that received foliar nutrition of humic acid along with RDF. This result was also consistent with those of Prashant (2021), who reported that the increase in plant height due to balanced and increased availability of nutrients, which might have played a significant role in increasing cell division and cell elongation. According to studies carried out by Karrimi *et al*. (2018) and Jolli *et al*. (2020), a high level of auxin production, including indoleacetic acid (IAA), was the primary cause of the increased plant height. Moreover, zinc is a key component of many enzyme's catalytic parts and is involved in the synthesis of tryptophan which is the precursor for the synthesis of IAA. IAA plays a role in the elongation and differentiation of cells. These outcomes concur with the maize research conducted by Verma *et al*. (2006).

TABLE 2

Plant height (cm) of succeeding greengram at different growth stages as influenced by foliar application of micronutrients in sweet corn - greengram cropping system

Treatments	30 DAS			45 DAS			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	9.27	9.15	9.21	17.40	20.81	19.11	28.21	28.82	28.51
T_2	11.35	11.21	11.28	19.49	23.33	21.41	30.01	32.15	31.08
T_3	11.87	12.07	11.97	21.04	24.68	22.86	30.80	33.65	32.22
T_4	12.58	13.05	12.82	24.05	26.58	25.32	33.56	35.92	34.74
T_5	12.06	12.42	12.24	22.00	25.17	23.59	31.06	34.38	32.72
T_6	12.26	12.76	12.51	23.18	26.02	24.60	32.24	35.43	33.84
T_7	13.78	15.39	14.59	26.01	28.62	27.32	35.33	38.01	36.67
T_8	14.02	16.03	15.02	26.77	29.61	28.19	36.58	38.52	37.55
T_9	12.93	13.35	13.14	25.14	27.68	26.41	34.17	36.58	35.38
T_{10}	13.29	14.68	13.99	25.57	28.06	26.82	34.75	37.22	35.98
S.Em. (±)	0.55	0.86	0.40	1.27	1.19	0.97	1.38	1.79	1.07
CD @ 5%	1.63	2.56	1.20	3.76	3.54	2.87	4.09	5.33	3.17

Note : RDF alone was applied for all the treatments except absolute control

Due to the effects of micronutrients mixture, humic acid and biostimulants in the sweet corn - greengram cropping sequence, plant heights of greengram varied considerably (Table 2). The treatment that received foliar application of MM_2@ 0.2 per cent + Humic acid @ 0.5 per cent in sweet corn showed significantly higher plant heights (15.02, 28.19 and 37.55 cm, respectively), while the absolute control showed lower plant heights (9.21, 19.11 and 28.51 cm, respectively) at 30, 45 DAS and harvest in greengram.

Leaf Area (cm^2 $plant^{-1}$) of Sweet Corn and Greengram

Fig. 1 and Table 3 represents the leaf area of sweet corn and greengram at different growth stages as

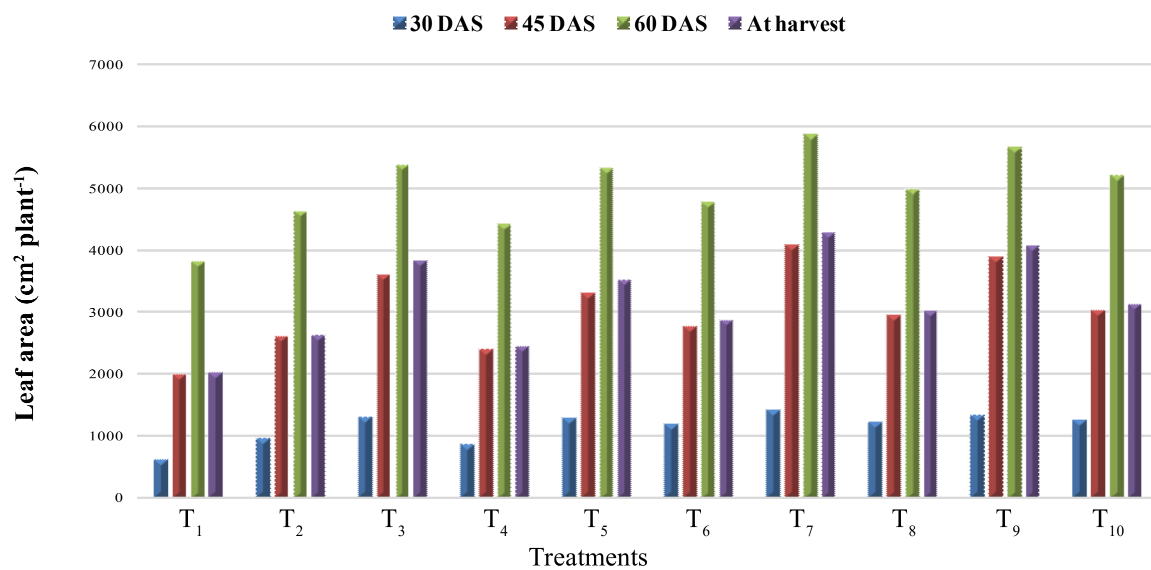

Fig. 1 : Leaf area of sweet corn as influenced by foliar application of micronutrients in sweet corn – greengram cropping system

TABLE 3

Leaf area (cm^2 $plant^{-1}$) of succeeding greengram at different growth stages as influenced by foliar application of micronutrients in sweet corn - greengram cropping system

Treatments	30 DAS			45 DAS			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	98	111	105	215	230	222	202	201	201
T_2	123	129	126	246	269	257	212	206	209
T_3	125	133	129	279	300	290	231	210	221
T_4	152	164	158	379	399	389	271	287	279
T_5	130	140	135	316	328	322	215	235	225
T_6	143	156	150	343	368	355	238	260	249
T_7	180	190	185	462	482	472	378	389	384
T_8	188	195	192	478	495	487	403	415	409
T_9	164	172	168	403	427	415	297	306	301
T_{10}	176	180	178	440	457	448	319	357	338
S.Em. (±)	11.47	10.37	7.39	27.67	30.50	22.00	22.65	17.87	11.37
CD @ 5%	34.09	30.81	21.95	82.21	90.61	65.36	67.30	53.10	33.77

Note : RDF alone was applied for all the treatments except absolute control

affected by the foliar application of micronutrients on a pooled basis.

At 30, 45, 60 DAS and harvest, the foliar application of MM_1 @ 0.1 per cent in conjunction with 0.5 per cent humic acid sprayed at 30 DAS resulted in noticeably greater leaf area measurements (1424, 4082, 5885 and 4275 cm^2 $plant^{-1}$, respectively). Lower values were obtained with absolute control (627, 1993, 3820 and 2030 cm^2 $plant^{-1}$, respectively), but it was comparable to the foliar application of MM_1 @ 0.1 per cent + Biostimulant spray @ 625 ml ha^{-1} at 30 DAS (1332, 3898, 5672 and 4074 cm^2 $plant^{-1}$, respectively).

Combination of NPK and the micronutrient application source increased the plant's physiological and metabolic activity, sparked growth and increased the leaf area per plant because it produced a greater leaf area than the control by absorbing more major nutrients. Bhangare *et al*., (2019), Asif *et al*. (2013), Manasa and Devaranavadagi (2015), Haghi *et al*. (2016) and Adarsha *et al*. (2019) reported similar findings in maize. The afore mentioned results also support the conclusions drawn by Hassan *et al*. (2019), who found that humic acid has beneficial effect on the availability of macro and micronutrients for absorption. This, in turn led to the development of vegetative growth, increased photosynthesis and an increase in the leaf area of the plant. According to Jolli *et al*. (2020), zinc and iron stimulate plant enzymes that are involved in the metabolism of carbohydrates, the preservation of cellular membrane integrity, protein synthesis and the regulation of auxin synthesis, all of which promote root and shoot growth and development. Similar outcomes were also reported by Karrimi *et al*. (2018), who noted that foliar application of zinc and iron at booting and silking along with RDF was associated with higher leaf area. This was attributed to improved nutrient absorption and translocation, which delayed senescence and abscission.

TABLE 4

Number of cobs plant^{-1}, fresh cob yield (q ha^{-1}) and green fodder yield (q ha^{-1}) of sweet corn as influenced by foliar application of micronutrients in sweet corn – greengram cropping system

Treatments	Number of cobs plant^{-1}			Fresh cob yield (q ha^{-1})			Green fodder yield (q ha^{-1})		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	1.04	1.11	1.08	54	59	56	141	128	134
T_2	1.20	1.21	1.21	152	154	153	245	168	207
T_3	1.44	1.31	1.38	163	164	163	250	248	249
T_4	1.14	1.15	1.15	148	150	149	238	162	200
T_5	1.38	1.30	1.34	162	162	162	249	238	243
T_6	1.31	1.27	1.29	155	157	156	250	182	216
T_7	1.52	1.34	1.43	177	184	181	285	277	281
T_8	1.33	1.30	1.31	157	158	158	251	199	225
T_9	1.49	1.32	1.40	172	177	175	268	260	264
T_{10}	1.34	1.30	1.32	157	159	158	253	219	236
S.Em. (±)	0.11	0.06	0.08	6.09	6.30	5.88	12.94	15.11	10.57
CD @ 5%	NS	NS	NS	18.09	18.71	17.46	38.44	44.91	31.39

Treatment details :

T_1 : Absolute control
T_2 : Recommended package of practices
T_3 : Foliar spray of MM_1
T_4 : Foliar spray of MM_2
T_5 : Humic acid spray @ 0.5%
T_6 : Biostimulant spray @ 625 ml ha^{-1}
T_7 : T_3 + Humic acid spray @ 0.5%
T_8 : T_4 + Humic acid spray @ 0.5%
T_9 : T_3 + Biostimulant spray @ 625 ml ha^{-1}
T_{10} : T_4 + Biostimulant spray @ 625 ml ha^{-1}

The residual effect of applying MM_2 (0.2%) foliarly and spraying humic acid at a rate of 0.5% on greengram produced significantly higher leaf area (192, 487 and 409 cm^2 plant^{-1}, respectively) at 30, 45 DAS and harvest, while the absolute control produced lower values (105, 222 and 201 cm^2 plant^{-1}, respectively).

Yield Parameters of Sweet Corn

Number of Cobs Plant^{-1}

The data presented in Table 5 showed that, in the sweet corn - greengram cropping sequence, the number of cobs plant^{-1} did not significantly change in response to the foliar application of micronutrients. But, when MM_1 was applied foliarly @ 0.1 per cent along with 0.5 per cent humic acid sprayed at 30 DAS, the highest number of cobs plant^{-1} (1.43) was registered and the lowest number of cobs plant^{-1} (1.08) was observed with absolute control.

Fresh Cob and Green Fodder Yield (q ha^{-1}) of Sweet Corn

In terms of increasing the yield of fresh cob and green fodder, the foliar application of MM_1@ 0.1 per cent plus humic acid @ 0.5 per cent sprayed at 30 DAS (181 and 281 q ha^{-1}, respectively) was statistically superior and on par with the foliar application of MM_1 @ 0.1 per cent + Biostimulant spray @ 625 ml ha^{-1} at 30 DAS (175 and 264 q ha^{-1}, respectively) (Table 5). On the other hand, under absolute control, which did not receive any outside nutrient sources, a lower yield of fresh cob and green fodder was noted (56 and 134 q ha^{-1}, respectively).

TABLE 5

Number of pods plant^{-1}, seed yield (kg ha^{-1}) and haulm yield (kg ha^{-1}) of succeeding greengram as influenced by foliar application of micronutrients in sweet corn – greengram cropping system

Treatments	Number of pods plant^{-1}			Seed yield (kg ha^{-1})			Haulm yield (kg ha^{-1})		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	13.15	13.86	13.51	398	398	398	1083	1018	1051
T_2	16.47	18.06	17.26	726	727	727	1665	1656	1660
T_3	19.29	21.77	20.53	775	776	775	1765	1746	1756
T_4	26.02	28.22	27.12	831	831	831	1843	1834	1839
T_5	21.85	23.62	22.73	815	816	815	1830	1827	1829
T_6	24.23	26.10	25.17	828	828	828	1839	1829	1834
T_7	28.31	29.48	28.89	935	937	936	1914	1981	1948
T_8	29.02	30.53	29.78	995	997	996	1920	2022	1971
T_9	26.91	28.73	27.82	880	881	881	1864	1963	1914
T_{10}	27.37	29.05	28.21	920	921	921	1894	1945	1919
S.Em. (±)	1.80	1.74	1.11	31.73	26.59	28.41	117.54	159.25	90.45
CD @ 5%	5.36	5.18	3.30	94.27	79.01	84.42	349.23	473.15	268.75

Note : RDF alone was applied for all the treatments except absolute control

The application of micronutrients mixture allowed maize plants to reach maximum yield and yield attributes, which was primarily responsible for the significantly higher fresh cob and green fodder yield (Ghaffari *et al*., 2011 and Jolli *et al*., 2020). According to Esfahani *et al*. (2014), increased photosynthetic qualities and increased grain production are both benefits of the more efficient mixed application of micronutrients. Sweet corn yields more fresh cob and green fodder when humic acid is added because it improves nutrient uptake and encourages stronger root and shoot growth. Larger and more numerous cobs are produced per plant as a result of increased nutrient availability and improved photosynthetic efficiency (Reddy *et al*., 2018).

Yield Parameters of Greengram

Number of Pods Plant^{-1}

Due to varying treatment effects in greengram, the number of pods plant^{-1} varied significantly (Table 5). In the absolute control, there were noticeably fewer pods plant^{-1} (13.51). Nonetheless, a higher number of pods plant^{-1} was observed in the residual effect of foliar application of MM_2 @ 0.2 per cent + Humic acid @ 0.5 per cent (29.78).

Seed and Haulm Yield (kg ha^{-1}) of Greengram

The pooled analysis as well as during both seasons showed notable differences in the greengram seed and haulm yields among the various treatments. The results showed that the absolute control had the lowest values (398 and 1051 kg ha^{-1}, respectively), while the residual effect of foliar application of MM_2 @ 0.2 per cent combined with spraying of humic acid @ 0.5 per cent recorded significantly superior seed and haulm yield of 996 and 1971 kg ha^{-1}, respectively.

Through their interactions with important metabolic processes, micronutrients were essential in maintaining the balanced internal mechanisms of plant growth and development. Thereby, encouraging the translocation of photoassimilates to the sink, *i.e.*, kernels and optimising the source-sink relationship within the plant.

It can be inferred that the treatments had varying effects on the parameters of growth and yield in sweet corn and greengram when subjected to source-sink manipulation. Thus, foliar spraying of MM_1 @ 0.1 per cent + 0.5 per cent humic acid (sweet corn) and foliar spraying of MM_2 @ 0.2 per cent + 0.5 per cent humic acid (greengram) was the most effective treatments among the others for increasing the yield of both the crops.

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Mysore J. Agric. Sci., 58 (4) : 214-222 (2024)

Harnessing Endophytic Bacteria from Finger Millet Landraces for Biocontrol of Foot Rot Disease

S. Priyadarshini[1], N. Umashankar[2], K. Nagaraju[3], L. Krishna Naik[4], H. R. Raveendra[5] and P. S. Benherlal[6]

[1,2,3&4]Department of Agricultural Microbiology, [6]Department of Plant Biotechnology, College of Agriculture, UAS, GKVK, Bengaluru, [5]AICRP on Small Millets, College of Agriculture, V. C. Farm, Mandya

e-Mail : priyaselvaraj0606@gmail.com

Authors Contribution

S. Priyadarshini : Conceptualization, investigation, draft preparation and data analysis;

N. Umashankar : Conceptualization, draft correction and framed research proposal;

K. Nagaraju ; L. Krishna Naik ; H. R. Raveendra & P. S. Benherlal : Draft correction and guidance

Corresponding Author :

S. Priyadarshini

Received : September 2024

Accepted : November 2024

Abstract

Finger millet (*Eleusine coracana* (L) Gaertn. subsp. *coracana*), a staple crop in arid and semi-arid regions of Africa and Asia, is praised for its drought resistance and high nutritional value. However, it faces significant yield losses due to foot rot caused by the soil-borne pathogen *Sclerotium rolfsii*. Chemical fungicides, while commonly used, pose environmental risks and contribute to fungal resistance. In search of solution, the best alternative for the chemical management is biological management. Thus, this study investigates the potential of bacterial endophytes isolated from finger millet landraces for biological control of foot rot. Totally sixty-nine endophytic bacteria were isolated from seeds, roots and leaves of finger millet landraces, by following surface sterilization and spread plating method for seeds, tissue imprinting for leaves and roots. These endophytes were screened for their antagonistic activity against *S. rolfsii* using a dual culture assay. Among sixty nine isolates, eight endophytic bacteria (AES, BMEL1, GDEL1, GES, HKES, KEL1, KER1 and KER2) exhibited maximum antagonistic activity with inhibition rates ranging from 44.39 per cent to 85.57 per cent were selected. Further these isolates were characterized morphologically (Gram staining) and biochemically (catalase activity, siderophore and hydrogen cyanide production). All the isolates were able to exhibit catalase activity, isolate AES able to produce highest siderophore and BMEL1, KEL1, KER1 and KER2 showed positive for hydrogen cyanide production. Thus, the result ensured the use of endophytes from landraces for sustainable management of foot rot in finger millet.

Keywords : Endophytes, Biocontrol, Finger millet landraces, *Sclerotium rolfsii*

Finger millet (*Eleusine coracana* (L) Gaertn. sub sp. *coracana*), renowned for its moderate drought resistance, is widely cultivated across the arid and semi-arid regions of Africa and Asia, serving as a staple for millions of people (Tadele, 2016). In India finger millet was cultivated in 8.91 lakh ha, where Karnataka alone accounts for over 5.27 lakh hectares, contributing more than 60 per cent of India's total production (Vennila and Murthy, 2021). Esteemed for its exceptional nutritional profile, the United States National Academies have designated finger millet as a 'super cereal'. It is rich in minerals and boasts a high micronutrient density (Kumar *et al.,* 2016). Nutritionally comparable to rice in terms of protein (6-8%) and fat (1-2%) content, finger millet surpasses both rice and wheat in mineral and micronutrient levels and also provides notable antioxidant and antibacterial properties (Verma & Patel, 2013 and Chandra *et al.,* 2016).

Finger millet is highly valued by local farmers for its resilience to stress conditions and resistance to a variety of pathogens (Goron and Raizada, 2015). Nevertheless, it remains susceptible to several diseases, with foot rot caused by *Sclerotium rolfsii* emerging as a significant threat, particularly under irrigated and high-rainfall conditions. This disease has been documented to cause yield losses exceeding 50 per cent (Nagaraja and Reddy, 2009). According to the All India Coordinated Research Project on Small Millets, foot rot is a primary cause of yield loss in Mandya and Jagdalpur regions, accounting for 15 per cent of the overall finger millet losses across India (Millets Pathology - 32nd AGM - 2021 - IIMR). To mitigate this significant issue, several fungicides have been in use, including propiconazole, hexaconazole, mycobutanil, thiophanate, tebuconazole and carbendazim, to control diseases caused by *Sclerotium rolfsii* (Das *et al.,* 2014). However, the intensive application of these chemicals poses significant environmental risks, raising serious concerns about the long-term sustainability of modern agricultural practices and the development of fungal resistance (Moss, 2008 and Cardoso *et al.,* 2010). Given that *S. rolfsii* is a soil-borne pathogen, fungicide application is often not economical, as it requires drenching the entire field and resistance development remains a common issue (Manu *et al.,* 2016). As a result, there is a growing interest in alternative method for managing plant diseases, one such approach is biological agents.

Biological agents in plant disease management have already been implemented in agricultural crop production. In recent decades, novel research on biological control of plant diseases has focused on the role of a particular class of microbes that colonize the internal tissues of host plants, known as endophytes (Mousa and Raizada, 2013). Consequently, endophytes have garnered significant attention as a potential source of natural solutions for agricultural challenges. These endophytes were present in each and every plant and possess numerous benefits (Srikanth *et al*., 2023). Thus endophytes are hypothesized to confer resistance to host plants against fungal pathogens (Mousa and Raizada, 2013). The promising role of endophytes in enhancing plant resilience naturally complements the adaptability seen in local landraces.

Local landraces, characterized by their dynamic populations and association with traditional farming systems, demonstrate remarkable adaptability to harsh and unpredictable environmental conditions. Disease incidence in these landraces is notably less than 25 per cent compared to commercial varieties, even without the application of fungicides (Villa *et al.,* 2005; Vom Brocke *et al.,* 2014; Sanchez-Martín *et al.,* 2017). This study posits that cross-inoculation of endophytes from landraces to susceptible varieties which could enhance pathogen resistance, leading to increased yield in an environmentally sustainable manner. Consequently, this research focused on isolating bacterial endophytes from finger millet landraces and assessing their effectiveness against foot rot caused by *Sclerotium rolfsii*.

Material and Methods

Isolation of Endophytes from Landraces of Finger Millet

Endophytes were isolated from various plant parts of landraces of finger millet, including roots, leaves and seeds. Seeds of landraces were procured from the All India Coordinated Research Programme on Millets (AICRP) at the Zonal Agricultural Research Station (ZARS), V. C. Farm, Mandya, Karnataka. The seeds were grown in the pots for the isolation of endophytes from the plant parts. The plant samples were initially washed and cut into 2-3 cm pieces. These pieces were surface-sterilized by immersing them in 70 per cent ethanol for one minute, followed by treatment with 1.5 per cent sodium hypochlorite for 2 mins. Subsequently, the samples were rinsed thoroughly with distilled water to eliminate any residual sodium hypochlorite, with the washing process repeated 5-6 times using sterile distilled water. The surface-sterilized samples were then blot-dried with sterile filter paper, cut into two halves and each half was placed on nutrient agar plates in triplicate. Spread plating was carried out from the final wash of surface sterilisation, serving as the control. The plates were incubated at room temperature for 24-48 hours (Jabborova *et al.,* 2020).

Screening for Biocontrol Activity of Endophytic Bacteria Against Foot Rot Pathogen

Dual Culture Assay

Endophytic isolates were assessed for their antagonistic activity against the foot rot pathogen, *Sclerotium rolfsii*, which was obtained from AICRP, ZARS, V. C. Farm, Mandya. The evaluation followed the dual culture plate assay method as described by Dennis and Webster (1971). In this method, both the endophytic bacterial isolate and the pathogen were inoculated on a single potato dextrose agar (PDA) plate. A 5 mm diameter disc of the pathogen was placed at the center of the PDA plate and a 24-hour-old culture of endophytic bacteria (at a concentration of 10^8 cfu/ml) was streaked at the edge of the plate. The plates were then incubated at 27 ºC for four to eight days, with each test conducted in triplicate. Observations were made once the pathogen had fully grown on the control plate. The percentage inhibition of the pathogen's growth was calculated using the formula suggested by Vincent (1927).

$$I = \frac{(C-T)}{C} \times 100$$

Where,

I = Per cent inhibition,

C = Growth of fungal plant pathogens in control (mm),

T = Growth of fungal plant pathogens in dual culture plate (mm)

The efficient isolates that inhibited the higher per cent growth of pathogen in the dual culture method were selected for further characterization.

Morphological Characterisation of Bacterial Endophytes

The following morphological tests *viz*., cell shape, Gram reaction were carried out to tentatively characterize the identified endophytes. The purified cultures, at log phase were observed microscopically for the cell morphological characteristics. Gram staining was carried out using the procedure given by Harrigan and McCance (2014). The slides were viewed with the compound microscope at 100 x under oil-immersion.

Biochemical Characterization of Efficient Endophytic Isolates

Siderophore Production

The bacterial isolates were spotted onto CAS (Chrome Azurol Sulfonate) plates and incubated at 28 ± 2 ºC for 24 and 72 hours to allow for bacterial growth. The plates were then examined for the presence of a yellow halo surrounding the bacterial colonies, which indicates positive siderophore production (Maheshwari *et al.,* 2019).

Catalase Hydrolysis

The catalase activity in the isolates was checked by flooding 3 per cent H_2O_2 over the bacterial colony. Formation of efferve scence was confirmed as positive, while the absence of bubbles or a few scattered bubbles was confirmed as negative (Shah *et al.,* 2021).

Hydrogen Cyanide

Hydrogen cyanide production was assessed following the method outlined by Bakker and Schippers (1987). Petri dishes containing 10 per cent Trypticase Soy Agar, supplemented with 4.4 g/L of glycine, were inoculated with the bacterial endophytes. The dishes were then inverted and covered with a lid that had been impregnated with a filter paper containing 0.5 per cent picric acid and 2 per cent sodium carbonate. The plates were incubated at 28 °C for three to five days. Cyanide production was indicated by a color change on the filter paper from yellow to orange-brown.

Statistical Analysis

The data was statistically analysed using OPSTAT statistical tool and the means were separated by Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Isolation of Endophytic Bacteria from Landraces of Finger Millet

A total of sixty-nine bacterial endophytes were isolated from twenty-four landraces of finger millet. The majority of these endophytes were obtained from seeds (34 isolates), followed by roots (18 isolates) and leaves (17 isolates) (Plate 1). This result is also validated by the results of Bhagyashree *et al*., (2023), were more number of endophytes were isolated from the seed of finger millet landraces. The abundance of seed-associated endophytes suggests that seeds might serve as important reservoirs for microbial diversity in finger millet landraces, potentially influencing seed germination and early seedling growth in adverse environmental conditions. As the result of elimination of seed-endophytic bacteria from these landraces reduced germination at the unfavourable environment (Arellano-Wattenbarger *et al.,* (2023). Endophytes in seed positively influence root and shoot development, contribute to root hair formation as these endophytes are in direct contact with root and shoot and enhance the chlorophyll content of seedlings (Shearin *et al.,* 2018). The isolates were subsequently purified and categorized based on their associated crop varieties. Among these, only those exhibiting distinct morphological traits, such as variations in colony shape, color and texture, wereselected for further characterization.

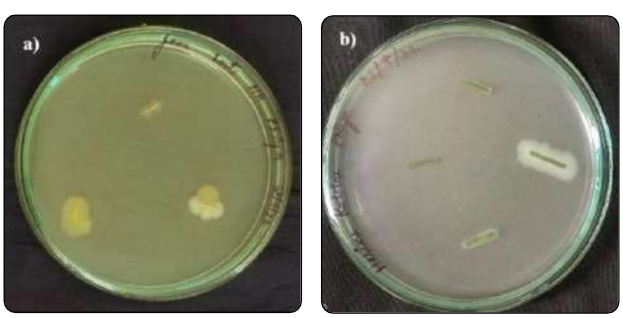


Plate 1 : Isolation of endophytic bacteria from the different parts of landraces of finger millet

Note : a) Isolation of endophyte from roots; b) Isolation of endophyte from leaves

TABLE 1

Endophytic bacteria isolated from landraces of finger millet

Land races	Isolates
Ayyan	AES
Benne mundaga	BMES1, BMES2, BMEL1, BMEL2, BMEL3, BMER1, BMER2
Bilikkadi	BES, BEL1, BEL2
Dodda	DES1, DES2
Gana	GES
Gidda	GDES1, GDES2, GDES3, GDEL1, GDEL2
Guli	GUES1, GUES2
Guppe	GPES1, GPES2
Gutteginthalu	GGES
Haalu	HES
Haaluguli	HGES1, HGES2, HGEL, HGER1, HGER2, HGER3
Hasina kombu	HKES, HKEL1, HKEL2, HKER1, HKER2, HKER3
Hasirumundaga	HMER1, HMER2
Jenu	JES, JEL1, JEL2, JER1, JER2, JER3
Kapputhene	KTES
Keenya	KES, KEL1, KEL2, KEL3, KER1, KER2
Kolimotte	KMES
Kuntukulu	KKES1, KKES2, KKES3
Mallige	MES
Mundaga	MUES, MUEL, MUER1, MUER2
Nepal	NES, NEL, NER
Shakthi	SES1, SES2
Thenemundaga	TES
Zimbabae	ZES1, ZES2

Note : E- Endophyte, S- Seed, L- Leaf and R- Root

Screening for Biocontrol Activity of Endophytic Bacteria against Foot Rot Pathogen

The antagonistic potential of sixty nine purified bacterial endophytes against *Sclerotium rolfsii* was assessed using a dual culture technique. Inhibition zones were measured to calculate the percentage of inhibition, which ranged from 85.57 per cent (exhibited by HKES) to 44.39 per cent (shown by KMES). Based on these results, eight isolates - AES,

BMEL-1, GDEL-1, GES, HKES, KEL-1, KER-1 and KER-2which significantly differed (P= < 0.005) from other isolates, were selected for further characterization basedon their superior inhibitory activity (Plate 2) (Fig. 1). This effectiveness may be due to the production of secondary metabolites and volatile organic compounds by the bacterial endophytes, which inhibit fungal growth and sclerotium germination and indirectly by inducing systemic resistance in plants (Li *et al.,* 2023 and Rajani *et al*., 2019). This evidently suggests that endophytes from landraces contribute to higher disease resistance compared to modern varieties, since landraces have been shown to be highly adaptive under multi-site evaluation. (Sanchez-Martín *et al.,* 2017).

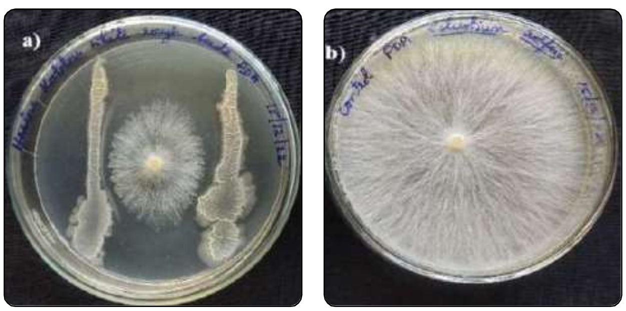


Plate 2 : Screening the biocontrol activity by dual culture technique

Note : a) biocontrol activity of HKES isolate b) control (*Sclerotium rolfsii*)

Characterisation of the Endophytes

Under gram staining and microscopic observation, among the 8 isolates, 6 were gram positive and 2 were gram negative. The morphological characters of the endophytic isolates are mentioned in the Table 2.

Biochemical Characterization of Efficient Bacterial Endophytic Isolates

The eight selected bacterial endophytes subjected to a series of biochemical assays to assess their potential for characterization and identification. These assays included tests for siderophore production, catalase activity and hydrogen cyanide (HCN) production. In the siderophore production test, the AES isolate, sourced from the seeds of the Aayan landrace, exhibited the largest yellow halo. This indicates a high level of siderophore production, which is essential for iron uptake and competitive inhibition of pathogenic microbes (Table 3) (Plate 3b). These results are consistent with those reported by Longoria-Espinoza *et al*. (2024), where endophytes isolated from potato plants also demonstrated significant side rophore production, as evidenced by the formation of a yellow halo around the bacterial colonies.

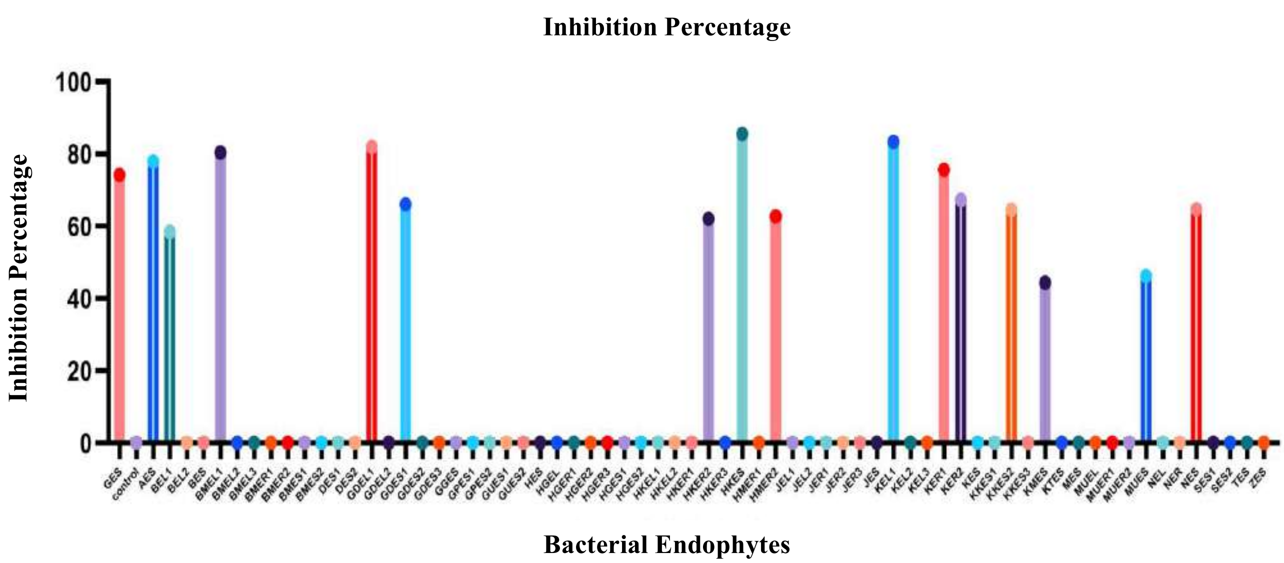


Fig. 1 : Antagonistic potential of endophytic bacterial isolates in dual culture technique

TABLE 2

Morphological characteristics of the endophytic bacteria isolated from landraces of finger millet

Isolates	Gram Staining	Shape	Colony Colour
GES	Negative	Cocci	White
HKES	Positive	Cocci	White
GDEL1	Positive	short rods	White
KEL1	Positive	short rods	White
BMEL1	Positive	short rods	White
KER2	positive	short rods	White
AES	Positive	Cocci	White
KER1	negative	Cocci	White

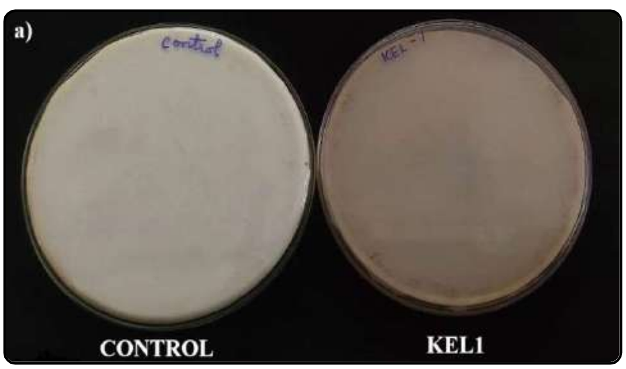
All endophyticisolates were tested positive for catalase activity, as indicated by the effervescence production when 3 per cent hydrogen peroxide was applied to the culture plates (Table 3) (Plate 3c). This result aligns with findings from Fariska *et al.* (2024), where endophytes isolated from cassava leaves also showed positive catalase activity, which is a key enzyme involved in the breakdown of hydrogen peroxide and protection of cells from oxidative damage.

TABLE 3

Biochemical Characterization of Efficient Bacterial Endophytic Isolates

Isolates	HCN Production	Siderophore Production	Catalase
GES	Negative	Cocci	White
AES	-	+++	+
BMEL1	+	++	+
GDEL1	-	++	+
GES	-	++	+
HKES	-	+	+
KEL1	+	+	+
KER1	+	+	+
KER2	+	++	+

Note : (-) -Negative, (+) -good, (++) -very good, (+++) -excellent



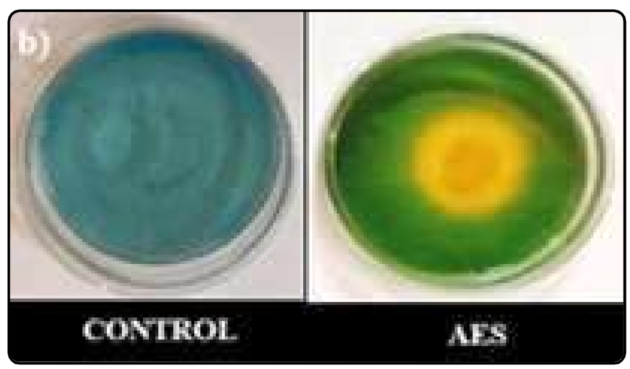


Plate 3 : (A) HCN Production of KEL1; (B) Siderophore production of AES; (C) Catalase activity of GDEL1

In the hydrogen cyanide production test, isolates BMEL1, KEL1, KER1 and KER2 exhibited positive results by changing the filter paper color from yellow to brown. This change indicates the production of hydrogen cyanide, a volatile compound known for its antifungal properties (Table 3) (Plate 3a). Shreshtha *et al*. (2024) also observed similar results in their study, where 66 per cent of 90 endophytes isolated from cucumber plants were capable of producing hydrogen cyanide, further supporting the efficacy of these compounds in microbial antagonism.

A total of sixty nine bacterial endophytes were initially screened for their biocontrol potential against *Sclerotium rolfsii*, the pathogen responsible for foot rot in finger millet. The dual culture assay identified eight isolates with significant antagonistic activity. The biocontrol efficacy of these isolates is likely due to the production of secondary metabolites, volatile organic compounds and allelochemicals that inhibit pathogen growth. Among these, isolates HKES-1, GDEL-1 and KEL-1 exhibited the highest levels of inhibition against *Sclerotium rolfsii*. These findings suggest that the endophytes from landraces not only offer potential as biological control agents but also possess the ability to with stand and thrive under varied environmental conditions. The promising results highlight the potential for utilizing these endophytes in sustainable agricultural practices to manage foot rot effectively while minimizing environmental impact.

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Growth Promotion in *Arabidopsis thaliana* Induced by Fungal Endophytes Isolated from Plants Growing in Extreme Habitats

RACHANA K. PAWAR AND KARABA N. NATARAJA
Department of Crop Physiology, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : nnkaraba@uasbangalore.edu.in

AUTHORS CONTRIBUTION

RACHANA K. PAWAR :
Conceptualization, design, data analysis and manuscript preparation;

KARABA N. NATARAJA :
Conceptualization, design, supervision and editing

Corresponding Author :
KARABA N. NATARAJA

Received : July 2024
Accepted : August 2024

ABSTRACT

Plants and microbes have co-evolved in nature over the past few years for their better adaptation. This intricate symbiotic relationship is captured in the hologenome concept, which emphasizes that the combined genome of plants and their associated microbial partners, function as a single evolutionary unit. It highlights the possibility of using beneficial microorganisms, including fungal endophytes, to increase plant growth and productivity by habitat-adapted symbiosis mechanism. According to earlier research, fungal endophytes activate specific physiological traits in crops. However, the specific ways in which these endophytes benefit plants and underlying mechanisms remain unclear. In this context, the objective of this study was to utilize the model system *Arabidopsis thaliana* to explore possible mechanisms of plant-endophyte interaction. Eight fungal endophytes (K-23, LAS-6, N-14, P-10, P-37, PJ-9, SF-5 and V4-J) previously isolated from extreme habitats were re-examined in terms of their colony morphology. Based on the leads from previous studies, five fungal endophytes (LAS-6, N-14, P-10, PJ-9 and SF-5) were selected and exposed for *In vitro* co-cultivation with new host *A. thaliana*. The highest colonisation percentage was observed for the SF-5 (67%) followed by P-10 (33%), LAS-6 (27%) and N-14 (33%), whereas a lower colonisation percentage was observed for PJ-9 (20%). Additionally, these endophytes showed growth promotion activity by improved photosynthetic leaf area, root dry weight and shoot dry weight in fourteen days old *Arabidopsis* seedlings. The identification of trait-specific endophytes and incorporation of hologenome-enrichment approach can serve as a sustainable and eco-friendly strategy for crop improvement.

Keywords : Fungal endophytes, Plant growth promotion, *Arabidopsis thaliana*

As the global population continues to surge, agricultural land dwindles and climate change poses significant challenges to crop production, there is an urgent need to explore innovative strategies to enhance crop growth and yield (IPCC, 2022). In recent times, various strategies, including genetic modification, mutational selection and targeted breeding, *etc.,* have been employed to incorporate traits from wild systems to improve the yield (Shen *et al.,* 2018; Ma *et al.,* 2023 and Singha & Singha, 2024). However, the success rate has been limited, and potential drawbacks, such as the inadvertent loss of beneficial genes and significant impacts on biodiversity, exist (Phillips, 2008 and Jacobsen *et al.,* 2013). Traditional genetic breeding approaches have largely exhausted the potential for yield improvements, necessitating the exploration of alternative methods. Therefore, novel approaches are being used to manipulate plants in an eco-friendly manner. In this context, the utilization of external, eco-friendly supplements has garnered attention as a means to meet the growing food demands sustainably.

One such approach is the manipulation of hologenome. The term 'hologenome' refers to the collective genetic material of an organism and the symbiotic microorganisms associated with it (Jefferson 1994). The concept emphasizes that the genomes of the microorganisms that live in or on an organism, as well as the genome of the organism itself, may interact and contribute to the traits and adaptations of the latter. The host organism (plant) and its associated microbial communities (in the apoplast) as a functional unit, play a crucial role in plant growth, adaptation and ecological interactions (Zilber-Rosenberg and Rosenberg, 2008).

The apoplastic organisms, the endophytes, are primarily fungi and bacteria, that reside without causing apparent harm to the plants. There are reports to suggest that plants have adapted to stressful environments by forming symbiotic associations with endophytes (Delaux and Schornack, 2021). The habitat-adapted symbiosis by endophytes represents a fascinating phenomenon with significant implications for plant health and ecosystem dynamics. By incorporating endophytes adapted to specific environmental conditions, crops can potentially exhibit enhanced stress resilience (Lata *et al.,* 2018). Endophytic fungi mainly rely on the apoplastic fluid to seek nutrients and develop mutualistic relationships with plants (Bacon and White, 2000; Kusari *et al.,* 2012 and Gouda *et al.,* 2016). As endophytes have facilitated better plant growth and development under stressful environments, it appears to be an interesting strategy if they can be employed to alleviate crop growth to increase agricultural production. Thus, understanding the mechanisms behind this endophyte-mediated growth promotion will open new opportunities for their commercial application in crop production. There is a possibility that endophytes can better crop growth even under normal conditions as they appear to provide external and additional resources for plants through their symbiotic associations (Rodriguez *et al.,* 2008; Sangamesh *et al*., 2018; Chitnis *et al*., 2020 and Dhanyalakshmi *et al.,* 2023).

Studies indicate that endophytes also play a crucial role in promoting early seedling growth in rice, green gram, soybean and cowpea (Vasanthakumari *et al*., 2019 and Ayesha *et al*., 2022). Recent reports suggest that these endophytes can improve the photosynthetic performance of plants by increasing internal CO_2 (Ci) concentration through their respiratory metabolism (Suryanarayanan *et al*., 2022) and contrary to this it is also argued that endophytes can minimise the photosynthetic limitation by increasing the triose phosphate utilisation and ribulose-1, 5-bisphosphate (RuBP) regeneration; Rho *et al*., 2020 and Bangari & Nataraja, 2023). There are compelling evidences to argue that endophytes impart stress tolerance in major crops such as rice (Sampangi Ramaiah *et al*., 2020 and Manasa *et al*., 2020), cucumber (Moghaddam *et al*., 2021), tomato (Pallavi & Nataraja, 2022) and maize (Zhang *et al*., 2018 and Siddiqui *et al*., 2022).

Numerous reports indicate the positive influence of endophytes on plant growth promotion. However, despite efforts to decipher the communication patterns between endophytes and their host (Sampangi Ramaiah *et al.,* 2019), the fundamental mechanisms underlying plant-endophyte interactions remain largely unexplored. Because of complex interactions, it would be ideal to use model system *A. thaliana* (Michal *et al*., 2011) for fruitful output within a short period. *A. thaliana* provides an added advantage in carrying out experiments due to the availability of ample bioresources, complete genome sequence information, and a rapid life cycle of approximately 45 days (TAIR, *https://www.Arabidopsis.org*). This model system also helps in studying the host-specificity of endophytes, a fundamental aspect of utilizing endophytes in commercial crops. The present study investigates the ability of the eight habitat-adapted fungal endophytes isolated from extreme habitats to colonize the new host *A. thaliana*. We demonstrate that the select endophytes colonize in model plants and enhance growth by activating growth traits.

TABLE 1

Habitat information of the fungal endophytes used in the study

Fungal strains	Plant location/habitat	Latitude (° N)	Longitude (° E)	Altitude (m) Above mean sea level (AMSL)
K-23	Kargil (J&K) mountains	34°34'223 ° N	76°72 573 ° E	2750
SF-5	Tamil Nadu coast	11.1271° N	78.6569° E	253
N-14	Namika La mountains	34°23'00° N	76°27'34° E	3832
LAS-6	Thar desert	27.4695° N	70.6217° E	250
P-10 P-37	Pangong Tso mountains	33°432 2.743 ° N	78°532 29.083 ° E	4250
PJ-9	Bellary, Dryland	15.3173° N	75.7139° E	610
V4-J	Pokkali soils	9.9667° N	76.3168°E	49.6

MATERIAL AND METHODS

Collection of the Endophytic Fungi

Endophytic fungi were collected from the fungal repository of the School of Ecology and Conservation Laboratory, Department of Crop Physiology, University of Agricultural Sciences, Bengaluru, India (kindly donated by Prof. R. Uma Shaanker). The collection comprises six *Fusarium* species designated as K-23 (*Fusarium incarnatum),* SF-5 (*Fusarium equiseti*), N-14 (*Fusarium* sp.), P-10 (*Fusarium* sp.), PJ-9 (*Fusarium* sp.), V4-J (*Fusarium chlamy dosporum)* and additionally, it includes two distinct species: LAS-6 (*Chaetomium globosum)* and P-37 (*Ulocladium dauci)*. These fungal endophytes were originally isolated from the wild plants thriving in extreme climatic conditions in India as indicated in Table 1.

Microscopic Observations of the Endophytic Fungi Morphology

For microscopic examination of fungus morphology, the slide culture technique was employed with slight modification of the method by Harris (1986) and Rosana *et al*. (2014). Approximately 1cm potato dextrose agar (PDA) square blocks were prepared and positioned in the middle of the slide. Subsequently, a sterile needle was utilized to inoculate endophytic fungi towards the four corners of the PDA block. Another slide was then pressed on top to ensure adhesion and the entire setup was placed in sterile petri dishes, followed by incubation at 28°C (Prakash and Bhargava, 2016). The growth of the fungi was observed 72 hours after incubation at various magnifications using the ZEISS imaging system (Carl Zeiss™ Axio Vert.A1 Inverted Microscope).

Co-cultivation of the Fungal Endophytes with Arabidopsis

Growth Condition of Endophytic Fungus : Mycelial discs from the mother culture were used to grow the endophytic fungi by placing them in petri dishes containing Potato Dextrose Agar (PDA) medium.

Growth Condition of A. thaliana : *A. thaliana* (Col) seeds were surface sterilized by Vapor-phase Sterilization with sodium hypochlorite and hydrochloric acid for 45 minutes (Lindsey *et al.,* 2017) and 20-30 seeds were placed in petri dishes containing half-strength Murashige and Skoog media (pH 5.7-5.8) without hormones, along with solidifying agent 0.8 per cent (w/v) agar (Murashige and Skoog 1962). Petri dishes were incubated for 48 hours at 4°C for seed stratification to ensure uniform germination. After the cold treatment, the petri dishes were incubated in the plant growth chamber (ARALAB plant growth chamber, serial no 2714) with 16/8 hours light and dark period, 22/24°C temperature and 65 per cent relative humidity.

Co-cultivation of A. thaliana and Endophytic Fungi : For *in vitro* co-cultivation, a modified Plant Nutrient Media (PNM) medium was used (Michal *et al.*, 2011). Mycelial discs from 4-week-old endophytic fungi were placed in petri dishes containing PNM media and incubated for 72 hours in the dark at 28°C, for control conditions PDA disc without endophytic fungus was placed. Twelve seedlings were taken per treatment with three replications each. Next, 10-12 days old *Arabidopsis* seedlings were placed on endophyte-inoculated PNM plates for co-cultivation and observations were recorded after one week with four biological replicates per replication and a total of three replications per treatment. Root dry weight (mg plant^{-1}) and shoot dry weight (mg plant^{-1}) were recorded after oven-drying the samples at 50°C for two days.

Leaf Area Measurement

The leaf area of *Arabidopsis* seedlings was measured by the non-destructive method. The photographs of individual *Arabidopsis* seedlings along with the measuring scale were manually captured from the top a week after co-cultivation. The individual photographs were processed using image analysis (Image J) software and images were converted to 8-bit format, the leaf area was estimated (Kokorian *et al.*, 2010).

Re-isolation of the Endophytic Fungi from *A. thaliana*

To confirm the colonization efficiency of the endophytic fungi, the leaf, stem and root tissues were cut into 0.5cm segments and surface sterilized with 70 per cent (v/v) ethanol for 50 seconds followed by sequential sterilization with 0.1 per cent (v/v) NaOCl for 60 seconds and 70 per cent (v/v) ethanol for 30s with intermittent rinse using sterile distilled water four to five times. (Arnold *et al.*, 2000). To ensure the effectiveness of the surface sterilization the cut segments were then imprinted on the PDA plates (Schulz *et al.*, 1993). Later the surface sterilized plant segments were placed on PDA plates supplemented with antibacterial antibiotic ingredient streptomycin sulfate (50-100 µg/ml) and incubated for five days at room temperature (27-28°C) (Suryanarayanan, 1992). The fungus emerged from the explants was isolated and pure cultured on fresh PDA plates using a sterile needle. The pure cultures were compared with their respective mother cultures for colony appearance, spore and hyphae structures using a Zeiss Fluorescence microscope (Carl Zeiss™ Axio Vert. A1 Inverted Microscope) (Domsch *et al.*, 1980 and Arx Von, 1981).

Per cent Colonization (%)

The extent of colonization was measured using the morphological method by counting the fungal emergence from the cut ends of the explants *i.e.* number of explants colonized by fungus to the total number of explants placed (colonization frequency) and multiplying it by 100 (Lawson *et al.,* 2014).

Molecular Identification of the Endophytic Fungi

Genomic DNA was isolated from the endophytic fungi by the cetyltrimethyl ammonium bromide (CTAB) method (Rogers and Bendich, 1994) and polymerase chain reaction (PCR) was carried out to amplify the Internal Transcribe Sequences (ITS) region of genomic DNA using ITS1 (TCCGTAGGTGAACCTGCGG) and ITS4 (TCCTCCGCTTATTGATATGC) as forward and reverse primers respectively (Martin and Rygiewicz, 2005). The PCR product amplified was purified and sequenced by the Sanger sequencing method. The FASTA sequence was BLASTn searched in the NCBI GenBank database (www.ncbi.nlm.nih.gov). Based on the maximum homology and per cent similarity, the identity was assigned to endophytes using the criterion described by Higgins *et al.*, 2007. The phylogenetic analysis was carried out using the Clustal W plugin from MEGA software, version 11.0 (Kumar *et al.*, 2016). Phylogenetic relatedness was determined by employing a UPGMA (unweighted pair group method with arithmetic mean) analysis method

(Stefan Van Dongen and Winnepenninckx, 1996) with 1000 bootstrap replications (Felsenstein, 1985).

Statistical Analysis

All the collected data sets were presented as mean ± standard error (SE), with a minimum of three samples per genotype serving as biological replicates and a Completely Randomised Design (CRD) was employed. The multiple comparison was done by employing Tukey's honestly significant difference (HSD) test. The data analysis was carried out using R software version 4.2.2 and all the graphs were drawn using ggplot2 package of R studio.

Results and Discussion

Identification and Re-confirmation of the Endophytic Fungi

The microscopic observation was done for all eight endophytes (K-23, LAS-6, N-14, P-10, P-37, PJ-9, SF-5 and V4-J). Results revealed that six out of eight endophytes belong to the *Fusarium* species. Among these, K-23 (*Fusarium incarnatum)* has an elevated network of mycelia, a fast-growth habit while the SF-5 (*F. equiseti*) showed soft white mycelia. Both the endophytes possess micro and macroconidia. Whereas, N-14 (*Fusarium* sp.) was sporulating and showed white mycelia with a red tinge on top and bottom of the petri dishes and P-10 (*Fusarium* sp.) produced red colour spores at the bottom of the plate with white to yellowish mycelia on top, PJ-9 (*Fusarium* sp.) showed a floccose white fungal mat and had a very thin mycelia and V4-J (*F. chlamydosporum)* has hyaline or light colour hyphae with septa and possesses thin filament-like structures with dull white mycelia as reported earlier (Walsh *et al*., 2004). The two other endophytes, LAS-6 belongs to *Chaetomium globosum* possess brown ascospores with black color spores and P-37 (*Ulocladium dauci)* was a slow-growing fungus with *Alternaria*-like colony morphology with pale brown conidiophores (Gannibal, 2018) (Fig. 1). LAS-6 was earlier identified as *Chaetomium* species has produced the fruiting body called perithecia covered by long hairs (Sangamesh *et al*., 2018).

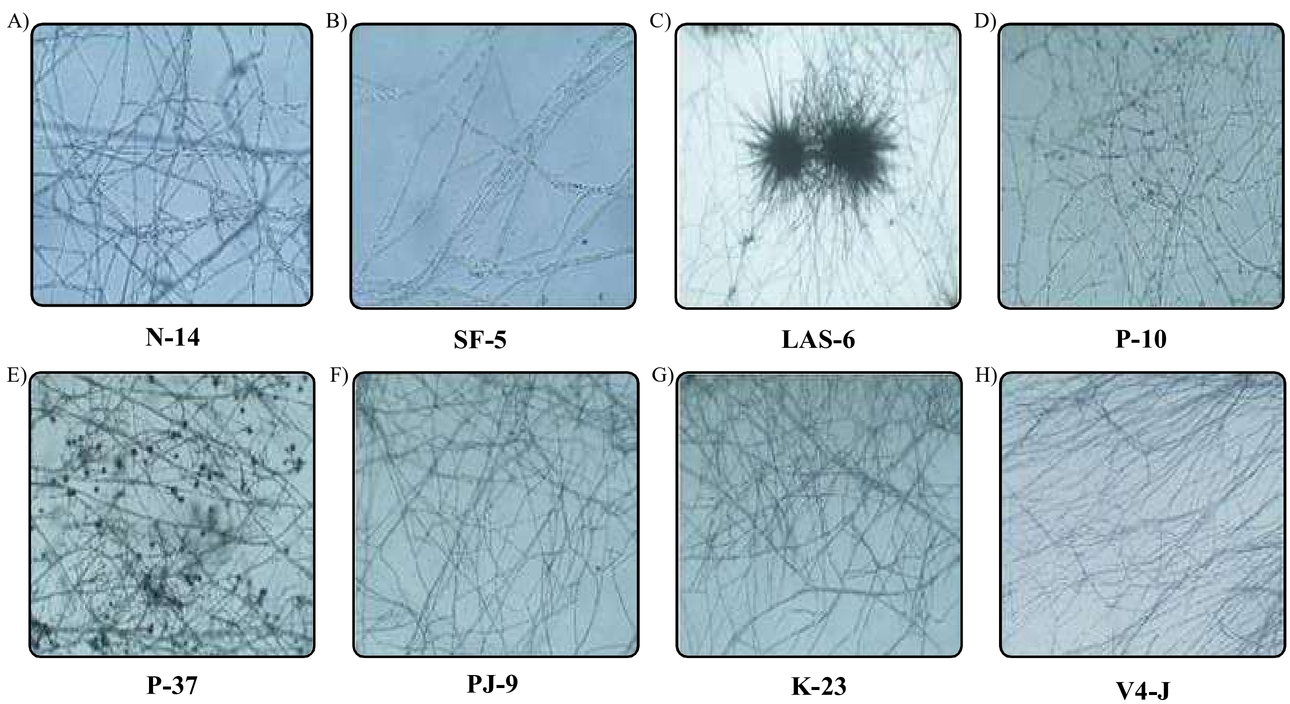

Fig. 1 : Microscopic observation of the endophytic fungi at 40x magnification. Mycelial structures of a) N-14, b) SF-5, c) LAS-6, d) P-10, e) P-37, f) PJ-9, g) K-23 and h) V4-J

Re-isolation of the Endophytic Fungi

Based on the leads from previous experiments in rice and tomato (Sangamesh *et al.,* 2018 and Pallavi & Nataraja, 2022), in this study an attempt has been made to understand the potential of five fungal endophytes (LAS-6, N-14, P-10, PJ-9 and SF-5) in new host *A. thaliana.* (Fig. 4). The colonisation percentage among the fungal endophytes differed significantly. The highest colonisation percentage was observed with the SF-5 treatment, reaching 67 per cent, while the lowest was observed with the PJ-9 treatment at 20 per cent. The other fungal endophytes showed moderate colonization percentage, with P-10 and N-14 both at 33 per cent and LAS-6 at 27 per cent. The control plants exhibited a zero per cent colonization rate, confirming the absence of any foreign organism contamination (Fig. 2a). *Fusarium* strains have been reported with a hallmark sign with tissue specificity causing vascular wilts (Alabouvette & Couteaudier, 1992 and Wang *et al*., 2020). However, the select fungi did not show a pathogenicity in the present study. Also, the majority of *Fusarium* endophytes have been shown to colonize roots (Fang *et al.,* 2019 and Zhang *et al.,* 2015). Further, the re-isolated endophytes were compared with the mother culture in terms of their morphology and mycelial structures (Fig. 2.b, c and d)) and subjected for molecular characterization. The sequence data of the PCR product confirmed the identity and *Fusarium sp.* as the closest match based on phylogeny (Fig. 3). This suggests that habitat-adapted fungal endophytes could successfully colonize the model system *Arabidopsis* symbiotically and promote early growth as observed in the case of *Serendipita indica* (Michal *et al*., 2011 and Vahabi *et al*., 2015).

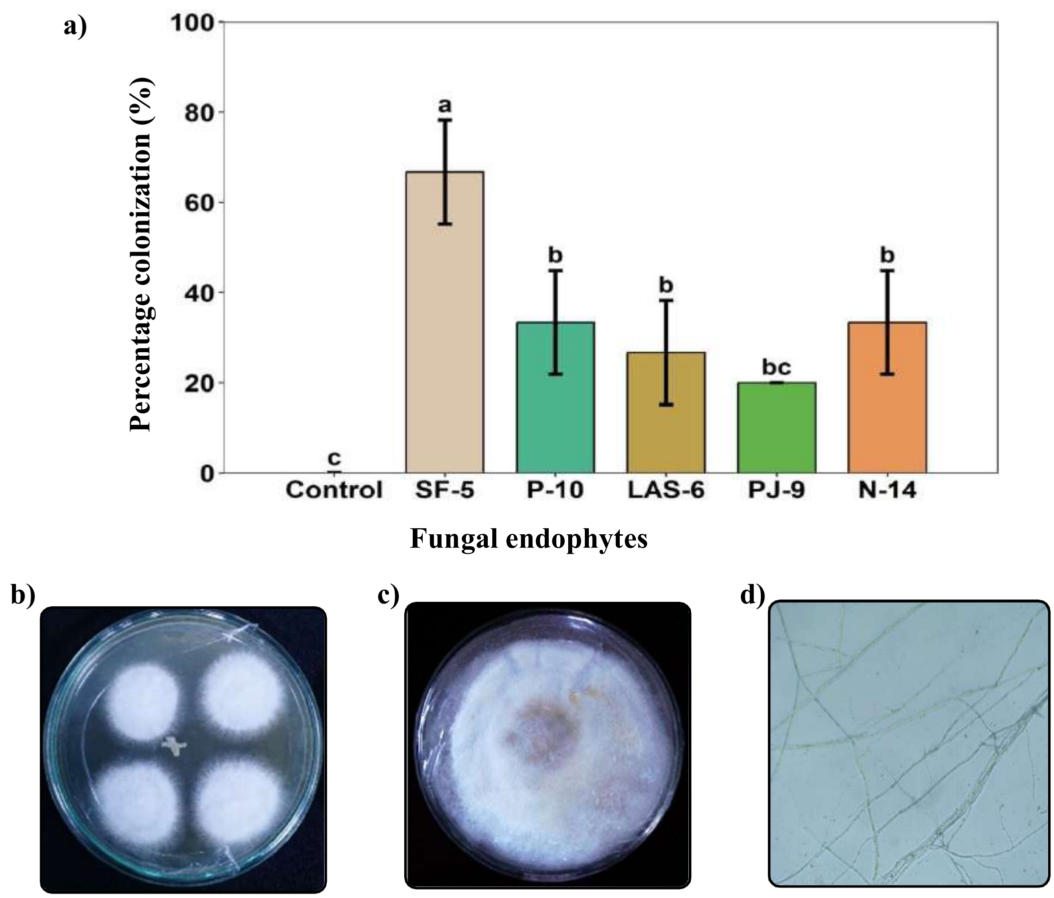

Fig. 2 : Assessment of fungal endophyte colonization in *A. thaliana.* a) Colonization percentage of the fungal endophytes in *A. thaliana*, b) confirmation of endophyte colonization (SF-5) in the tissue segments of *Arabidopsis* roots by re-isolation, c) comparison of colony morphology with mother culture and d) microscopic observation of the re-isolated fungus at 40x magnification

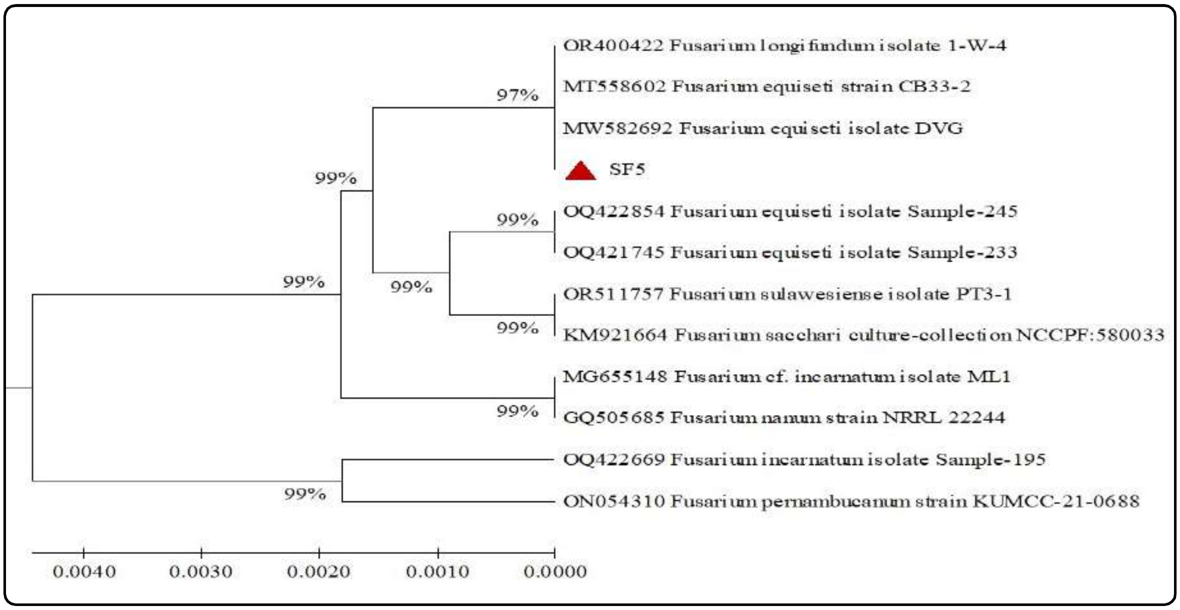

Fig. 3 : Phylogram generated from UPGMA (unweighted pair group method with arithmetic mean) analysis based on ITS sequence data

Endophyte-induced Activation of the Physiological Traits Associated with Growth

The study indicated that the five endophytes could efficiently colonize the new host (Fig. 2) and significantly increased rosette leaf area in the endophyte co-cultivated plants compared to the control, which did not show any growth response. The highest rosette leaf area was observed in the P-10 (122.43 mm^2) followed by SF-5 (98.13 mm^2), LAS-6 (87.10 mm^2), N-14 (85.06 mm^2) and control plants showed 31.10 mm^2 (Fig. 4 and 5a). This could be because, these endophytes are known to modulate

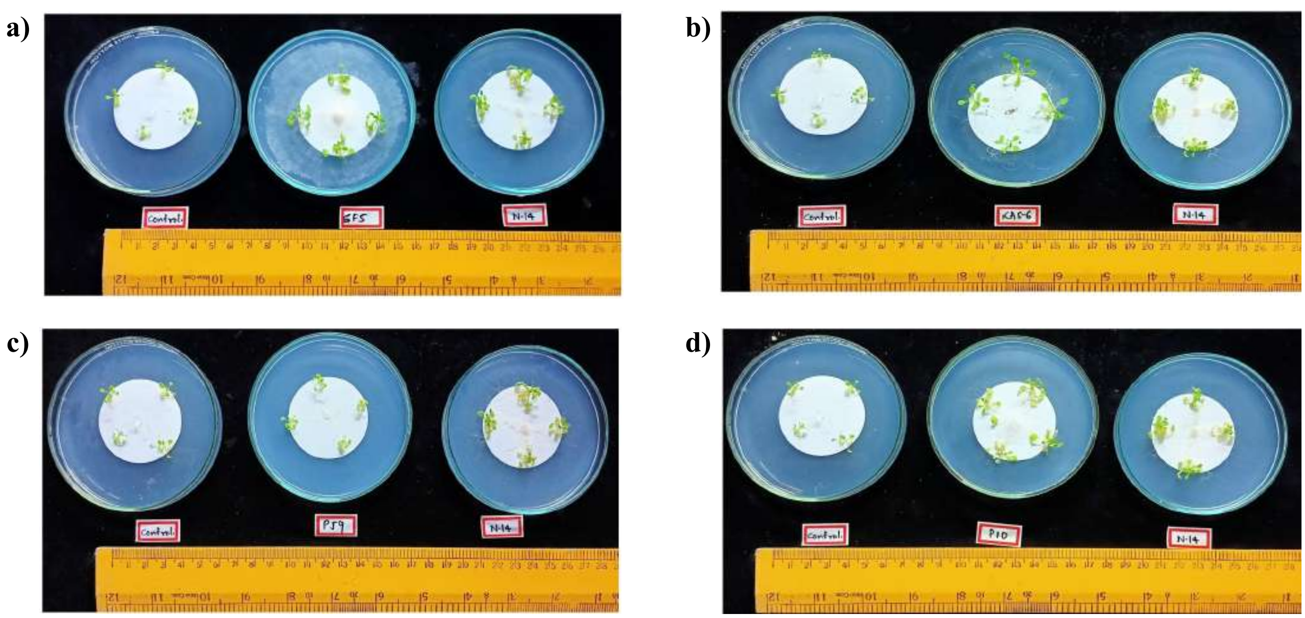

Fig. 4 : Co-cultivation of endophytic fungi with the young *Arabidopsis* seedlings. Photographs depicting the *in vitro* co-cultivation of *Arabidopsis* seedlings with endophytes, a) control, SF-5 and N-14 b) control, LAS-6 and N-14, c) control, PJ-9 and N-14 and d) control, P-10 and N-14

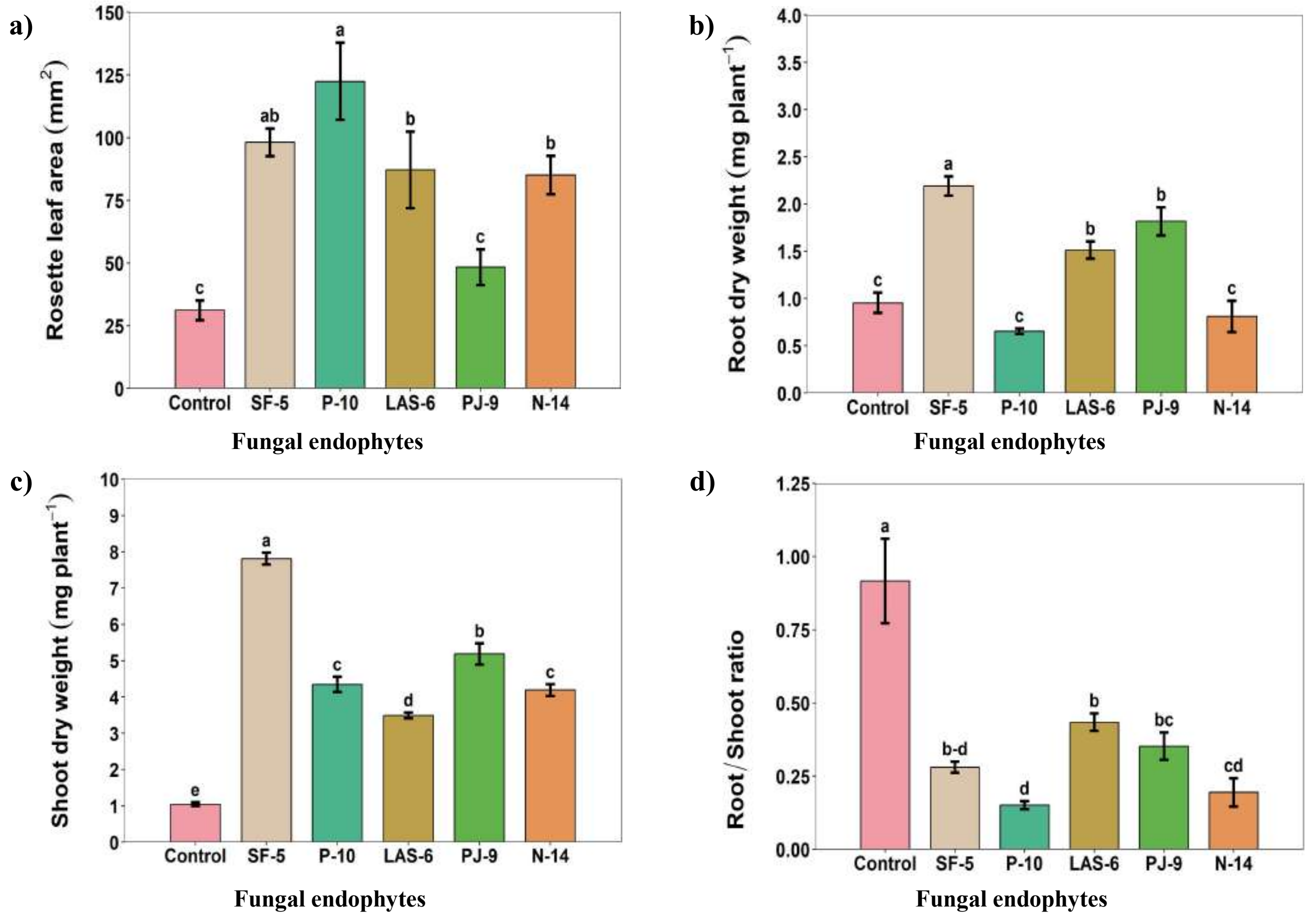

Fig. 5 : Growth response of the endophyte-enriched plants in the young *Arabidopsis* seedlings. a) Effect of fungal endophyte colonisation on the photosynthetic leaf area of *Arabidopsis* seedlings, b) Root dry weight (mg plant^{-1}), c) shoot dry weight (mg plant^{-1}) and d) root/shoot ratio

phytohormone levels in the host to induce growth promotion and impart stress resilience (Xu *et al*., 2018 ; Suebrasri *et al*., 2020). Additionally, N-14 was taken as a negative control, however, there was also a significant increase in the leaf area of plants treated with N-14 compared to control plants. Fungal endophytes form essential constituents of the leaf intercellular spaces and have a huge impact on photosynthesis (Suryanarayanan *et al*., 2022 and Bangari & Nataraja, 2023).

Interestingly, while comparing SF-5, P-10, LAS-6, PJ-9 and N-14 treated seedlings to the control group, the difference in leaf area was significant and was approximately two-fold and higher, indicating a substantial and noteworthy impact of these fungal endophytes in increasing the photosynthetic leaf area (Fan *et al*., 2020 and Rozpądek *et al.,* 2018).

Plant root and shoot biomass are crucial parameters for assessing the plant response to carbon, nutrient cycling and biomass partitioning. The root-to-shoot biomass ratio is a key indicator of plant resource allocation (Qi *et al.,* 2019). The present study showed an increased root dry weight (mg plant^{-1}) and shoot dry weight (mg plant^{-1}) in endophyte colonised *Arabidopsis* seedlings compared to control plants (Fig. 5b and c). Further, the root-to-shoot ratio was highest in the control group (0.91), followed by LAS-6 (0.43), PJ-9 (0.35), SF-5 (0.28), N-14 (0.19) and P-10 (0.15) (Fig. 5d). This suggests that endophytes balance the growth of the plant and improve water and nutrient absorption. Increased biomass accumulation in shoots suggests an increase in growth with improved resource acquisition facilitated by the endophytes, plants can allocate more energy to shoot growth, leading to a lower root-to-shoot ratio. This results in more significant above-ground biomass (Fig. 5c), which is often advantageous for photosynthesis and overall plant productivity. This observation shows the impact of endophyte colonization on plant physiological aspects, shedding light on its ability to optimize resource utilization for sustained growth and development. Endophytes play a crucial role in enhancing plant vitality by improving the uptake of macro and micronutrients from the soil organic substances and increasing the availability of these nutrients to the host (Rana *et al*., 2020; Mei *et al*., 2024 and Xue *et al*., 2024).

Identification of trait-specific endophytes, capable of activating inducible traits will have a huge impact on improving plant's water mining and uptake of nutrients. This kind of physiological adaptation aims to enhance the plant's ability to extract water and nutrients under water-limited conditions. This study highlights the potential of selected endophytes to activate the physiological traits, offering valuable insights into plant growth promotion and sustained yield. This approach not only signifies a potential strategy for mitigating the adverse impacts of climate change but also underscores its pivotal role in advancing crop improvement efforts.

Acknowledgements : The authors would like to thank Prof. R. Uma Shaanker, Department of Crop Physiology, UAS-B for providing the endophyte culture. The authors are grateful to the Indian Council of Agricultural Research (ICAR) - Centre for Advanced Agricultural Science and Technology (CAAST), activity1 1c- 'Next-generation technologies for micro-biome enabled seed priming' (ICAR_NAHEP; F. No./NAHEP/CAAST/2018-19; AB/AC7703) and ICAR, National Innovations on Climate Resilient Agriculture (NICRA) (F.No.2-13 (34)/21-22/NICRA dated 22 December 2021) for the financial support and RKP is thankful to the University Grants Commission (UGC), Savitribai Jyotirao Phule Fellowship for Single Girl Child (SJSGC), Government of India for providing research fellow ship during doctoral degree programme.

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Mysore J. Agric. Sci., 58 (4) : 235-249 (2024)

Management of Oriental Fruit Fly, *Bactrocera dorsalis* (Hendel) in Custard Apple Ecosystem

S. M. Ranjitha[1], G. Keshavareddy[2], Vidya[3] and H. S. Latha[3]
[1,2&3]Department of Agricultural Entomology, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
[4]AICRP on Dry Land Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : keshavaa_reddy@rediffmail.com

Authors Contribution

S. M. Ranjitha :
Investigation, analysis, draft prepration and data collection;

G. Keshavareddy :
Conceptualization, framed research proposal, draft correction and supervision;

Vidya :
Data collection;

H. S. Latha :
Correction of manuscript

Corresponding Author :
G. Keshavareddy

Received : July 2024
Accepted : August 2024

Abstract

Studies were made on the monitoring and management of fruit fly, *Bactrocera dorsalis* (Hendel) by installing different combinations of colour and shape of methyl eugenol based parapheromone traps during pre-harvest (September to October 2021) and post-harvest period (January to February 2022) in *Arka Sahana* custard apple ecosystem at the University of Agricultural Sciences, GKVK, Bengaluru. In the pre-harvest period, the data revealed that yellow colour with cylindrical shape trap attracted the highest mean number of fruit flies (300.30 ± 32.58), followed by transparent bottle trap (69.44 ± 46.21), yellow colour with sphere shape trap (64.63 ± 28.69) and white colour trap with trapezoidal shape (60.56 ± 39.64) which were on par with each other. The transparent trap with trapezoidal shape captured significantly the lowest number of fruit flies (28.75 ± 8.73). During the post-harvest period the maximum mean number of fruit flies were was attracted to yellow coloured traps with cylindrical and sphere shapes with 39.63 ± 9.29 and 31.75 ± 6.66, respectively. This was followed by transparent bottle trap (20.00 ± 6.33). The lowest mean numbers of fruit flies were captured in white colour (9.63 ± 2.76) and transparent colour (7.31 ± 2.44) traps with trapezoidal shapes, which showed lower trapping efficiency in the custard apple ecosystem. In the study bio-efficacy of five different insecticides treated along with jaggery, the results at 5, 10 and 15 days after treatments revealed that Acetamiprid + jaggery (65.04, 67.36 and 69.29%, respectively) and dinotefuran + jaggery (61.89, 62.25 and 63.55%, respectively) were found superior chemicals in reducing the mean per cent fruit infestation by the fruit flies. However, deltamethrin + jaggery (43.82, 43.86 and 47.45%, respectively) was found to be the least effective insecticidal treatment in reducing the mean per cent fruit infestation as compared to other chemical treatments in the custard apple ecosystem.

Keywords : Fruit fly, *Bactrocera dorsalis* (Hendel), Custard apple, *Arka sahana*, Insecticides, Management

Custard apple (*Annona squamosa* L.) is one of the most popular arid fruit crops, belongs to the family Annonaceae. The crop originated in West Indies, later it distributed all over the tropics and subtropics regions of the world, including Canada, Peru, India, Mexico, South and Central America, Brazil, Bermuda and Egypt. In the world, Canada is the largest exporter of custard apples contributing about 11.87 per cent of the world's share. In India, Assam, Bihar, Odisha, Rajasthan, Gujarat, Madhya Pradesh, Uttar Pradesh, Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu are the major states under custard apple cultivation. Among these, Maharashtra and Gujarat are the leading states in custard apple production (Annonymous, 2018).

The custard apple is an important dessert fruit crop, cultivated across the world and widely distributed in tropical and subtropical parts. Fruits are widely regarded as protective food necessary for maintaining human health due its nutritional values (Vittal *et al*., 2023). Similarly custard apple fruit has become more popular in recent years due to its medicinal value. As like jackfruit, the seed and fruit extract of custard apple exhibited antimicrobial activities and rich in antioxidant and phenol compounds (Valeeta *et al*., 2023). Fruits are very sweet, delicious and nutritionally rich in carbohydrates, proteins, minerals and antioxidants. Annona fruits are generally used fresh and also in preparing bakery products like nutritional custard apple powders, sweets and icecreams (Nair and Agrawal, 2017). Custard apple is thriving well in hot and dry climates as well as soils with little salinity or acidity (Kumar *et al*., 2021). The crop tolerates and survives in all the abiotic factors and it does not affect much in fruit production or yield. But biotic factors like insect pests are the major one that cause maximum yield losses in custard apples (Maruthadurai and Karuppaiah, 2014). There are about 20 species of insect pests have been reported to attack the crop. Among them Striped mealybug, *Ferrisia virgata* (Cockerell), Pink mealybug, *Maconellicoccus hirstus* (Green), Citrus mealybug, *Planococcus citri* (Risso), Passion vine mealybug, *Planococcus pacificus* Cox (Hemiptera: Pseudococcidae) and Mango mealy bug, *Perissopneumon ferox* Newstead are the major ones causing significant yield loss (Butani, 1976). The most destructive pest in the custard apple is mealy bugs, which cause about 50 to 60 per cent of yield losses. But in recent years, fruit fly has been an important threat in the custard apple production, causing 25-50 per cent yield loss in custard apple (Math, 2017).

The oriental fruit fly, *Bactrocera dorsalis* (Hendel) belongs to the order Diptera and family Tephritidae. It is characterized as an invasive polyphagous pest and has a severe impact on the global production of commercial fruits. The genus, *Bactrocera* comprises 651 described species, of which 50 were considered economically important pests of fruit crops (Vargas *et al*., 2015). Among the destructive category of the fruit fly species, *B. dorsalis* consisting of 52 species complexes, of these 8 are considered as economically important by Drew and Hancock (1994). As of 2017, *B. dorsalis* had been detected in four continents (Asia, Africa, North America and South America) and Oceania, including 75 countries and more than 124 regions. *Bactrocera dorsalis* has a global spatial expansion in the past 11 decades, which has been spread widely, especially in the last three decades (Zeng *et al*., 2019). The host range of *B. dorsalis* is associated with a total of 632 plant taxa, with key plant families including Anacardiaceae, Annonaceae, Clusiaceae, Lauraceae, Moraceae, Myrtaceae, Rutaceae, Sapotaceae and Solanaceae (Liquido *et al*., 2017). The extensive cultivation of custard apple, in turn enhances the incidence of insect pests. But now-a-days, fruit flies (Tephritidae) are becoming major pests, causing significant fruit yield loss in custard apple orchards (Maruthadurai and Karuppaiah, 2014). Fruit flies are an important quarantine pest that directly harms the fruit and indirectly reduce the quality, yield and fruit shipment (Clarke *et al*., 2005). Understanding the global distribution and expansion of *Bactrocera dorsalis* is crucial for developing effective pest management strategies to mitigate its impact on commercial fruit production worldwide.

The farmers are often unable to notice the fruit fly infestation in custard apple until the liquid oozes out from the ripened fruits, which leads to severe damage to the fruit yield and quality. Farmers have little idea about the management practices of fruit fly in custard apple since the early days until today. The total life cycle from egg to adult fly requires about 16 to 18 days. After mating, the gravid female starts laying eggs within 4 to 5 days. Under optimum conditions, a female fly can lay more than 371.9 ± 60.78 eggs on custard apple fruit during its lifetime. Eggs are laid on fruit rind by piercing the fruit with the help of a sharp ovipositor. The eggs of fruit flies are elliptical, smooth, elongated, slightly curved and tapering at one end. The incubation period is 1.50 ± 0.48 days. The hatched maggots are cylindrical, apodous with an elongated body pointed anteriorly. The larval duration is completed in 8.5 ± 0.84 days. The grown-up larva emerges from the fruit, drops to the ground, enters into the soil and pupation takes place in a dark brown puparium. The pupal period lasted for 12.1 ± 1.79 days. The total life cycle from egg to adult emergence is about 18 to 23 days (Naik *et al.,* 2017).

Among the various management strategies, the male annihilation technique with methyl eugenol para pheromone based trap is the most effective and environmentally friendly tool to manage the fruit fly (Ballo *et al.,* 2020). The response of fruit flies to visual stimuli like shape, size and colour helps to design better traps in order to increase the capturing efficiency for mass trapping and monitoring of fruit flies (Younus *et al*., 2022). Further, there are no official chemical management practices recommended either by State Agricultural Universities or National Horticultural Research Institutions specifically for controlling fruit flies in custard apple. The selection of insecticides for chemical trials was based on the published literature on chemical recommendations for fruit flies in other fruit crops. A few other chemicals, like lambda cyhalothrin and chlorantraniliprole, which have a shorter waiting period on vegetables and fruit crops and being relatively safer for human beings, were also chosen for chemical trials to evaluate their efficacy against fruit flies in the custard apple ecosystem.

Material and Methods

The experiment was conducted in *Arka Sahana* custard apple orchard situated at the All India Co-ordinated Research Project for Dry Land Agriculture, University of Agriculture Sciences (UAS), GKVK campus, Bengaluru. For the study, four different commercially available traps *viz.,* Pest Control India Pvt. Ltd. (PCI) trap, KVK Hirehalli trap, Bio-pest Management Pvt. Ltd. trap, Yellow trap (Brand) and self-prepared Bottle trap (Fig. 1), were evaluated. In all the traps, plywood blended with methyl eugenol from PCI Pvt. Ltd., was used. In order to kill the attracted fruit flies in the trap, a few drops of cypermethrin 10 % EC in the ratio of 1:1 with water were smeared on the surface of the methyl eugenol baits. The traps were tied to the custard apple trees at an average height of 1.2 to 1.5 m from the ground level following Randomized Block Design (RBD). Each custard apple tree was 5m apart.

Fig. 1: Four different commercially available traps used in the experiment

Preparation of Bottle Trap

The bottle trap was prepared by using a kinley water bottle of one liter capacity. At the top $1/3^{rd}$ portion of the water bottle, 2 windows of 2.5 cm length x 2 cm width were cut at equal distance with the help of a red-hot needle. The windows were cut on two sides and bottom leaving the top side, which was used as a hinge by lifting up in order to prevent rainwater from entering the water bottle trap.

Experimental Layout

A block of 1.2 acres area containing uniform canopy sized custard apple trees of *Arka Sahana,* was selected for the field experiment. A single trap was tied to each tree and each tree represented one replication. Four such replications for each commercial trap design were maintained. The observations on trap catches were noted on a weekly basis by collecting the fruit flies in butter paper covers separately from each trap. The samples were labelled and brought to the lab where the number of fruit flies trapped in each trap were counted separately. These observations were continued for two months. Later the specimens were

TABLE 1

Different types of traps used for trapping fruit fly in custard apple ecosystem

Treatments	Commercial Traps	Colour and shape of the trap
T_1	PCI trap	Yellow colour with sphere shape
T_2	KVK Hirehalli trap	White colour with trapezoidal shape
T_3	Biopest trap	Transparent with trapezoidal shape
T_4	Yellow trap	Yellow colour with cylindrical shape
T_5	Bottle trap	Transparent water bottle

identified with the help of the taxonomist Dr. K. J. David at ICAR- National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru. The adult flies were identified as *Bactrocera dorsalis* and there was no species composition observed. This experiment was conducted in two phases, during pre-harvest (September-October, 2021) and post-harvest (January- February 2022) of custard apple fruits. Treatments and their details used in the experiment are listed in Table 1.

Evaluation of Efficacy of Insecticides against Fruit Fly

Evaluation of the relative efficacy of different insecticides against fruit fly on custard apple was conducted in two trials; one during the second fortnight of August and the other during first fortnight October, 2021 at All India Co-ordinated Research Project (AICRP) for Dry Land Agriculture, GKVK, Bengaluru. The experiment was laid out in Randomised Block Design with six treatments including untreated control. Each treatment was replicated four times with individual custard apple plant representing one replication. The *Arka Sahana* custard apple hybrid released by ICAR- Indian Institute of Horticultural Research, Hessaraghatta, Bengaluru, was selected for the experiment since it is highly susceptible to fruit fly infestation. The first insecticidal treatments were imposed during the month of August when fifty per cent fruits in the plants attained physiological maturity. The second trial was conducted in the month of October when the late borne fruits in the plants attain physiological maturity to check the efficacy of respective chemicals against the fruit fly infestation. The data on fruit infestation and number of maggots in 5 randomly selected fruits per replication was recorded by destructive sampling method at 5, 10 and 15 days after treatments imposition. Later the per cent reduction in fruit damage by fruit fly over control was worked out for each treatment.

Statistical Analysis

The trap catch data and the mean per cent fruits infested by *B. dorsalis* in custard apple after treatments imposition were worked out and values were then subjected to single factor analysis of variance (ANOVA) using SPSS Software. The critical difference (CD) at 5 per cent probability level was used as the test criterion.

RESULTS AND DISCUSSION

Trapping Efficiency of Different Commercially Available Traps during Post-Harvest Period (September - October, 2022)

The mean number of *B. dorsalis* fruit flies collected in each trap of different colours and shapes during the pre-harvest period is given in Table 2.

During the first fortnight of September 2021, the data on fruit flies trapped revealed that the highest mean number of fruit flies was captured in a yellow coloured trap with a cylindrical shape (292.00 ± 31.50) which was significantly superior over the other traps and showed higher trapping efficiency in the custard apple ecosystem. This was followed by a transparent bottle trap (134.50 ± 16.78) and the next best traps in the descending order of efficiency were white with a

TABLE 2

Trapping efficiency of different traps of fruit fly during pre-harvest period

Treatments	Mean number of fruit flies trapped				Pooled mean
	September 2021		October 2021		
	1ST Fortnight	2nd Fortnight	1st Fortnight	2nd Fortnight	
Yellow colour sphere shape trap	(104.50 ± 12.12) c	(39.25 ± 12.09)bc	(65.50 ± 3.51) b	(49.25 ± 4.65) bc	(64.63 ± 28.69) b
White colour trapezoidal shape trap	(116.75 ± 11.56) bc	(55.75 ± 3.30) b	(45.25 ± 4.79) bc	(24.50 ± 2.08) d	(60.56 ± 39.64) b
Transparent colour trapezoidal shape trap	(38.25 ± 4.99) d	(17.25 ± 3.59) d	(28.25 ± 6.85) c	(31.25 ± 5.74) cd	(28.75 ± 8.73) c
Yellow colour cylindrical shape trap	(292.00 ± 31.50) a	(257.75 ± 24.01)a	(328.25 ± 26.99)a	(323.21 ± 22.69) a	(300.30 ± 32.58) a
Transparent bottle trap	(134.50 ± 16.78) b	(25.75 ± 5.74) cd	(54.50 ± 4.51) b	(63.00 ± 3.37) b	(69.44 ± 46.21) b
SEm±	4.17	5.13	6.69	6.53	6.90
CD at 5%	12.84	15.79	20.60	20.11	21.28
CV	12.97	12.60	13.46	12.81	14.18

Data in each column followed by same alphabet/s are not differed significantly

trapezoidal shape (116.75 ± 11.56), which were statistically on par with each other with respect to their trapping efficiency of fruit flies. These were followed by yellow coloured trap with a sphere shape (104.50 ± 12.12). However, the lowest mean number of fruit flies was collected in a transparent trap with a trapezoidal shape (38.25 ± 4.99), which showed significantly the lowest trapping efficiency and captured minimum number of fruit flies as compared to the other traps (Fig. 2).

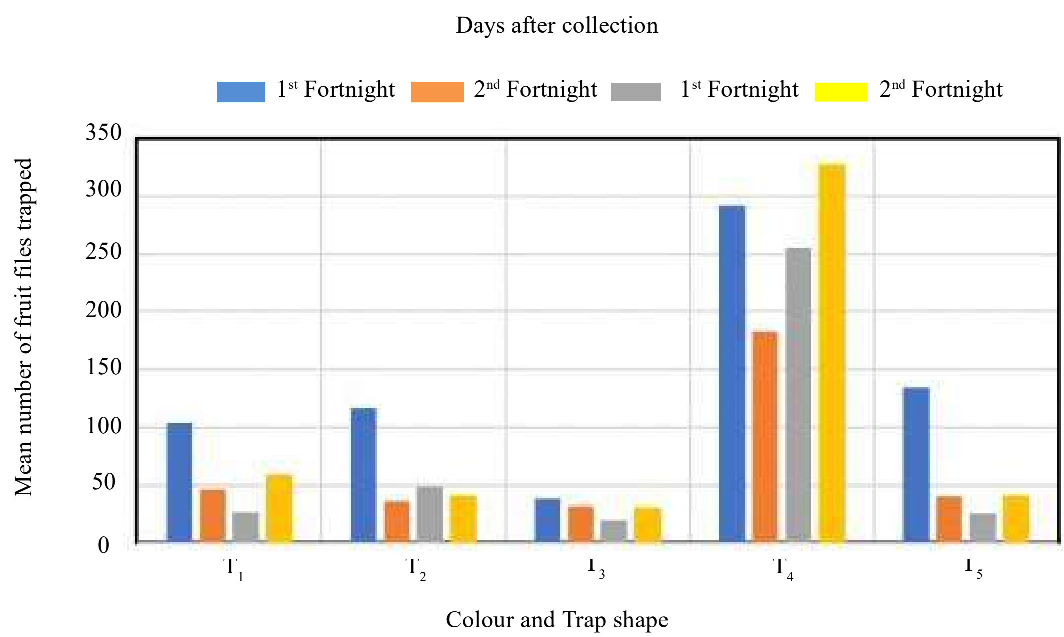

Fig. 2 : Mean number of fruit flies captured during Pre-harvest period (September- October 2021) of custard apple orchard

The observations on fruit flies trapped during the second fortnight of September (pre-harvest period) revealed that the yellow coloured trap with a cylindrical shape (257.75 ± 24.01), captured a significantly higher number of fruit flies as compared to others. This was followed by a white colour trap with a trapezoidal shape (55.75 ± 3.30), which is on par with yellow colour sphere shape trap (39.25 ± 12.09). The transparent bottle trap (25.75 ± 5.74) and transparent trap with trapezoidal shape (17.25 ± 3.59) showed similarity in trapping efficiency and captured significantly the lowest number of fruit flies.

During the first fortnight of October 2021, the yellow coloured trap with a cylindrical shape (328.25 ± 26.99), was significantly superior over other traps in fruit fly trapping. This was followed by yellow colour trap with a sphere shape (65.50 ± 3.51), transparent bottle trap (54.50 ± 4.51) and white colour trap with a trapezoidal shape (45.25 ± 4.79), which showed statistically similar in trapping efficiency. However, the lowest mean number of fruit flies, (28.25 ± 6.85) was captured in transparent trap with a trapezoidal shape, which trapped significantly the lowest number of fruit flies as compared to other traps.

The data on the trapping efficiency of fruit flies during the second fortnight of October revealed that among different traps, the yellow coloured trap with a cylindrical shape captured the highest mean number of fruit flies (323.21 ± 22.69), which was superior to all the other trap designs in trapping fruit flies in the custard apple ecosystem. The next best traps were the transparent bottle trap (63.00 ± 3.37) and the yellow colour trap with sphere shape (49.25 ± 4.65), which were statistically on par with each other and showed similar trapping efficiency towards fruit flies, *B. dorsalis*. These were followed by transparent trap and white colour trap with a trapezoidal shape with mean number of fruit flies trapped of 31.25 ± 5.74 and 24.50 ± 2.08, respectively, which were both lowest and statistically on par with each other with respect to their trapping efficiency.

Trapping Efficiency of Different Commercially Available Traps during Post-Harvest Period (January-February, 2022)

The mean number of *B. dorsalis* fruit flies trapped in different colour and shape traps during the post-harvest period is given in Table 3.

TABLE 3

Trapping efficiency of different traps of fruit fly during post-harvest period

Treatments	Mean number of fruit flies trapped				Pooled mean
	January 2022		February 2022		
	1ST Fortnight	2nd Fortnight	1st Fortnight	2nd Fortnight	
Yellow colour sphere shape trap	(28.00 ± 2.94) b	(24.50 ± 11.70) a	(35.50 ± 5.07) a	(39.00 ± 3.16) b	(31.75 ± 6.66) b
White colour trapezoidal shape trap	(11.75 ± 1.71) d	(6.25 ± 4.03) c	(12.00 ± 1.83) c	(8.50 ± 1.91) d	(9.63 ± 2.76) d
Transparent colour trapezoidal shape trap	(8.25 ± 0.96) e	(4.25 ± 1.50) c	(10.00 ± 1.41) c	(6.75 ± 2.06) d	(7.31 ± 2.44) d
Yellow colour cylindrical shape trap	(37.00 ± 2.16) a	(30.00 ± 6.68) a	(39.25 ± 2.22) a	(52.25 ± 3.40) a	(39.63 ± 9.29) a
Transparent bottle trap	(22.75 ± 2.75) c	(13.50 ± 5.07) b	(27.50 ± 4.20) b	(16.25 ± 2.22) c	(20.00 ± 6.33) c
SEm±	0.96	1.35	1.28	1.26	1.48
CD at 5 %	2.96	4.15	3.97	3.88	4.57
CV	13.04	12.46	11.38	11.81	13.39

Data in each column followed by same alphabet/s are not differed significantly

In the first fortnight of January during the post-harvest period, the data revealed that the yellow coloured trap with cylindrical shape captured the highest number of fruit flies (37.00 ± 2.16), which was superior to the other traps. This was followed by yellow color trap with a sphere shape (28.00 ± 2.94) and transparent bottle trap (22.75 ± 2.75) and these were on par with each other in trapping efficiency in the custard apple ecosystem. However, the least number of fruit flies were recorded in white coloured and transparent trap with a trapezoidal shape with 11.75 ± 1.71 and 8.25 ± 0.96, respectively.

The observations on the trapping efficiency of fruit flies by using different traps during the second fortnight of January, at the post-harvest period revealed that, among all the traps, the yellow coloured traps with cylindrical and sphere shapes captured the highest number of fruit flies 30.00 ± 6.68 and 24.50 ± 11.70, respectively, which were statistically on par in their trapping efficiency. These were followed by transparent bottle trap (13.50 ± 5.07). The white colour and transparent trap with trapezoidal shape recorded 6.25 ± 4.03 and 4.25 ± 1.50, respectively and thus captured the lowest mean number of fruit flies and were on par with each other in their trapping efficiency.

The data for the first fortnight of February revealed that the highest mean number of fruit flies were trapped in yellow coloured trap with cylindrical and sphere shape with 39.25 ± 2.22 and 35.50 ± 5.07, respectively. Both of these traps were on par with each other and were significantly superior to the other traps. The next best treatment was a transparent bottle trap with 27.50 ± 4.20 number of fruit flies captured during the first fortnight of February. However, lowest mean number of fruit flies *i.e.,* 12.00 ± 1.83 and 10.00 ± 1.41 were captured in white and transparent trap with trapezoidal shape, respectively and both traps showed statistically similar trapping efficiency with respect to *B. dorsalis* as compared to other traps in the custard apple ecosystem.

During the second fortnight of February at post-harvest period, yellow colour trap with cylindrical shape showed the highest trapping efficiency of fruit flies (52.25 ± 3.40) and was significantly superior over all the other traps. This was followed by yellow coloured sphere shaped trap with a mean number of fruit flies of 39.00 ± 3.16 being trapped during the same period. The next best trap was the transparent bottle trap with 16.25 ± 2.22 mean number of the fruit flies captured. The white colour and transparent trap with trapezoidal shape captured the lowest mean number of fruit flies *i.e.,* 8.50 ± 1.91 and 6.75 ± 2.06, respectively (Fig. 3).

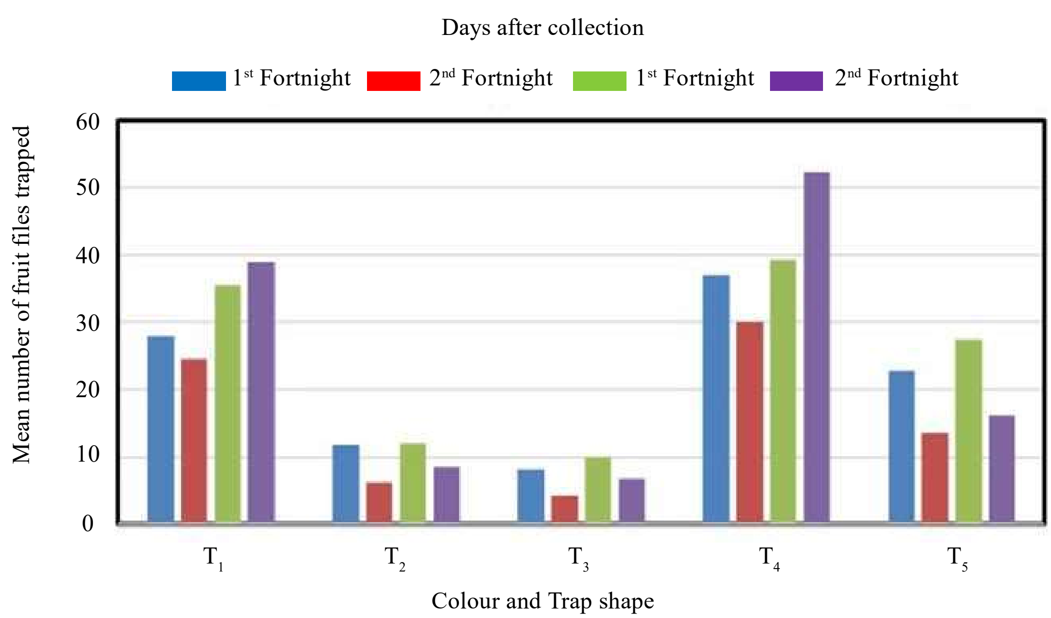

Fig. 3 : Mean number of fruit flies captured during Post-harvest period (January- February 2022) of custard apple orchard

In the present study, among commercially available traps of various colours and shapes that were evaluated for their trapping efficiency in custard apple ecosystem, the yellow colour trap with cylindrical shape captured the highest mean number of fruit flies and was significantly superior over all the other traps. This was followed by yellow coloured trap with sphere shape. Even though surface area of cylindrical shape trap was less, it attracted more number fruit flies, it may be due to presence of entry holes on either side of the trap. So, flies can easily get entry into the trap. But in case of yellow trap, the entry hole was below the trap, so it was difficult for flies to find the holes to enter the trap. The colour of the traps played an important role in attracting fruit flies in addition to methyl eugenol. The yellow colour traps attracted more fruit flies since the yellow/ orange or green colour resembles the host colour, as a visual cue for attracting the fruit flies. Further, earlier researchers have also reported that fruit flies are active during the morning and late afternoon. During this period, given a choice, fruit flies were attracted more to the colour green. This is clear evidence that fruit flies have colour choice. The present outcome was supported by earlier workers (Verghese *et al*., 2002 and Bajaj & Singh, 2020) who reported that deep yellow colour traps attracted a greater number of fruit flies as compared to the other coloured traps. Further, Stark and Vargas (1992) also observed that yellow and white coloured traps attracted a greater number of *B. dorsalis* as compared to green, red and black coloured traps in the guava orchard. They mentioned the reason for the preference of *B. dorsalis* to yellow colour which might be due to the better reflectance of yellow colour during the day under sunlight.

Agrawal and Yadav (2022) found that, yellow and green coloured vertical traps attracted more number of *B. dorsalis, B. nigrotibialis* (Perkins)*, B. correcta* (Bezzi) and *B. zonata* (Saunders) species as compared to transparent traps in the guava orchard. Ravikumar (2006) observed that yellow coloured traps were more efficient in trapping a greater number of *Bactrocera* spp. flies in guava orchards. Further, they also reported that cylindrical shaped traps and sphere shaped traps attracted a higher number of *B. dorsalis* in guava and mango orchards, respectively.

The outcome of the current studies on the efficiency of selected among different commercially available traps in trapping fruit flies was also in close agreement with Younus *et al*. (2022) who have reported that among the tested traps, the cylindrical bottle trap trapped the highest number of *Bactrocera* spp. in peach orchards. Bajaj and Singh (2018) observed that triangular, cylindrical and sphere shaped traps provided with methyl eugenol para pheromone attracted a greater number of *B. zonata* and *B. dorsalis*. Kumar and Laskar (2019) also reported that yellow coloured traps attracted the significantly highest number of *B. cucurbitae*. Katsoyannos and Kouloussis (2001) also found that yellow and orange coloured sphere shaped traps attracted a greater number of olive fruit fly, *B. oleae* (Rossi) as compared to white and blue coloured sphere shaped traps. However, Rajitha and Viraktamath (2005) found that *B. correcta* (Bezzi) was attracted to sphere shaped and cylinder-shaped traps, while *B. zonata* (Saunders) was attracted more to bottle traps. Further, they also reported that *B. dorsalis* did not show any preference for trap shapes in guava orchard but, in mango orchard it showed preference for sphere shaped traps.

In the present investigation, it was found that the transparent bottle attracted more fruit flies next best in custard apple ecosystem. These findings were in comparable with those of Math (2017) who observed that, *B. dorsalis* were attracted more towards transparent bottle traps as compared to green, blue and white colour traps in the custard apple ecosystem, whereas Sikandar *et al*. (2017) reported that yellow and transparent traps attracted a greater number of *B. dorsalis* and *B. zonata* fruit flies in the citrus orchard. Susanto *et al*. (2020) have also reported that bottle traps impregnated with methyl eugenol trapped the highest number of fruit flies. Hussain *et al*. (2022) observed that pet bottle traps capture more *B. zonata* and *B. dorsalis*.

Efficacy of Selected Insecticides against Fruit Fly in the August Month (Trial-I), 2021

Efficacy testing trial of selected insecticides against fruit fly was conducted during second fortnight of August, 2021 at All India Co-ordinated Research Project (AICRP) for Dry Land Agriculture, GKVK, Bengaluru. The data on the efficacy of selected insecticides against the fruit fly, *B. dorsalis* infesting custard apple are presented in Table 4.

Five days post-treatment, in trial-I found that all five treatments were significantly superior over the control. Acetamiprid + jaggery (62.92%) and dinotefuran+ jaggery (59.36%) were the best treatments and equally effective in reducing the mean per cent fruit infestation over control. These were followed by chlorantraniliprole + jaggery (51.25%) and lambda-cyhalothrin + jaggery (47.93%) treatments which were on par with each other. Deltamethrin + jaggery (43.12%) was the least effective treatment against fruit fly infestation but, was found significantly superior over the untreated control.

The mean per cent reduction in fruit fly infestation at ten days after the post-treatment application revealed that, all the treatments were significantly superior over the untreated control. Acetamiprid + jaggery (63.89%) and dinotefuran + jaggery (62.14%) was the best treatments in reducing the mean per cent fruit infestation as compared to the other treatments. This were followed by chlorantraniliprole + jaggery (54.35%) and lambda cyhalothrin + jaggery (50.53%) treatments which were found equally effective in reduction of the mean per cent fruit infestation by fruit fly. Deltamethrin + jaggery (45.85%) was found be the least effective treatment in reducing the mean per cent fruit infestation but, was significantly superior over the control in reducing the fruit fly infestation.

The observations recorded fifteen days after post treatments revealed that, all five chemical treatments were significantly superior over the untreated control. Among them, acetamiprid + jaggery (69.47%) was found significantly superior over all other treatments in reducing the mean per cent fruit infestation. This was followed by dinotefuran + jaggery (65.26%). The next best treatments were chlorantraniliprole + jaggery (57.05%) and lambda-cyhalothrin + jaggery (55.62%) which were on par with each other in reducing the mean per cent fruit infestation by fruit fly. These were followed by deltamethrin + jaggery (44.78%) and it was found to be least effective treatment in reducing the mean per cent fruit infestation by fruit fly, but it was significantly superior over the untreated control (Table 4).

Efficacy of Selected Insecticides against Fruit Fly in the October Month (Trial-II), 2021

Five days after the treatment application, it was found that all the treatments were significantly superior over the untreated control by recording higher mean per cent reduction in fruit fly infestation. Out of five insecticides tested against fruit fly, acetamiprid + jaggery (67.33%) and dinotefuran + jaggery (63.94%), were the best treatments and were on par with each other in reducing the mean per cent fruit infestation as compared to other chemical treatments. These were followed by chlorantraniliprole + jaggery (55.91%) and lambda-cyhalothrin + jaggery (51.98%), which were equally effective against the fruit fly infestation. Deltamethrin + jaggery (46.81%) was found the least effective treatment but significantly superior over the untreated control in reducing mean per cent fruit infestation by fruit fly.

Ten days after the treatment imposition, the data revealed that acetamiprid + jaggery (69.37%) was found to be the best treatment in suppressing the fruit fly infestation and it was significantly superior over all other treatments. This was followed by dinotefuran + jaggery (64.63%) and chlorantraniliprole + jaggery (62.53%) which were on par with each other. These were followed by lambda-cyhalothrin + jaggery (57.25%) which was the next best treatment in reduction of mean per cent fruit infestation. The least effective insecticide treatment was the deltamethrin + jaggery (48.31%) against the fruit fly infestation as compared to all other chemical treatments but, it was found significantly superior over the untreated control.

The mean per cent reduction in fruit fly infestation at fifteen days after the treatments, data revealed that

TABLE 4

Efficacy of selected insecticides against fruit fly, *B. dorsalis* on custard apple in the months of August (Trial-I), October (Trial-II) and pooled data during 2021

Treatments + jaggery @ 5 g/l	Mean per cent reduction in fruit infestation (Trial-I)			Mean per cent reduction in fruit infestation (Trial-II)			Mean per cent reduction in fruit infestation (Pooled data)		
	5 DAT	10DAT	15 DAT	5 DAT	10DAT	15 DAT	5 DAT	10DAT	15 DAT
Chlorantraniliprole 18.5% SC @ 0.3 ml/l	60.79 (51.25) b	66.00 (54.35) b	70.41 (57.05) c	68.50 (55.91) b	78.66 (62.53) c	81.56 (64.58) bc	64.64 (53.54) b	63.95 (53.14) c	68.37 (55.78) c
Lambda-cyhalothrin 5% EC @ 0.5 ml/l	55.09 (47.93) bc	59.54 (50.53) bc	68.05 (55.62) c	62.03 (51.98) b	70.67 (57.25) b	78.21 (62.18) c	60.80 (51.24) b	66.73 (54.80) c	71.26 (57.63) bc
Dinotefuran 20% SG @ 0.3 g/l	73.87 (59.36) a	77.93 (62.14) a	82.37 (65.26)b	80.65 (63.94) a	81.61 (64.63) b	85.15 (67.37) ab	77.76 (61.89) a	78.18 (62.25) b	79.79 (63.55) ab
Acetamiprid 20% SP @ 0.3 g/l	79.23 (62.92) a	80.45 (63.89) a	87.59 (69.47) a	85.14 (67.33) a	87.55 (69.37) a	89.70 (71.39) a	82.19 (65.04) a	85.03 (67.36) a	86.70 (69.29) a
Deltamethrin 2.8% EC @ 1 ml/l	50.21 (43.12) c	51.47 (45.85) c	49.61 (44.78) d	53.14 (46.81) c	55.73 (48.31) d	59.23 (50.37) d	47.99 (43.82) c	48.02 (43.86) d	54.27 (47.45) d
Control (Untreated)	0.00 (0.00) d	0.00 (0.00) d	0.00 (0.00) e	0.00 (0.00) d	0.00 (0.00) e	0.00 (0.00) e	0.00 (0.00) d	0.00 (0.00) e	0.00 (0.00) e
SEm±	2.01	1.95	1.88	2.85	2.31	2.32	2.69	2.33	3.09
CD at 5%	8.34	6.78	7.32	6.98	8.76	7.41	8.47	7.35	8.75
CV (%)	10.65	7.89	9.58	8.49	7.49	8.76	8.38	7.03	8.92

DAT- Days after treatment. Values in parentheses are Arc sin transformed. Data in each column followed by same alphabet/s are not significantly different by DMRT at p=0.05

all the treatments were significantly superior over the untreated control. Acetamiprid + jaggery (71.39%) and dinotefuran + jaggery (67.37%) were found to be the best treatments in reducing the fruit fly infestation as compared to all other treatments and statistically on par with each other. The next best treatments were chlorantraniliprole + jaggery (64.58%) and lambda-cyhalothrin + jaggery (62.18%), which were equally effective in reducing the mean per cent custard apple fruit infestation by fruit flies. However, deltamethrin + jaggery (50.37%) was found to be the least effective insecticidal treatment in reducing mean per cent fruit infestation but was found significantly superior over untreated control (Table 4).

Efficacy of Insecticides against Fruit Fly, *B. dorsalis* (Pooled Data)

The pooled data on the efficacy of different insecticides against fruit fly, *B. dorsalis* infesting custard apple are presented in Table 4.

At fifth day after the post-treatments, all the chemical treatments were significantly superior over the untreated control by recording lesser mean per cent fruit infestation in all the insecticide treatments. Acetamiprid + jaggery (65.04%) and dinotefuran + jaggery (61.89%) were the best treatments in reducing the mean per cent fruit infestation by the fruit fly. These were followed by chlorantraniliprole + jaggery (53.54%) and lambda-cyhalothrin + jaggery (51.24%), which were equally effective against the fruit fly infestation. Deltamethrin + jaggery (43.82%) was found to be the least effective insecticidal treatment in reducing mean per cent fruit infestation as compared to other chemical treatments but was found significantly superior over the untreated control.

The observations revealed that ten days post-treatments, all the treatments were significantly superior over the untreated control. Among them, acetamiprid + jaggery (67.36%) was found to be the highly effective treatment in reduction of per cent fruit infestation by fruit fly compared to all other treatments. This was followed by dinotefuran + jaggery (62.25%) and significantly differ from lambda-cyhalothrin + jaggery (54.80%) and chlorantraniliprole + jaggery (53.14%), which were on par with each other. Deltamethrin + jaggery (43.86%) was found to be the least effective insecticidal treatment in reducing the mean per cent fruit infestation but it was found significantly superior over the untreated control.

At fifteen days after treatment imposition, the data revealed that, all the treatments were significantly superior over the untreated control. Acetamiprid + jaggery (69.29%) and dinotefuran + jaggery (63.55%) were found to be the best treatments and statistically on par with each other in reducing the per cent fruit infestation compared to all other treatments. These were followed by lambda-cyhalothrin + jaggery (57.63%) and chlorantraniliprole + jaggery (55.78%), which were equally effective against the fruit fly infestation in custard apple. The least effective treatment in reducing the mean per cent fruit infestation was deltamethrin + jaggery (47.45%) compared to other chemical treatments, but it was found significantly superior over the untreated control.

From the pooled data, out of five insecticides evaluated against fruit fly, *B. dorsalis* in *Arka Sahana* custard apple orchard, acetamiprid 20%SP @ 0.3 g/l + jaggery @ 5 g/l and dinotefuran 20%SG @ 0.3 g/l + jaggery @ 5 g/l were found as superior treatments and recorded lowest mean per cent fruit infestation at 5, 10 and 15 days post-treatments. The next best treatments were chlorantraniprole 18.5%SC @ 0.3 ml/l + jaggery @ 5 g/l and lambda-cyhalothrin 5 % EC @ 0.5 ml/l + jaggery @ 5 g/l and they showed equal effectiveness against the fruit fly infestation in custard apple. Deltamethrin 2.8 % EC @ 1 ml/l + jaggery @ 5 g/l was found the least effective treatment against the fruit fly infestation in custard apple ecosystem (Table 4). The effectiveness of acetamiprid against fruit flies in custard apple in the present study is in confirmation with the findings of Reynolds *et al.* (2017) who reported that fruits treated with acetamiprid and fenthion reduced the mean number of maggots and pupal formation (0.00 and 0.004) and (0.004 and 0.00), respectively, in peach against *Bactrocera tryoni*. Further, Olszak and Maciesieak

(2004) also reported that acetamiprid 20 % SP @ 0.125 kg/ha and thiacloprid 480 SC @ 0.1kg/ha were most effective insecticides in reducing the cherry fruit fly (*Rhagoletis cerasi*) damage in sweet cherry orchard which also supported the current findings. Ali *et al*. (2021) reported that trichlorfon insecticide showed highest mortality against *B. cucurbitae* followed by acetamiprid.

The next best treatments observed in the present chemical evaluation studies against fruit flies are chlorantraniliprole 18.5%SC @ 0.3 ml/l + jaggery @ 5 g/l and lambda cyhalothrin 5%EC @ 0.5 ml/l + jaggery @ 5 g/l. These results were in concurrence with that of Teixeria *et al*. (2009) who worked on lethal and sub-lethal chemical effects on three species of *Rhagoletis* fruit flies *i.e., R. pomonella* (Walsh) in apple, *R. mendex* (Curran) in blue berry and *R. cingulata* (Loew) in cherry, where they observed that 500 mg of chlorantraniliprole per litre of water caused significantly higher mortality of fruit fly maggot population in all of the three *Rhagoletis* spp. in the field trials. Oke (2008) reported that lambda-cyhalothrin was found to be better insecticide against melon fruit fly in cucumber compared to deltamethrin. Stark and Vargas (2009) studied the toxicity of thiamethoxam, tefluthrin, imidacloprid, fipronil and lambda-cyhalothrin after application to sand and soil as drenches for control of the melon fly, *B. cucurbitae* (Coquillett). They found lamda-cyhalothrin was the best insecticide in controlling melon fly infestation than the diazinon, tefluthrin, fipronil and thiamethoxam. The present findings are in close agreement with that Meena (2011) who reported that lambda cyhalothrin (0.004%) and spinosad (0.002%) were the most effective treatments against melon fruit fly infestation in tomato. Khatun *et al*. (2016) reported that per cent fruit infestation and number of marketable fruits/m^2 were higher in abamectin 1.8 EC (15.66 and 2.12, respectively) and lambda-cyhalothrin 2.5 EC treatments (17.23 and 1.85, respectively).

Similarly, Abrol *et al*. (2019) reported that lambda cyhalothrin (0.004%) treatment was best against the fruit fly in bottle gourd, followed by deltamethrin (0.0028%) and spinosad (0.002%). Sharma and Gupta (2019) reported that lambda-cyhalothrin (0.004%) was superior chemical against *Bactrocera* spp. in cucumber crop. Sawai *et al*. (2014) reported that deltamethrin (0.0016%), DDVP (0.05%), emamectin benzoate (0.0016%) recorded significantly the lowest fruit damage with 22.83, 24.05 and 24.79 per cent, respectively in ridge gourd. Srinivas *et al*. (2018) observed lowest number of ovipositional punctures, lowest number of maggots, lowest per cent fruit infestation and highest marketable cucumber fruit yield against melon fly in spinosad 45 SC (0.15 ml/l) and dichlorvos 76 EC (1.0 ml/l) treatments followed by deltamethrin 2.8 EC (1 ml/l).

From the obtained results, it is concluded that traps with yellow colour and cylindrical or sphere shape followed by transparent bottle impregnated with methyl eugenol can efficiently attract and catch a greater number of fruit flies in the pre and post-harvest period in a custard apple orchard. It is also an eco-friendly method for monitoring the fruit fly, *B. dorsalis* population. The management studies to test the efficacy of different chemical insecticides against fruit fly shows that acetamiprid + jaggery and dinotefuran + jaggery emerged as the most promising treatments.

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Mysore J. Agric. Sci., 58 (4) : 250-257 (2024)

Effect of Gamma Irradiation on Vegetative and Floral Traits in French Marigold (*Tagetes patula* L.)

A. Ranjitha Ayodhya[1], R. Vasantha Kumari[2], Chikkalingaiah[3], Anuradha Sane[4], Mudalagiriyappa[5] and P. Venkatesha Murthy[6]

[1,2&6]Department of Horticulture, [3]Department of Sericulture, [5]Department of Agronomy, College of Agriculture, UAS, GKVK, Bengaluru - 560 065, [4]Division of Fruit Crops, IIHR, Hesaragatta, Bengaluru

e-Mail : ayodhyaranjitha426@gmail.com

Authors Contribution

A. Ranjitha Ayodhya & R. Vasantha Kumari : Conceptualization, design, data analysis and manuscript writing;

Chikkalingaiah ; Anuradha Sane ; Mudalagiriyappa & P. Venkatesha Murthy : Manuscript editing and supervision

Corresponding Author :
A. Ranjitha Ayodhya

Received : August 2024
Accepted : September 2024

Abstract

A study was carried out in the Floriculture unit, Department of Horticulture, University of Agricultural Sciences, GKVK, Bengaluru from 2022-2024 on 'Effect of gamma irradiation on vegetative and floral traits in French marigold (*Tagetes patula* L.)'. The experiment was laid out in a randomized complete block design with seven treatments replicated thrice. Six gamma doses *i.e.,* 50 Gy, 100 Gy, 150 Gy, 200 Gy, 250 Gy and 300 Gy and control (untreated) as treatments were imposed on seeds of marigold. In M1 generation, maximum plant height (19.50, 21.50 and 24.50 cm), number of primary branches per plant (4.50, 5.50 and 6.57), number of secondary branches per plant (13.50, 18.50 and 22.50), plant spread at EW (10.50, 14.60 and 18.50 cm), plant spread at NS (12.70, 14.67 and 20.50 cm) was recorded by 50 Gy gamma ray dosage at 30, 60 and 90 DAT, respectively. Minimum days taken for flower bud initiation (36.27), days to fifty per cent flowering (82.60), days taken for full flowering (90.50), maximum flower size (5.07 cm), shelf life (2.17 days), number of flowers per plant (19.50), fresh weight of flowers 10 in (g) (330), fresh weight of flower per m^{-2} (g) (3960), fresh weight of flower per hectare (t/ha) (16.30) were recorded at 50 Gy. Among all the treatments 50 Gy had performed better over other treatments.

Keywords : French marigold, Mutagens, Gamma irradation, Vegetative, Floral traits

Marigold is a promising ornamental plant of family Asteraeae, grown commercially in distant parts of the world retrieved from different species of *Tagetes viz., T. tenuifolia, T. erecta, T. patula, T. lucida.* French marigold (*Tagetes patula* L.) native of Central and South America, especially, Mexico. This is an annual, upright, dense, moderately sized herb, height ranging from 1 to 3 ft having odd-pinnately compound, dentate, oblong green leaves. Flowers are brightly coloured, showy, capitulate inflorescence having ray and disc florets. Marigold plants thrive best in hot and dry as well as humid weather conditions. They grow best throughout the year under both tropical and subtropical conditions, but require mild climatic conditions for optimum growth and flowering. The colours of marigold range from yellow to gold to orange, red and mahogany.

Mutation breeding has paved a way to create genetic diversity and induce desirable characters in existing varieties. Conventional breeding is a time-consuming process for genetic improvement of the floriculture crops. Mutation breeding has emerged as an alternative, efficient and an innovative methodology to produce heritable changes particularly for flower color and quality. Genetic variation is essential in any plant breeding programme for crop improvement. Induced mutations are highly effective to enhance natural genetic resources (Jain, 2006). The initial phase in any crop enhancement initiative involves evaluating genetic variability, achievable through hybridization or induced mutation. Induced mutagenesis emerges as a potent mechanism for instigating intrinsic genetic diversity, crucial for cultivating high-yielding varieties.

Mutation breeding employs both chemical and physical mutagens to induce novel recombination, fostering variability (Smitha *et al*., 2022). Mutations may arise spontaneously or due to exposure to radiation or chemicals. Extensive studies across various crops underscore the efficacy of mutation in provoking variability and crafting cultivars with enhanced traits. This approach plays a pivotal role in crop improvement programs, contributing to the development of resilient and high-performing plant varieties. (Alka *et al*., 2013 and Suna *et al*., 2016). Mutagenic agent like gamma has been widely used for the development of assorted traits of crops but the success of mutation depends on its dose applied. An induced mutation takes lesser time for release of new variety. New varieties developed through mutation breeding are identical to parent variety except for the character improved. Gamma rays are known to influence plant growth and development by inducing cytological, genetical, biochemical, physiological and morphogenetic changes in cells and tissues (Tiwari *et al*., 2010).

Induced mutations in ornamentals comprise traits such as altered flower characters (color, size, morphology and fragrance), leaf characters (form, size and pigmentation), growth habit (compact, climbing and branching) and physiological traits such as changes in photoperiodic response, early flowering, free flowering, improved keeping quality and tolerance to biotic and abiotic stresses. The main advantage of mutation breeding in vegetatively propagated crops is the ability to change one or a few characters of an outstanding variety without altering the unique part of the genotype (Datta, 2014). Induced mutation may produce new genetic variation for plant types in the existing varieties (Anita *et al*., 2011).

Material and Methods

The present investigation was carried out at the Floriculture and Ornamental Section, Department of Horticulture, University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bengaluru during 2022-24. Geographically the place is located in Eastern dry zone (Zone-5) of Karnataka. The experiment was laid out in randomized complete block design replicated thrice and gamma irradiation doses *viz.,* T_1 (control), T_2 (50 Gy), T_3 (100 Gy), T_4 (150 Gy), T_5 (200 Gy), T_6 (250 Gy) and T_7 (300 Gy) as treatments were imposed on seeds of marigold of variety *Arka Madhu*. The LD_{50} value obtained was 49.46 at 150 Gy.

The seeds of marigold were collected from ICAR - Indian Institute of Horticultural Research, Hesaraghatta, Bengaluru. The seeds were exposed to different doses of Co gamma rays *viz.,* 50Gy, 100Gy, 150Gy, 200Gy, 250 Gy and 300 Gy for 30 seconds at gamma chamber, ICAR - Indian Institute of Horticultural Research, Hesaraghatta, Bengaluru. Untreated seeds were used as control.

Results and Discussion

Plant Height (cm)

The effect of different doses of gamma irradiation had significant impact on plant height at different growth intervals of 30, 60 and 90 DAT (Fig. 1). Among the different doses, the maximum plant height of 19.50, 21.50 and 24.50 cm was recorded at the 50 Gy dose at 30, 60 and 90 DAT, respectively. This was followed by 100 Gy dose, in which plant height of 16.50, 18.53 and 22.53 cm at 30, 60 and 90 DAT, respectively was recorded. The minimum plant height of 12.50, 13.50 and 14.50 cm was recorded at the 300 Gy dose at 30, 60 and 90 DAT, respectively, when compared to the control (15.50, 18.50 and 20.50 cm at 30, 60 and 90 DAT, respectively) in the M_1 generation. This might be due to auxin degradation and inactivates auxin synthesis. These results are in conformity with the findings of Singh *et al.* (2009) in marigold, Banerji and Datta (2002) in chrysanthemum.

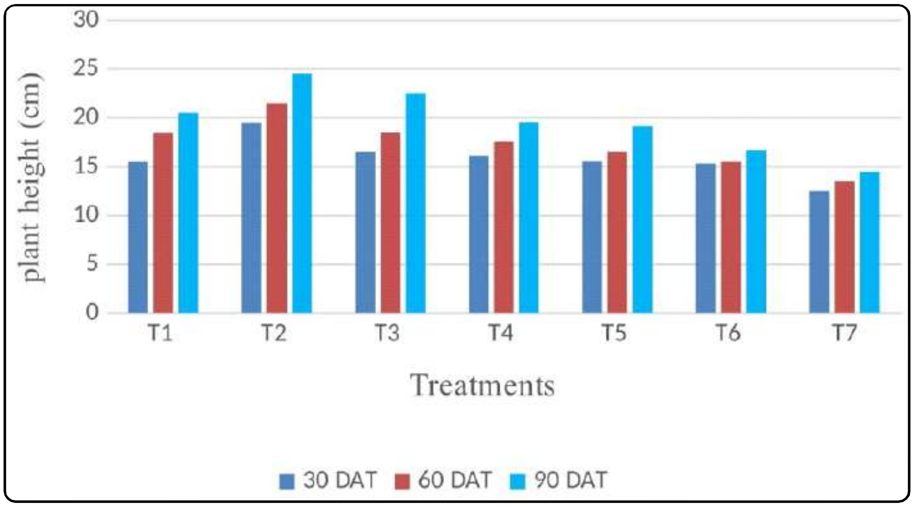

Fig. 1 : Effect of different doses of gamma irradiation on plant height (cm) at different interval in M_1 generation

Plant Spread (N-S) (cm)

The effect of different doses of gamma irradiation had significant effect on plant spread (N-S) at different growth intervals of 30, 60 and 90 DAT (Table 1). Among the different doses, the maximum plant spread of 12.70, 14.67 and 20.50 cm was recorded at the 50 Gy dose at 30, 60 and 90 DAT, respectively. This was followed by the 100 Gy dose, in which plant spread of 9.57, 12.50 and 18.57 cm at 30, 60 and 90 DAT, respectively was recorded. The minimum plant spread of 8.33, 8.50 and 14.60 cm was recorded at the 300 Gy dose at 30, 60 and 90 DAT, respectively, when compared to the control (8.50, 11.50 and 12.50 at 30, 60 and 90 DAT, respectively) in the M_1 generation. These results are in accordance with findings of Singh *et al.* (2009) in marigold, Banerji and Datta (1993) in chrysanthemum and Dhange *et al*., (2023) in stevia.

Plant Spread (E-W) (cm)

The effect of different doses of gamma irradiation had significant impact on plant spread (E-W) at different

TABLE 1

Effect of gamma irradiation on plant spread (N-S) & (E-W) at different interval in M_1 generation

Gamma rays	Plant spread (N-S) & (E-W) (cm)					
	30 DAT (N-S)	30 DAT (E-W)	60 DAT (N-S)	60 DAT (E-W)	90 DAT (N-S)	90 DAT (E-W)
T_1 (Control)	8.50 b	8.50 a	11.50 bc	12.50 b	12.50 e	14.60 b
T_2 (50 Gy)	12.70 a	10.50 a	14.67 a	14.60 a	20.50 a	18.50 a
T_3 (100 Gy)	9.57 b	9.57 a	12.50 b	12.63 b	18.57 a	15.50 b
T_4 (150 Gy)	9.33 b	7.57 b	11.50 bc	10.57 bc	17.53 b	13.57 b
T_5 (200 Gy)	8.50 b	7.50 b	10.57 c	9.50 c	16.63 c	12.60 c
T_6 (250 Gy)	8.40 b	7.40 b	9.50 c	8.50 d	15.50 d	10.57 d
T_7 (300 Gy)	8.33 c	7.27 c	8.50 d	8.07 d	14.60 e	10.10 d
Grand mean	9.33	8.33	11.25	10.91	16.55	13.63
F test	*	*	*	*	*	*
SEm±	0.09	0.06	0.13	0.11	0.05	0.17
CD (5 %)	0.28	0.20	0.39	0.35	0.15	0.52

growth interval of 30, 60 and 90 DAT (Table 1). Among the different doses, the maximum plant spread of 10.50, 14.60 and 18.50 cm was recorded at the 50 Gy dose at 30, 60 and 90 DAT, respectively. This was followed by the 100 Gy dose, in which plant spread of 9.57, 12.63 and 15.50 cm at 30, 60 and 90 DAT, respectively was recorded. The minimum plant spread of 7.27, 8.07 and 10.10 cm was recorded at the 300 Gy dose at 30, 60 and 90 DAT, respectively, when compared to the control (8.50, 12.50 and 14.60 at 30, 60 and 90 DAT, respectively) in the M_1 generation. These findings were well supported by the work of Singh *et al.* (2009) in marigold and Dhange *et al*., (2023) in stevia.

Number of Primary Branches Per Plant

The effect of different doses of gamma irradiation had significant effect on number of primary branches per plant at different growth intervals of 30, 60 and 90 DAT (Table 2). Among the different doses, the highest number of primary branches, 4.50, 5.50 and 6.57 was recorded at the 50 Gy dose at 30, 60 and 90 DAT, respectively. This was followed by the 100 Gy dose, in which number of primary branches, 3.63, 4.63 and 5.67 at 30, 60 and 90 DAT, respectively was recorded. The lowest number of primary branches, 3.17, 4.10 and 5.27 was recorded at 300 Gy dose at 30, 60 and 90 DAT, respectively, when compared to the control (3.40, 4.17 and 5.47 at 30, 60 and 90 DAT, respectively) in the M_1 generation. These results are in accordance with findings of Singh *et al.* (2009) in marigold and Banerji and Datta (1993) in chrysanthemum.

Number of Secondary Branches Per Plant

The effect of different doses of gamma irradiation had significant impact on number of secondary branches per plant at different growth intervals of 30, 60 and 90 DAT (Table 3). Among the different doses, the highest number of secondary branches, 13.50, 18.50 and 22.50, was recorded at the 50 Gy dose at 30, 60 and 90 DAT, respectively. This was followed by the 100 Gy dose, in which 12.60, 15.60 and 18.57 secondary branches at 30, 60 and 90 DAT, respectively was recorded. The lowest number of secondary branches, 10.07, 12.57 and 13.50 was recorded at the 300 Gy dose at 30, 60 and 90 DAT, respectively, when compared to the control (11.50, 14.53 and 16.47 at 30, 60 and 90 DAT, respectively) in the M_1 generation. These results are in accordance with

TABLE 2

Effect of gamma irradiation on number of primary branches per plant at different interval in M_1 generation

Gamma rays	Number of primary branches per plant		
	30 DAT	60 DAT	90 DAT
T_1 (Control)	3.40 ^{b}	4.17 ^{c}	5.47 ^{b}
T_2 (50 Gy)	4.50 ^{a}	5.50 ^{a}	6.57 ^{a}
T_3 (100 Gy)	3.63 ^{b}	4.63 ^{b}	5.67 ^{ab}
T_4 (150 Gy)	3.53 ^{b}	4.40 ^{b}	5.53 ^{b}
T_5 (200 Gy)	3.50 ^{b}	4.27 ^{c}	5.40 ^{bc}
T_6 (250 Gy)	3.33 ^{b}	4.20 ^{c}	5.30 ^{c}
T_7 (300 Gy)	3.17 ^{b}	4.10 ^{d}	5.27 ^{c}
Grand mean	3.58	4.47	5.60
F test	*	*	*
SE.m±	0.09	0.15	0.08
CD (5 %)	0.27	0.46	0.26

TABLE 3

Effect of gamma irradiation on number of secondary branches per plant at different interval in M_1 generation

Gamma rays	Number of secondary branches per plant		
	30 DAT	60 DAT	90 DAT
T_1 (Control)	11.50 ^{c}	14.53 ^{bc}	16.47 ^{c}
T_2 (50 Gy)	13.50 ^{a}	18.50 ^{a}	22.50 ^{a}
T_3 (100 Gy)	12.60 ^{b}	15.60 ^{b}	18.57 ^{b}
T_4 (150 Gy)	11.50 ^{c}	14.50 ^{bc}	16.60 ^{c}
T_5 (200 Gy)	10.60 ^{d}	14.27 ^{c}	15.73 ^{d}
T_6 (250 Gy)	10.40 ^{d}	13.53 ^{d}	14.23 ^{d}
T_7 (300 Gy)	10.07 ^{d}	12.57 ^{e}	13.50 ^{e}
Grand mean	11.45	14.79	16.80
F test	*	*	*
SE.m±	0.12	0.06	0.13
CD (5 %)	0.38	0.19	0.40

findings of Singh *et al.* (2009) in marigold and Banerji and Datta (1993) in chrysanthemum.

Days Taken for Flower Bud Initiation

The effect of different doses of gamma irradiation on the days taken for flower bud initiation was significant (Table 4). Among the different doses, early flower bud initiation was recorded in the control group (34.50 days), followed by the 50 Gy dose (36.27 days). In contrast, the 300 Gy dose was the late to attain flower bud initiation (40.17 days) in the M_1 generation. This might be due to higher doses of gamma rays inactivate auxins and gibberellins which control flowering and it may also activate inhibitors that delay flowering in marigold. These results are in accordance with findings of Misra and Mahesh (1993) in gladiolus, Misra and Bajpai (1983) and Kumari *et al.* (2013) in chrysanthemum.

Days to 50 Per Cent Flowering

The effect of different doses of gamma irradiation had a significant impact on the days to 50 per cent flowering (Table 4). Among the different doses, the early 50 per cent flowering, 82.60 days, was recorded at the 50 Gy dose. In contrast, the 300 Gy dose recorded the late, 87.50 days, to achieve 50 per cent flowering, when compared to the control (83.50 days) in the M_1 generation. This might be due to higher doses of gamma rays inactivate auxins and gibberellins which control flowering and it may also activate inhibitors that delay flowering in marigold. The days to 50 per cent flower increased with increase in doses of gamma rays in marigold. These results are in accordance with Kumari *et al.* (2013) in chrysanthemum and Dilta *et al.* (2003) in chrysanthemum.

TABLE 4

Effect of gamma irradiation on days taken for flower bud initiation, days to 50 per cent flowering and days taken for full flowering in M_1 generation

Gamma rays	Days taken for flower bud initiation	Days to 50 per cent flowering	Days taken for full flowering
T_1 (Control)	34.50 ^{d}	83.50 ^{c}	89.50 ^{e}
T_2 (50 Gy)	36.27 ^{cd}	82.60 ^{d}	90.50 ^{d}
T_3 (100 Gy)	37.60 ^{c}	83.53 ^{c}	92.50 ^{c}
T_4 (150 Gy)	38.50 ^{b}	84.53 ^{b}	93.50 ^{bc}
T_5 (200 Gy)	39.50 ^{ab}	85.60 ^{b}	94.50 ^{b}
T_6 (250 Gy)	39.83 ^{ab}	86.50 ^{a}	95.50 ^{ab}
T_7 (300 Gy)	40.17 ^{a}	87.50 ^{a}	96.00 ^{a}
Grand mean	38.05	84.82	93.14
F test	*	*	*
SE.m±	0.20	0.04	0.11
CD (5 %)	0.61	0.14	0.34

Days Taken for Full Flowering

The effect of different doses of gamma irradiation had significant effect on days taken for full flowering (Table 4). The shortest duration to attain full flowering (89.50 days) was recorded in the control, followed by (90.50 days) at the 50 Gy dose. In contrast, the 300 Gy dose resulted in the late to attain full flowering (96.00 days) when compared to the control (89.50) in the M_1 generation. These results are in accordance with Singh *et al.* (2009), they observed that day to bloom increased with increase in doses of gamma rays in marigold. Dilta *et al.* (2003), in chrysanthemum.

Flower Size (cm)

Flower size is one of the important parameters that determines the consumer preference for a specific size of flower. The effect of different doses of gamma irradiation had a significant impact on flower size (Fig. 2). The results clearly indicated that the maximum flower size (5.07 cm) was recorded at the 50 Gy dose, which was significantly better compared to other doses. Conversely, the minimum flower size (3.27 cm) was recorded at 300 Gy dose, when compared to the control (3.74 cm) in the M_1 generation. These results were in confirmation with study of Singh *et al.* (2009) in marigold and Kumari *et al.* (2013) in chrysanthemum.

Shelf life (days)

Shelf life is a significant factor in determining the keeping quality of flowers, as they often need to be

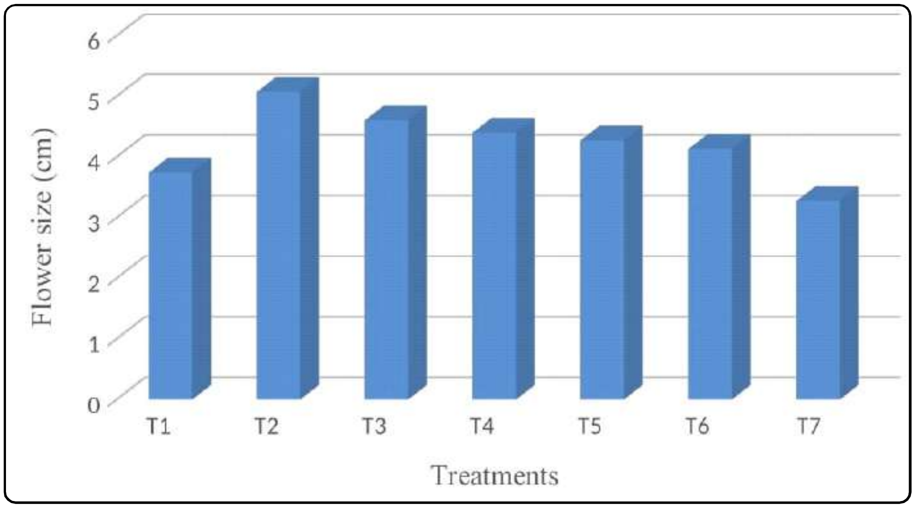

Fig. 2 : Effect of gamma irradiation on shelf life (days) at different interval in M_1 generation

transported over great distances. Longevity indicates whether flowers are suitable for distant markets; otherwise, market values would decline due to a reduction in quality. The effect of different doses of gamma irradiation on the shelf life of marigold had a significant impact (Fig.3). The treatment that provided the best shelf life (4.27 days) was recorded in control, followed by 2.17 days at the 50 Gy dose. In contrast, the lowest shelf life (1.13 days) was recorded at the 300 Gy dose, in the M_1 generation. This might be due to the influence of gamma irradiation on the shelf life of flowers by altering their physiological and biochemical properties.

Number of Flowers Per Plant

The effect of different doses of gamma irradiation had significant effect on number of flowers developed per plant (Table 5). Significant differences were observed among the various treatments of gamma irradiation studied. Among them the highest number of flowers per plant (40.33) was recorded at 50 Gy dose. The least (29.67) production of flowers was noticed at 300 Gy dose when compared to control in M_1 generation. These results are in line with findings of Sisodia and Singh (2014) recorded in gladiolus and Latha and Dharmatti (2018) in marigold.

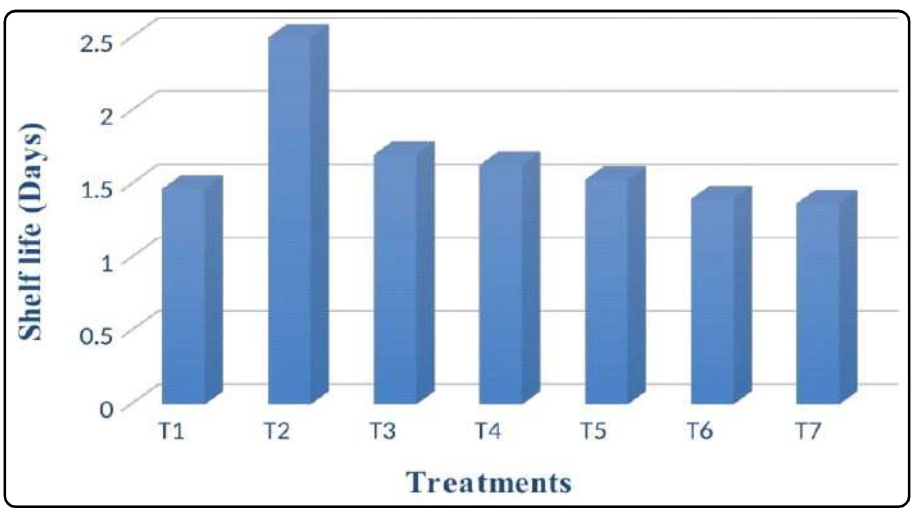

Fig. 3 : Effect of gamma irradiation on shelf life (days) at different interval in M_1 generation

TABLE 5

Effect of gamma irradiation on number of flowers per plant, fresh weight of flower (10) in g, fresh weight of flower per plot, fresh weight of flower per hectare in M_1 generation

TreatmentDoses of gamma ray (Gy)	Number of flowers per plant	Fresh weight of flower (10) in g	Fresh weight of flower per plot	Fresh weight of flower per hectare
T_1 (Control)	31.67 ^{d}	270 ^{e}	3240 ^{f}	13.33 ^{bc}
T_2 (50 Gy)	40.33 ^{a}	330 ^{a}	3960 ^{a}	16.30 ^{a}
T_3 (100 Gy)	37.00 ^{b}	312 ^{b}	3744 ^{b}	15.41 ^{ab}
T_4 (150 Gy)	34.67 ^{b}	280 ^{c}	3360 ^{c}	13.83 ^{b}
T_5 (200 Gy)	33.67 ^{c}	264 ^{c}	3168 ^{d}	13.04 ^{b}
T_6 (250 Gy)	32.33 ^{c}	258 ^{d}	3096 ^{e}	12.74 ^{bc}
T_7 (300 Gy)	29.67 e	196 ^{f}	2352 ^{g}	9.68 ^{d}
Grand mean	34.19	272.85	3274.28	13.47
F test	*	*	*	*
SEm±	0.91	1.304753	15.65704	0.043219
CD (5 %)	2.79	4.020345	48.24414	0.13317

Fresh Weight of 10 - Flowers (g)

The effect of different doses of gamma irradiation had significant effect on fresh weight of 10- flowers (g) (Table 5). The lower doses *i.e.,* 50 Gy gamma irradiation succeeded in achieving a higher fresh weight of flower (330 g) which was significantly higher than all the other treatments. Apart from 50 Gy, good yield performance was exhibited by 100 Gy with (312 g) followed by 150 Gy. Among the treatments, 300 Gy was ranked with the lowest fresh weight (196 g) in M_1 generation. These results are in line with findings Latha and Dharmatti (2018) in marigold.

Fresh Weight of Flowers Per m-^{2} (g)

The effect of different doses of gamma irradiation on fresh weight of flowers per m-^{2} (g) (Table 5). Higher fresh weight of flowers per m-^{2} (g) was recorded at 50 Gy dose (3960 g per m-^{2}), which was due to higher flower weight obtained per plant. On the other hand, lowest fresh weight of flowers per m-^{2} (g) was recorded at 300 Gy dosage of gamma irradiation (2352 g per m-^{2}) due to lower flowers attributed per plant and was significantly different from other treatments studied. These results are in line with findings Latha and Dharmatti (2018) in marigold.

Fresh Weight of Flowers Per Hectare (t/ha)

The effect of different doses of gamma irradiation had significant effect on fresh weight of flowers per hectare (Table 5). Higher fresh flower weight per hectare was recorded at 50 Gy dosage of gamma irradiation (16.30 t/ha) which was considerably superior when compared to the other treatments. Since 300 Gy dosage of gamma irradiation recorded lower fresh flower weight per m-^{2} consequently the fresh flower weight per hectare was found to be lowest (9.68 t/ha). Differences among the doses for fresh flower weight per hectare were highly significant. 50 Gy was followed by 100 Gy with yield (15.41 t/ ha) and 150 Gy (13.83 t/ha) in M_1 generation. These results are in line with findings Latha and Dharmatti (2018) in marigold.

On the basis of present investigation, it may be concluded that gamma irradiation had exerted the significant effect on vegetative and floral traits in Marigold. Gamma irradiation doses at 50 Gy found beneficial for various growth, flowering traits in Marigold. Lower doses of gamma rays *i.e.,* below 50 Gy can be applied in marigold for further crop improvement. There are limited studies on gamma irradiation in marigold using seeds, so the findings of this study on vegetative and floral traits could be used as reference for mutation breeding in other cultivars of marigold.

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Bio-efficacy of Different Post Emergent Herbicides on Weed Dynamics and Productivity of Horsegram

SAHAJA DEVA[1], B. SAHADEVA REDDY[2] AND A. V. S. DURGAPRASAD[3]
[1&2]Department of Agronomy, RARS, Tirupati, [3]Department of Plant Breeding, ARS, Ananthapuram, ANGRAU, A. P.
e-Mail : sahajadeva@angrau.ac.in

AUTHORS CONTRIBUTION

SAHAJA DEVA :
Conducting experiment;

B. SAHADEVA REDDY :
Technical guidance and supervision;

A. V. S. DURGAPRASAD :
Technical support and Supervision

Corresponding Author :
SAHAJA DEVA

Received : July 2024
Accepted : August 2024

ABSTRACT

Effective weed management is crucial for the successful cultivation of horsegram (*Macrotyloma uniflorum*), a drought-tolerant leguminous crop. This study evaluates the bio-efficacy of various herbicides on weed dynamics and the productivity of horsegram. Field experiments were conducted under AICRP on Arid legumes at ARS Ananthapuramu, where different herbicide treatments were compared with hand weeding and a weedy check during *kharif* 2023. The experiment comprised of eight post emergent treatments which include six herbicides treatments (quizalofop ethyl, haloxyfop-R-methyl, clodinafop propargyl, fenoxaprop-p-ethyl, propaquizafop, imazethapyr sprayed at 15-20 DAS), two hand weedings at 20 and 40 DAS and weedy check replicated thrice in Randomized Block Design. Major weeds were *Rottboellia cochinchinensis* among grasses, *Fimbriocytis* spp. among sedges, *Celosia argentea, Murdania nudiflora* and *Digitaria sanguinalis* among broadleaved weeds. Quizalofop ethyl and Propaquizafop effectively controlled *Rottboellia cochinchinensis* and *Fimbriocytis spp*. Imazethapyr effectively controlled broad leaved weeds. The results demonstrated that hand weeding twice recorded higher seed yield, haulm yield and net returns. Among herbicide treatments, quizalofop ethyl @ 50 g a.i./ha as PoE at 15 - 20 DAS recorded higher seed yield (807 kg/ha), haulm yield (1588 kg/ha) and net returns (15535 Rs/ha) and imazethapyr @ 40 g a.i./ha as PoE at 15 - 20 DAS recorded higher B:C ratio (2.84).

Keywords : Herbicides, Horsegram, Imazethapyr, Quizalofop ethyl, Weed management

HOSEGRAM is one of the important climate resilient indigenous grain legume crops in India (Kiran Kumar *et al.,* 2023). Effective weed management is a critical factor in the successful cultivation of horsegram (*Macrotyloma uniflorum*), a hardy leguminous crop prized for its drought tolerance and nutritional benefits. In regions characterized by semi-arid conditions, horsegram is a vital source of sustenance and income. However, the productivity of this resilient crop is often hindered by the persistent challenge of weed competition. Weeds compete with horse gram for vital resources such as water, nutrients and sunlight, leading to reduced crop yields and compromised quality. In Andhra Pradesh, horse gram is cultivated on approximately 150,000 hectares with annual production of around 90,000 metric tons and average productivity of about 600 kg/ha (https://iipr.icar.gov.in/horsegram/). Traditional weed control methods, such as manual weeding and mechanical cultivation, though effective, are labor-intensive and time-consuming. These methods pose significant challenges for smallholder who often lack the resources and labor necessary for consistent weed management. In response to these challenges, the use of chemical herbicides has emerged as a viable alternative, offering a more efficient and cost-effective solution for weed control in horsegram cultivation. Herbicides, when used appropriately, can significantly reduce weed pressure, thereby enhancing crop growth and yield. The adoption of herbicides in weed management practices has shown promise in increasing agricultural productivity by minimizing the competition between crops and weeds. However, the use of chemical herbicides also raises concerns regarding environmental safety, human health and the potential development of herbicide-resistant weed species.

This manuscript aims to investigate different herbicides for chemical weed management. It will explore the efficacy of various herbicides in controlling different weed species commonly found in horsegram fields, the optimal application rates and timing and the impact of herbicide use on crop yield and quality. Additionally, the manu script will address the potential risks associated with herbicide use and discuss strategies for mitigating these risks to promote sustainable weed management practices. By synthesizing current research and field studies, this work seeks to provide a comprehensive overview of chemical weed management in horsegram. It aims to offer valuable insights for farmers, agronomists and agricultural policymakers to enhance weed control practices, improve crop productivity and ensure the sustainability of horsegram cultivation.

Material and Methods

Field experiment was conducted at Agricultural Research Station, Aanthapuramu under AICRP on Arid legumes during *kharif*, 2023. The experimental site is located in scarce rainfall zone of Andhra Pradesh with average annual rainfall of 550 mm and geographical coordinates of the site are approximately 14.68° N latitude and 77.60° E longitude.The soil at the experimental site is red sandy loam. Soils were slightly alkaline with pH of 7.97, EC of 0.07 with low Organic carbon (0.09%), low nitrogen (212.9 kg/ha) low phosphorus (12.7 kg/ha), medium in potassium (294 kg/ha) and low micronutrients (Copper-0.08 ppm, Manganese-0.59 ppm, iron-0.43 ppm, zinc-0.50 ppm). Experiment was laid in Randomized Block Design with three replications and eight treatments comprised of T1-quizalofop-p-ethyl @ 50 g a.i./ha, T2-Haloxyfop-R-methyl @ 100 g a.i./ha, T3-clodinafop propargyl @ 60 g a.i./ha, T4-Fenoxaprop-p-ethyl @ 90 g a.i./ha, T5-propaquizafop @ 100 g a.i./ha, + T6-imazethapyr @ 40 g a.i./ha as PoE at 15-20 DAS, T7-Hand weeding at 15-20 DAS and 35-40 DAS, T8-Weedy check. ATPHG 11 was taken as test variety and sowing was done with seed drill. 4 kg of Nitrogen, 10 kg of Phosphorus and 8 kg potash supplying fertilizers were broadcasted before sowing.The average maximum temperature over the recorded period was 32.95°C, and the average minimum temperature was 20.12°C. The average morning relative humidity was 83.08 per cent, while the average evening relative humidity was 46.61 per cent. The average wind speed was 7.50 kmph. The total rainfall recorded was 284.8 mm over 19 rainy days. The average sunshine hours per week were 6.13 hours and the average evaporation rate was 6.75 mm per week.

Growth and yield parameters like plant height, number of branches/plants, plant population, number of pods/plants, number of seeds/pods, pod weight, seed weight, pod length was recorded before harvesting. Weed density and weed dry matter were recorded at 60, 75, 90 DAS and harvest in one square meter area. Harvesting was done with sickles to ground level and dried. Threshing was done by trampling with tractor and seed and bhusa yield was recorded separately. Weed Control Efficiency, Weed Index, Harvest Index, Rain Water Use Efficiency, Production Efficiency were calculated by using the specified formulae. Economics were calculated by taking prevailing labour wages and market prices of inputs and outputs into consideration.

Harvest index (%) = Economic yield / Biological yield x 100 (Donald, 1962).

Where, Economic yield = Seed yield

Biological yield = Seed yield + bhusa yield

Rain Water use Efficiency (kghamm^{-1}) = Yield (kg ha^{-1})/ Total water use (mm) (Cheema *et al.,* 1991)

Production efficiency (kg ha-1 day-1) = Seed Yield (kg ha-1)/ Duration of the crop (days) (Tomar and Tiwari, 1990).

Weed Index (%) = Maximum seed yield -Seed yield from treated plot/ Maximum seed yield x 100 (Gill and Vijaya Kumar, 1966).

Weed Control Efficiency (%) = DWC–DWT/ DWC x 100

Where, WCE = Weed control efficiency (%) DWC = Dry weight of weeds in weedy check plot (g) DWT = Dry weight of weeds in treated plot (g) (Mani *et al*. 1973)

Gross return (Rs. ha^{-1}) = (Seed yield x price) + (bhusa yield x price)

Net returns (Rs. ha^{-1}) = Gross return (Rs. ha^{-1}) - Cost of cultivation (Rs. ha^{-1})

Benefit: cost ratio = Gross returns (Rs. ha^{-1})/ cost of cultivation (Rs. ha^{-1})

The collected data were subjected to statistical analysis using SPSS. Analysis of variance (ANOVA) was performed to determine the significance of treatment effects. Means were compared using the Least Significant Difference (LSD) test at a 5 per cent probability level.

Results and Discussion

Species Wise Weed Density

Major Weeds Associated with Horsegram : *Rottboellia cochinchinensis, Fimbriocytis* spp*, Commelina diffusa, Commelina benghalensis, Celosia argentea, Andrographis* spp*, Leucasaspera, Cyperus rotundus, Murdania nudiflora, Digitaria sanguinalis, Rubiat ictorum* were the major weeds associated with horsegram. Fig. 1 clearly shows that most predominant weeds were *Fimbriocytis spp, Murdania nudiflora, Rottboellia cochinchinensis, Digitaria sanguinalis* and *Celosia argentea* accounting for 83 per cent of the total weeds observed.

Growth Parameters

The growth parameters, including plant population, plant height, and the number of branches per plant, varied significantly across different weed management treatments in horsegram (Table 1).The plant population ranged from 30.33 to 35.33 plants per square meter. Treatment T7 recorded the highest plant

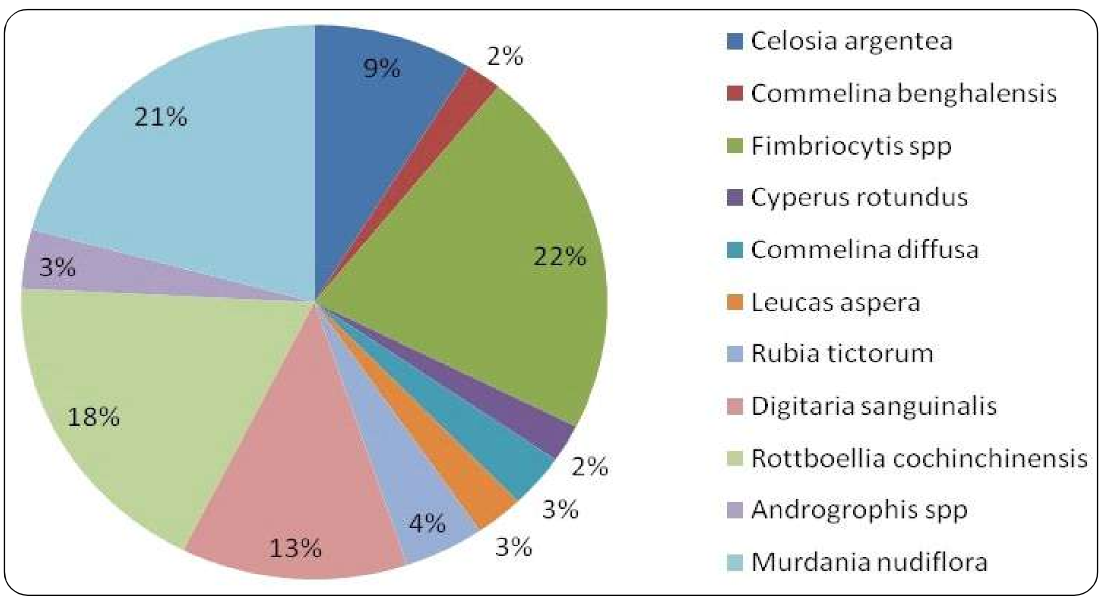

Fig. 1 : Species wise weed frequency in experimental field (no./sq.m.)

TABLE 1

Influence of different weed management practices on growth and yield of horsegram

Treatments	Plant population (No./sq.m)	Plant height (cm)	No. of branches/ plant	Pod length (cm)	No. of seeds/ pod	No. pods/ plant	100 Fresh pod weight (g)	100 dry pod weight (g)	1000 fresh seed weight (g)	1000 dry seed weight (g)	Seed yield (kg/ha)	Bhusa yield (kg/ha)
1	34.33	69.67	8.33	4.93	5.3	86.9	51.0	23.0	74.4	42	807	1588
T2	32.33	52.00	6.67	4.43	5.0	71.5	45.0	19.2	68.0	38	663	1451
T3	32.66	57.33	7.33	4.60	5.0	74.6	47.8	21.6	69.2	39	692	1500
T4	32.33	52.00	7.00	4.60	5.0	72.7	46.4	21.3	68.8	38	673	1451
T5	34.00	69.33	8.00	4.83	5.3	86.0	49.5	22.5	71.8	41	799	1582
T6	34.00	68.33	8.00	4.73	5.3	84.4	47.8	22.0	69.2	40	785	1565
T7	35.33	91.00	8.33	4.93	5.3	111.0	52.0	23.5	79.2	44	1125	1900
T8	30.33	49.00	6.33	4.17	5.0	66.3	45.0	18.4	64.4	37.6	615	1246
CD @ 5%	NS	2.34	NS	NS	NS	6.84	NS	2.05	0.33	0.33	70.68	202.66
CV	-	2.11	-	-	-	4.78	-	5.46	2.63	4.66	5.24	7.54

population (35.33 plants/sq.m), while T8 had the lowest (30.33 plants/sq.m). Among herbicide treatments, T1 had the highest plant population (34.33 plants/sq.m), followed closely by T5 and T6 (34.00 plants/sq.m each), The tallest plants were observed in T7 (91.00 cm), significantly higher than the shortest plants in T8 (49.00 cm). Among herbicide treatments, the tallest plants were observed in T1 (69.67 cm) and T5 (69.33 cm). The number of branches per plant varied from 6.33 (T8) to 8.33 (T1 and T7). T1 had the highest number of branches (8.33), followed by T5 and T6 (8.00 each). Treatments T1, T5, T6 and T7, which had higher numbers of branches per plant, likely benefited from reduced weed pressure, which otherwise competes for nutrients and space. It suggests that this treatment provided optimal conditions for horsegram growth by effectively reducing weed competition This observation aligns with findings from Kumar *et al*. (2017), who reported that effective weed management practices can enhance plant growth by minimizing competition for light, nutrients and water.

Yield and Yield Attributes

The yield and yield attributes were significantly influenced by the different weed management practices (Table 1). Pod length ranged from 4.17 cm (T8) to 4.93 cm (T1 and T7). Among herbicide treatments, T1 recorded higher pod length (4.93 cm) followed by T5 (4.83). The number of seeds per pod was consistently around 5 across treatments, with T1, T5, T6 and T7 showing slightly higher values (5.3 seeds/pod). The number of pods per plant was highest in T7 (111.0) and lowest in T8 (66.3). Among herbicide treatments, T1 recorded higher no. of pods/plant (86.9) followed by T5 (86.0) and T6 (84.4). This indicates that the weed management practice in T7 and T1 significantly enhanced the reproductive capacity of the plants. The 100 fresh pod weight varied from 45 g (T2 and T8) to 52 g (T7) and the 100 dry pod weight ranged from 18.4 g (T8) to 23.5 g (T7). Among herbicide treatments, T1 showed higher 100 fresh and dry pod weight of 51.0 and 23.0 g, respectively. Similarly, the 1000 fresh seed weight and 1000 dry seed weight were highest in T7, indicating that effective weed management can enhance the overall quality and weight of the produce. Among herbicide treatments, higher 1000 fresh and dry seed weight were recorded in T1 with 74.4 and 42.0 g, respectively. Seed yield ranged from 615 kg/ha (T8) to 1125 kg/ha (T7). Higher seed yield was recorded in T1 with 807 kg/ha followed by T5 with 799 kg/ha. Bhusa yield followed a similar trend, with T7 having the highest yield (1900 kg/ha) and T8 the lowest (1246 kg/ha). Among herbicide, treatments T1 recorded higher bhusa yield of 1588 kg/ha followed by T5 with 1582 kg/ha. These results suggest that effective weed control, as seen in T7 and T1, can substantially improve both seed and bhusa yields. The results align with previous studies that emphasize the importance of effective weed management in enhancing crop growth and yield. For instance, Singh *et al*. (2018), found that integrated weed management practices lead to higher yields and better crop performance by maintaining lower weed biomass. Meena *et al*. (2019) observed that effective weed control leads to improved seed quality and higher market value. Fig. 2, shows that no. of pods/ plant and seed yield were positively correlated which indicate that increase in number of pods increases seed yield. Findings are in support with Rajesh Naik *et al.,* 2022.

Economic analysis revealed significant differences in cost of cultivation (COC), gross returns (GR), net returns (NR) and benefit-cost (B: C) ratio among treatments (Table 2). The COC ranged from Rs.7600/ha (T8) to Rs. 15600/ha (T7), indicating that some weed management practices are more cost-intensive than others. T7 had the highest Gross Returns (Rs. 32866/ha) and Net Returns (Rs. 17266/ha), while T8 had the lowest Gross Returns (Rs. 18490/ha) and moderate NR (Rs. 10890/ha). This shows that despite the higher

TABLE 2

Economics of horsegram as influenced by different weed management practices

Treatment	Cost of Cultivation (Rs/ha)	Gross Returns (Rs/ha)	Net Returns (Rs/a)	Benefit: Cost ratio
T1	8620	24155	15535	2.80
T2	9560	20201	10641	2.11
T3	9798	21046	11248	2.15
T4	9758	20462	10704	2.10
T5	10560	23937	13377	2.27
T6	8280	23532	15252	2.84
T7	15600	32866	17266	2.11
T8	7600	18490	10890	2.43

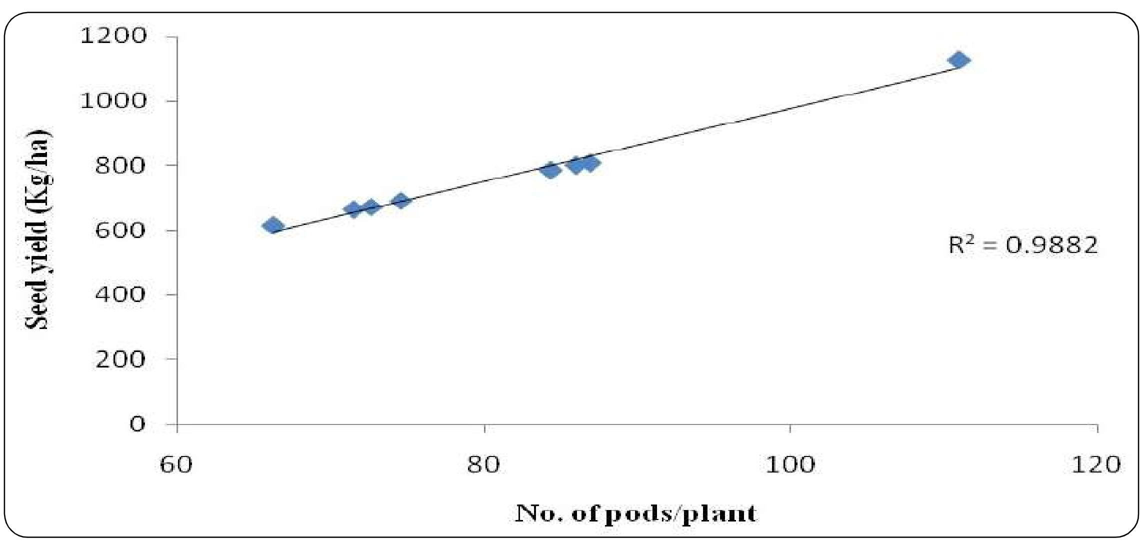

Fig. 2 : Linear regression of no. of pods/plant and seed yield

cost of cultivation, the returns in T7 are substantially higher, making it economically beneficial. Among herbicide treatments, higher gross returns and net returns were recorded in T1 with 24155 and 15535 Rs./ha, respectively. The B:C ratio was highest in T6 (2.84), followed by T1 (2.80) and T7 (2.11), suggesting that these treatments are more profitable. Kumar *et al*. (2017) reported that integrated weed management practices can lead to higher economic returns due to better resource utilization and reduced competition from weeds. This is in line with the study by Patel *et al*. (2016), which showed that integrated weed management practices, although costlier, result in higher economic benefits due to increased yields.

Total Weed Density, Weed Dry Matter and Weed Control Efficiency

Total weed density, dry matter and Weed Control Efficiency is presented in Table 3. Lowest weed density, drymatter and highest weed control efficiency were recorded in T7. Among herbicide treatments, lowest weed density, dry matter and higher weed control efficiency were recorded in T1 followed by T5 at 60, 75, 90 DAS and at harvest. The reduction in weed density and dry matter observed in Treatment T7 (100% weed control efficiency at 60 DAS) aligns with findings from other studies that emphasize the effectiveness of certain herbicides and mechanical methods in reducing weed populations. For example, Ghosh *et al*. (2012) reported that the integration of mechanical weeding and herbicide application can significantly reduce weed biomass in legume crops. The highest weed control efficiency observed in Treatment T7 and T1 indicates the effectiveness of the weed management strategy employed in this treatment. This is consistent with the findings of Chauhan and Johnson (2010), who found that integrated weed management practices, including the

TABLE 3

Weed density, drymatter and Weed Control Efficiency at different growth stages in horsegram as influenced by different weed management practices

Treatments	Weed density (no./m^2)				Weed drymatter (g/m^2)				Weed control efficiency (%)			
	60	75	90	har	60	75	90	har	60	75	90	har
T1	4.18 (17.5)	4.10 (16.8)	3.77 (14.2)	2.20 (4.8)	7.24 (52.4)	7.02 (49.3)	6.69 (44.8)	3.84 (14.7)	33.33	33.33	29.43	53.79
T2	7.25 (52.6)	6.59 (43.4)	5.42 (29.4)	3.87 (!5.0)	10.56 (111.5)	9.98 (99.6)	8.94 (79.9)	8.00 (64.0)	2.76	5.22	5.70	3.73
T3	6.45 (41.6)	5.74 (32.9)	5.11 (26.1)	2.81 (7.9)	9.83 (96.6)	9.63 (92.7)	8.90 (79.2)	6.97 (48.6)	9.48	8.55	6.12	16.13
T4	6.71 (45.0)	5.75 (33.1)	5.28 (27.9)	3.60 (!3.0)	10.56 (111.5)	9.98 (99.6)	8.94 (79.9)	8.00 (64.0)	2.76	5.22	5.70	3.73
T5	5.35 (28.6)	5.28 (27.9)	4.95 (24.5)	2.63 (6.9)	8.37 (70.1)	8.11 (65.8)	7.90 (62.4)	5.74 (32.9)	22.93	22.98	16.67	30.93
T6	5.99 (35.9)	5.46 (29.8)	5.06 (@5.6)	2.63 (6.9)	9.71 (94.3)	9.65 (93.1)	8.74 (76.4)	6.18 (38.2)	10.59	8.36	7.81	25.63
T7	0.00 (0.0)	2.33 (5.4)	3.43 (11.8)	1.14 (1.3)	0.00 (0.0)	4.48 (20.1)	5.48 (30.0)	3.84 (!4.7)	100.00	57.45	42.19	53.79
T8	8.21 (67.4)	6.92 (47.9)	5.84 (34.1)	4.58 (21.0)	10.86 (117.9)	10.53 (110.9)	9.48 (89.9)	8.31 (69.1)	0.00	0.00	0.00	0.00
CD @ 5%	1.62	1.74	1.04	0.74	2.44	2.50	1.96	1.12	-	-	-	-
CV	16.80	18.88	12.27	14.45	16.54	16.44	13.78	10.07	-	-	-	-

Weed density and weed dry matter values are transformed through square root transformation.
Values in paranthesis are original alues

use of pre-emergence herbicides, can achieve high weed control efficiency in legume crops.

Species Wise Weed Density and Relative Density of Weeds

The species wise weed density varied significantly across treatments, with some species like *Celosia argentia* and *Digitaria sanguinalis* showing high densities in multiple treatments, while others like C*ommelina benghalensis* and *Cyperus rotundus* were less prevalent (Fig. 2 and Fig. 3). The relative density of weed species depicted in Fig. 4, showed that weed management practices had a remarkable effect. In major treatments, *Fimbriocytis* spp and *Murdania nudiflora* contributed major relative density. *Rottboellia cochinchinensis* among grasses, *Fimbriocytis* spp among sedges, *Celosia argentea, Murdania nudiflora Digitaria sanguinalis* among broadleaved weeds were the major weeds in experimental fields. This differential response to weed management practices can be explained by the selective efficacy of herbicides and mechanical

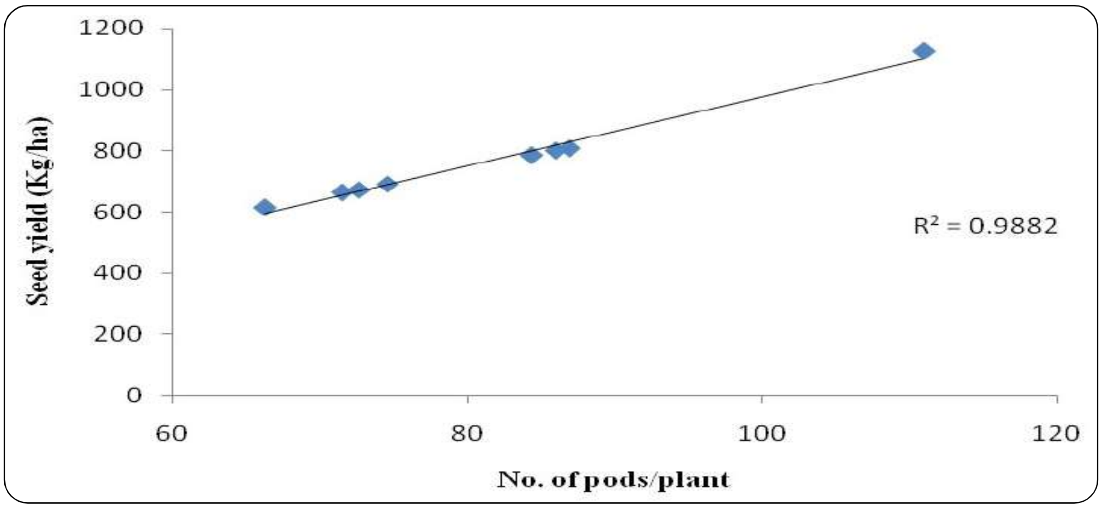

Fig. 2 : Linear regression of no. of pods/plant and seed yield

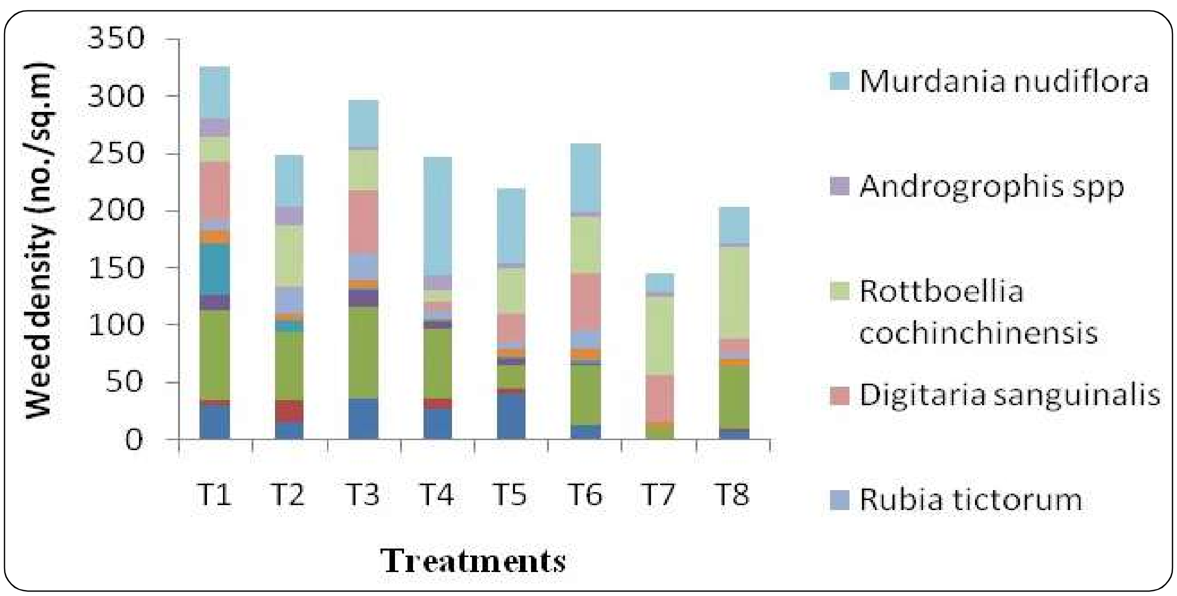

Fig. 3 : Species wise weed density in horsegram in different treatments

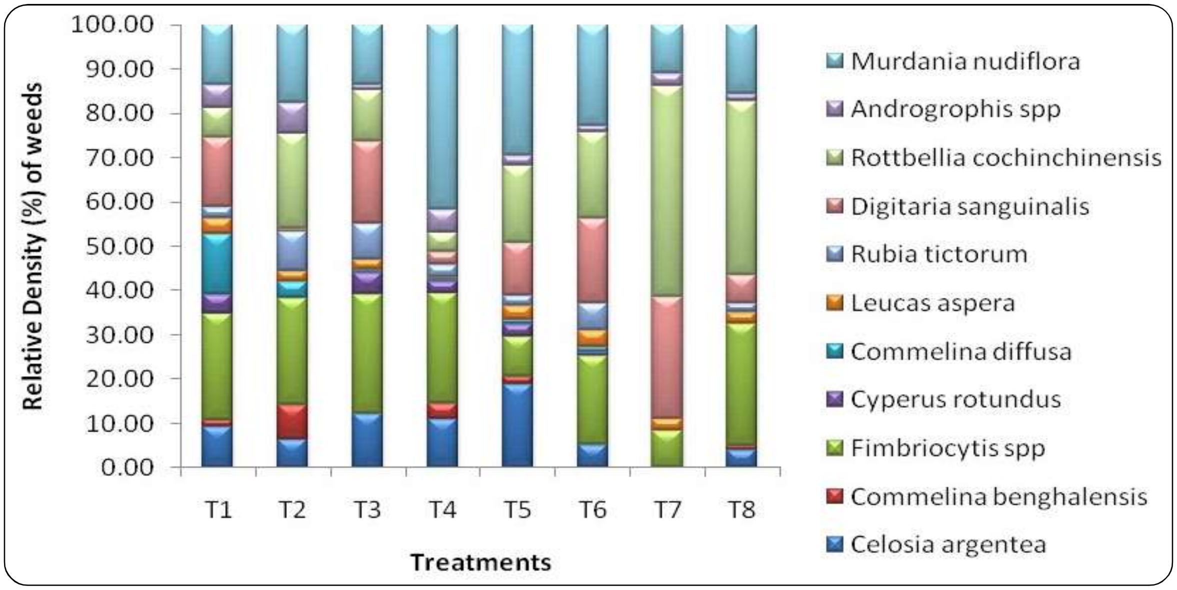

Fig. 4 : Relative density (%) of weeds in horsegram in different treatments

methods against specific weed species. According to Chauhan *et al*. (2011), certain herbicides are more effective against broadleaf weeds, while others target grass species more effectively. This specificity can influence the composition of weed species in the field.

Harvest Index, Weed Index, Rain Water use Efficiency and Production Efficiency

Harvest index was highest (37.17%) in T7 treatment, indicating a greater proportion of economic yield relative to the total biomass produced (Table 4). The low weed index in T7 signifies effective weed suppression, leading to better crop performance. High rain water use efficiency (5.15 kg/ha.mm) and production efficiency (9.37 kg/ha/day) in T7 demonstrate the treatment's effectiveness in utilizing available resources for optimal crop production. Among herbicide treatments higher harvest index (34.02%), weed index (28.1%), Rain Water Use Efficiency (3.70 kg/ha.mm) and Production Efficiency (6.73 kg/ha/day) was recorded in quizalofop-p-ethyl @ 50 g a.i./ha followed by propaquizafop @ 100 g a.i./ha. These findings are consistent with Sharma *et al*. (2015), who reported that efficient weed management enhances resource use efficiency, resulting in higher productivity.

TABLE 4

Harvest Index, Weed Index, Rain Water Use Efficiency and Production Efficiency as influenced by different weed management practices in horsegram

Treatment	Harvest Index (%)	Weed Index (%)	Rain Water Use Efficiency (Kg/ha.mm)	Production Efficiency (kg/ha/day)
T1	34.02	28.1	3.70	6.73
T2	31.35	40.7	3.04	5.52
T3	31.56	38.2	3.17	5.77
T4	31.68	39.9	3.08	5.61
T5	33.55	28.8	3.66	6.66
T6	33.39	30.1	3.59	6.54
T7	37.17	0.0	5.15	9.37
T8	33.10	45.3	2.82	5.13

Marginal Cost, Returns and Savings over Hand Weeding

T1 and T6 offer the highest total savings, indicating they are financially advantageous compared to hand weeding. T2, T3 and T4 result in negative total savings, meaning they are more costly compared to hand weeding. T8 has the highest cost savings, but its total savings are lower than T1 and T6 due to its higher marginal returns. Overall, T1 and T6 stand out as the most beneficial treatments in terms of net savings, while T2, T3, and T4 are less cost-effective (Table 5).

TABLE 5

Marginal returns, Marginal cost and savings over hand weeding

Treatment	Marginal cost (Rs/ha)	Marginal Returns (Rs/ha)	Cost Savings over hand weeding (Rs/ha)	Total savings over hand weeding (Rs/ha)
T1	-6980	-1731	6980	5249
T2	-6040	-6625	6040	-585
T3	-5802	-6018	5802	-216
T4	-5842	-6562	5842	-720
T5	-5040	-3889	5040	1151
T6	-7320	-2014	7320	5306
T7	-	-	-	-
T8	-8000	-6376	8000	1624

This study demonstrates that effective weed management practices significantly improve the growth, yield and economic returns of horsegram cultivation. Treatment T7 emerged as the most effective strategy, providing the highest plant height, number of branches, yield attributes and economic returns. However, other treatments like T6 and T1 also offered substantial benefits, making them viable alternatives. Implementing effective weed management strategies is crucial for optimizing horsegram production and ensuring sustainable agricultural practices. Future research could explore the long-term impacts of these practices on soil health and crop performance.

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Characterization of *Rhizoctonia bataticola* (Taub.) Butler Inciting Dry Root Rot Disease in Pigeonpea

Sailaja Medikurthi, A. S. Padmaja, H. K. Ramappa and Devaraja
Department of Plant Pathology, College of Agricultre, UAS, GKVK, Bengaluru - 560 065
e-Mail : sailaja6433@gmail.com

Authors Contribution

Sailaja Medikurthi : Conducting experiment;

A. S. Padmaja : Technical guidance and supervision;

H. K. Ramappa & Devaraja : Technical support and Supervision

Corresponding Author :
Sailaja Medikurthi

Received : September 2024
Accepted : October 2024

Abstract

Pigeonpea is the second most important pulse crop in India. The crop suffers from many diseases, of which dry root rot is gaining importance in recent years due to changes in climatic conditions and the crop is affected at seedling and flowering stage. In the present study the susceptible cv. ICP2376 was inoculated with the pathogen and the symptoms *viz*; drying and bark shredding were produced upon infection. The morphological characters such as colony characters, microsclerotia and growth on different media, pH conditions revealed that the pathogen is *Rhizoctonia bataticola* which was further confirmed by molecular identification with specific primers. This study suggests that the parasitic phase of the pathogen is present in the region causing dry root of pigeonpea and pycnidial stage is not produced on the inoculated plants

Keywords : Pigeonpea, Dry root rot, Rhizoctonia bataticola, Characterization

Pigeon pea [*Cajanus cajan* (L.) Mill sp.] is a legume crop species belongs to the family *Fabaceae*. It is the major *kharif* crop and the second most important pulse crop after chickpea in India. It is consumed on a large scale in South Asia and is a major source of protein for the population of Indian sub-continent. Approximately, 88 per cent of the global pigeonpea is consumed as food (dal) (Rao *et al*., 2010). The productivity of pigeonpea is limited by a range of biotic and abiotic factors. Some of the abiotic factors include erratic rainfall, water logging, drought, increased temperature, among biotic factors, the major damage is caused by diseases and insects.

Pigeonpea is known to be affected by fungi, bacteria, viruses, nematodes and phytoplasma. The economically important diseases are wilt caused by *Fusarium udum* (Butler), *Phytopthora* blight by *Phytophthora drechsleri* Tucker f. sp. *cajani,* pigeonpea sterility mosaic disease caused by an Emara virus and more recently dry root rot caused by *Rhizoctonia bataticola* (Taub.) Butler (pycnidial stage: *Macrophomina phaseolina*). Two asexual sub-phases of *Macrophomina* are: (1) a saprophytic phase (*Rhizoctonia bataticola*) that forms microsclerotia and mycelia and (2) a pathogenic phase (*M. phaseolina*) present in host tissues that forms microsclerotia, mycelia and pycnidia. In the pathogenic stage the fungus is non-host specific and attacks broad spectrum of economically important crops such as common beans, maize, soybean, mungbean, urdbean and sesame *etc*. (Dhingra and Sinclair, 1978). *R. bataticola* is a widespread, soil-borne fungal pathogen that infects over 500 different plant species. The pathogen affects crop plants and induces a variety of diseases, such as seedling blight, root rot, charcoal rot, wilt, stalk rot, stem blight, fruit rot, seedling decay and leaf blight (Dhingra & Sinclair, 1978 and Ram *et al.,* 2018).

Dry root rot of pigeonpea caused by *Rhizoctonia bataticola* occurs in many grain legumes when the plants are exposed with moisture stress (Hwang *et al*., 2003) and can cause 50 to 100 per cent yield loss under favourable conditions. Pigeonpea dry root rot is characterised by drooping and drying of the leaves, dark and extensive rotting of the root system, damaged lateral roots and the roots become brittle with shredding of the bark. The affected plants are very easy to uproot from the soil and the roots also become discoloured due to the presence of black microsclerotia on the roots (Nene *et al*., 1991 and Vamsikrishna *et al*., 2021).

Climate change has increased the incidence of dry root rot in recent years since the growing crop is predisposed to high temperatures and moisture stress due to uneven rainfall (Rai *et al.,* 2022 and Reddy *et al.,* 2016). It is very difficult to control the disease once initiated, as the pathogen is soil-borne which can survive in the soil over a long time in the form of sclerotia and also has a wide host range. Therefore, even crop rotation may not be effective to control the disease. Management of the disease requires a comprehensive understanding of causal organism. Hence, the present study was undertaken to know the cultural, morphological and molecular characters of the fungi associated with dry root rot disease in pigeonpea.

Material and Methods

Collection and Isolation of the Pathogen

The pigeonpea roots showing typical symptom of dry root rot were collected from pigeonpea plots, GKVK, Bengaluru. The pigeonpea roots showing bark peeling and disintegrated roots were cut into small bits measuring about 2mm and surface sterilized in sodium hypochlorite (1%) for one minute and washed repeatedly twice in sterile distilled water to remove the traces of sodium hypochlorite, before transferring them to sterile potato dextrose agar (PDA) plates under aseptic conditions. The plates were incubated at the temperature of 28 ± 2°C and observed for fungal growth. The pure culture of the fungus was obtained by hyphal tip isolation method. To test pathogenicity of dry root rot pathogen two methods *viz*., blotter paper method (Nene *et al*., 1981) and sick pot technique were employed. The pathogenicity test was conducted using susceptible pigeonpea cultivar ICP 2376. Re-isolation of the pathogen from the affected portions was compared with the original culture of *R. bataticola*.

Survey for the Incidence of Dry Root Rot in Pigeonpea Growing Areas

A survey for the prevalence of dry root rot of pigeonpea was carried out in Doddaballapura taluk, Bengaluru. The incidence was assessed by counting the number of plants showing typical symptoms like bark peeling, root disintegration and the per cent disease incidence was calculated.

$$\text{Per cent disease incidence} = \frac{\text{Number of plants infected}}{\text{Total number of plants examined}} \times 100$$

Cultural and Morphological Characterization

The cultural characters of *R. bataticola* was studied on the following synthetic and semi-synthetic solid and liquid media *viz*., Richard's agar, Czapek dox agar, Sabouraud's dextrose agar, Corn meal agar and Water agar and semisynthetic media *viz*., Potato dextrose agar, Potato carrot dextrose agar, Oat meal agar, Carrot agar and Host extract agar. Twenty mL of each medium was poured into the Petri plates. After solidification, five mm disc of *R. bataticola* was placed at the centre of the plate. Each set of experiment was replicated thrice and plates were incubated at 28 ± 2°C for 9 days. The cultural characters such as the colony diameter, colony color, type of margin, presence or absence of sclerotia, number of sclerotial bodies per microscopic field and the size of sclerotial bodies were recorded. In liquid broth media, the pathogen was grown and all the cultures were harvested on the 11th day. Cultures were filtered through Whatman No. 1 filter paper, which were dried to a constant weight in an electric oven at 60°C and weighed immediately on an electric balance and the weight of dry mycelia were recorded.

In order to study the best pH for mycelial growth of pathogen, it was tested in a range of pH from 4 to 9. For the experiment, 50 mL of potato dextrose broth was poured in 100 mL capacity conical flasks. The pH of potato dextrose broth was adjusted to various ranges from 4 to 9 by using pH meter adding standard 1M NaOH or 1M HCl. All the flasks were inoculated with 5 mm agar discs and incubated at 28 ± 1ºC. After ten days of inoculation, it was filtered through Whatman no. 1 filter paper and mycelial mats were collected. These mycelial mats were dried in hot air oven at 60⁰C for 2 hours. Dry weight of the mycelial mat was recorded. The data obtained were statistically analysed.

Molecular Characterization

The flasks containing PDB were inoculated with mycelial mats of *R. bataticola* by using a sterilized cork borer. The inoculated flasks were cotton plugged and put into BOD incubator at 25 ± 2°C temperature with 80 ± 5 per cent RH for proper growth of the fungus. After 7 days of inoculation, fully grown mycelial mats were harvested and genomic DNA was isolated using Cetyl Trimethyl Ammonium Bromide (CTAB) protocol described by Gontia-Mishra *et al*. (2013). The DNA was amplified using the universal ITS primers. The ITS region of DNA was amplified by PCR with ITS1 (5-TCCGTAGGTGAACCTGCGG-3') and ITS4 (5' TCCTCCGCTTATTGATATGC-3') (White *et al*., 1990). ITS1/ ITS4 amplified by PCR using initial denaturation at 94°C for 5min, denaturation at 94°C for 30sec, annealing at 55 °C for 60sec, elongation at 72°C for 90 sec (35 cycles) and final elongation at 72°C for 7 min.

Along with ITS region, specific primers *viz*., MpTefF/MpTefR and MpCalF/MpCalR (Table 1) were also amplified by PCR with initial denaturation for 2 min at 94°C, denaturation at 94°C for 1 min, annealing at 63°C for 30 sec, elongation for 1 min at 72°C (30 cycles) and final elongation at 72°C for 10 min. The Electrophoresis of PCR products was carried out using 1 to 1.2 per cent agarose gel and observed under UV light with the help of Bio-Rad Gel documentation system. The DNA was sequenced by Sanger's method by Eurofins Genomics India Pvt. Ltd, Bengaluru, Karnataka. The resulting sequences were analysed for homologies using the sequences deposited in the GenBank by using BLASTn analysis at http://www.ncbi.nlm.nih.gov.

Results and Discussion

A large number of dry root rot infected pigeonpea plants showing typical symptoms like drying, extensive rotting of roots, bark shredding and discoloration of affected portions (Plate 1a and b) were collected from the field. The pathogenicity was proved and found to be identical with respect to all the morphological characters on PDA (Plate 2). Similarly, Nene *et al*. (1981) and Manjunatha (2009) proved pathogenicity of *R.bataticola* by blotter paper technique.

The morphological and growth characters were studied. The mycelium was pale white in color in the initial stages of growth, eventually turned to dark grey to black in color as and when sclerotia formation started. Mycelia aggregated to form numerous dark brown to black colored microsclerotia noticed on the back side of the culture plate.

Table 1

List of specific primers used for the molecular characterization of *M. phaseolina*

Primers	Primer sequence (Forward/Reverse)	Tm (°C)	G + C (%)	Product size (bp)
MpCalF	CAATCTCTTTCTCCCCTACAGGA	58.97	47.83	403
MpCalR	ACTGCGCAAAAGCGCCAGTAAAC	65.25	52.17	
MpTefF	AAACACACTTTTCGCACTCCTGC	62.57	47.83	
MpTefF	TATGCTCGCAGAGAAGAACACGA	61.97	47.83	217

Plate 1a : Pigeonpea affected with dry root rot (Seedling and flowering stage)

Plate 1b : Bark shredding and disintegration of dry root rot infected root system

Healthy seedling and infected seedling Infected root system

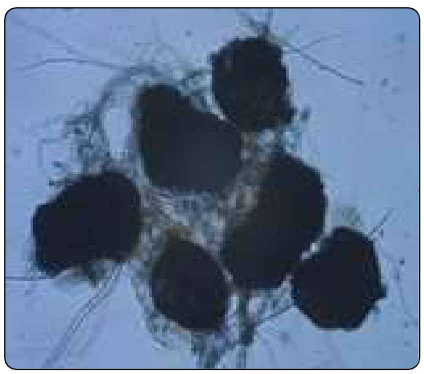
Plate 2 : Testing pathogenicity on susceptible pigeonpea cultivar ICP 2376

Fungal colony on PDA-upper side

Lower side

Growth on PDB

Plate 3 : Pure culture of *R. bataticola*



Sclerotial bodies

Right angle branching of mycelium

Plate 4 : Morphological characters of *R.bataticola* causing dry root rot in pigeonpea

Right-angled mycelial branching and constriction of hyphae at the point of branching were observed. The size, form and growth pattern of the microsclerotia varied, ranging from scattered to clustered (Plate 3 & 4). The pathogen was confirmed as *Rhizoctonia bataticola* based on the morphological, cultural characteristics and the fungus ability to grow on media.

The survey was undertaken in Doddaballapura of Bangalore urban and Bangalore rural districts. The dry root rot was recorded with the range of 0-25 per cent (Table 2).

The variation in cultural characters was observed by growing the pathogen in different media. Richard's agar recorded the maximum radial growth with mean colony diameter of 90.00 mm followed by corn meal agar (87.53 mm) (Table 3). Among different semi-synthetic solid media,

TABLE 2

Incidence of dry root rot in pigeonpea growing area

Taluk	Village	Per cent Incidence
Doddaballapura	Honnaghatta	0-10
	Neralaghatta	0-25
	Gundasandra	5-25
	Tippuru	5-15
Nelamangala	Nelamangala	15-20
Bangalore-North	Yelahanka	0-10

TABLE 3

Effect of different solid media on cultural characters of *R. bataticola*

Media	Colony colour	Type of growth	Type of margin
	Synthetic media		
Richard's agar	Light grey	Partial aerial mycelia	irregular
Czapeks dox agar	Greyish black	Mycelia immersed	Irregular
Sabouraud's dextrose agar	Dark grey	Immersed mycelia	Irregular
Water agar	Light black	Partial aerial mycelia	Uniform
Corn meal agar	Greyish black	Partial aerial mycelia	Uniform
	Non-synthetic media		
Potato dextrose agar	Greyish black	Partial aerial mycelia	Uniform
Carrot agar	Greyish black	Partial aerial mycelia	Uniform
Potato carrot agar	Greyish black	Partial aerial mycelia	Uniform
Oatmeal agar	Light grey	Fluffy growth	Uniform
Host extract agar	Light grey	Partial aerial mycelia	Uniform

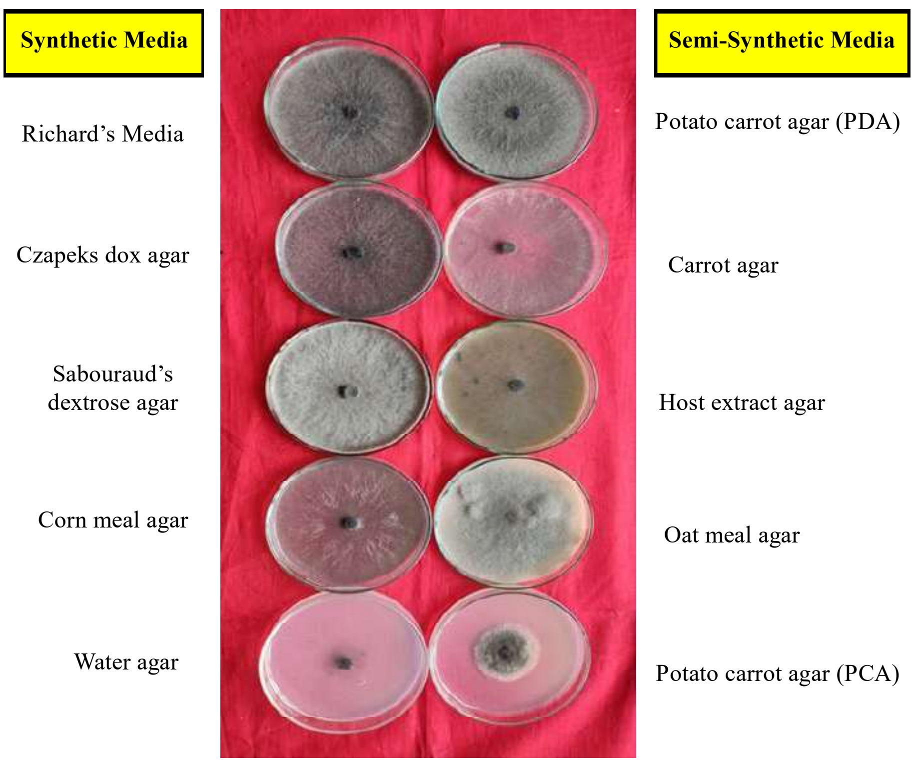


Plate 5 : Effect of different solid media on radial growth of *R. bataticola*

maximum radial growth was observed in potato dextrose agar (PDA) with mean colony diameter of 90.00 mm followed by host extract agar (88.50 mm) (Table 3 and plate 5). All the eleven different synthetic and semi-synthetic solid media showed high variation in their microsclerotial production, the PDA recorded the maximum production of microsclerotia per microscopic field (52.33) followed by carrot agar

Table 4

Influence of solid media on growth and sclerotial production of *R. bataticola*

Media	Radial growth (mm)	Number of scleorotia/ microscopic field (10x)	Sclerotial size (mm) (40x)
Richard's agar	90.00	45.66	1.21 x 0.95
Czapeks dox agar	85.40	40.00	1.35 x 1.38
Sabouraud's dextrose agar	86.40	47.33	1.45 x 1.17
Water agar	36.23	32.00	0.86 x 0.59
Corn meal agar	87.53	37.33	1.10 x 0.74
Potato dextrose agar	90.00	52.33	1.78 x 1.37
Carrot agar	86.00	50.66	0.75 x 0.58
Potato carrot agar	38.17	30.66	1.00 x 0.90
Oatmeal agar	85.50	45.00	1.43 x 1.11
Host extract agar	88.50	35.00	0.62 x 0.47

(50.66) and the size of the microsclerotia varied from 1.78 x 1.37 mm to 0.62 x 0.47 mm (Table 4).

The colony color in different semi-synthetic media, including PDA, carrot agar and potato carrot agar, exhibited a partially aerial mycelium which is greyish black in color with a uniform border. However, host extract agar had a light green and oat meal agar exhibited light grey colored colony with fluffy growth. In contrast to Czapek dox agar, corn meal agar and Sabouraud's agar, which had a greyish to blackish color, Richard's agar and water agar developed light grey to black colored aerial mycelia with irregular to uniform margins.

The good growth on PDA may be due to the high concentration of carbohydrates (17.47g per 100 g), which may encourage the vegetative growth and also provide additional nutrients (Sahi *et al*., 1992; Wasseer *et al.,* 1992; Monga & Sheo, 1994; Singh & Kasir, 1994; Jha & Dubey, 2000; Meena *et al.,* 2001; Manjunatha, 2009 and Tandel *et al.,* 2012). Poor pathogen development was seen in water agar (36.48 mm), however in host extract agar the smallest sclerotial size (0.62 x 0.47 mm) was recorded. The pycnidial stage was never produced in culture (Grover and Sakhuja, 1981) stating that the pathogen under the study is only the parasitic phase.

For liquid media, mycelial mats were harvested 11 days after inoculation and dry weight was recorded as described in the previous chapter. Among the different liquid media tested, Richard's broth (1010.52 mg) recorded the significantly higher dry mycelial weight as compared to other liquid media, followed by potato dextrose broth (983.03 mg), oat meal broth (776.52 mg) and malt extract broth (203.51 mg). The dry weight of mycelium was very poor in carrot broth (91.73 mg), potato carrot dextrose broth (44.09 mg) and in host extract broth (36.91 mg)

Table 5

Effect of different liquid media on cultural characters of *R. bataticola*

Media	Mean dry mycelial weight (mg)
Potato Dextrose Broth (PDB)	983.03
Richard's Broth	1,010.52
Oatmeal Broth	776.52
Malt Extract Broth	203.51
Carrot Broth	91.73
Potato Carrot Dextrose Broth	44.09
Host Extract Broth	36.91
C.D.	175.98
SE(m)	57.46
C.V	22.14

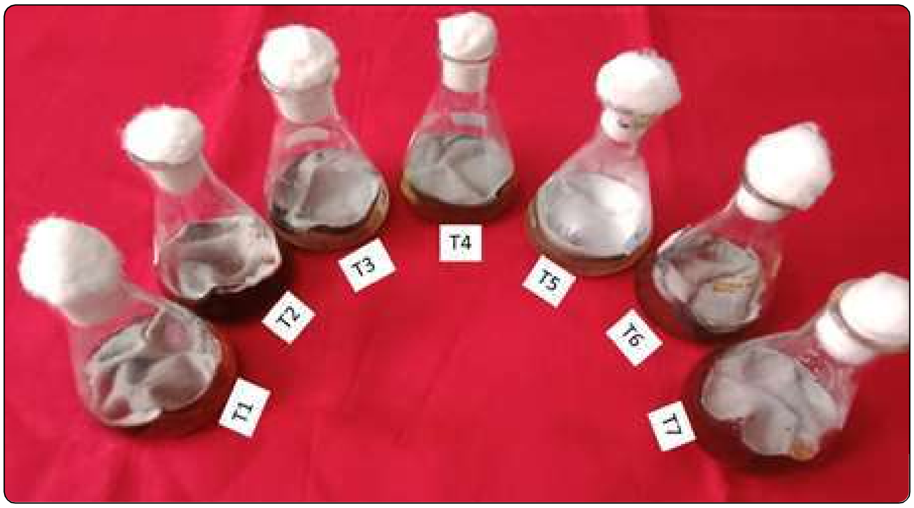


Plate 6 : Effect of different liquid media on dry mycelial weight of *R. bataticola*

(Table 5 and Plate 6). The present findings suggested the use of Richard's broth and potato dextrose broth for good dry mycelial weight. The similar findings are also recorded by other researchers, Jha & Dubey (2000), Suriachandraselvan *et al*. (2004), Tandel *et al.* (2012) and khan *et al*. (2012), where they have noticed best growth of fungus on Richard's solution.

Effect of pH on the Growth of *R. bataticola*

R. bataticola grew at all six pH levels, however the highest dry mycelial weight was found at pH 6.0 (539.16 mg), followed by pH 7.0 (465.50 mg), pH

TABLE 6
Effect of pH on fungal biomass of *R. bataticola in vitro*

Treatment pH level	Dry mycelial weight (mg)
4	241.33
5	288.57
6	539.16
7	465.5
8	364.17
9	260.5

Plate 7 : Effect of different pH on dry mycelial weight of *R. bataticola*

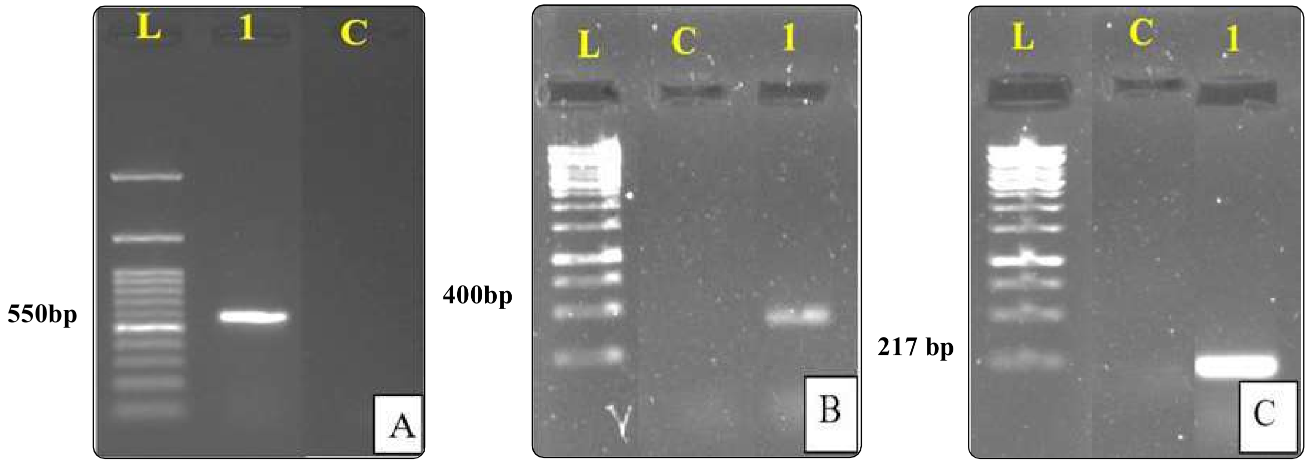


Plate 8 : ITS rDNA and specific region amplification of *R. bataticola* A) Amplification of ITS region with band size of 550 bp B) Amplification of MpCalF/MpCalR with band size of 400 bp and C) Amplification of MpTefF/MpTefR with band size of 217 bp, L- Lane with 1 kb ladder, 1- Sample, C- Control

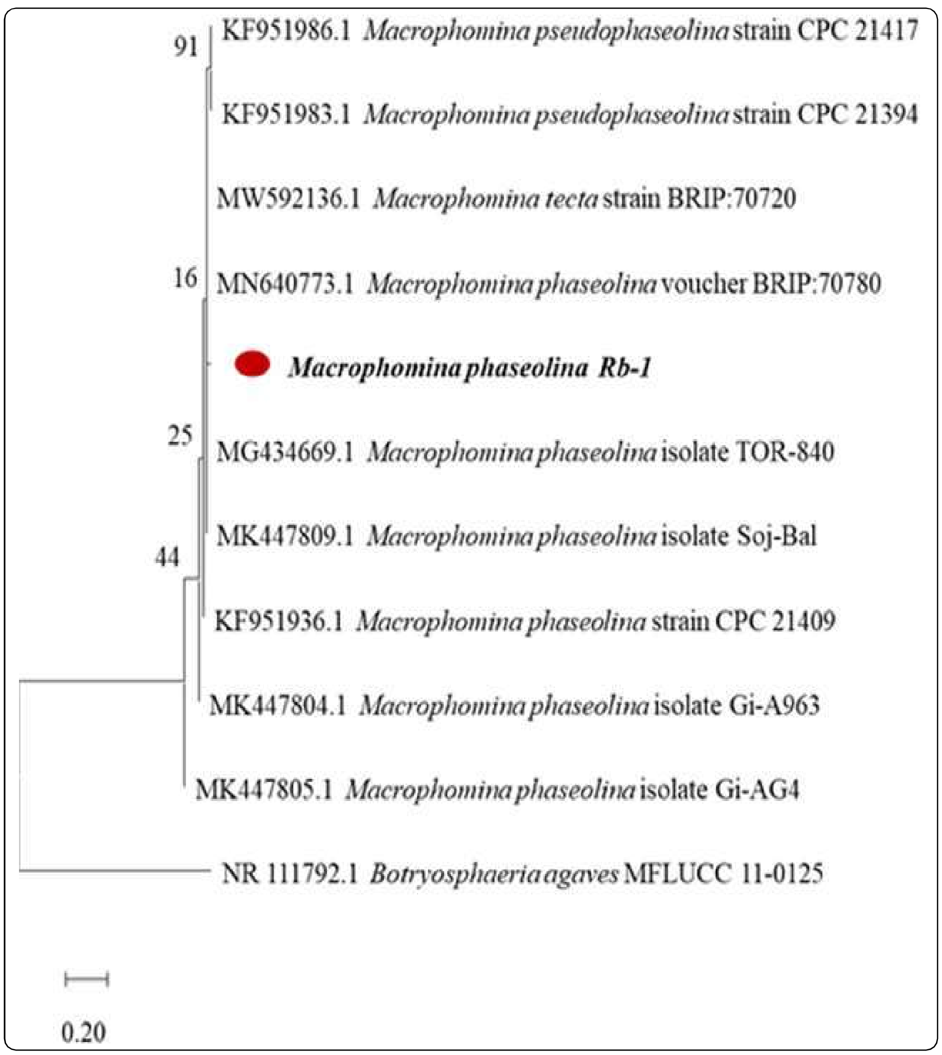


Plate 9 : Phylogenetic analysis using ITS sequence with other *Macrophomina* isolates by using Neighbour joining tree method in MEGA11 software. NR 111792 *Botryosphaeria agaves* MFLUCC 11-0125 used as outlying sequence

8.0 (364.17 mg) and pH 5.0. (288.57 mg) (Table 6, and Plate 7). The pH values between 6 and 7 favours the pathogen. Kulkarni (2000), Chowdary and Govindaiah (2007) and Bhupathi and Theradimani (2018) found highest growth of *Macrophomina* at pH 7.0 affecting maize, blackgram and mulberry respectively. Kaur *et al.* (2013) reported maximum mean dry mycelial weight at pH 6 and 7.

Molecular Identification of the Pathogen

The PCR amplification of the pathogen DNA was carried out using ITS1 and ITS4 region and specific primers (MpTefF/MpTefR and MpCalF/MpCalR). DNA isolated from *R. bataticola* showed an expected amplicon of ~550 bp to ITS1/ITS4, ~400 bp to MpCalF/MpCalR and ~217 bp to MpTefF/MpTefR (Table 7 and Plate 8).

BLASTn results of ITS and specific primers confirmed that the pathogen is *Rhizoctonia bataticola* (Pycnidial stage: *Macrophomina phaseolina*). Phylogenetic analysis was done using ITS, Cal and Tef gene sequences with other *Macrophomina* isolates by using Neighbour joining tree method in MEGA11 software (Plate 9, 10 and 11). The identification of

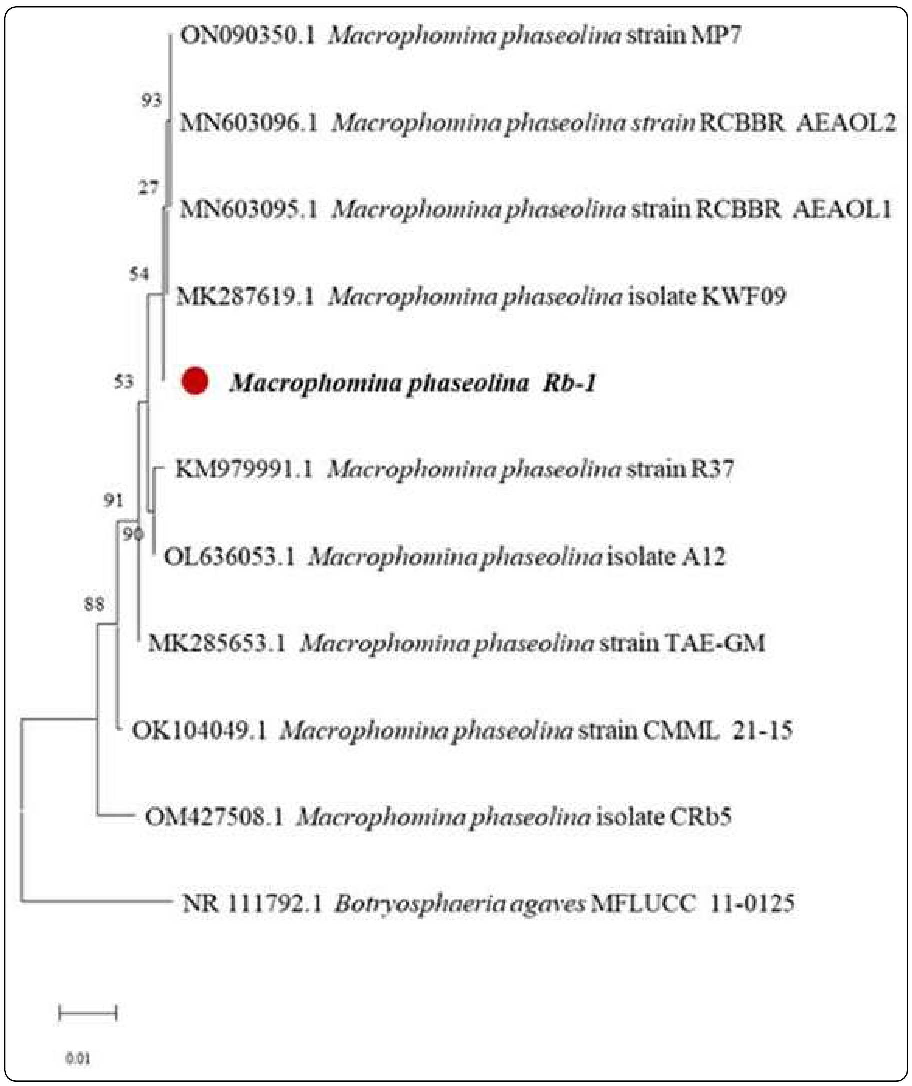


Plate 10 : Phylogenetic analysis using ITS sequence with other *Macrophomina* isolates by using Neighbour joining tree method in MEGA11 software. NR 111792 *Botryosphaeria agaves* MFLUCC 11-0125 used as outlying sequence

TABLE 7
Sequence homology of *M. phaseolina* with Genbank accession number

Primers	Accession number	Homology* (%)	Reference accession number
ITS1/ITS4	OP577492	99.21	MN689707
MpTefF/ MpTefR	OP799547	99.64	MN355988
MpCalF/MpCalR	OP787211	100.00	MN640773

(*Per cent identity with reference sequence, which is indicated as reference accession number).

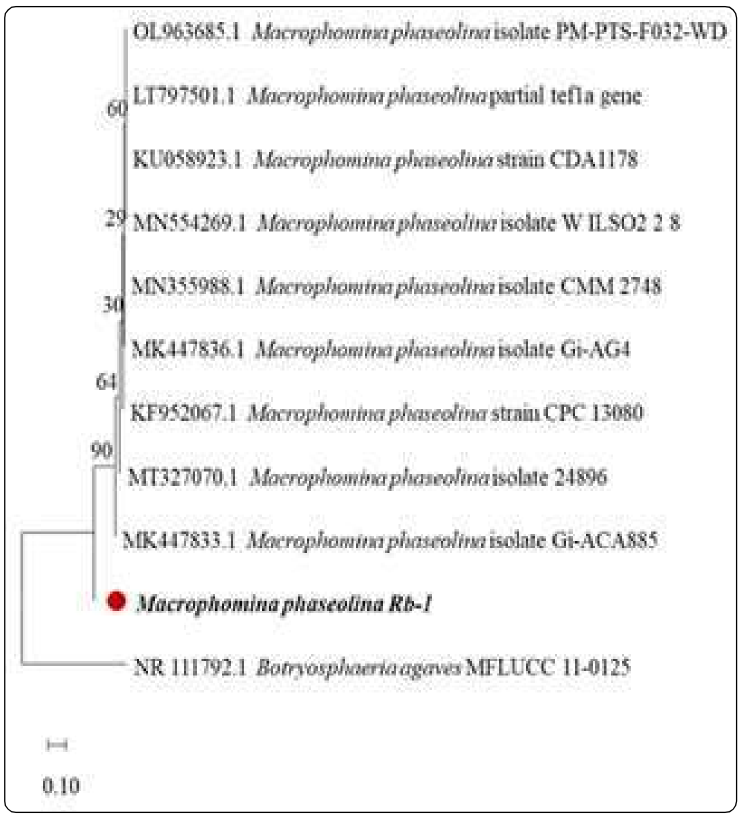


Plate 11 : Phylogenetic analysis using Tef1 gene sequence with other Macrophomina isolates by using Neighbour joining tree method in MEGA11 software. *Botryosphaeria agaves* used as outlying sequence

Rhizoctonia bataticola was done based on morphological characters described by Ashby (1927), Manjunatha (2009) and Dubey and Aghakhani (2009) as well as based on molecular basis by using ITS1/ ITS4 molecular markers (Dubey and Aghakhani, 2009; Sunkad *et al.,* 2023) and specific primers described by Santos *et al*. (2020). ITS sequencing of the 18S rRNA region has been used to identify *M. phaseolina* from a variety of hosts (Babu *et al*., 2007; Romanelli *et al*., 2014 and Khan *et al*., 2017).

Present investigations on dry root rot disease of pigeonpea included isolation, identification and pathogenicity, cultural and molecular characterization, efficacy of different solid, liquid media and pH on the growth of *Rhizoctonia bataticola* (Taub.) Butler

[Pycnidial stage: *Macrophomina phaseolina* (Tassi) Goid] causing dry root rot disease. This is the first report of dry root in pigeonpea from Southern Karnataka. The pathogen was confirmed as *Rhizoctonia bataticola* based on the morphological, cultural characteristics and the fungus ability to grow on media. Richard's agar, potato dextrose agar (PDA) and Richard's broth supported the maximum growth of the pathogen. *R. bataticola* grew at all pH levels however the highest dry mycelial weight was found at pH 6.0. DNA isolated from *R. bataticola* showed an expected amplicon of ~550 bp, ~400 bp and ~217 bp to ITS, Cal gene and to Tef gene, respectively. The parasitic phase of *R. bataticola* is present in the region and the management practices should be aimed to eradicate or inhibit the pathogen in soil, as the pycnidial stage of the pathogen is not present in the region. However, the studies on host range, epidemiology and management have to be undertaken for controlling the disease spread in pigeonpea crop system.

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Mysore J. Agric. Sci., 58 (4) : 281-287 (2024)

Physico-Chemical Parameters and Microbial Population Dynamics in *Jeevamrutha* Bioformulations of Different Cow Breeds

SATHWIK M. N. RAJ[1], R. MUTHURAJU[2], M. T. SANJAY[3] AND M. K. MURALI[4]
[1,2&4]Department of Agricultural Microbiology, [3]Department of Agronomy,
College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : sathwik080996@gmail.com

AUTHORS CONTRIBUTION

SATHWIK M. N. RAJ :
Conceptualization, carried out experiment, data analysis and draft preparation;

R. MUTHURAJU &
M. T. SANJAY :
Conceptualization, draft correction and supervision;

M. K. MURALI :
Data analysis and draft preparation

Corresponding Author :
SATHWIK M. N. RAJ

Received : September 2024
Accepted : September 2024

ABSTRACT

Jeevamrutha is a complex biodynamic microbial liquid formulation prepared from indigenous ingredients such as cow dung, cow urine, pulse flour, jaggery, soil and water. *Jeevamrutha* has been used by Indian farming community for centuries and deeply rooted in traditional organic farming practices. To understand the physico-chemical dynamics of *jeevamrutha* during the incubation period, pH and EC were analysed up to 7th day of incubation. The C/N ratio and microbial population were estimated up to 8th day to determine if microbial load reduces beyond 7th day. The final pH 5.05, 5.05, 5.20 and 5.20, electrical conductivity 1.38, 1.44, 1.44 and 1.43 dSm^{-1} and the decrease in C/N ratio from 20.77 to 13.55, 19.19 to 11.77, 21.42 to 14.63 and 20.88 to 13.48 in Hallikar, Deoni, Ongole and HF *jeevamrutha,* respectively. The decrease in C/N ratio of *jeevamrutha* during the incubation period corresponds to increase in the microbial population. The relatively high microbial population on 7th day justifies the field application of jeevamrutha by farmers after 7-8 days of incubation.

Keywords : Electrical conductivity, Jeevamrutha, Microbial load, pH

ORGANIC farming has become a key focus in global development due to increasing demand for safe and healthy food, long-term sustainability and concerns about environmental pollution from the negligent use of agrochemicals (Mahdi *et al*., 2012). Practicing sustainable agriculture can prevent pesticides and toxic substances from entering the food chain while also help to avoid soil and water pollution (Boraiah *et al*., 2017). Organic farming mainly focuses on use of on-farm organic resources to sustain soil health (Nath *et al*., 2023). The extensively applied organic manures like farm yard manure, green manures, vermicompost and non-edible oil cakes are needed to accomplish the nutritional requirements of crops. The narrow availability of these bulky organic manures requires their integration with supplementary available options. Liquid organic fertilizer formulations like *Panchagvya*, *Beejamrutha* and *Jeevamrutha* are often used as plant growth enhancing substances prepared with material available with farmers. They are rich sources of beneficial microflora that support and promote plant growth, leading to improved vegetative growth and higher-quality yields (Devakumar *et al*., 2011).

Natural Farming is a chemical-free agricultural system rooted in Indian tradition, enriched by modern ecological knowledge, resource recycling and on-farm resource optimization. It is viewed as an agroecology-based diversified farming system that integrates crops, trees and livestock with functional biodiversity. Nearly 10 lakh hectares of land is covered under natural farming in India

(National Mission on Natural Farming Management and Knowledge Portal, 2022). The use liquid formulations like *jeevamrutha*, *beejamrutha* and *panchagavya* are integral part of natural farming.

Jeevamrutha is a complex biodynamic microbial liquid formulation prepared from indigenous ingredients such as cow dung, cow urine, jaggery, pulse flour, soil and water. *Jeevamrutha* has been used by Indian farming community for centuries and deeply rooted in Indian natural farming practices (Palekar, 2006). Microflora in *jeevamrutha* play a vital role in improving soil quality. The beneficial microbes in *jeevamrutha* directly or indirectly improves plant growth by the secretion of growth hormones, biofertilization, stimulation of root growth, rhizoremediation and plant stress control (Prasad *et al*., 2017). With this view, a study was carried out to study the changes in pH and electrical conductivity and realize the influence of nutrient content mainly the C/N ratio on microbial population during its preparation.

Material and Methods

Sample Collection

The cow dung and urine samples of milch breeds of Hallikar, Deoni, Ongole and Holstein- Friesian (HF) were sourced from Rashtrotthana Goshala, Doddaballapur, Karnataka (13.40°N, 77.52°E). The average age of these cows were 4-5 years. The cow's feeding habit did not include any feed concentrates and were not administered any hormonal injections. The samples were placed in ice box, transported to laboratory and stored at 4ºC for further studies.

Plate 1 : List of ingredients used for the preparation of *jeevamrutha*

Preparation of *Jeevamrutha*

Materials required (1L): Cow dung-50g; Cow urine- 50mL; Jaggery-10g; Chickpea (gram) flour-10g; Soil-2.5g; Water- to make up the volume. Gram (chickpea) flour and jaggery samples were sourced from organically certified seller. Gram flour is rich source of proteins, carbohydrates and fatty acids, where jaggery is natural source of sucrose, fructose, glucose, minerals and vitamins (Hend *et al*., 2020 and Sharifi-Rad *et al*., 2023). The top soil was collected from Mahatma Gandhi Botanical Garden, University of Agricultural Sciences, Bangalore. These materials in exact proportion were mixed together into a non-metal container and water was added to make the volume to 1L. This preparation was mixed twice every day and allowed to ferment for 7 days (Palekar, 2006).

Determination of Physicochemical Properties and Microbial Load of *Jeevamrutha*

Measurement of pH, Electrical Conductivity (EC) and C/N Ratio of *Jeevamrutha*

Jeevamrutha samples were harvested at 24 h intervals starting from 0-day to 7-day of incubation. Changes in pH and electrical conductivity (EC) of *jeevamrutha* were measured using pH and EC meter (Rayment and Higginson, 1992). The organic carbon content in *jeevamrutha* was determined using wet oxidation method by Walkley and Black (1934) while, nitrogen content was determined using Micro-Kjeldahl method described by Allison (1965) up to 8 days of incubation at every 24 hours intervals.

Microbial Population in *Jeevamrutha*

Microbial population was estimated by standard plate count technique at 24 hours intervals up to 8 days of incubation. Different dilutions of *jeevamrutha* bioformulation were plated on nutrient agar, Martin's rose bengal agar and Kusters agar to enumerate general bacteria, fungi, actinomycetes population respectively. The plates were incubated at 28 ± 2 ºC and the observations were recorded after 24 hours of incubation for bacteria, 4872 hours of incubation for fungi and actinomycetes. Microbial count were recorded as colony forming units per mL (cfu/mL) of *jeevamrutha* sample tested.

Statistical Analysis

All the experimental data were subjected to statistical analysis using Web Agri Statistical Package (WASP 2.0) software and means were compared using Duncan's multiple range test (DMRT).

Results and Discussion

Jeevamrutha undergoes a series of physicochemical and biological changes during incubation.

pH and Electrical Conductivity (EC) Parameters of *Jeevamrutha*

An initial pH of 7.8 was recorded on 0th day in Hallikar *jeevamrutha*. A sharp drop in the pH to 4.0 was observed after 24 h of incubation. This was followed by a gradual rise in pH until which stabilized at 5.05. Simultaneously, rise in EC value from 0.90 to 1.38 dSm^{-1} was observed (Fig. 1), during incubation period. Similarly, in Deoni *jeevamrutha*, pH dropped from 8.0 (0th day) to 4.0 (1st day) followed by stable increase in pH to 5.05 on 7th day while, EC increased from 0.96 to 1.44 dSm^{-1} (Fig. 2).

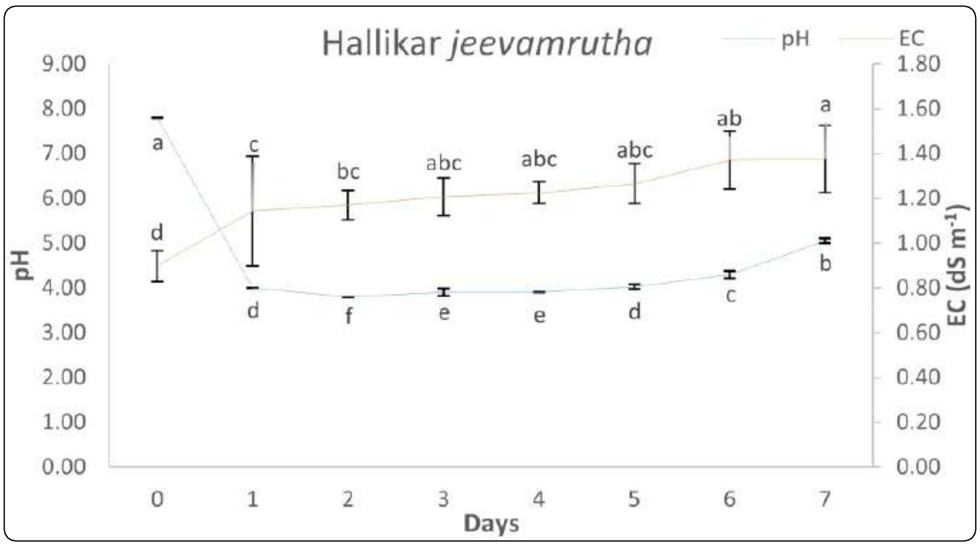

Fig. 1 : A graphical representaion of pH and EC in Hallikar *jeevamrutha* during incubation period

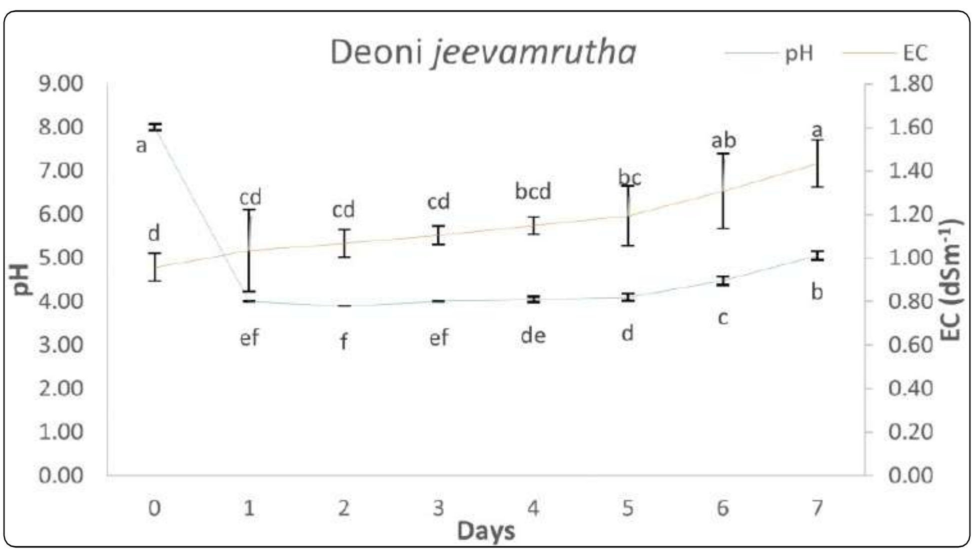

Fig. 2 : A graphical representaion of pH and EC in Deoni *jeevamrutha* during incubation period

The pH decreased from 7.90 to 5.20 and EC increased from 1.01 to 1.44 dSm^{-1} from 0^{th} day to 7^{th} day in Ongole *jeevamrutha* (Fig. 3) while, pH lowered to 5.20 and EC increased to 1.43 dSm^{-1} on 7^{th} day in HF *jeevamrutha* (Fig. 4).

The demand for carbon in the presence of complex nutrients is primarily satisfied by free sugars during fermentation. Sugars are converted to volatile fatty acids (VFAs) and organic acids (OAs) during this process thus lowering the system's pH (Ferreira and Mendes-Faia, 2020). Further, on the depletion of sugars, microbes utilize protein, releasing ammonia from amino acids, thereby increasing pH (Ferreira & Mendes-Faia, 2020 and Mira-de-Orduna *et al*., 2001). The increase in number of free ions due to the breakdown of complex substrates into simpler ones explains the increase in electrical conductivity during incubation period. The cow breeds do not have influence on changes in pH and EC, however, the nutrient content and microbial load of jeevamrutha depends on feeding habit of the animal.

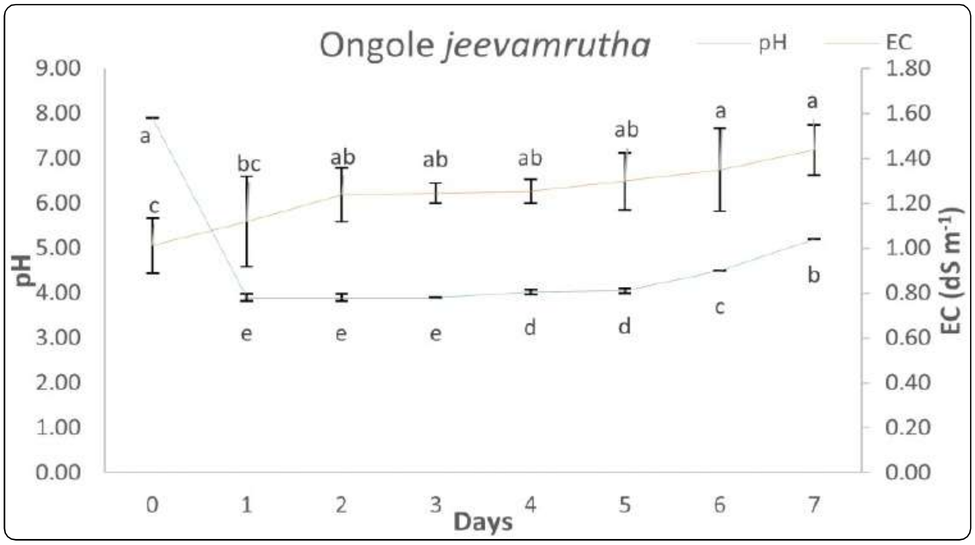

Fig. 3 : A graphical representaion of pH and EC in Ongole *jeevamrutha* during incubation period

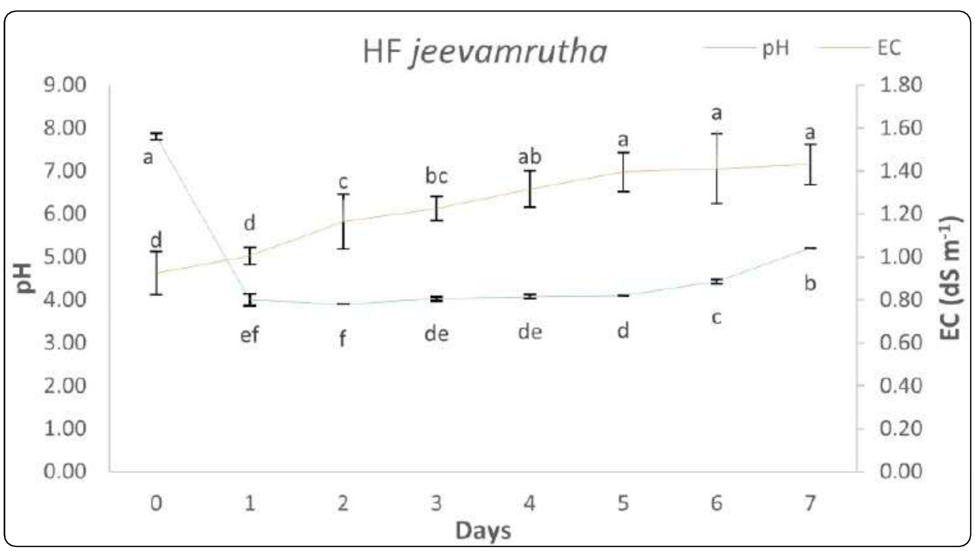

Fig. 4 : A graphical representaion of pH and EC in HF *jeevamrutha* during incubation period

Microbial Load and C/N Ratio of *Jeevamrutha*

The C/N ratio declined from 20.77 (0th day) to 13.55 (8th day) in Hallikar *jeevamrutha* while, Deoni *jeevamrutha* showed a drop in C/N ratio from 19.19 to 11.77 during incubation period. Similarly, a decline in C/N ratio from 21.42 to 14.63 and 20.88 to 13.48 was recorded in Ongole and HF *jeevamrutha* respectively. This indicates the continuous utilization of C and N rich substrates by microbes for their multiplication. But an increase in C/N ratio in all *jeevamrutha* samples on 5th day suggested the release of sugars from complex polysaccharides like cellulose and hemicellulose in the fermenting medium (Table 1). Subsequent drop in C/N ratio beyond 7th day may be due to release of nitrogen from protein in the form of ammonia (Duraivadivel *et al*., 2022).

There was an increase in bacterial population from 23.75X10^{6} to 38.00X10^{6} cfu/mL, 18.50X10^{6} to 32.75X10^{6} cfu/mL, 35.00X10^{6} to 49.25X10^{6} cfu/mL and 22.50X10^{6} to 36.00X10^{6} in Hallikar, Deoni (Table 1), Ongole and HF *jeevamrutha* from 0th day to 1st day respectively (Table 2). The readily available

TABLE 1

Microbial load and C/N ratio of Hallikar and Deoni *jeevamrutha* during 8 days of incubation

Parameters	Day-0	Day-1	Day-2	Day-3	Day-4	Day-5	Day-6	Day-7	Day-8
Hallikar									
C/N ratio	20.77^{a}	19.39^{b}	18.66^{c}	17.49^{d}	15.47^{e}	13.30^{h}	14.15^{g}	14.61^{f}	13.55^{h}
Bacteria(10^{6} cfu/mL)	23.75^{g}	38.00^{e}	30.25^{f}	31.00^{f}	39.50^{e}	50.25^{d}	68.50^{c}	79.00^{a}	72.75^{b}
Fungi(10^{4} cfu/mL)	10.25^{ef}	8.50^{f}	12.75^{bcd}	13.00^{bcd}	11.25^{de}	12.00^{cde}	13.25^{bc}	14.50^{b}	16.75^{a}
Actinobacteria (10^{3} cfu/mL)	1.25^{c}	1.75^{bc}	2.25^{abc}	2.25^{abc}	2.25^{abc}	1.00^{c}	2.50^{abc}	3.25^{ab}	3.75^{a}
Deoni									
C/N ratio	19.19^{a}	17.58^{b}	16.86^{c}	15.72^{d}	13.63^{e}	11.52^{h}	12.48^{g}	12.88^{f}	11.77^{h}
Bacteria(10^{6} cfu/mL)	18.50^{f}	32.75^{de}	28.00^{e}	30.25^{e}	37.00^{d}	49.50^{c}	65.25^{b}	75.50^{a}	75.50^{a}
Fungi(10^{4} cfu/mL)	8.75^{de}	9.75^{e}	11.75^{abc}	12.75^{ab}	8.75^{bcd}	10.25^{abcd}	11.00^{cd}	13.75^{a}	13.75^{a}
Actinobacteria (10^{3} cfu/mL)	1.50^{c}	2.00^{bc}	2.25^{bc}	2.25^{bc}	2.25^{bc}	1.25^{c}	2.50^{bc}	3.00^{ab}	4.00^{a}

Note : Means with different superscripts within the rows are significantly different (n=3)

TABLE 2

Microbial load and C/N ratio of Ongole and HF *jeevamrutha* during 8 days of incubation

Parameters	Day-0	Day-1	Day-2	Day-3	Day-4	Day-5	Day-6	Day-7	Day-8
Ongole									
C/N ratio	21.42^{a}	20.45^{b}	19.57^{c}	18.39^{d}	16.48^{e}	14.38^{g}	15.06^{g}	15.65^{g}	14.63^{f}
Bacteria(10^{6} cfu/mL)	35.00^{f}	49.25^{d}	41.00^{e}	43.25^{e}	52.00^{d}	65.75^{c}	81.25^{b}	91.50^{a}	90.25^{a}
Fungi(10^{4} cfu/mL)	11.00^{d}	12.75^{cd}	12.50^{cd}	14.25^{bc}	12.00^{cd}	13.00^{cd}	14.50^{bc}	16.50^{ab}	17.50^{a}
Actinobacteria (10^{3} cfu/mL)	1.00^{c}	2.50^{abc}	2.00^{bc}	2.50^{abc}	2.00^{bc}	0.75^{c}	2.00^{bc}	3.25^{ab}	4.00^{a}
HF									
C/N ratio	20.88^{a}	19.30^{b}	18.23^{c}	17.32^{d}	15.31^{e}	13.23^{g}	13.90^{g}	14.43^{g}	13.48^{f}
Bacteria(10^{6} cfu/mL)	22.25^{f}	36.00^{d}	28.25^{e}	30.50^{e}	38.75^{d}	51.75^{c}	68.00^{b}	80.00^{a}	78.50^{a}
Fungi(10^{4} cfu/mL)	12.25^{cd}	11.25^{d}	13.75^{bc}	15.00^{ab}	12.50^{cd}	13.75^{bc}	14.75^{ab}	15.00^{ab}	16.50^{a}
Actinobacteria (10^{3} cfu/mL)	2.00^{b}	3.50^{a}	2.50^{ab}	1.75^{b}	2.50^{ab}	1.50^{b}	2.50^{ab}	2.50^{ab}	3.25^{a}

Note : Means with different superscripts within the rows are significantly different (n=3) sugars like glucose, fructose and sucrose are used rapidly. However, the narrow access to these sugars from jaggery causes subsequent decline in population on 2nd day. An upward trend in bacterial population was observed beyond 3rd day upto 7th day in all *jeevamrutha* samples because of availability of nutrients from other complex polysaccharides like cellulose and hemicellulose which are sourced through cow dung. A drop in bacterial population after 7th day may be due to exhaustion of nutrients.

An increase in fungal population from 10.25x10^4 to 16.75x10^4 cfu/mL, 8.75x10^4 to 13.75x10^4 cfu/mL, 11.00x10^4 to 17.50x10^4 cfu/mL and 12.25x10^4 to 16.50x10^4 cfu/mL from 0th day to 8th day was recorded in Hallikar, Deoni, Ongole and HF *jeevamrutha,* respectively. Fungal population continues to increase beyond 8 days (Devakumar *et al*., 2014) as they prefer acidic to near neutral pH and because of their natural ability to degrade the undigestible and partially degraded polysaccharides better than other microbial groups. Similarly, an upward trend was observed in actinobacterial population from 0th day to 8th day of incubation (Table 1 & Table 2) in all *jeevamrutha* samples. Acidic pH may be the reason for low count of actinobacteria during incubation period as they favour neutral to alkaline pH (Hamid *et al*., 2015).

The acidic pH of *jeevamrutha* at the end of incubation lead to the conclusion that it is a fermentative type of product. There was an increase in electrical conductivity due to the build-up of free ions at the end of fermentation period. The cow breeds as such do not have influence on pH and EC changes, but the grazing habit and feed source can influence the nutrient content and microbial population in *jeevamrutha*. The decrease in C:N ratio of *jeevamrutha* during the incubation period corresponds to increase in the microbial population. Farmer's practise of field application of *jeevamrutha* after 7-8 days of incubation could be justified by the relatively high microbial load observed during these days.

Acknowledgment : Authors would like to thank Dr. Malali Gowda, Director, DNA life Organization and Karnataka Science and Technology Promotion Society (KSTePS) for financial assistance through DST-PhD fellowship.

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Mysore J. Agric. Sci., 58 (4) : 288-295 (2024)

Opinion Leadership in Agricultural Communities : A Comparative Analysis of Identification Methods

S. Sidharth[1], Manmeet Kaur[2] and Keesam Manasa[3]
[1&3]Department of Dairy Extension, NDRI, Karnal - 132 001
[2]Department of Extension Education, Punjab Agricultural University, Ludhiana - 141 004
e-Mail : sidoachira@gmail.com

Authors Contribution

S. Sidharth :
Conceptualisation, manuscript writing and Conducting experiment;

Manmeet Kaur :
Conceptualisation, supervision and editing;

Keesam Manasa :
Statistical analysis and data interpretation

Corresponding Author :
S. Sidharth

Received : July 2024
Accepted : July 2024

Abstract

Accurately identifying opinion leaders within agricultural communities is crucial for effective dissemination of agricultural innovations and improved farming practices. This study compares various identification methods, sociometric survey, key informant's method, self-designation and observation to highlight their respective advantages and limitations. The sociometric survey, while time-intensive, emerged as the most reliable method, identifying opinion leaders based on community nominations and social network metrics. The key informant's method, although practical, showed a 66 per cent overlap with sociometric results, indicating potential biases from informants. Self-designation revealed a subset of quasi-leaders who view themselves as influential but are not recognized by their peers, while the observation method proved less feasible due to time constraints and investigator familiarity with the community. The study also examined the socio-personal characteristics of identified opinion leaders, finding them to be older, better educated and wealthier in terms of landholding compared to the general farmer population. The application of Social Network Analysis (SNA) provided deeper insights into information dissemination patterns, revealing that opinion leaders rely more on formal sources like extension agents and universities and digital platforms such as smartphones and WhatsApp, whereas general farmers depend primarily on fellow farmers and input dealers.

Keywords : Opinion leaders, Sociometric survey, Social network analysis (SNA), Communication strategies

Opinion leadership, according to Rogers (2003), is 'the degree to which an individual is able informally to influence other individuals' views or overt conduct in a desired way with relative frequency.' According to this description, the opinion leadership technique for purposeful dissemination may be defined as a communicative method that employs significant others who can influence or assist others in making decisions to accept new technologies (Thakur *et al*., 2016). In the modern day scenario, several opinion leaders have become influential members of online communities and are recognized as key sources of advice for other consumers. In other words, they act as the bridge that connects the change agents and farmers within an agricultural community. It is quite often found that while making the decision to adopt a particular innovation, followers are more likely to follow the opinion of these leaders rather than traditional methods (Hinz *et al*., 2014, Narayan *et al*., 2011 and Risselada *et al*., 2014). To identify opinion leaders in society, one can utilise traditional features of opinion leaders that have been described by various research and discover persons that fit into the categories (Bhandari *et al.,* 2003).

The sociometric technique stands out as a widely employed method for identifying opinion leaders, it offers a systematic approach to gather data on community leaders. Originating from the pioneering work of Hiss *et al*. (1978), sociometric analysis involves interviews, observations and diary entries to ascertain an individuals' perceptions of leadership within a community. Studies of Sen (1969) in Indian villages and Van (1964) in Dutch farming communities exemplify the application of sociometric methods in identifying opinion leaders based on features like advice-seeking behavior and regular contact. In contrast, the informant's rating method, as illustrated by Mancuso (1969) and Kelly (1991), relies on key informants to identify influential figures within specific social groups. Kelly's approach, particularly in targeting opinion leaders among rural LGBT populations, emphasizes the importance of selecting informants strategically to ensure the accuracy of data collection. Additionally, snowball sampling emerges as a valuable tool, especially in identifying 'hidden groups' like homeless individuals or drug users, as highlighted by Faugier and Sargeant (1997) and Morrison (1988). This method, recognized for its effectiveness in non-random data collection, has been instrumental in studies addressing sensitive or marginalized population.

The observation method, though less common in opinion leadership research, provides valuable insights into leadership dynamics within specific contexts. Studies like that of Macrk *et al.* (2000) in Italian corporations and Tsmitri *et al.* (2015) in rural Greek communities utilize participant observations and self-designation approaches to identify opinion leaders and categorize them into distinct groups. While Rogers (2003) notes the observation technique's limited use, its employment in studies like these underscores its relevance in understanding opinion leadership dynamics. Overall, the different methodological approaches highlight the complexity of identifying opinion leaders and illustrates the importance of employing different strategies to capture the social dynamics within communities.

Social Network Analysis (SNA) is a methodological approach that examines the relationships and structures within a network, focusing on how information flows among different actors. In agricultural research, SNA is particularly valuable for understanding how farmers and opinion leaders access and disseminate information (Thuo, 2012). By mapping and analyzing the connections between various information sources, researchers can identify key influencers and the most effective channels for communication. This approach allows the understanding of the social dynamics and informational sources within farming communities in an era where social media has become one of the most popular source of information sharing (Dishant, 2023). The effectiveness of various attempts by government agencies and universities should also be taken into account like 'Village Adoption Program (VAP) which aims at agricultural production and encouraging farmers to practice more scientific farming (Shivashankar, 2023). In the context of this study, SNA helps to highlight the differences between farmers and opinion leaders regarding their information sources. It reveals the extent to which opinion leaders, considered more cosmopolitan, rely on formal and digital sources compared to the general farming population. By identifying central nodes, such as extension agents and digital tools, SNA can inform strategies to enhance the dissemination of agricultural knowledge and innovations, ultimately supporting more effective agricultural practices and decision-making.

METHODOLOGY

This study focuses on identifying the opinion leaders within different communities employing different strategies such as sociometric, self-designation, observation method and key informants rating method. The opinion leaders identified through the different methods have been compared to understand the accuracy of each method and ascertain which method is the most suitable in identifying the leaders in varying scenarios. Social network analysis has been used to identify the differences between the farmers and opinion leaders taking into account degree centrality, betweenness centrality and closeness centrality. The study was conducted in Ludhiana district of Punjab, where three villages were randomly selected as the study locale. All the respondents in the villages were selected as respondents making a total sample size of 214 farmers.

Results and Discussion

Results of Different Methods of Identification of Opinion Leaders

In the baseline survey we identified the opinion leaders based on different methods such as sociometric survey, key-informant method, observational method and self-designation. Furthermore, we compared the results obtained through each method and identified the pros and cons of each method.

Sociometric Survey

During the sociometric survey, each farmer was given three choices to identify the person they consider as the opinion leaders. After sociometric survey, the results were dichotomised and a social network analysis was done in order to identify the closeness, betweenness and eigenvector centrality of each farmer based on the opinions received. From this data, a total of five opinion leaders were selected from each village totaling to 15 leaders. Later on, the physical accessibility, ease of contact and level of relationship of these farmers with the selected opinion leaders were studied. From sociometric survey it was shown that respondents 24, 25, 6, 55 and 42 had the most number of nominations from the Village 1. Similarly, respondents 6, 2, 17, 12 and 37 from village 2 and 12, 11, 9, 7 and 17 from village 3 had the most number of nominations. Although the time taken for sociometric survey was more, the results yielded were mostly accurate.

Key Informants Method

While sociometric method has given somewhat satisfying results, it is evident to note that every time the investigator may not have the necessary resources and time to through the laborious process of a sociometric survey. Here, key informant method comes into play. The ADO (Agriculture Development Officer), Village head and other members of the gram panchayat were taken as the key informants for this method.

Out of the 15 farmers who were selected through sociometric method, we got 10 respondents as the same through key informant method also. This leaves us with a 66 per cent similarity in terms of results. The key informant method is heavily dependent upon the nature of the informant and depends upon the bias of the informant. It was a common pattern to notice the informants recommending farmers close to them as opinion leaders thinking of potential benefits they would gain.

Self-designation of Farmers

The Table 2 shows the percentage of farmers who consider themselves as the opinion leader. This type of self-designation reflects the confidence of the farmer in terms of their superiority and influence over other farmers.

Here 21 (9.81%) farmers designated themselves as opinion leaders while only 15 leaders were selected on the basis of nominations received. While it may be worthwhile to note that all the opinion leaders who were selected on the basis of sociometric survey did not consider themselves as leaders while there were farmers who had considered themselves as an

Table 1

Selected opinion leaders according to sociometric and key informants method

Method used	Village 1	Village 2	Village 3
Nominated Respondents (Sociometric)	24,25,6,55 and 42	6,2,17,12 and 37	12,11,9,7 and 17
Nominated Respondents (Key Informants method)	4,25,6,32 and 42	6,2,11,12 and 15	12,60,9,7 and 17
Percentage of similarity	60 per cent	60 per cent	80 per cent

TABLE 2

Frequency of opinion leaders expressed as a percentage of all those who regard themselves as opinion leaders (Self-designation)

Village 1 (n1=69)	Village 2 (n2=74)	Village 3 (n3=71)	Total (N=214)
9 (12.16)	7 (7.44)	5 (7.04)	21 (9.81)

opinion leader were not selected on sociometric survey. The latter were called as quasi leaders of the village.

Observation Method

The observation method was found to be inappropriate to find the opinion leaders in this particular study. As the time frame of the study was limited and the investigator was not native to the locality, it was physically not practical to identify the opinion leaders in the limited time span.

Characteristics of Opinion Leaders

The comparison between farmers and opinion leaders based on their socio-personal characteristics reveals distinct differences in gender, age, marital status, education and landholding. Both groups are predominantly male, with 97.97 per cent of farmers and 100 per cent of opinion leaders being men. Age distribution varies significantly; while farmers are relatively evenly spread across the age brackets, opinion leaders are generally older, with 86.66 per cent being between 39-67 years. Marital status shows a similar pattern, with a high percentage of both groups being married, though slightly higher among opinion leaders (86.66%) compared to farmers (82.41%). Educational attainment highlights a

TABLE 3

Distribution of respondents (farmers) and opinion leaders according to their socio-personal characteristics

Parameters	Categories	FarmersTotal (n=199)	Opinion Leaders Total (n=15)
		f (%)	f (%)
Gender	Male	191 (97.97)	15 (100)
	Female	8 (2.03)	- -
Age	(25-38)	77 (36.36)	2 (13.33)
	(39-52)	64 (32.66)	6 (40)
	(53-67)	58 (29.64)	7 (46.66)
Marital status	Single	35 (17.59)	2 (13.33)
	Married	164 (82.41)	13 (86.66)
Education	Primary education	19 (9.54)	- -
	Secondary Education	18 (9.45)	- -
	Matric Education	84 (42.21)	3 (20)
	PUC	52 (26.13)	9 (60)
	Graduation	26 (13.06)	3 (20)
Land Holding	Marginal (<1 ha)	26 (13.06)	- -
	Small (1-2 ha)	75 (37.68)	- -
	Semi-medium (2-4 ha)	55 (27.63)	1 (6.66)
	Medium (4-10 ha)	22 (11.05)	4 (26.66)
	Large (>10 ha)	21 (10.55)	10 (66.66)

marked disparity: opinion leaders are better educated, with 60 per cent having completed PUC and 20 per cent holding graduation degrees, whereas the majority of farmers have only matriculated or possess lower educational qualifications. Regarding landholding, opinion leaders are predominantly large landowners, with 66.66 per cent owning more than 10 hectares, contrasting with farmers who mostly have small to semi-medium holdings, with only 10.55 per cent having large landholdings. These differences suggest that opinion leaders are typically older, more educated and wealthier in terms of land ownership compared to the general farming population.

Understanding Sources of Information of Opinion Leaders and Farmers

Another important point of consideration is the source of information between these 2 respondents. The opinion leaders are considered to be more cosmopolite than other farmers within the community. We performed a social network analysis with 2 node network to identify the major source of information for them.

Table 4 presents the centrality measures of various information sources in the information network of farmers. Degree centrality, which indicates the number of direct connections a node has, is highest for fellow farmers (0.854) and input dealers (0.844), suggesting that these sources are the most directly connected within the network. Smartphone usage also shows high degree centrality (0.759), indicating its widespread direct use among farmers. Closeness centrality, measuring how quickly information can spread from a node to all other nodes in the network, is again highest for fellow farmers (0.789) and input dealers (0.778), emphasizing their roles in efficiently disseminating information. Betweenness centrality, which reflects the extent to which a node lies on the shortest path between other nodes, is notably high for fellow farmers (0.236) and input dealers (0.230),

TABLE 4

2-Mode Centrality Measures for information network of farmers

Source	Degree Centrality	Closeness Centrality	Betweenness Centrality
Extension Agent	0.724	0.664	0.124
University	0.663	0.618	0.102
Smartphone	0.759	0.693	0.129
Print Media	0.095	0.376	0.002
Fellow Farmer	0.854	0.789	0.236
Input Dealer	0.844	0.778	0.230
WhatsApp	0.538	0.541	0.052
YouTube	0.613	0.585	0.070
Facebook	0.417	0.483	0.027
Apps	0.241	0.418	0.008

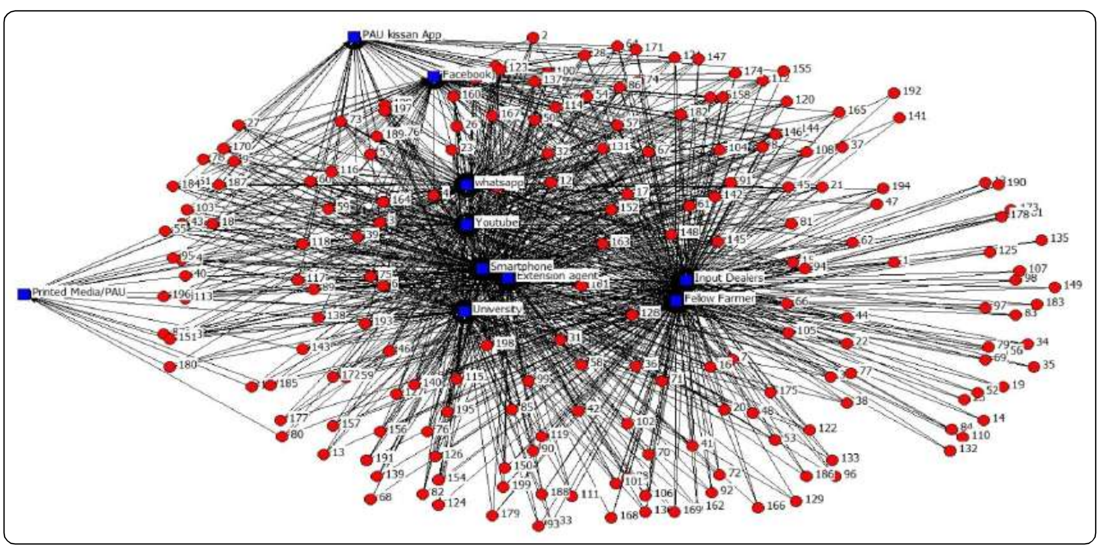

Fig. 1 : Network analysis of Farmers

indicating their critical role as intermediaries in the information flow. Interestingly, traditional sources like print media show very low centrality measures across all metrics, suggesting limited influence. Digital platforms such as Whats App, YouTube, and Facebook have moderate centrality scores, reflecting their emerging but still secondary role in the information network.

Table 5 provides the centrality measures for various information sources in the information network of opinion leaders. Extension agents have the highest degree centrality (0.933), closeness centrality (0.943), and betweenness centrality (0.145), indicating they are the most connected, efficient and influential intermediaries in disseminating information among opinion leaders. Smartphones also have high degree (0.867) and closeness centrality (0.892), highlighting their extensive use and efficiency in information dissemination. Universities and WhatsApp show significant centrality measures, with both having degree and closeness centralities at 0.800 and 0.846, respectively, underscoring their importance as major information sources. Print media, while lower than digital sources, still shows a moderate degree (0.467) and closeness centrality (0.673), indicating a notable role, though less central compared to digital and direct sources. Fellow farmers and input dealers have lower centrality measures, particularly in degree and betweenness, indicating they are less central in the information network of opinion leaders compared to their roles in the general farmer network. This analysis reveals that opinion leaders rely heavily on formal sources like extension agents and universities, as well as digital tools like smartphones and WhatsApp, highlighting their cosmopolitan nature and diverse information sources compared to general farmers.

TABLE 5

2-Mode Centrality Measures for information network of opinion leaders

Source	Degree Centrality	Closeness Centrality	Betweenness Centrality
Extension Agent	0.933	0.943	0.145
University	0.800	0.846	0.095
Smartphone	0.867	0.892	0.099
Print Media	0.467	0.673	0.059
Fellow Farmer	0.333	0.623	0.010
Input Dealer	0.400	0.647	0.048
WhatsApp	0.800	0.846	0.079
YouTube	0.667	0.767	0.043
Facebook	0.533	0.702	0.025
Apps	0.467	0.673	0.020

This research points out the complexity and significance of accurately identifying opinion leaders

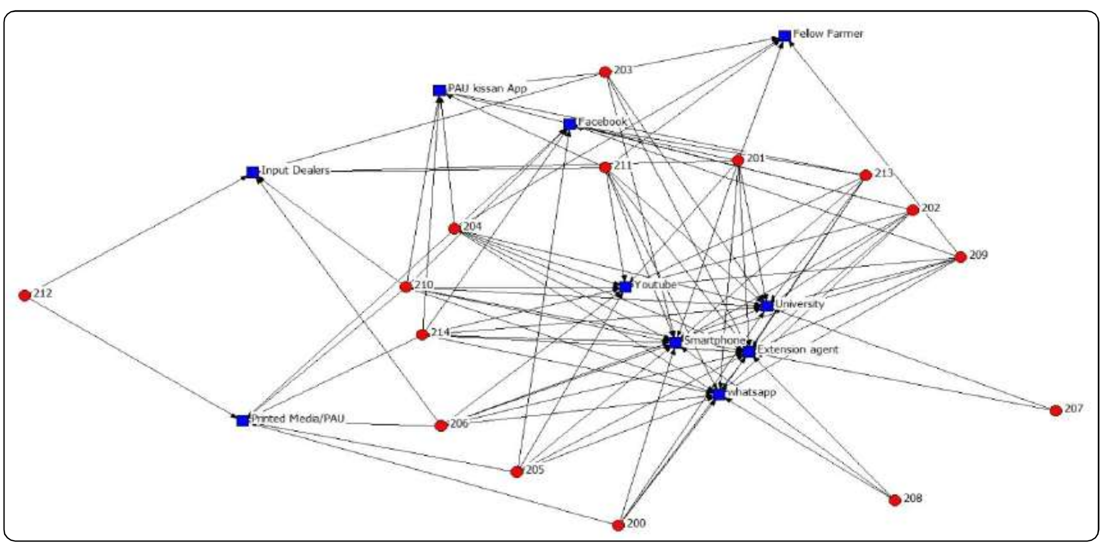

Fig. 2 : Network analysis of opinion leaders

within agricultural communities. Through a comparative analysis of various identification methods-sociometric survey, key informant's method, self-designation and observation-distinct advantages and limitations of each approach were identified. The sociometric survey, despite being time-intensive, yielded the most reliable results, highlighting key opinion leaders based on community nominations and social network metrics. The key informant's method, while more practical, showed a 66 per cent overlap with the sociometric results, suggesting some reliability but also susceptibility to biases from informants. Self-designation revealed a subset of quasi-leaders who perceive themselves as influential but are not recognized as such by their peers, indicating a discrepancy that warrants further exploration. The observation method, constrained by time and the investigator's familiarity with the community, proved less feasible in this context.

The socio-personal characteristics of identified opinion leaders diverged markedly from the general farmer population, with opinion leaders being predominantly older, better educated and wealthier in terms of landholding. This demographic profile aligns with their role as key influencers within their communities. The application of Social Network Analysis (SNA) provided deeper insights into the information dissemination patterns among farmers and opinion leaders. The analysis revealed that opinion leaders have a more cosmopolitan nature, relying heavily on formal sources like extension agents and universities, as well as digital platforms such as smartphones and WhatsApp. In contrast, general farmers primarily depend on fellow farmers and input dealers for information. These findings have practical implications for agricultural extension programs and policy-making. By leveraging the strengths of different identification methods and understanding the information networks within farming communities, more effective communication strategies can be developed. These strategies can facilitate the dissemination of agricultural innovations, ultimately supporting improved farming practices and decision-making.

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Soybean Cultivation in Dharwad District of Karnataka - Economics and Resource Use Efficiency Analysis

SHILPA A. HABIB, M. K. ARAVINDA KUMAR, A. S. SHASHI KIRAN AND M. S. RAMU
Department of Agricultural Economics, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : shilpa111habib@gmail.com

AUTHORS CONTRIBUTION

SHILPA A. HABIB : Conceptualization, data collection, data analysis and manuscript preparation;

M. K. ARAVINDA KUMAR : Conceptualization, data collection and review of manuscript;

A. S. SHASHI KIRAN & M. S. RAMU : Conceptualization supervision and editing of manuscript

Corresponding Author :
SHILPA, A. HABIB

Received : February 2024
Accepted : July 2024

ABSTRACT

Soybean (*Glycine max* L.) is known as 'golden bean' and grown in India for dual purpose that is oil seed as well as pulse crop. In the year 2022-23, the study was undertaken to assess the economics of soybean cultivation in Dharwad district, focusing on Dharwad and Kalaghatgi taluks in Karnataka, India. The data was gathered from a sample of 90 respondents, comprising 30 small & medium farmers, 30 large farmers and 30 market intermediaries. Cost of cultivation of soybean showed that large farmer incurred higher costs per acre (Rs.55,501) compared to small & medium farmers (Rs.48,147). Returns per rupee of expenditure indicated a marginally higher profitability for large farmers (1.27) compared to the small & medium farmers (1.25). Resource use efficiency was attempted using Cobb-Douglas type of production function. For small & medium farmers, under-utilization was observed for seed, FYM, chemical fertilizer, plant protection chemicals, human labour and over-utilization for weedicide and machine labour. Similarly, large farmers exhibited under-utilization for FYM, chemical fertilizer, plant protection chemicals, human labour, weedicide and over-utilization for seed and machine labour. As observed from the results there is scope for reallocation of inputs for optimum level of usage. Implementing recommended packages of practices can optimize returns, ensuring sustainable soybean cultivation in the study area.

Keywords : Soybean cultivation, Cobb-douglas production function, Resource use efficiency, Cost of cultivation, Package of practices

SOYBEAN (*Glycine max* L.) is known as the 'miracle crop' or 'golden bean' because of its versatile nutritional qualities (Lyngdoh *et al.,* 2019). Originating in East Asia around 1100 BC, this globally cultivated legume has evolved into a key player, contributing approximately 25 per cent to the world's edible oil production and constituting around two-thirds of the total protein concentrate produced worldwide, serving as an economical and substantial source for livestock feed (Chawan *et al*., 2023). Brazil emerged as the largest producer, accounting for 38.7 per cent of the world production, followed by the United States (31%), Argentina (13.50%), China (5%) and India at 3 per cent (Anonymous, 2022a). India, ranking fourth in soybean cultivation area and fifth in production, significantly influences the global soybean landscape. In Karnataka, during 2021-22, soybean covered 3.81 lakh hectares, Bidar district claimed the highest area (48.70%) under soybean cultivation followed by Belagavi (26.10%), Dharwad (10.47%), Kalaburgi (4.70%), Haveri

(4.52%) and Bagalkot districts (0.40%) (Anonymous, 2022b).

Recognizing the emerging significance of soybean cultivation, in response many research on soybean taken up in Belagavi (Vasudeva, 2018)) and Bidar (Vijaykumar *et al.,* 2017) the researcher shifted the focus to Dharwad district, which has third largest area under soybean in the state as the improved seed varieties DSB series were released by University of Agricultural Sciences, Dharwad and increasing area due to demand from the agro-processing units and better price for produce. Hence, soybean cultivation is a noteworthy concern that demands attention and further investigation. With this background the researcher undertook the study during 2022-23 to analyze the cost of cultivation and resource use efficiency in soybean cultivation in Dharwad district of Karnataka.

Methodology

Study Area

Dharwad district was purposively selected and the two taluks *viz.,* Dharwad (33.64%) and Kalaghatgi (33.14%) were selected as they had the highest area under soybean in the district (Anonymous, 2021). The newly released varieties of DSB series in Dharwad has encouraged farmers to take up more area and increasing demand from processing units. Five villages from each taluk were selected and six respondents from each village comprising three sample respondents each belonging to 'small & medium' and 'large' landholding size classification. From each category 30 farmers were interviewed, amounting to total sample size of 60 farmers. The sample farmers were interviewed on various aspects such as general farm and household characteristics, socio-economic parameters like education *etc.* Details on cultivation practices adopted in soybean and cost of cultivation were collected.

Tabular analysis, farm management cost and return concept *viz*., Cost-A, Cost-B, Cost-C (Palanisami *et al*., 2002), profitability analysis and Cob-Douglas production function were employed to analyse the data.

Interest on Working Capital

It was calculated for the crop season. The interest was assessed at an annual rate of 7 per cent, in line with the seasonal agricultural loan lending rates of the nationalized banks.

Interest on Fixed Capital

It was calculated at the rate of 12 per cent, as the fixed deposits in commercial banks fetched this rate of interest. Interest was considered on the value of the assets after deducting the depreciation cost for the year and apportioned for the total duration of the crop which is approximately three months hence six per cent is taken.

Profitability Analysis

Farm Business Income

Farm business income = Gross income - Cost A_2

Farm Investment Income

Farm Investment income = Farm business income - Imputed value of family labour

Returns Per Rupee of Investment

$$\text{Returns Per Rupee of Investment} = \frac{\text{Total returns}}{\text{Tota costs}} \quad \ldots\ldots (1)$$

Resource use Efficiency

The resource use efficiency in soybean cultivation was studied by fitting the Cobb-Douglas type of production function given below to the farm level data given by Cobb and Douglas in 1928.

$$\mathbf{Y = aX_1b_1X_2b_2X3b_3X_4b_4X5b_5X_6b_6X_7b_7} \quad \ldots\ldots. (2)$$

Where,

Y = Output (q/farm)

X_1 = Seeds (kg/farm)

X_2 = FYM (kg/farm)

X_3= Chemical Fertilizers (Rs./farm)

X_4 =Plant Protection Chemicals (PPC) (Rs./farm)

X_5= Human Labor (mandays/farm)

X_6= Weedicide (Rs./farm)

X_7 = Machine (hr/farm)

a = Constant

u = Random Variable

b_1 to b_7 = elasticity coefficients of respective inputs

Results and Discussion

Table 1, presents various socio-economic attributes such as average age, average years of schooling, average family size, average landholding size and average soybean cultivation area per farm for the surveyed respondents. Notably, these characteristics exhibited higher values among large farmers as compared to small and medium farmers. The socio-economic profile outlined in Table 1 aligns with the observations made by Nandini and Kiresur (2013) in terms of age distribution, educational attainment and family size of the respondents.

Economics of Cultivation of Soybean

The economic aspects of soybean cultivation for small & medium farmers, large farmers in Dharwad and Kalaghatgi taluks of Dharwad district have been summarized in Tables 2, 3 and 4.

Table 1

Socio-economic profiles of respondents in the study area

Particulars	Small & medium farmers (n=30)	Large farmers (n=30)
Average age (years)	47.53	50.13
Average no. of years of schooling	6.27	6.73
Average family size (No.)	7.00	8.00
Average size of landholding (acre)	6.43	20.31
Average area under soybean per farm (acre)	2.95	5.98

Table 2

Cost of cultivation of soybean (per acre)

Particulars	Units	Small & medium farmers			Large farmers		
		Qty.	Value (Rs.)	Per cent	Qty.	Value (Rs.)	Per cent
Seed	Kg	30.62	1776	4.02	33.88	1965	3.79
Human labour	md	24.82	10176	23.02	33.44	13710	26.47
Machine labour	hr	2.92	4380	9.91	3.45	5175	9.99
Bullock labour	pair day	0.43	421	0.95	1.01	989	1.91
Manures	t	2.67	6702	15.16	2.8	7028	13.57
Chemical fertilizers	Rs.		1232	2.79		1453	2.81
PPC	Rs.		1633	3.69		1821	3.52
Miscellaneous	Rs.		510	1.15		760	1.47
Interest on working capital @ 7 per cent per annum	Rs.		939	2.12		1152	2.22
Total variable Costs (TVC)	Rs.		27770	62.82		34054	65.74
Land revenue	Rs.		50	0.11		50	0.10
Depreciation	Rs.		2560	5.79		3165	6.11
Rental value of owned land	Rs.		10120	22.89		10120	19.54
Interest on fixed capital @ 12 per cent per annum	Rs.		930	2.10		1004	1.94
Managerial cost @10 per cent of working capital	Rs.		2777	6.28		3405	6.57
Total fixed costs (TFC)	Rs.		16437	37.18		17745	34.26
Total cost (TVC+ TFC)	Rs.		44208	100.00		51799	100.00

TABLE 3

Cost structure of soybean cultivation

(Rs. /acre)

Particulars	Small & medium farmers(n=30)		Large farmers (n=30)	
	Rs.	Per cent	Rs.	Per cent
Value of hired human labour	8126	17.90	12685	23.92
Value of hired machine labour	2891	6.37	3105	5.86
value of owned machine labour	1489	3.28	2070	3.90
Value of purchased seed	1776	3.91	1965	3.71
Value of Bullock labour	421	0.93	990	1.87
Value of owned farmyard manure	1675	3.69	1945	3.67
Value of purchased farmyard manure	5027	11.08	5083	9.38
Value of chemical fertilizers and PPC	2866	6.31	3274	6.17
Land revenue	50	0.11	50	0.09
Interest on working capital@ 3.5 per cent	939	2.07	1152	2.17
Depreciation	2560	5.64	3165	5.97
Miscellaneous expenses	510	1.12	760	1.43
Cost A1	28330	62.42	36243	68.34
Cost A2 (Cost A1+ Rent paid for leased in land)	28330	62.42	36243	68.34
Interest on fixed capital@ 6 per cent	762	1.68	822	1.55
Cost B1(Cost A1 + Interest on fixed capital)	29092	64.10	37065	69.89
Rental value of owned land	10120	22.30	10120	19.08
Cost B2 (Cost B1 + Rent paid for leased in land + Rental value of owned land)	39212	86.39	47185	88.98
Imputed value of family labour	2050	4.52	1025	1.93
Cost C1 (Cost B1 + Imputed value of family labour)	31142	68.61	38090	71.83
Cost C2 (Cost B2 + Imputed value of family labour)	41262	90.91	48210	90.91
Management cost (10 % of Cost C2)	4126	9.09	4821	9.09
Cost C3 (Cost C2 + Management cost i.e., 10 % of Cost C2)	45389	100	53032	100

The cultivation cost was higher for large farmers at Rs.51,799 compared to small and medium farmers at Rs.44,208 (Table 1). Among small and medium farmers, approximately 37.18 per cent of the total cost was attributed to fixed costs, while 62.82 per cent was variable costs. Similarly, among large farmers, fixed costs constituted 34.26 per cent of the total cost, with variable costs making up the remaining 65.74 per cent (Table 2). Among the variable cost the human labour accounted for larger proportion in case of both large and small and medium farmers and in the fixed cost the rental value of owned land accounted maximum.

The Table 3 expressed the cost structure and their per cent share in total cost of soybean cultivation (Cost C_3) in Dharwad district. The cost incurred by large farmers was more compared to small & medium farmers in the study area (Fig. 1). These findings are on par with Medat *et al.* (2016) and Purushottam (2018).

There Exist a Discrepenacy in Cost of Cultivation of Soybean in Traditional and CACP cost Concepts Method. As Author as Considered the Additional Management Cost in the CACP Concepts.

The Table 4, revealed that large farmers had more main product yield and by-product yield than small &

TABLE 4

Farm business analysis of soybean

(per acre)

Particulars	Small & medium farmers (n= 30)	Large farmers (n= 30)
Total cost of cultivation (Rs./ac)	45389	53032
Total variable cost (Rs./ac)	27770	34054
Total fixed cost (Rs./ac)	17618	18978
Main product yield (q/ac)	10.22	11.84
Market price of main product (Rs./q)	5310	5420
By-product yield (q/ac)	6.32	7.95
Market price of by-product (Rs./q)	390	390
Cost of production (Rs./q)	4200	4217
Gross income (Rs./ac)	56733	67273
Net income over total cost (Rs./ac)	11344	14242
Net income over variable cost (Rs./ac)	28963	33220
Returns per rupee of investment	1.25	1.27
Farm business income (Rs./ac)	28403	31030
Family labour income (Rs./ac)	17521	20088
Farm investment income (Rs./ac)	26353	30005

medium farmers. The large farmers had more gross income than small & medium framers. The Returns per rupee of investment for large farmers was 1.27 which was Slightly more than the small & medium farmers (1.25). The large farmers had more farm business income, family labour income and farm investment income over small & medium farmers (Table 4). These results are in similar line with the study conducted by Pachpute *et al.* (2017) cost and returns of soybean in Marathwada Region of Maharashtra stated that, the output-input ratio of soybean was 1.36. The current study results are on par with that of Agarwal and Singh (2015) on soybean cultivation in the Ratlam district of Madhya Pradesh, the output-input ratio for overall farmers was 1.54 which indicates that the soybean crop is profitable. A similar study was conducted by Perke *et al.* (2018) to study the economics of soybean in Hingoli district of Maharashtra where the output-input ratio was 1.46 indicating that soybean is a profitable enterprise. Introduction of soybean had helped to improve their socio economic conditions, large number of small and marginal farmers probably because even under minimum agricultural inputs, management practices and climatic adversities, it fetches profitable returns to the farmers, as it was evident from the cost of cultivation of soybean.

Resource use Efficiency in Case of Small & Medium Farmers

The Marginal Value Product (MVP) to Marginal Factor Cost (MFC) ratio provides valuable insights.

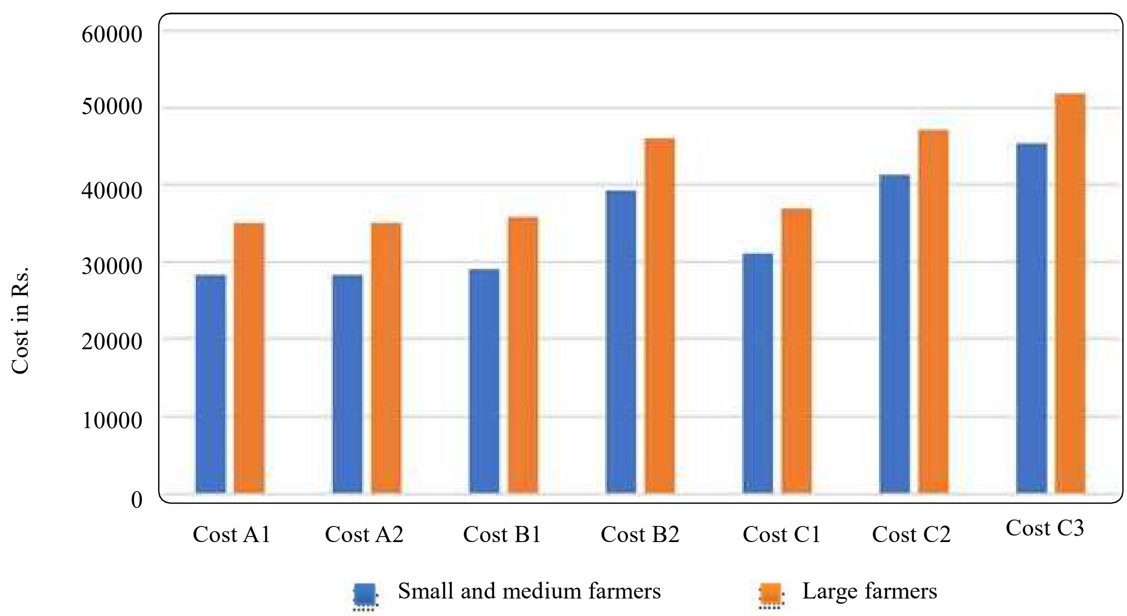

Fig. 1 : Comparison of cost structure of the small & medium and large farmers in the study area

The efficiency ratio (MVP: MFC) for seed (11.12), FYM (2.01), Chemical fertilizer (1.63), Plant protection chemicals (6.81), human labor (1.77) and weedicide (1.13) surpasses one. This implies the underutilization of these resources, suggesting an untapped potential for increased soybean production through their enhanced utilization. These findings align with the research conducted on resource use efficiency and resource use pattern of soybean in Dharwad district of Karnataka by Priyadarshini *et al.* (2018) while only the plant protection chemicals contradicted as it was overutilized in Priyadarshini's finding. Conversely, the profitability ratio for machine labor (-1.35) is less than one, indicating an over-utilization of this resource. Therefore, a reduction in the application of machine labor is recommended to achieve an optimal level of soybean production. The sum of elasticities (1.08) almost indicating constant returns to scale (Table 5). Despite a recommended package of practice suggesting 73.75 kgs of seed per farm and 2.4 tons of FYM per acre, small & medium farmers, with an average landholding of 2.95 acres, are using around 90.33 kgs of seed and 7.88 tons of FYM. It emphasized that these resources should be optimally utilized, considering the significant contributions of seeds and FYM to soybean yield.

Resource use Efficiency in Case of Large Farmers

The efficiency ratio (MVP: MFC) for FYM (2.33), Chemical fertilizer (3.54), Plant protection chemicals (5.99), human labor (1.04), weedicide (1.28) and machine labor (4.28) exceed one, suggesting underutilization of these resources in soybean production. This implies the potential for increased soybean production by enhancing the use of these

TABLE 5

Resource use efficiency of small & medium farms (per farm)

Particulars	Units	Geometric mean level of use of input	Elasticity coefficient		MVP	MFC (Rs.)	r
Yield (Y)	q/farm	31.80					
Seeds (X_1)	kg	89.11	0.33 (2.16)	**	652.48	58.66	11.12
FYM (X_2)	t	8.62	0.25 (3.21)	***	5035.23	2510	2.01
Chemical Fertilizers (X_3)	Rs.	3888.11	0.04 (0.18)		1.63	1	1.63
Plant protection chemicals (X_4)	Rs.	5748.44	0.22 (1.19)		6.81	1	6.81
Human labor (X_5)	md	70.45	0.28 (1.81)	*	706.90	409	1.77
Weedicide(X_6)	Rs.	2860.73	0.02 (0.33)		1.13	1	1.13
Machine Labor (X_7)	hr	4.22	-0.06 (0.61)		-2439.41	1800	-1.35
Returns to scale	∑bi		1.08				
Coefficient of multiple determination	R^2	0.94					

Note : 1. r=MVP/MFC, where MFC = Marginal factor cost (¹) ; MVP = Marginal value product(¹)

2. ***, ** and * indicate significance at one per cent, five per cent and ten per cent level of probability, respectively.

3. Figures in parentheses represent 't' value

resources. The results align with the findings of Priyadarshini *et al*. 2018, but the plant protection chemicals contradict the results. On the other hand, the profitability ratio of seed (-5.15) is less than one, indicating an over-utilization of this resource. Therefore, reducing the application of seeds is recommended to achieve an optimal level of soybean cultivation (see Table 6). These findings align with a study conducted to analyse the resource use efficiency of soybean in Belagavi district of Karnataka by Vasudeva *et al.* (2018) where as it contradicts the result findings of Priyadarshini *et al.* 2018, Similar results have been found in the study conducted by Pawar and Tawale (2011) on the resource use efficiency of soybean. Despite a recommended package of practice suggesting 2.4 tons of FYM per acre for an average large farm with 5.98 acres, farmers are using 16.74 tons. It is emphasized that farmers should optimally utilize FYM and machine labor, given their significant contributions to soybean yield.

There is no significant difference between small and medium farmers and large farmers, as small area was allocated for soybean cultivation in case of both the categories of farmers.

Soybean contributing to human nutrition, animal feed and a myriad of industrial application, making it a key stone for both food security and economic growth. The Cost C3 of soybean cultivation was Rs.45,389 for small and medium farmers, Rs.53,032 for large farmers. Despite the higher cultivation costs, large farmers achieved a per-acre gross return of Rs.67,273; outperforming the returns of Rs.56,733 for small & medium farmers. Large farmers also demonstrated higher returns per rupee of cost of cultivation (1.27) compared to small and medium farmers (1.25). The results obtained from the resource use efficiency

TABLE 6

Resource use efficiency of large farms (per farm)

Particulars	Units	Geometric mean level of use of input	Elasticity coefficient	MVP	MFC (Rs.)	r
Yield	q/farm	78.05				
Seeds (X_1)	kg	203.97	-0.15 (1.21)	-323.53	62.80	-5.15
FYM (X_2)	t	17.75	0.24 *** (2.96)	5884.42	2525	2.33
Chemical Fertilizers (X_3)	Rs.	9713.06	0.08 (0.62)	3.54	1	3.54
Plant protection chemicals (X_4)	Rs.	12141.47	0.17 (1.02)	5.99	1	5.99
Human labour (X_5)	md	203.43	0.20 (1.67)	430.25	415	1.04
Weedicide (X_6)	Rs.	7164.98	0.02 (0.41)	1.28	1	1.28
Machine Labor (X_7)	hr	9.91	0.18 ** (2.01)	7855.42	1835	4.28
Returns to scale	∑bi		0.74			
Coefficient of multiple determination	R^2	0.94				

Note : 1. r =MVP/MFC where, MFC = Marginal factor cost ([1]); MVP = Marginal value product ([1])
2. ***, ** indicates significant at one per cent and five per cent level of probability, respectively.
3. Figures in parentheses represent 't' value.

using Cobb - Douglas production function revealed the underutilization of resources like farmyard manure, chemical fertiliser, plant protection chemicals *etc* and over - utilization of machine labour. These trends emphasize the untapped potential for resource reallocation, particularly in optimizing the use of seeds, manure, machine labor and human labor, encouraging the adoption of Good Agricultural Practices (GAP) and recommended package of practices for enhanced returns from soybean cultivation.

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Mysore J. Agric. Sci., 58 (4) : 304-311 (2024)

Screening of Recombinant Inbred Lines (RILs) and Identification of Stable RILs Resistant to Late Leaf Spot Disease in Groundnut (*Arachis hypogaea* L.)

N. Shilpa[1], N. Marappa[2], C. R. Jahir Basha[3], H. B. Mahesh[4] and D. L. Savithramma[5],
[1,2,4&5]Department of Genetics and Plant Breeding and [3]Department of Plant Pathology,
College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : nmaass@gmail.com

Authors Contribution

N. Shilpa :
Design, data analysis and manuscript writing;

N. Marappa ;
C. R. Jahir Basha ;
H. B. Mahesh and
D. L. Savithramma :
Conceptualization, supervision and editing

Corresponding Author :
N. Marappa

Received : May 2024
Accepted : July 2024

Abstract

Groundnut is one of the important leguminous oilseed crops. Prime objective of groundnut breeding lies in development of Late Leaf Spot (LLS) disease resistance cultivars with higher productivity as LLS is one of the most devastating diseases in groundnut. In the present study, 94 RILs were phenotyped during *kharif* 2022 under three environmental conditions and were screened for LLS disease reaction, pod yield and its related traits. ANOVA explained significant difference between the RILs, which accounted for sufficient amount of variation. Mean performance of the RILs under three locations were used to identify the resistant RILs with higher pod yield using Principal Component (PC) approach and biplot was drawn to group the RILs based on disease reaction. PC1 and PC2 explained 89.39 *per cent* variance out of total variability. Sixteen RILs exhibited stable performance for disease resistance and pod yield. The identified RILs shall be further evaluated for their stability and can be utilised as resistance sources in groundnut breeding programs.

Keywords : Biplot, LLS disease, PCA approach, RILs, Resistance breeding

Groundnut (*Arachis hypogaea* L.) is one of the principal oil seed crops in the world. It is popularly known as 'King of oil seeds' because of its high edible oil content and utilized for human consumption as vegetable oil, table purpose and confectionery, while fodder for livestock. It contains edible oil (44-53%), protein (23-25%), carbohydrate (20%), fibre (3%), calcium, phosphorus, iron, thiamine (B1), riboflavin (B2) and niacin. It is widely grown in tropics and subtropics and is important to both small and large commercial producers. Groundnut is a self-pollinated crop belonging to the family *Fabaceae* and ploidy level is allotetraploid (2n = 4x = 40).

In India, among the oil seed crops grown such as sunflower (905 kg/ha), rapeseed and mustard (14.58 kg/ha) and soyabean (10.59 kg/ha), productivity of groundnut is highest which makes it as the leading oil seed crop. The trend of groundnut productivity since 1950, reports that the productivity has increase by three times but at present yield plateau is reached. This allows one to look into the constraints present in groundnut cultivation.

Biotic and abiotic stresses are the major constraints that affect quantity and quality of the groundnut. Several other reasons are attributed for low yield levels in India *viz*., lack of improved high yielding cultivars, cultivation under shallow soils of low fertility, uneven rainfall distribution, continuous cropping without rotation of crop, low plant population and incidence of foliar diseases and pests. Majority of the commercially grown varieties belong to Spanish bunch types (*Arachis hypogaeas* sp. *fastigiata*) and they are highly susceptible to foliar diseases namely, rust caused by *Puccinia arachidis*, early and late leaf spots, stem rot (*Sclerotium rolfsii*) and collar rot (*Aspergillus niger*).

Late leaf Spot (LLS) disease is caused by *Pheoisariopsis personata* (*Cercosporidium personatum*) and is of significant concern for peanut growers. LLS disease typically manifests as small, circular to irregularly shaped lesions on the leaves. The lesions are initially small, dark brown to black that enlarge to about 3-8 mm diameter. Infection starts at around 55-57 days after sowing, and results in premature senescence and shedding of leaves, resulting in over 50 per cent yield loss (Waliyar, 1991). LLS disease in severe cases causes complete defoliation and yield losses linearly increases at the rate of 2.2 to 2.8 per cent per 10 per cent increase in defoliation (Anco *et al*., 2020). Yield loss due to rust and LLS can go up to 70 per cent in India when fungicides are not applied (Subrahmanyam *et al*., 1995). In Karnataka major hotspot regions for LLS disease are Tumkur district majorly Pavagaga and Sira taluks. The present status of yield loss due to LLS diseased in reported to be 13.5 per cent in Karnataka (Anonymous, 2022).

Majority of farmers depend on chemical control, as it is the available option to combat the disease and reduce yield losses. But usage of fungicides comes with ecological and human health concerns and also increases cost of production by 10 per cent (Monyo *et al*., 2009). In addition, the quality of groundnut is adversely affected by fungicides when compared with non-fungicide treated groundnut (Hammonds *et al*., 1976). Chemical control is not an eco-friendly approach for long term sustainability of agriculture, and also creates financial burden for small and marginal farmers (Coffelt and Porter, 1986). Therefore, an alternate strategy to control LLS disease in groundnut, resistant cultivars has to be developed using plant breeding approaches (Woodward *et al*., 2014).

Screening and identification of resistant cultivars is the primary objective of resistance breeding. In the present study attempt was made to screen recombinant inbred lines (RILs) for LLS disease resistance and identify resistant RILs under field conditions.

MATERIAL AND METHODS

The present research work was carried out at three locations in *kharif* 2022. Experimental plots, K-block, University of Agricultural Sciences, GKVK, Bengaluru (E1), College of Agriculture, VC Farm, Mandya (E2) and Agricultural Research Station (ARS), Pavagada (E3). The plant material in the present study comprised of 94 F_6 RIL population derived from the cross TMV 2 and GPBD 4. Data was recorded for all plants from each line for LLS disease reaction and yield related traits. The observations were recorded in augmented design along with checks and parents. 'Spreader row' method was used for recording LLS disease reaction. The genotype TMV 2 was used as a spreader row, since the variety is highly susceptible to create natural epiphytotic condition for the spread of the disease. It was replicated after an interval of four lines. Late leaf spot (LLS) disease incidence scoring was performed by using a modified 9-point scale (Subramanyam *et al.,* 1995) during the *kharif* season when disease incidence more. The scale had a 1-9 disease score and extent of leaf area destroyed (0-100%) which showed the linear relationship among each other depending on the percentage of the disease-damaged leaf region. During LLS disease severity, the incidence of disease was recorded on the 60, 70, 90 and 105th days after sowing. Along with this pod yield per plant was also recorded. The severity of the disease was converted into *per cent* disease index (PDI) using formula (Table 1).

Percentage disease index will be calculated using formula :

$$PDI = \frac{\text{Sum of individual ratings}}{\text{No. of leaves observed x maximum scale}} \times 100$$

TABLE 1
Classification based on the reaction to LLS disease

Disease Reaction	Score
Immune	0
Resistance	0 - 3.50
Moderately resistance	3.51 - 4.50
Moderately susceptible	4.51 - 5.60
Susceptible	Above 5.60

Principal Component Analysis (PCA) was computed based on the correlation matrix using data from PDI at different intervals along with pod yield in XLSTAT 2014, Copyright Addinsoft 1995-2014 (http://www.xlstat.com) as followed by Iqbal *et al*. (2014). RILs were categorized into four groups (A, B, C and D) based on their performance for disease resistance. Group A - accessions expressing resistance, Group B - accessions that are moderately resistant, Group C - accessions that are moderately resistant and Group D - accessions that are susceptible.

RESULTS AND DISCUSSION

Analysis of variance (ANOVA) F_6 RILs of cross TMV 2 × GPBD4

The ANOVA for disease reaction at different intervals (Table 2) of F_6 generation revealed the significant differences among the RILs for the trait under consideration This indicates presence of greater amount of variability even after achieving maximum homozygosity. The results were further supported by the fact that the range for the traits was quite wide suggesting presence of extreme RILs which can be further improved following simple selection. Gopinath *et al*. (2008); Savita (2012); Mallikarjun, (2014); Bhavya (2015) and Jambagi *et al*. (2020) have also reported significant differences among RILs for pod yield related traits in groundnut. The mean performance of RILs for pod yield under disease stress and control conditions across three locations is graphically presented in Fig. 1. It is worth noticing that pod yield of few RILs such as RIL 9, RIL, RIL 13, RIL 19, RIL 67, RIL 88 were high and comparable under both the conditions.

Biplot Analysis Based on Principal Component Analysis

Principal Component analysis is a method to find the linear combination that accounts for as much as variability as possible. In the present study principal component (PC) analysis was carried out to group genotypes of groundnut into different categories based on the mean performance for reaction to LLS. This method distinguishes resistant RILs on the bases of disease reaction. Principal component (PC) analysis had been performed and the corresponding biplot were

TABLE 2
Mean sum of squares of F_6 RIL population derived from the cross TMV 2 × GPBD 4 in groundnut for late leaf spot disease reaction

Source	Df	PDI@ 60 DAS	PDI@ 75 DAS	PDI@ 90 DAS	PDI@ 105 DAS	PYP
Treatment (ignoring Blocks)	96	0.76 *	2.6 **	1.45 *	2.45 **	32.15 *
Check	2	3.11 **	18.11 **	33.17 *	28.14 *	43.45 **
Test vs. Check	1	19.46 **	7.62 **	5.67	6.69	12.67 **
Test	93	1.3	2.04 *	3.24 *	5.43 **	34.67 *
Block (eliminating Treatments)	6	0.47	0.56	0.67	0.18	21.56 *
Error	12	0.6	0.16	0.34	0.18	12.45

Df = Degrees of freedom; *significant @P = 0.05
PWP = Pod weight per plant (g); *significant @P = 0.01
PDI = per cent disease incidence; DAS = Days after sowing; PYP = Pod yield per plant

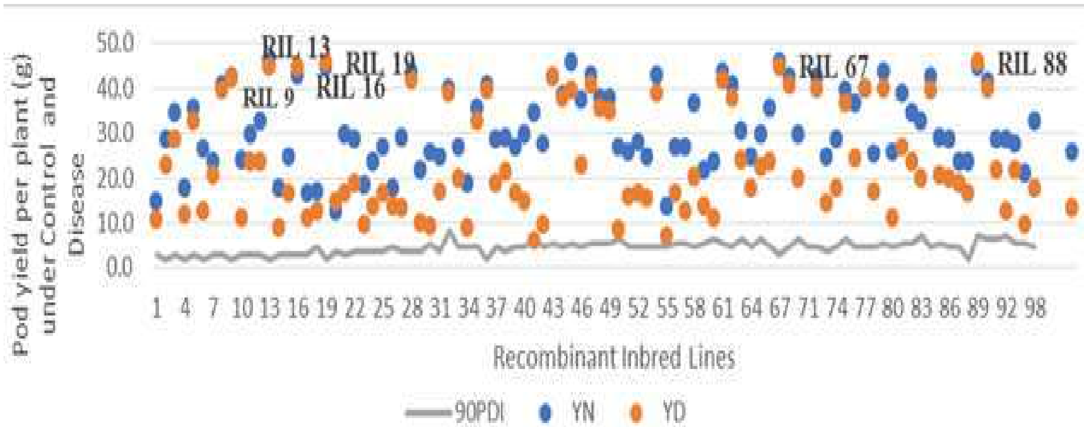

Fig. 1 : Responses of the recombinant inbred lines for mean pod yield per plant under control and disease pressure condition of three locations

Note : 90PDI: LLS disease reaction at 90 DAS; YN : Pod yield per plant under control condition; YD : Pod yield per plant under disease condition

drawn. The first two PC accounted for maximum variation of 89.39, 91.91 and 97.76 per cent of the total variance in the data under disease stress and control conditions. Our results were in accordance with the findings of Makinde and Ariyo (2010). Anthony *et al*. (2011) also reported that the first four PCs accounted for 76.92 per cent of the total variation among 50 genotypes. The results showed high positive loadings for pod yield per plant for PC1 and negative loadings were noticed for disease reaction at different intervals for PC2. Thus, biplot was drawn based on first two principal components, which shows overview of inter-relationships among pod yield and disease reaction.

The relationships among pod yield and disease reactions were graphically presented I biplot of first (PC1) and second (PC2) principal component analysis of 94 RIL population. The relationships, similarities and dissimilarities among disease reactions and pod yield per plant was explained based on indices correlation matrix from PCA using XLSTAT *ver*. 2022 (XLSTAT solutions).

The cosine of the angle between the index vectors represents their approximate positive (acute angle) or negative (obtuse angle) correlation. As disease and yield are negatively correlated they fall in different quadrant in the biplot. The biplot analysis is a useful tool often used by many researches in plant breeding (Adalid *et al*., 2010; Joshi *et al*., 2011; Panthee *et al*., 2013; Hernandez *et al*., 2014 and Thi, 2016). In the present study, biplot was drawn using pooled data of three locations. Based on resistance and susceptibility reaction, RILs were grouped into four groups. RILs that fall in group A quadrant is considered as resistant and RILs in group D is considered as susceptible. PC1 and PC2 explained 89.39 per cent variance that accounted for total variation (Table 3).

TABLE 3

Estimates of eigen values and percentage of variation under GKVK of RIL population developed from the cross TMV 2 × GPBD 4

Principal components (PCs)	Eigen value	Variability (%)	Cumulative (%)
1	4.897	54.58	54.58
2	1.467	34.81	89.39
3	0.390	6.503	95.89
4	0.127	2.122	98.01
5	0.066	1.108	99.12
6	0.052	0.874	100.00

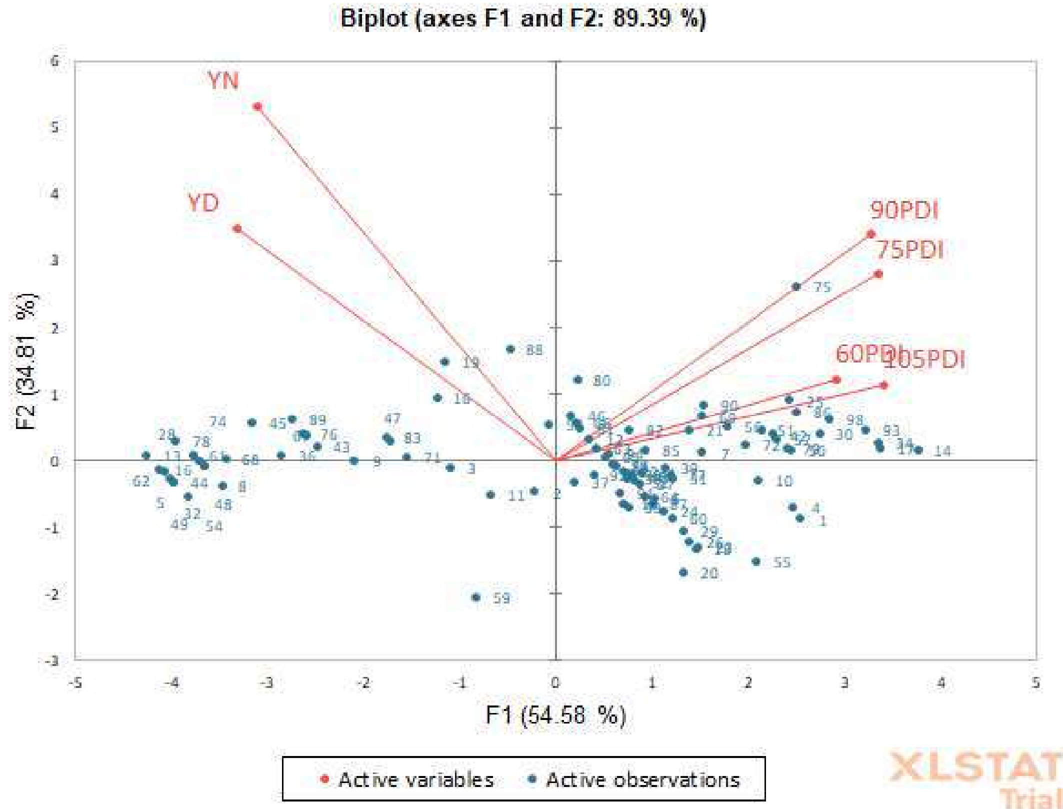

Fig. 2 : Identification of LLS resistant F_6 RILs using Biplot analysis combining three locations

Note : YN : Pod yield per plant under control condition; YD : Pod yield per plant under disease condition

TABLE 4

Superior RILs of groundnut from cross TMV 2 × GPBD 4 for LLS disease resistance, pod yield and related traits across three environments selected based on *per se* performance

RIL No.	Pods per plant	Pod yield per plant (g) under disease	Pod yield per plant (g) under control	Kernel per plant	Kernel yield per plant (g)	Sound Mature Kernel *per cent* (%)	Shelling *per cent*
19	43.5	44.5	43.9	88.4	30.7	79.5	69.9
88	41.6	41.6	43.2	77.3	27.8	75.6	64.3
67	39.8	43.8	42.8	72.8	28.9	69.7	67.5
13	44.6	43.7	42.1	81.6	27.9	77.4	66.2
16	38.5	41.0	41.6	72.5	26.9	71.4	64.6
45	43.4	39.7	41.3	80.2	27.8	69.3	67.3
9	38.6	42.0	41.2	77.9	26.8	61.6	65.0
43	40.5	42.6	41.2	74.1	26.4	73.7	64.0
28	42.6	41.7	40.8	79.3	27.6	69.3	67.6
36	40.5	39.6	40.7	76.7	22.7	73.7	55.7
83	39.6	39.9	40.3	69.6	21.9	64.9	54.3

Continued....

TABLE 4 Continued....

RIL No.	Pods per plant	Pod yield per plant (g) under disease	Pod yield per plant (g) under control	Kernel per plant	Kernel yield per plant (g)	Sound Mature Kernel *per cent* (%)	Shelling *per cent*
78	41.6	39.3	40.1	75.3	25.9	62.7	64.6
47	42.5	42.7	40.0	79.2	24.6	69.7	61.4
61	41.6	41.6	39.8	76.9	27.9	63.4	70.4
74	40.9	39.6	38.3	72.1	20.7	66.2	54.0
68	39.8	38.9	36.8	76.7	24.5	65.5	66.5
TMV 2	23.7	13.8	17.8	38.9	7.90	69.1	67.8
GPBD 4	35.8	29.9	24.8	68.8	14.9	73.6	65.7
GKVK 27 (C)	38.9	23.9	25.8	73.7	17.8	72.7	68.9

Note : C-Check

When biplot was drawn eighteen RILs were found to be resistant and also ranked highest with regard to pod yield per plant (Fig. 2). Zare, (2012) used the same method to identify drought tolerant genotypes in barley. Similarly, in safflower by Bahrami *et al*. (2014), in Tomato by Thi *et al*. (2016) and Suresh, (2018) and in Groundnut by Savita *et al*. (2014), Jambagi *et al*. 2020a, Pooniya *et al*. (2020) and Shilpa *et al*. (2023). The results of the present study were comparable with Fernandez (1992), Kaya *et al*. (2002), Golabadi *et al*. (2006), Farshadfar *et al*. (2012), Zare (2012), Bahrami *et al*. (2014) and Brdar-Jokanovic *et al*. (2014 and 2017).

Identification of superior RILs resistant to LLS disease

In comparison with parents and checks, 16 superior RILs were identified that were resistant to LLS disease across three locations (Table 4) *viz*., RIL 19, RIL 88, RIL 67, RIL 13, RIL 16, RIL 45, RIL 9, RIL 43, RIL 28, RIL 36, RIL 83, RIL 78, RIL 47, RIL 61, RIL 74 and RIL 68. These were selected based on biplot method and ranking them based on its *per se* performance for pod yield per plant. In these resistant RILs, pods per plant ranged from 43.5 in RIL 19 to 39.8 in RIL 68. Shelling per cent in these RILs ranged from 69.9 to 66.5 per cent. The performance was these RILs should be confirmed by evaluating them under multi locations/ years for LLS disease resistance and pod yield related traits. Late these superior RILs can be exploited in future groundnut breeding programs.

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Mysore J. Agric. Sci., 58 (4) : 312-319 (2024)

Influence of Nano-Urea on Productivity and Quality of Fodder Oat (*Avena sativa* L.) in Southern Dry Zone of Karnataka

B. G. Shekara, N. M. Chikkarugi and N. Rani
AICRP on Forage Crops and Utilization, Zonal Agricultural Research Station, V.C. Farm, Mandya - 571 405
e-Mail : bgshekar66@gmail.com

Authors Contribution

B. G. Shekara :
Selection of research Problems, plan of work, study design & it's execution, analysis and interpretation of data;

N. M. Chikkarugi & N. Rani :
Investigation, data collection, compilation, statistical analysis and draft preparation

Corresponding Author :
B. G. Shekara

Received : July 2024
Accepted : August 2024

Abstract

The field experiment was conducted at Zonal Agricultural Research Station, Vishweshwaraiah Canal farm, Mandya during *rabi* 2022 & 2023 with an objective of identifying optimum concentrations of Nano urea for obtaining maximum growth, yield and quality in fodder oat under irrigated situation. The experiment consisted of ten treatments, which was laid out in randomized block design with three replications. The treatments included were T_1: Control (without N, only P & K), T_2: 100 per cent recommended dose of fertilizers (100:40:30 NPK kg/ha- 50% N as basal +25% N at 20 DAS + 25% N at 40 DAS), T_3: 75 per cent recommended dose of N + nano urea @ 0.2 per cent spray twice @ 20 & 40 DAS, T_4: 50 per cent recommended dose of N + nano urea @ 0.2 per cent of spray applied twice at 20 & 40 DAS, T_5: 75 per cent recommended dose of N + nano urea @ 0.4 per cent foliar spray applied twice at 20 & 40 DAS, T_6: 50 per cent recommended dose of N + nano urea @ 0.4 per cent @ 20 & 40 DAS, T_7: 75 per cent recommended dose of N + nano urea @ 0.6% @ 20 & 40 DAS, T_8: 50 per cent recommended dose of N + nano urea @ 0.6 per cent of spray @ 20 & 40 DAS, T_9: 75 per cent recommended dose of N + normal urea (2% spray) twice @ 20 & 40 DAS, T_{10}: 50 per cent recommended dose of N + normal urea (2% spray) twice @ 20 & 40 DAS. The pooled data revealed that, application of 100 per cent recommended dose of nitrogen recorded significantly higher plant height (148.8 cm), leaf stem ratio (0.52), green forage (338.7 q ha^{-1}), dry matter (77.5 q ha^{-1}) and crude protein yield (3.59 q ha^{-1}). Similarly, higher gross returns, net returns and benefit cost ratio was also recorded with application of 100 per cent recommended dose of fertilizer (76214 Rs. ha^{-1}, 49950 Rs. ha^{-1} and 2.90, respectively).

Keywords : Fodder oat, Nano urea, Green fodder yield, Dry matter yield, Crude protein yield

Oat (*Avena sativa* L.) is a winter season fodder crop which can be grown in areas with limited irrigation facilities. It is short duration and known to produce high green biomass with rich nutritive forages (Shekara *et al*., 2019). There is a possibility of utilizing the re-growth and its yield potential both for forage and seed production production making it a dual purpose crop. Apart from development of high yielding varieties, adequate nutrition plays a major role in getting higher biomass and quality.

The majority of nano-fertilizers are either synthetic or altered versions of conventional fertilizers, raw fertilizer components or botanical, microbial or animal extracts (Husen and Iqbal, 2019). Nano fertilizers slowly release nutrients throughout the growth period of the crop, allowing plants to absorb nutrients efficiently without experiencing losses like leaching, volatilization, fixation etc. (Guru *et al.,* 2015). Plants can absorb nano fertilizers easily due to their high surface area to volume ratio

(Al-Juthery and Saadoun., 2018). Compared to conventional fertilizer application, nano fertilizers reduce nutrient loss, resulting in 20-30 per cent higher use efficiency (Kumar *et al.,* 2020a and Kumar *et al.,* 2020b). Nano particles or nano encapsulated nutrients have the properties to release nutrients effectively on demand that regulate plant growth and enhance activity (Derosa *et al.,* 2010). Foliar application of nano fertilizers might boost nutrient production and improve plant nutrition when compared to regular fertilizers. The usage of nano fertilizers extends the time and rate of elements released in the plant system, allowing it to match plant nutritional requirements (Kumar *et al.,* 2021). The plant can absorb the maximum amount of nutrients resulting in an increase in crop yield. Keeping these things in view, the present investigation was undertaken to know the different concentration of nano urea on growth, green forage yield and quality in fodder oat.

Material and Methods

The present investigation was carried out at Zonal Agricultural Research Station, Vishweshwaraiah Canal Farm, Mandya, during *rabi* 2022 & 2023 with an objective of identifying optimum concentrations of Nano urea on growth, yield and quality of fodder oat under irrigated situation. The experimental site is situated in the Southern Dry Zone (ACZ-VI) in Karnataka and is 695 meters above mean sea level. It is positioned between 12° 45' and 13° 57' North latitude and 76° 45' and 78° 24' East longitude. The soil is sandy loam in texture at the experimental location and has a neutral soil reaction of 7.13, low organic carbon (0.43%), medium levels of accessible phosphorus (46.3 kg/ha), potassium (159.0 kg/ha) and low levels in available nitrogen (243.0 kg/ha).

The ten treatments combinations, *viz.,* T_1: Control (without N, only P & K), T_2: recommended dose of fertilizers (100:40:30 NPK kg/ha- 50% N as Basal +25% N at 25 DAS + 25% 45 DAS, T_3: 75% recommended dose of N + Nano urea @ 0.2% foliar spray twice @ 25 & 45 DAS, T_4: 50% recommended dose of N + nano urea @ 0.2% foliar spray twice @ 25 & 45 DAS, T_5: 75% recommended dose of N + nano urea @ 0.4% spray twice @ 25 & 45 DAS, T_6: 50 % recommended dose of N + Nano urea @ 0.4% spray @ 25 & 45 DAS, T_7: 75% recommended dose of N + nano urea @ 0.6% spray applied twice @ 25 & 45 DAS, T_8: 50% recommended dose of N + nano urea @ 0.6% spray @ 20 & 40 DAS, T_9: 75% recommended dose of N + Urea (2% spray) @ 20 & 40 DAS, T_{10}: 50% recommended dose of N + Urea (2% spray) @ 25 & 45 DAS. Two sprays of Nano urea (4% nitrogen) and normal urea (46% nitrogen) were done at 25 and 45 days after sowing, with a spray solution of 500 liters of water per hectare. The recommended dose of nitrogen was applied in three splits (50% at basal, 25% at 25 days and remaining 25% at 45 days after sowing). The treatments were replicated thrice in Randomized complete block design. The well known fodder oat variety RO-11-1 was sown during 3rd week of October at a row spacing of 25 cm. The cultural operations and other production practices were followed as per local recommendations. The crop was harvested when crop attained 50 per cent of flowering and the known quantity random sample green fodder was obtained from each plot at the time of harvest for the purpose of analyzing the quality of the fodder. These samples were dried in the sun for a few hours and then heated to 70±2 °C thermostatically controlled electric oven until they reached a constant weight. The known quantity of powdered samples was collected in order to analyze the nitrogen content of the plant using the micro-Kjeldahl method (Jackson, 1973) and other quality parameters. The yield of green fodder was converted into a dry matter yield (q/ha) based on the dry matter content of the samples; the same samples were also used to determine the yield and content of crude protein (A.O.A.C., 1965). The experimental data obtained were subjected to statistical analysis adopting Fisher's method of analysis of variance as outlined by Gomez and Gomez, 1984. Overall differences were tested by 'F' test at 5 per cent level of significance. In Case if signidicant results, critical difference (CD) at 5 per cent level of probability was calculated for testing the difference between the two treatment means. The economics was worked out with prevailing market price.

TABLE 1

Growth parameters of fodder oat as influenced by nano-urea

Treatments	Plant height (cm)			Leaf Stem Ratio		
	2022	2023	Mean	2022	2023	Mean
T1 : Control (without N)	98.6	104.6	101.6	0.41	0.36	0.38
T2 : RDF (Recommended dose of fertilizers) (N:P:K @100:40:30 kg/ha)	140.0	157.6	148.8	0.43	0.62	0.52
T3 : 75 % recommended dose of N + Nano urea @ 0.2 % spray	136.9	141.4	139.1	0.37	0.43	0.40
T4 : 50 % recommended dose of N + Nano urea @ 0.2 % spray	123.6	117.0	120.3	0.34	0.38	0.36
T5 : 75 % recommended dose of N + Nano urea @ 0.4 % spray	128.3	140.8	134.5	0.35	0.47	0.41
T6 : 50 % recommended dose of N + Nano urea @ 0.4 % spray	130.3	126.2	128.3	0.36	0.45	0.40
T7 : 75 % recommended dose of N + Nano urea @ 0.6 % spray	138.3	144.6	141.5	0.37	0.53	0.45
T8 : 50 % recommended dose of N + Nano urea @ 0.6 % spray	123.8	134.4	129.1	0.42	0.45	0.45
T9 : 75 % recommended dose of N + Urea (2 % spray)	138.0	143.5	140.8	0.38	0.58	0.48
T10 : 50 % recommended dose of N + Urea (2 % spray)	127.3	138.6	133.3	0.47	0.46	0.46
S. Em+	5.63	4.61	3.62	0.02	0.02	0.013
C.D at 5%	16.84	13.81	14.75	0.05	0.53	0.04

Note : RDF = Recommended dose of fertilizers; Nano urea and urea was sprayed at 25 and 45 days after sowing and recommended dose of P and K is common for all treatments; Application of recommended dose of nitrogen in two splits (50% N as basal and 25% at 25 days after sowing and remaining 25% at 45 days after sowing)

RESULTS AND DISCUSSION

Growth Parameters : The mean plant height recorded at harvest was significantly influenced by varied nitrogen levels (Table 1). The significantly higher mean plant height was recorded with application of 100 per cent recommended dose of nitrogen (148.8cm). The control *i.e.,* without nitrogen application recorded significantly lower plant height (101.6 cm). This may be attributed to application of more nutrients during early vegetative and crop development stages, which led to maximum plant height. Apart from this nitrogen plays a pivotal role in photosynthetic activity and protein synthesis which might promote cell division and cell elongation that in turn accelerate vegetative growth. This is in conformity with the findings of Bhilare & Joshi, 2008; Rana *et al.* (2013); Somashekar *et al.* (2015); Lahri *et al.* (2021) and Navya *et al.* (2022).

The mean leaf stem ratio was significantly higher with application of 100 per cent recommended dose of nitrogen (0.52). Whereas, lower leaf stem ratio was recorded with no nitrogen application (0.38). It is mainly due to rapid expansion of dark green foliage which intercept more solar radiation for the production of photosynthates, which resulting in higher meristematic activity and nitrogen also influence on productivity of more functional leaves for a longer period of time. Similar results were reported by Kumawat *et al.* (2016); Vimal *et al.* (2017) and Lagad *et al.* (2020).

Yield Parameters : Application of 100 per cent recommended dose of fertilizers recorded higher green forage yield (338.7 q/ha), which was on par with application of 75 per cent recommended nitrogen with normal urea 2 per cent spray and nano urea @ 0.6 per cent spray twice at 25 and 45 days after sowing (322.3 q and 306.4 q ha^{-1}, respectively) (Table 2). The no nitrogen treatment (control), recorded significantly lower mean green fodder yield (210.8 q ha^{-1}). The nano urea applied treatment recorded lower yield as compare to normal urea due to low nitrogen content in nano urea and it is not sufficient meet out the requirement of the crop. This is mainly due to nitrogen plays a pivotal role in metabolic process in plants such as cell division and expansion, enzymatic

TABLE 2

Yield parameters of fodder oat as influenced by nano-urea

Treatments		Green Forage Yield (q ha^{-1})			Dry Matter Yield (q ha^{-1})		
		2022	2023	Mean	2022	2023	Mean
T1	: Control (without N)	171.7	249.8	210.8	33.8	47.0	40.4
T2	: RDF (Recommended dose of fertilizers) (N:P:K @100:40:30 kg/ha)	299.8	377.7	338.7	66.4	88.7	77.5
T3	: 75 % recommended dose of N + Nano urea @ 0.2 % spray	251.3	304.7	278.0	51.5	62.5	57.0
T4	: 50 % recommended dose of N + Nano urea @ 0.2 % spray	213.6	276.1	244.9	45.2	54.3	49.8
T5	: 75 % recommended dose of N + Nano urea @ 0.4 % spray	269.4	299.4	284.4	52.7	64.6	58.7
T6	: 50 % recommended dose of N + Nano urea @ 0.4 % spray	218.6	288.8	253.7	43.0	62.5	52.7
T7	: 75 % recommended dose of N + Nano urea @ 0.6 % spray	277.5	335.4	306.4	56.3	76.4	66.4
T8	: 50 % recommended dose of N + Nano urea @ 0.6 % spray	226.8	298.8	262.8	44.9	62.7	53.8
T9	: 75 % recommended dose of N + Urea (2 % spray)	285.8	358.7	322.3	62.4	83.0	72.7
T10	: 50 % recommended dose of N + Urea (2 % spray)	245.0	307.8	276.4	47.6	69.4	58.5
	S.Em+	14.2	16.7	9.7	4.6	3.8	2.4
	C.D at 5%	42.5	49.9	29.05	13.8	11.4	7.19

Note : RDF = Recommended dose of fertilizers; ·Nano urea and urea was sprayed at 25 and 45 days after sowing and recommended dose of P and K is common for all treatments;Application of recommended dose of nitrogen in two splits (50% N as basal and 25% at 25 days after sowing and remaining 25% at 45 days after sowing)

activity, photosynthetic efficiency, meristematic activity which led to better vegetative growth which is evidenced by higher plant height and leaf stem ratio and in turn resulted higher green biomass production. The findings of Patel *et al*. (2007); Singh & Sumeria (2010); Dubey *et al*. (2013); Bhoya *et al*. (2013) and Meena *et al*. (2021) also confirmed the same results. The highest forage yield with nano urea was confirmed with the findings of Abdel (2018); Naveena *et al*. (2021a) and Shekara *et al*. (2022).

Application of recommended dose of fertilizer recorded significantly higher dry matter yield on pooled basis (77.5 q ha^{-1}), which was on par with application of 75 per cent recommended nitrogen along with normal urea 2 per cent spray twice at 25 and 45 days after sowing (72.7 q ha^{-1}) (Table 2). The no-nitrogen treatment (control) recorded significantly lower dry matter yield (40.4 q ha^{-1}), The increased dry matter yield might be due to enhanced crop growth and photosynthetic activity which led to better supply of carbohydrates, better partitioning of photosynthates and higher accumulation of nutrients ultimately resulted in higher dry matter content and green biomass yield, which led to higher dry matter yield. The similar findings were reported by Singh *et al.* (2012); Meena *et al.* (2021); Naveena *et al*. (2021b) and Theerthana *et al*. (2022).

The crude protein yield is one of the important quality parameters and it was significantly influenced by nitrogen levels. Application of 75 per cent recommended nitrogen along with 2 per cent urea spray twice at 25 and 45 days after sowing recorded significantly higher yield (4.51 q ha^{-1}), whereas control recorded lowest crude protein yield (2.05 q ha^{-1}). The similar trend was noticed with total digestible crude protein yield. This might be due to nitrogen which is constituent of amino acids and regulates cellular metabolism of amino acids and proteins that forms biological catalysts of phosphorylated compounds involved in energy transformation. Nitrogen is a structural constituent of cell and cell wall, thus, increasing the quality of fodder by improving the protein content. Similar results were reported by Shekara *et al.* (2015) and Meena *et al.* (2021).

TABLE 3

Quality parameters of fodder oat as influenced by nano-urea

Treatments	Crude Protein (%)			Crude fiber (%)			Crude Protein Yield (q ha^{-1})			Crude fiber Yield (q ha^{-1})		
	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
T1 : Control (without N)	5.13	5.03	5.08	33.8	33.8	33.8	1.73	2.38	2.05	11.4	15.9	13.7
T2 : RDF (Recommended dose of fertilizers) (N:P:K @100:40:30 kg/ha)	4.80	4.47	4.63	25.2	23.4	24.3	3.19	3.97	3.59	16.7	20.8	18.8
T3 : 75 % recommended dose of N + Nano u rea @ 0.2 % spray	6.40	6.37	6.38	26.5	25.6	26.1	3.26	4.00	3.63	13.7	16.0	14.8
T4 : 50 % recommended dose of N + Nano urea @ 0.2 % spray	5.83	5.37	5.60	27.5	27.5	27.5	2.65	2.91	2.79	12.4	14.9	13.7
T5 : 75 % recommended dose of N + Nano urea @ 0.4 % spray	4.67	4.53	4.60	27.0	26.9	26.9	2.45	2.93	2.70	14.3	17.4	15.8
T6 : 50 % recommended dose of N + Nano urea @ 0.4 % spray	4.40	4.37	4.38	28.7	27.3	28.0	1.89	2.73	2.31	12.3	17.0	14.8
T7 : 75 % recommended dose of N + Nano urea @ 0.6 % spray	5.57	5.77	5.67	27.3	26.4	26.9	3.13	4.40	3.75	15.3	20.4	17.9
T8 : 50 % recommended dose of N + Nano urea @ 0.6 % spray	5.40	5.13	5.27	26.9	27.4	27.2	2.44	3.23	2.85	12.1	17.2	14.7
T9 : 75 % recommended dose of N + Urea (2 % spray)	6.30	6.10	6.20	24.0	23.5	23.8	3.92	5.07	4.51	15.0	19.5	17.3
T10 : 50 % recommended dose of N + Urea (2 % spray)	5.43	5.53	5.48	26.6	27.6	27.1	2.59	3.84	3.20	12.7	19.1	15.9
S.Em+	0.19	0.17	0.17	0.72	0.7	0.5	0.26	0.27	0.16	1.2	1.3	0.8
C.D at 5%	0.57	0.52	0.49	2.15	2.06	1.61	0.79	0.80	0.47	NS	NS	2.43

Note : RDF = Recommended dose of fertilizers; Nano urea and urea was sprayed at 25 and 45 days after sowing and recommended dose of P and K is common for all treatments; Application of recommended dose of nitrogen in two splits (50% N as basal and 25% at 25 days after sowing and remaining 25% at 45 days after sowing)

TABLE 4

Economics of fodder oat as influenced by nano-urea

Treatments	Gross returns (Rs./ha)			Net returns (Rs./ha)			B:C ratio		
	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
T1 : Control (without N)	38626	56213	47419	14083	30670	22376	1.57	2.20	1.89
T2 : RDF (Recommended dose of fertilizers) (N:P:K @100:40:30 kg/ha)	67453	84975	76214	41689	58211	49950	2.62	3.17	2.90
T3 : 75 % recommended dose of N + Nano urea @ 0.2 % spray	56546	68558	62552	28846	39858	34352	2.04	2.39	2.22
T4 : 50 % recommended dose of N + Nano urea @ 0.2 % spray	48069	62115	55092	20674	33720	27197	1.75	2.19	1.97
T5 : 75 % recommended dose of N + Nano urea @ 0.4 % spray	60620	67361	63990	31920	37661	34790	2.11	2.27	2.19
T6 : 50 % recommended dose of N + Nano urea @ 0.4 % spray	49179	64980	57080	20824	35625	28225	1.73	2.21	1.97
T7 : 75 % recommended dose of N + Nano urea @ 0.6 % spray	62433	75465	68949	32813	44845	38829	2.11	2.46	2.29
T8 : 50 % recommended dose of N + Nano urea @ 0.6 % spray	51026	67230	59128	21711	36915	29313	1.74	2.22	1.98
T9 : 75 % recommended dose of N + Urea (2 % spray)	64298	80715	72506	38085	53502	45793	2.45	2.97	2.71
T10 : 50 % recommended dose of N + Urea (2 % spray)	55118	69255	62187	29210	42347	35779	2.13	2.57	2.35

Note : Cost of nano urea- Rs.480/litre; Cost of Urea- Rs.5.62/kg; Selling price of green fodder – Rs.225 q^{-1}

The crude fiber yield was significantly influenced by nitrogen levels and concentrations of nano urea (Table 6). The 100 per cent recommended nitrogen recorded significantly higher crude fiber yield (18.83 q ha^{-1}). Whereas, no nitrogen treatment recorded lower crude fiber yield (13.67 q ha^{-1}). The increase in crude fiber yield with higher level of nutrients is mainly due to higher dry matter production and crude fiber content. Higher level of fertilizers application delay the maturity particularly by nitrogen. Whereas, lower dose of fertilizers application leads to forced maturity with short life span of time and this might be governing the phenomenon of fiber syntheses. This is in agreement with the findings of Pathan *et al.* (2012) and Singh *et al.* (2012).

Economic analysis : The higher mean gross returns, net returns and benefit cost ratio was recorded with application of 100 per cent recommended dose of fertilizer (Rs.76214 ha^{-1}, Rs.49950 ha^{-1} and 2.90, respectively) followed by application of 75 per cent nitrogen along with normal urea 2 per cent spray twice at 25 & 45 days after sowing (Rs.72506 ha^{-1}, Rs.45793 ha^{-1} and 2.71, respectively). The no nitrogen treatment recorded lower net returns (Rs.22376 ha^{-1}) and BC ratio (1.89). The increased net returns and B:C ratio may be due to higher green forage yield with lower cost of cultivation which resulted in higher gross and net returns. Similar results were reported by Yogendra *et al.* (2020), Mohammad (2021) and Ajithkumar *et al.* (2021).

Based on the results it can be inferred that 100 per cent recommended dose of fertilizers or 75 per cent recommended nitrogen along with normal urea 2 per cent spray or 0.6 per cent of nano urea twice at 25 and 45 days after sowing found viable and economical for getting higher green forage yield and quality in fodder oats under southern dry zone of Karnataka.

Acknowledgement : The authors are grateful to AICRP on Forage crops & Utilization, IGFRI, Jhansi and University of Agricultural Sciences, Bangalore for financial support and facilities for carryout research work at Zonal Agricultural Research Station, V. C. Farm, Mandya.

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Mysore J. Agric. Sci., 58 (4) : 320-328 (2024)

Study of Chemical Fertilizers Consumption in India: Comparative and Forecasting Approach

SHIV KUMAR SINGH PUNDHIR[1] AND SANDEEP KUMAR[2]
[1]School of Business and Management, Christ University, Bengaluru - 560 029
[2]Department of Mathematics, Noida Institute of Engineering and Technology, Greater Noida, Uttar Pradesh - 201 306
e-Mail : shivpundhir@gmail.com

AUTHORS CONTRIBUTION

SHIV KUMAR SINGH PUNDHIR : Data analysis and manuscript prepration;

SANDEEP KUMAR : Conceptualization and theoretical framework of problem

Corresponding Author :
SHIV KUMAR SINGH PUNDHIR

Received : July 2024
Accepted : August 2024

ABSTRACT

The chemical fertilizers are used to increase crop yield. The excessive use of chemical fertilizers damages soil, air and water quality which is fatal for human health. In this work, a mathematical model is developed to forecast fertilizer consumption in India. Historical data for the period of 2001 to 2021 is analyzed to find trend patterns by using a scatter diagram and a mathematical model is developed by using the method of least square. The forecast accuracy of the model is verified using Mean Absolute Deviation (MAD) and Mean Absolute Percentage Error (MAPE) concepts. Fertilizer consumption in the top five states regarding daily used crops and fruit production is also analyzed. Fertilizer consumption in India is also compared with the USA, China, Brazil and Australia.

Keywords : Fertilizers, Forecasting, Least square method, Trend equation, Forecast accuracy

IN the past fertilizers were developed naturally in villages which were beneficial for land and the environment. To increase crop production farmers used chemical fertilizers. Chemical fertilizers contain mainly three nutrients Nitrogen, Phosphorus and Potassium. This extensive worldwide use of fertilizers causes serious environmental problems like ozone depletion, soil health problems and water, soil and air pollution. As per statistics due to the increasing world population, 40-60 per cent of crops are grown with the help of fertilizers and pesticides. The sad part is that almost 50 per cent or more of the population is feeding these crops. Fertilizers will support soil to grow plants but excessive use of fertilizers damages the fertility of the soil by increasing acids in the soil. The use of these fertilizers also harms water balance on the earth. Phosphates and nitrates available in fertilizers when mixed with lake or river water are destroying the lives of animals living on earth and in the water. Many birds and animals lose their life due to these nitrates and phosphates. Also when this water is used by humans, it causes many incurable diseases. A lot of research have been done, which proves that excessive use of fertilizer is too dangerous for the environment, soil, water, air and human health. Patra *et al.* (2016) observed that improper utilization of fertilizers is the cause of the environmental problem. Kumari *et al.* (2014) studied the adverse effects of fertilizers and pesticides on humans and found that long-term use of these crops will cause health problems. They recommended eco-friendly fertilizers to increase crop production. Miah *et al.* (2014) studied the effect of fertilizers on the health of farmers in Bangladesh. Nicolopoulou *et al.* (2016) studied on impact of chemical pesticides on human health. Getahun and Keefer (2016) studied that fertilizers cause degradation of groundwater quality. Vinothkanna *et al.* (2020) studied the impact of fertilizers on soil quality degradation. Sharma and Singhvi (2017) studied the effect of pesticides and fertilizers on human health. Choudhary *et al.* (2014) studied the adverse effect of pesticides on farmers' health. Kumar *et al.* (2013) studied to know the impact of pesticides on the environment and health of farmers. Thuy (2015) studied the impact of Dichloro-diphenyl-trichloroethane (DDT) on human health. He found that due to long residual efficacy and accumulation through the food chain, it badly affects human health. Yargholi and Azarneshan (2014) studied that the long-term effect of chemical fertilizers highly affects the soil. Pahalvi *et al.* ((2021) found that excessive fertilizer consumption damage the soil, water and air quality. Srivastav (2020) found that pesticides and chemical fertilizers damage water and soil quality. Ramalingam *et al.* (2022) studied the impact of nitrate-containing water on human health in South India. They found that nitrate is the most significant issue in human health. Tyagi *et al.* (2022) found that excessive use of chemical fertilizers increases crop yield but also damages environmental sustainability. Chemical fertilizers degrade soil, water, and the quality of produced foods. Devi *et al.* (2022) found that chemical fertilizer consumption is increased in developing countries to get more yield. Chemical fertilizers are used unscientifically and sometimes banned chemicals were used which causes serious ecosystem damage. Tripathi *et al.* (2020) found that chemical fertilizers enhance greenhouse gas emissions and decrease soil quality. Wang and Lu (2020) found that China increased N-fertilizers consumption to increase crops of maize, wheat and rice which causes fatal to human health. Dhankhar and Kumar (2023) examined the impact of chemical fertilizers and pesticides on human health. Srivastav *et al.* (2024) found that consumption of NPK fertilizers has increased worldwide, due to which people are drinking nitrate-containing polluted water which causes severe health issues. They suggested to create awareness among farmers for the use of organic fertilizers. Alam *et al.* (2024) studied the water pollution due to chemical fertilizers consumption in Bangladesh. They found that fertilizer consumption highly contributed to water pollution in Bangladesh. Cha *et al.* (2024) suggested to use organic fertilizers to control environmental pollution and toxicity in the soil and water due to chemical fertilizers.

Before globalization, countries like India had large agricultural land to produce sufficient food crops to support their population. However, after globalization and the exponential growth of the real estate market, a big part of agricultural land was acquired by real estate companies and industries. To fulfill the demand, farmers rapidly increased the use of fertilizers to grow more crops. India's population is also increasing rapidly, to feed the people of India, farmers have to yield more crops in the limited agricultural land using chemical fertilizers and pesticides.

In this work, the researchers investigated yearly fertilizers consumption and developed a forecast model using the method of least square to predict fertilizers consumption in India. The trend of consumption of fertilizers in India's top five states regarding the production of daily used crops and fruits is also studied.

Material and Methods

Forecast Model : In this section, forecast model is developed to predict fertilizers consumption in India. Data for the period from 2001 to 2021 is analyzed to develop the model. The forecast model is developed using the method of least square.

Table 1

Yearly consumption of NPK fertilizers (kg/hectare) in India

Year	Fertilizers (kg/hectare)	Year	Fertilizers (kg/hectare)
2001	86.7	2013	130.8
2002	91.5	2014	118.5
2003	86.1	2015	127.5
2004	88.2	2016	130.7
2005	94.5	2017	124.4
2006	104.5	2018	127.9
2007	112.3	2019	133.1
2008	115.3	2020	127.8
2009	127.2	2021	137.2
2010	135.3		
2011	146.3		
2012	142.3		

Source : https://www.rbi.org.in

To examine the trend pattern of fertilizers consumption in India, a scatter diagram is plotted. From Fig. 1, we can see that fertilizers consumption in India follows a positive linear trend.

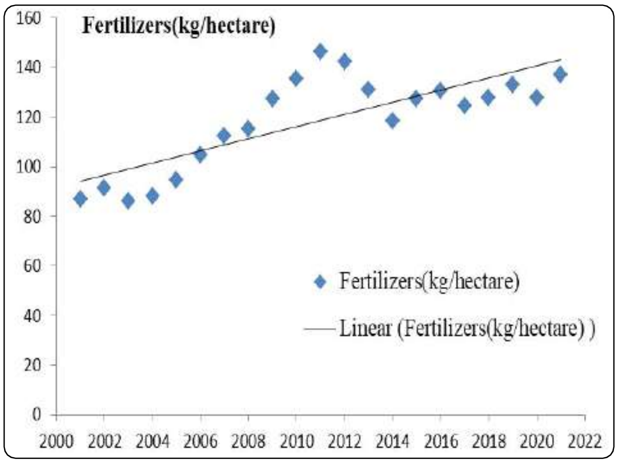

Fig. 1 : Scatter diagram of consumption of fertilizers in India

The trend equation according to the method of least square will be will be $y_e = a+bx$.

To find a and b two normal equations will be solved.

$\sum y = na + b\sum x$ ....(1)

$\sum xy = a\sum x + b\sum x^2$ ....(2)

Where y is the actual consumption of fertilizers and y_e represent the expected consumption of fertilizers (kg/hectare). For each year a year code x is provide. For the base year 2001, year code will be one and for the others year code will be the distance of that year from the base year. So the corresponding x can be found by the formula, year code (x) = current year-base year.

In Table 2 data is shown to develop the linear trend equation, $y_e = a + bx$ using the method of least square.

The trend equation will be $y_e = a + bx$ with the base year 2001.

To find a and b two normal equations given below are developed by putting the corresponding data in Table 2.

Table 2

Table for the method of Least Square

Year	Fertilizers (kg/hectare)	X	xy	x^2
2001	86.7	1	86.7	1
2002	91.5	2	183	4
2003	86.1	3	258.3	9
2004	88.2	4	352.8	16
2005	94.5	5	472.5	25
2006	104.5	6	627	36
2007	112.3	7	786.1	49
2008	115.3	8	922.4	64
2009	127.2	9	1144.8	81
2010	135.3	10	1353	100
2011	146.3	11	1609.3	121
2012	142.3	12	1707.6	144
2013	130.8	13	1700.4	169
2014	118.5	14	1659	196
2015	127.5	15	1912.5	225
2016	130.7	16	2091.2	256
2017	124.4	17	2114.8	289
2018	127.9	18	2302.2	324
2019	133.1	19	2528.9	361
2020	127.8	20	2555.8	400
2021	137.2	21	2880.15	441
	$\sum y$=2488	$\sum x$=231	$\sum xy$=29248.45	$\sum x^2$=3311

$\sum y = na + b\sum x$ ....(3)

$\sum xy = a\sum x + b\sum x^2$ ....(4)

So equation (3) and (4) can be written as

$2488 = 21a + 231b$ ....(3)

$29248.45 = 231a + 3311b$ ....(4)

Solving the above equations we found a and b. So value of a is 91.61 and values of b is 2.44.

The trend equation of fertilizers consumption in India will be $y_e = 91.61 + 2.44x$. with the base year 2001.

Forecast Accuracy : In this section, accuracy of the forecast model is verified with the help of Mean Absolute Deviation (MAD) and Mean Absolute Percentage Error(MAPE).

Notations used are shown below

y : Actual fertilizers consumption (kg/hectare)

y_e : Expected or forecasted fertilizers consumption (kg/hectare) as per trend equation. This can be obtained by putting corresponding values of x in the equation $y_e = 91.61 + 2.44x$.

Deviation = Actual value - Forecast value

MAD : Mean absolute deviation = Average of the total absolute deviations

$$MAD = \frac{\sum (\text{Actual value - Forecast value})}{n}$$

MAPE is defined by

$$MAPE = \frac{1}{n}\left(\sum \frac{|\text{Actual-Forecast}|}{\text{Actual}} x100\right)$$

$$\text{Forecast error in percentage} = \frac{|\text{Actual-Forecast}|}{\text{Actual}} \quad x100$$

Results and Discussion

MAD is a measurement of forecast accuracy in quantities. From the above Table 3, MAD from the year 2013-2021 is less than one. From the above Table 3, the MAPE is less than 10 percentages, so we can say that the forecast model is having a good forecast accuracy. Expected fertilizers consumption for the year 2030 and 2040 can be obtained by putting values of x=30 and x=40 in equation y_e =91.61+2.44x. So expected fertilizers consumption for the year 2030 and 2040 will be 164.81 kg/hectare and 384.41 kg/hectare respectively.

Uttar Pradesh, Haryana, Punjab, Madhya Pradesh, and West Bengal states produce daily consumable crops. We can see from the figures shown below that in each state fertilizers consumption follows a positive linear trend. Only in Madhya Pradesh average fertilizer consumption is below 100 kg/ hectare. In Uttar

Table 3

Study of forecast accuracy

Year	Actual fertilizers	Expected fertilizers	Abs deviation	MAD	MAPE	Percentage error
2001	86.7	94.05	7.35	7.35	8.48	8.48
2002	91.5	96.49	4.99	2.50	6.97	5.45
2003	86.1	98.93	12.83	4.28	9.61	14.90
2004	88.2	101.37	13.17	3.29	10.94	14.93
2005	94.5	103.81	9.31	1.86	10.72	9.85
2006	104.5	106.25	1.75	0.29	9.22	1.67
2007	112.3	108.69	3.61	0.52	8.36	3.21
2008	115.3	111.13	4.17	0.52	7.77	3.62
2009	127.2	113.57	13.63	1.51	8.09	10.72
2010	135.3	116.01	19.29	1.93	8.71	14.26
2011	146.3	118.45	27.85	2.53	9.65	19.04
2012	142.3	120.89	21.41	1.78	10.10	15.05
2013	130.8	123.33	7.47	0.57	9.76	5.71
2014	118.5	125.77	7.27	0.52	9.50	6.14
2015	127.5	128.21	0.71	0.05	8.91	0.56
2016	130.7	130.65	0.05	0.00	8.35	0.04
2017	124.4	133.09	8.69	0.51	8.27	6.99
2018	127.9	135.53	7.63	0.42	8.14	5.97
2019	133.1	137.97	4.87	0.26	7.91	3.66
2020	127.79	140.41	12.62	0.63	8.01	9.88
2021	137.15	142.85	5.7	0.27	7.82	4.16

Pradesh, Haryana, Punjab and West Bengal fertilizers consumption is above 150 kg/hectare. In 1990, consumption was 80 kg/hectare and it doubled in Uttar Pradesh and West Bengal. In Punjab and Haryana, it is more than 200 kg/hectare. Maharashtra, Tamil Nadu, Andhra Pradesh, Jammu and Kashmir and Uttar Pradesh are the states that produce a large number of fruits in India. In Jammu and Kashmir, fertilizers use is below 100 kg/hectare, while in other states it is above 100 kg/hectare. In Andhra Pradesh and Tamil Nadu fertilizers consumption is more than 200 kg/hectare.

Graphical Representation of the use of Fertilizers for the Top Five States in Terms of Daily used Crops Production : In this section, data is graphically represented for the five states which are Uttar Pradesh, Haryana, Punjab, Madhya Pradesh and West Bengal, which produce the measure part of daily consumable crops in India.

In Fig. 2 to Fig. 6, fertilizer consumption pattern of five states that produce daily consumable items like wheat, rice and pulses are shown. Wheat and rice are mostly produced in Uttar Pradesh, Haryana and Punjab. In Haryana and Punjab, fertilizer consumption is more than 200 kg/hectare while in Uttar Pradesh it is 170 kg/hectare. West Bengal is a big producer of rice, where fertilizer consumption also shows a linear increasing growth. Mostly pulses are produced in

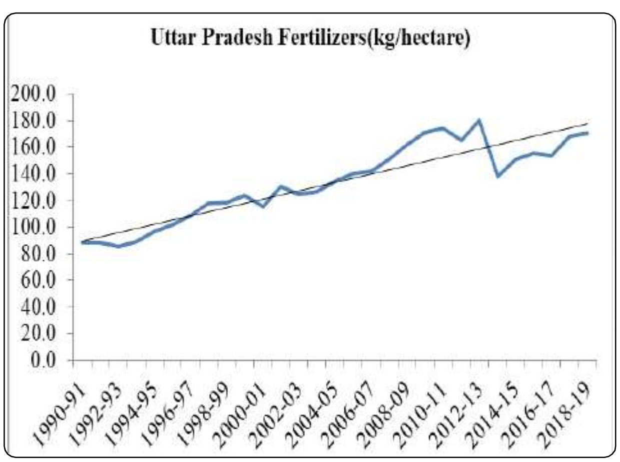

Fig. 2 : Consumption of fertilizers (kg/hectare) in Uttar Pradesh

Source : https://www.rbi.org.in/ScriptspublicationsView.aspx?id=20070

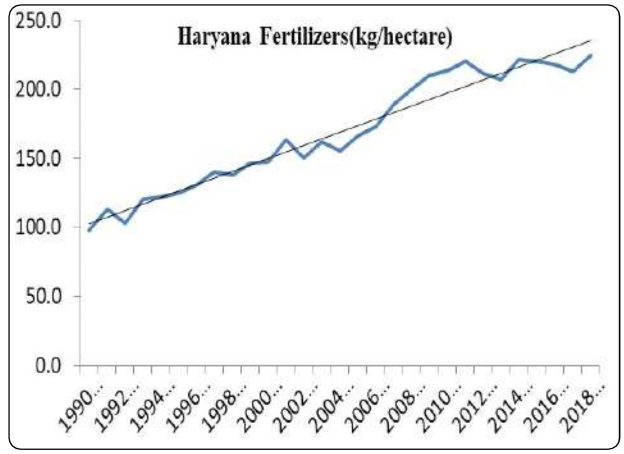

Fig. 3 : Consumption of fertilizers (kg/hectare) in Haryana

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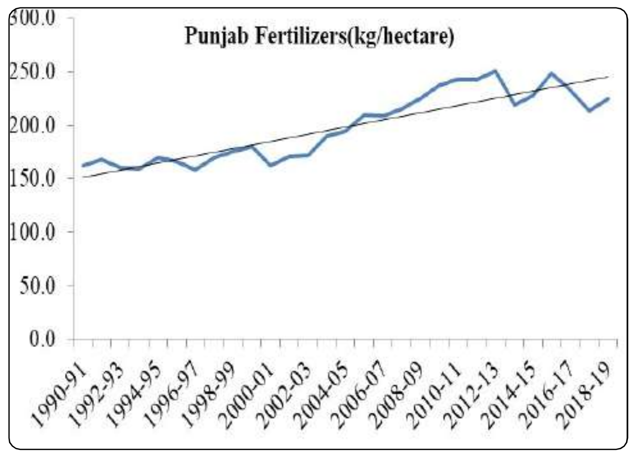

Fig. 4 : Consumption of fertilizers (kg/hectare) in Punjab

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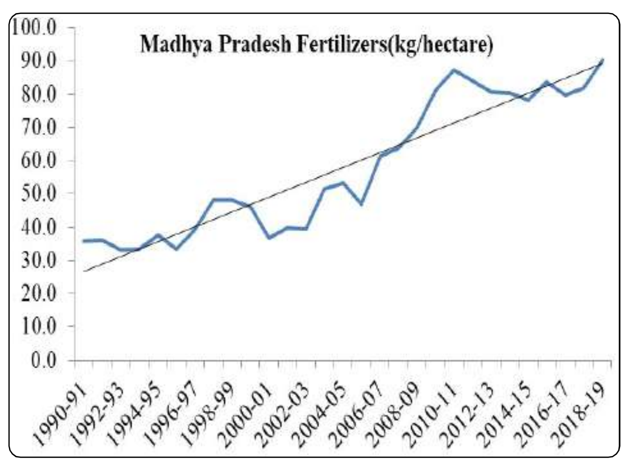

Fig. 5 : Consumption of fertilizers (kg/hectare) in Madhya Pradesh

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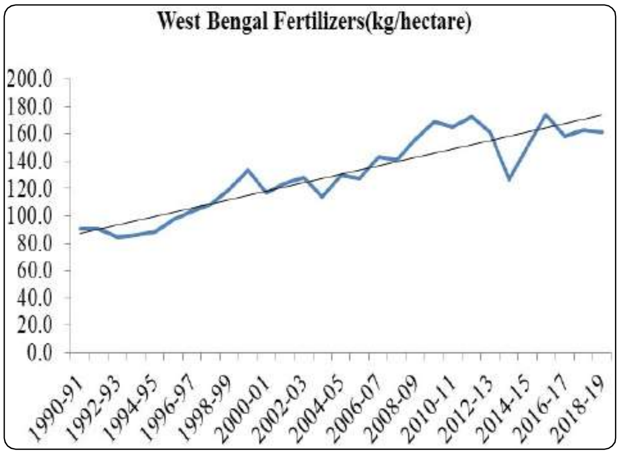

Fig. 6 : Consumption of fertilizers (kg/hectare) in West Bengal

Source : https://www.rbi.org.in/Scripts/PublicationsView.aspx?id=20070

Madhya Pradesh, in Madhya Pradesh fertilizer consumption is also increasing yearly. Wheat, pulses, and rice are very important crops for human survival in India. These crops are consumed in all regions of India. A high consumption of chemical fertilizers used for the production of daily consumed crops damage the human health.

Graphical Representation of the use of Fertilizers for the Top States in Terms of Popular Fruits in India : In this section, fertilizers consumption data is graphically represented for the states Maharashtra, Tamil Nadu, Andhra Pradesh and Jammu and Kashmir, which produces a large number of fruits in India.

In Fig. 7 to Fig. 10, fertilizers consumption trends of Maharashtra, Tamil Nadu, Andhra Pradesh and Jammu and Kashmir are shown. These states produce a large number of fruits in India. Maharastra is the second largest fruit producer after Andhra Pradesh in India. Apple is largely produced by the Jammu and Kashmir. 81 percentages of banana and mango are produced by the Tamilnadu. In all four states, we can see that fertilizer consumption is showing a linear positive growth which is very harmful to the environment, ecology and human health.

In Fig. 11, fertilizers consumption in India is compared with the countries like China, Brazil, USA and Australia. China, Brazil, USA, Australia and India are world's top five agricultural producing countries.

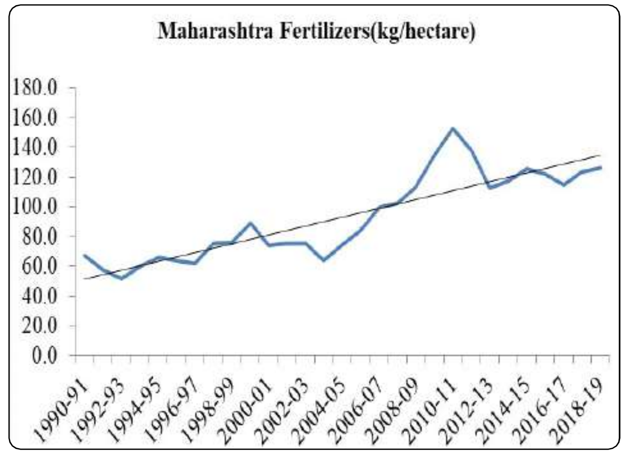

Fig. 7 : Consumption of fertilizers (kg/hectare) in Maharashtra

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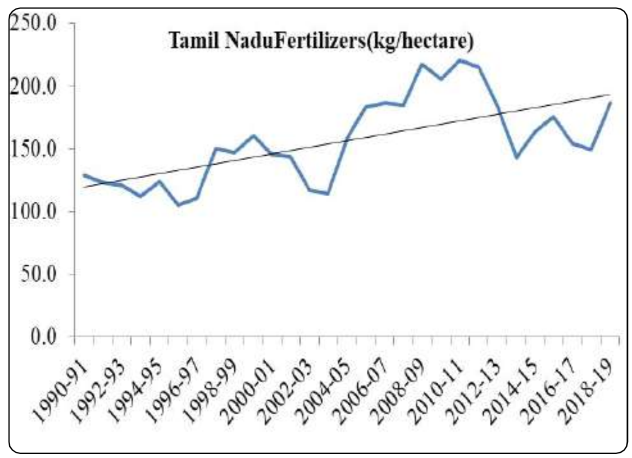

Fig. 8: Consumption of fertilizers (kg/hectare) in Tamil Nadu

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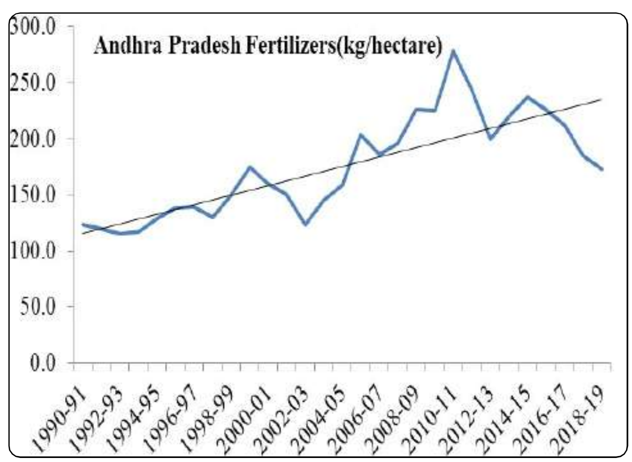

Fig. 9 : Consumption of fertilizers (kg/hectare) in Andhra Pradesh

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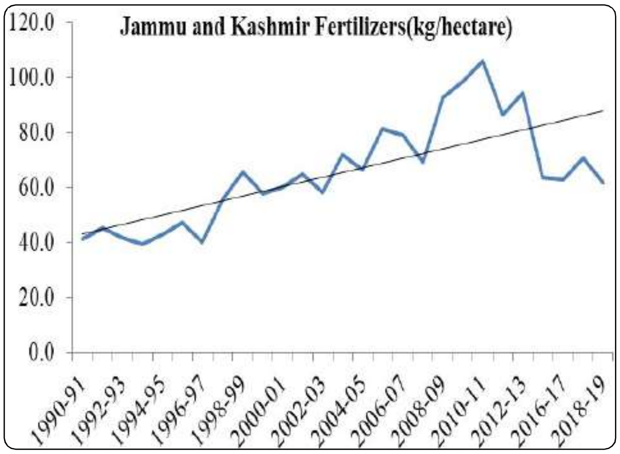

Fig. 10 : Consumption of fertilizers (kg/hectare) in Jammu and Kashmir

Source : https://www.rbi.org.in/ScriptsPublicationsView.aspx?id=20070

From Fig. 11, we can see that India is at third position after China and Brazil in fertilizers consumption worldwide. The USA and Australia are behind India. In China fertilizers consumption is more than 300 kg/hectare. In the last twenty years fertilizer consumption in India has shown a positive growth. Since India is also a highly populated country like China, fertilizers consumption is increasing yearly and in future it may be uncontrollable.

In this work, consumption of NPK fertilizers (kg/hectare) in India from 2001 to 2021 is examined. Using the method of least square a trend equation is developed for the historical data. According to the graph and trend equation, it is found that in India fertilizers consumption is increasing rapidly. According to the model expected fertilizers (NPK) consumption in India for the year 2030 and 2040 will be 164.81 kg/hectare and 384.41 kg/hectare respectively.

Fertilizers consumption in the five states of India, which produce the maximum daily consumable and essential agricultural products, following a linear increasing pattern. In Punjab and Haryana, it is an alarming condition where fertilizers consumption is crossing 250 (kg/hectare). Fertilizers consumption in the five states that produce the maximum fruits in India follows a linear positive trend. In Fig. 11, a comparative graph of the consumption of fertilizers

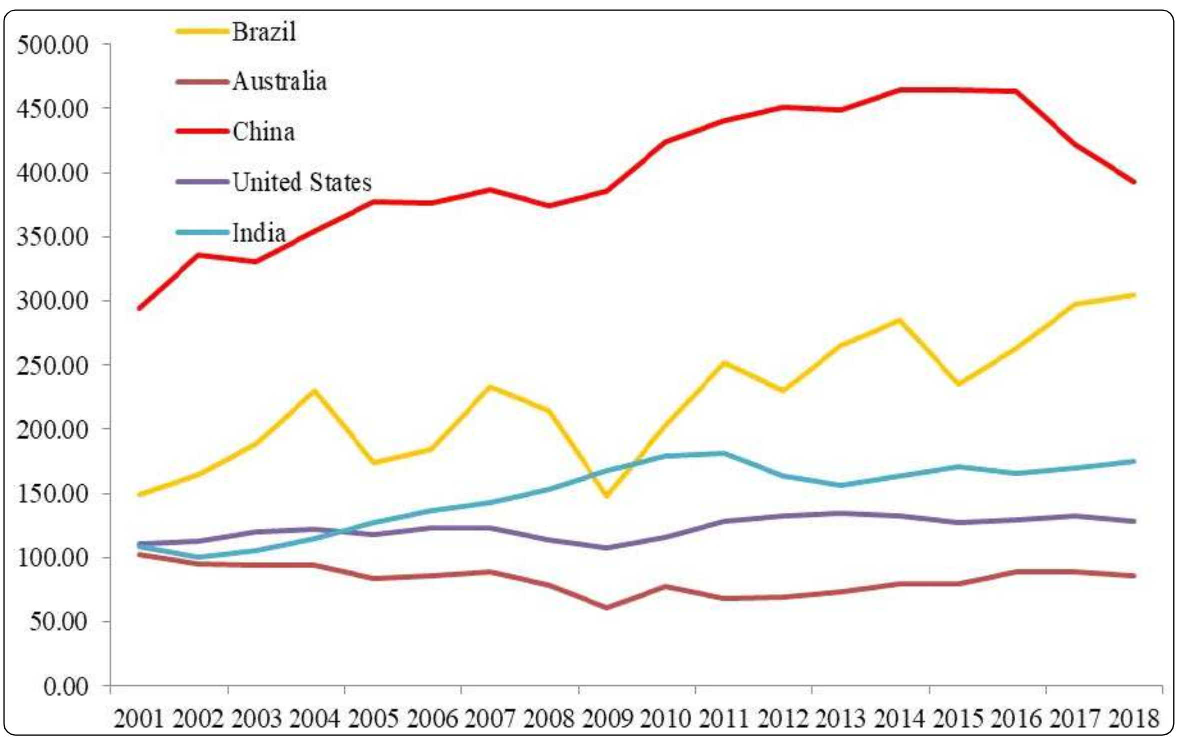

Fig. 11 : Comparison of consumption of fertilizers (kg/hectare) in India with other countries

Source : https://data.worldbank.org/indicator/AG.CON.FERT.ZS in India and other four countries like USA, China, Australia and Brazil is plotted and it is found that in India average fertilizers consumption is more than USA and Australia. As excessive use of fertilizers affects the environment and human health, the consumption of chemical fertilizers should be controlled.

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Genetic Variability Studies on Resistance to Sorghum Downy Mildew Disease in MAGIC Population of Maize (*Zea mays* L.)

M. S. Sowmya[1], H. C. Lohithaswa[2], G. Jadesha[3], P. Mahadevu[4], N. Mallikarjuna[5] and A. Mohan Rao[6]

[1]Department of Genetics and Plant Breeding, College of Agriculture, UAS, GKVK, Bengaluru - 560 065, [2]AICRP on Pigeonpea, ZARS, UAS, Bangalore, [3,4&5]AICRP on Maize, ZARS, V. C. Farm, Mandya, [6]AICRP on Potential Crops, UAS, Bangalore - 560 065

e-Mail : lohithaswa.chandappa@gmail.com

Authors Contribution

M. S. Sowmya : Conceptualization, design, data analysis and draft writing;

H. C. Lohithaswa : Conceptualization, editing and manuscript prepartion;

G. Jadesha : Manuscript prepartion, editing and data analysis;

P. Mahadevu ; N. Mallikarjuna & A. Mohan Rao : Editing and manuscript prepartion

Corresponding Author :
H. C. Lohithaswa

Received : May 2024
Accepted : June 2024

Abstract

Development of the host plant resistance is an effective way to mitigate yield losses and to maintain self-sufficiency in maize. Sorghum downy mildew (SDM) is an important foliar disease in maize and is known to hinder its production potential. Thus, the development and identification of inbred lines resistant to SDM can contribute to minimizing the losses caused by SDM. In this regard, a set of 1331 Multiparent Advanced Generation Intercross (MAGIC) Recombinant Inbred Lines (RILs) were screened for their response to SDM at ZARS, V.C. Farm Mandya during *kharif* 2022. Results from the analysis of variance indicated the presence of a substantial amount of variability for disease response. The disease incidence ranged from 0 to 100 per cent with a mean disease incidence of 78.07 per cent. The genetic estimates PCV, GCV, GAM and broad sense heritability were high indicating the ample scope for identifying and selecting the resistant lines. Skewness and kurtosis values were -0.61 and 2.70, respectively suggesting the involvement of many genes with duplicate gene interaction for resistance. Out of 1331 RILs, 37 were resistant, 47 were moderately resistant, 158 were moderately susceptible and 1089 were susceptible.

Keywords : Maize, Sorghum downy mildew, MAGIC RILs, Resistance, Skewness, Kurtosis

Maize is the third most important staple food crop worldwide contributing to the nation's food and nutritional security. Photosynthetically efficient (C4), day-neutral and highly adaptive nature of the maize makes it suitable for cultivation in most of the agro-climatic regions. This crop is incredibly versatile and finds application in various industries beyond food, including animal feed, ethanol production and as a raw material in the manufacturing of bioplastics (Lohithaswa *et al.,* 2022). India contributes nearly 2.13 per cent of maize to the global food market which is grown in an area of 205.87 million ha (FICCI, 2023). Recently, due to increased area under maize cultivation, the growing of uniform crop varieties, shrinkage in genetic diversity, high density planting and high fertility management made maize highly sensitive to many of the biotic and abiotic production constraints. In addition to this, changing climate makes the crop vulnerable to many of the new emerging pests and diseases (Gazal *et al*., 2018). Annual yield losses in maize caused by diseases (excluding viral) are estimated around 4-14 per cent globally (Zhu *et al*., 2021). Sorghum downy mildew (SDM), caused by an oomycetes fungus [*Peranosclerospora sorghi* (Weston and Uppal) C. G. Shaw], is prevalent in three states of peninsular India *i.e.*, Karnataka, Andhra Pradesh and Tamil Nadu. It is known to cause a yield loss of up to 30-40 per cent (Rasheed *et al*., 2023). Disease incidence at the early crop stages leads to death of the plants and at the later crop stages plants become sterile. Though SDM can be controlled by the use of fungicides, its effectiveness in controlling the disease is variable (Sumathi *et al.,* 2020). Further, the development of resistance to fungicides and the evolution of different pathotypes of *P. sorghi* make the need for genetic resistance in maize cultivation a mandate. Thus, the development and deployment of the host plant resistance is considered to be an effective, eco-friendly and long-term viable strategy to mitigate the yield losses due to diseases (Nair *et al.,* 2004).

Selection is the most critical step in plant breeding and the effectiveness of selection depends on the extent of variability for the target trait in the base population (Banakara *et al.,* 2022 and Mujjassim *et al.,* 2023). Variability generated through deliberate crossing is the major source to recover the desired recombinants. Biparental crosses, which are produced by crossing two contrasting and complementary parents are successful in analyzing the complex genetic architecture of the traits. However, these bi-parental mapping populations (BMPs) will segregate only for two alleles, have poor mapping resolution and less power of QTLs detection (Mahan *et al*., 2018). Consequently, multi-parental mapping populations were developed to address the pitfalls of BMPs. These populations are renowned for increasing trait variability through a greater number of recombination events by disrupting strong linkages (Huang *et al.,* 2015; Dell Aqua *et al.,* 2015; Mahan *et al.,* 2018 and Desai *et al.,* 2022). Among the multi-parental populations, Multi parental Advanced Generation Inter Crosses (MAGIC) and Nested Association Mapping (NAM) populations are the major ones. MAGIC lines are the fine scale mosaics of the genomic regions from more than two founder parents with maximum trait variability coverage (Mackey and Powell, 2007). Recent studies have shown that multi parental populations can be an excellent source for generating superior inbred lines and can speed up genetic gain. Higher recombination rates with a broad range of variability for target traits will indirectly assist in effective selection. Genetic studies of SDM resistance have shown polygenic inheritance with a predominance of additive gene effects (Sumathi *et al.,* 2020 and Rasheed *et al*., 2023). Thus, the use of recombinant inbred lines derived from complex crosses like MAGIC is known to offer numerous benefits over inbreds derived from crossing two contrasting parents in identifying the resistance source to devastating disease like Sorghum downy mildew. Hence, the present investigation was undertaken to identify the sources of resistance to sorghum downy mildew in a MAGIC RIL population.

Material and Methods

The material used for the study comprised of a set of 1331 MAGIC Recombinant Inbred Lines (RILs) obtained from crossing eight elite founder parents (Table 1). The procedure followed for deriving RILs is given in Fig. 1. The MAGIC RILs were planted in an augmented design (Federer, 1956) with SKV 50

Table 1

List of maize inbred lines used in the development of multi-parental population

Inbred	Pedigree details	Characteristic features
PDM-4341	(Comp8551 × Comp 8527 × Ageti76 × MDR) -9- 4-2-8-7-1-1-2-1-L-1-1	Significant GCA effects for grain yield (kg/ha)
VL109545	[CL-G2501 × CML170]-B-2-3-2-BB-3-BB	Resistant to Northern corn leaf blight (NCLB)
CML451	((NPH-28-1/G25)/NPH-28-1)-1-2-1-1-3-1-B	Drought tolerant
CAL1443	(CTS013008/AMATLC0HS71-1-1-2-1-1-1-B*5/Nei402020)-B*5	Resistant to NCLB

Continued....

TABLE 1 Continued....

Inbred	Pedigree details	Characteristic features
CM 212	USA/ACC No.2132 (Alm)-3-2-f-#-13-#-bulk	Resistant to Fusarium stalk rot (FSR)
SKV50	SKV-50 (population 147-F_2 # 89-3-2-B-1-B)	Resistant to NCLB, Sorghum downy mildew (SDM), Polysora rust (PR)
CAL1518	SW5-10-B*5-2	Significant GCA effects for test weight
CM 202	C121 (EARLY)	Susceptible to NCLB, SDM but resistant to FSR

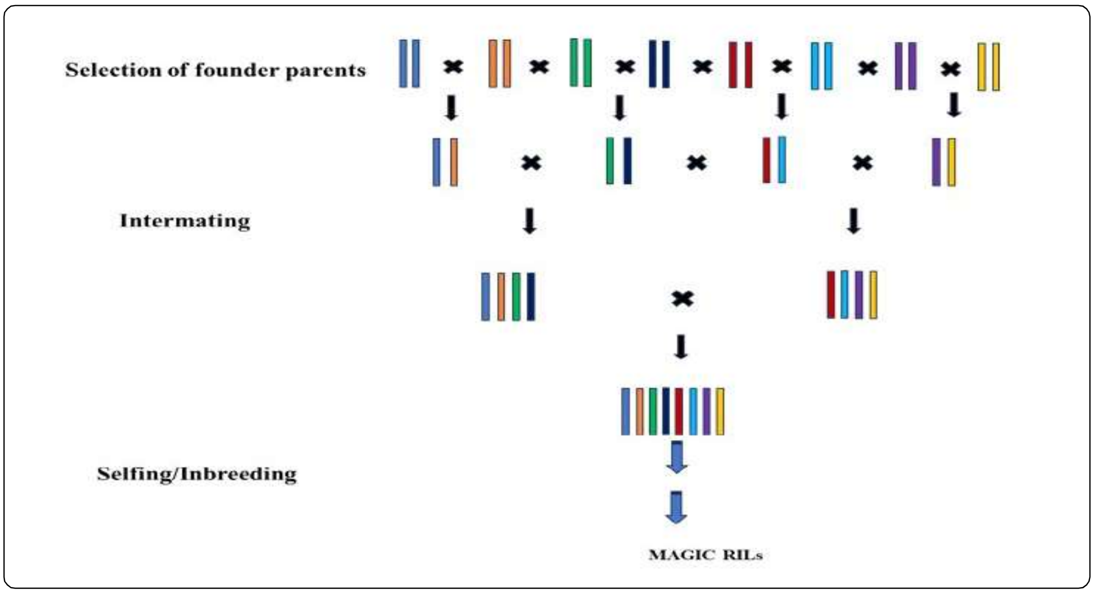


Fig. 1 : Strategy used for deriving Multiparent advanced generation inter cross recombinant inbred lines

and African tall as resistant and susceptible checks, respectively during *kharif* 2022 at ZARS, V.C. Farm, Mandya. The MAGIC RILs were planted in 2 m rows with a spacing of 60 cm between the rows and 20 cm between the plants.

Artificial Inoculation and Data Recording

To ensure the proper disease spread, artificial inoculation was carried out. Disease spread was ascertained by planting spreader rows 15-20 days before taking up sowing of main test entries (Hooda *et al.,* 2018). To ensure uniform disease spread, infected leaves were collected and washed with water and spore suspension thus resulted was sprayed on the 7 days old plants during midnight. Observations were recorded at 45 days after sowing. Per cent disease incidence (PDI) was calculated using the formula given below.

$$PDI = \frac{No.\ of\ infected\ plants}{total\ number\ of\ plants} \times 100$$

Disease scoring was done following the method given by Pupipat (1976) as given below.

Infection rate (%)	Disease reaction
≤ 10	Resistant (R)
10.1-25	Moderately resistant (MR)
25.1-50	Moderately susceptible (MS)
≥ 50	Susceptible (S)

Statistical Analysis

Recorded data were subjected to arcsine transformation using the PBIB package (Kaur *et al.,* 2017) in R-Studio and subjected to statistical analyses. Analysis of variance was performed using the '*augmented RCBD*' package in R software version 3.3.2. Descriptive statistics *viz*., mean, variance and standard deviation were estimated using the '*psych'* package in R software.

Variability Parameters

Phenotypic and genotypic coefficient of variation (PCV and GCV) were calculated by the formula given by Burton and DeVane (1953).

$$\text{PCV (\%)} = \frac{\sqrt{\sigma_p^2}}{\overline{X}} \times 100$$

$$\text{GCV (\%)} = \frac{\sqrt{\sigma_g^2}}{\overline{X}} \times 100$$

where, $\overline{X}$ = grand mean

σ_g^2 = genotypic variance

σ_p^2 = phenotypic variance

Broad sense heritability (H) was estimated using the following formula (Allard, 1960).

$$H = \frac{\sigma_g^2}{\sigma_p^2} \times 100$$

where,

σ_g^2 = genotypic variance

σ_p^2 = phenotypic variance

Expected Genetic advance (GA) was calculated by the following formula (Allard, 1960).

$$\text{GA} = k \times h_b^2 \times \sqrt{\sigma_p^2}$$

where, k = selection differential (2.06) at 5% selection intensity

$\sqrt{\sigma_p^2}$ = phenotypic standard deviation

The genetic advance as a percentage of the mean was estimated as:

$$\text{GAM} = \frac{GA}{\overline{X}} \times 100$$

Where, GA = genetic advance; $\overline{X}$ = grand mean

Third- and fourth-degree statistics *viz*., skewness and kurtosis were calculated to know the nature of gene action and number of genes involved in controlling the trait using R software Version 4.1.3 and the package '*moments*'.

Results and Discussion

Results from ANOVA indicated the presence of a substantial amount of genetic variability for the disease response (Table 2). The disease incidence ranged from 0 to 100 per cent with a mean disease incidence of 78.07 per cent. The per cent disease

Table 2

Analysis of variance for Sorghum downy mildew disease severity in Multiparent advanced generation inter cross derived recombinant inbred lines of Maize

Source of variation	Degrees of freedom	Mean Sum of squares
Genotypes adjusted		
Blocks (ignoring genotypes)	41	0.41 ***
Genotypes (eliminating Blocks)	1332	0.17 ***
Genotypes : Check	1	9.06 ***
Genotypes : Test and Test vs. Check	1331	0.16 ***
Block adjusted		
Genotypes (ignoring Blocks)	1332	0.18 ***
Genotypes : Check	1	9.07 ***
Genotypes : Test	1330	0.16 ***
Genotypes : Test vs. Check	1	13.78 ***
Block (eliminating genotypes)	41	0.04
Residuals	41	0.04
CV (%)		17.77

CV : Co-efficient of Variation; *** Significant at P = 0.001; ** Significant at P = 0.01; * Significant at P = 0.05

incidence in the resistant (SKV50) and the susceptible check (African tall) were 18.72 and 74.65 per cent, respectively.

Estimates of Genetic Parameters

The observable phenotype is the result of genotype (G), environment (E) and their interaction (G×E). Estimation of phenotypic and genotypic coefficients of variations gives an idea about the trait variability in the material under study. The idea of coefficient of variation mainly GCV pinpoints the reliability of using the breeding material in genetic improvement programmes. Estimated descriptive statistics and genetic parameters are represented in Table 3. Estimated PCV (33.75%) and GCV (28.94%) were high indicating the presence of a substantial amount of trait variability, thus, the selection would be rewarding. However, the magnitude of the phenotypic coefficient of variation was higher than that of the genotypic coefficient of variation, indicating the significant role of the environment in the trait expression (Magar *et al.,* 2021).

TABLE 3

Descriptive statistics and genetic parameters of Multiparent advanced generation inter cross derived recombinant inbred lines for sorghum downy mildew disease reaction in Maize

Parameters	Values
Minimum	0
Maximum	100
Range (%)	100
Mean (%)	78.07
Mean per cent disease incidence in resistant check (%)	18.72
Mean per cent disease incidence in susceptible check (%)	74.65
Standard deviation	26.61
Skewness	-0.61
Kurtosis	2.70
Phenotypic Coefficient of Variation (%)	33.75
Genotypic Coefficient of Variation (%)	28.94
Heritability (Broad sense) (%)	73.55
Genetic advance over per cent mean (%)	51.21

In addition to PCV and GCV, the estimates of heritability and genetic advance would provide better insight on the reliability of using them as a selection criterion in breeding programmes (Johnson *et al.,* 1955 and Desai *et al.,* 2022). The estimated broad sense heritability was high with higher genetic advance over per cent mean with values 73.55 and 51.21 per cent, respectively. Compared to bi-parental mapping population, multi-parental mapping populations are expected to show increased trait variation and heritability indicating its relevance in resistance breeding (Desai *et al*., 2022). A combination of high heritability and high genetic advance over per cent mean for a trait, implies the role of additive gene effects, suggesting the scope for selection of resistant progenies (Rasheed *et al.,* 2023 and Jhadav *et al.,* 2019).

Skewness and Kurtosis

Skewness is a measure of symmetry of the normal distribution. However, kurtosis is a measure of the peakedness of the distribution. The knowledge about skewness will aid in understanding the genetic basis for variation in the trait (Fisher *et al.,* 1932). In plant breeding information about the skewness and kurtosis will help in understanding the nature of gene action (Fisher *et al.,* 1932) and the number of genes involved in controlling the trait expression (Robson, 1956), respectively. Positive skewness indicates complementary gene interaction while negative skewness indicates duplicate gene interaction (Desai *et al.,* 2022). Whereas, a kurtosis value of <3 indicates the platykurtic curve visualising the involvement of a large number of genes in governing the trait, while kurtosis of >3, is leptokurtic indicating the involvement of the few genes in trait expression. The skewness and kurtosis values were -0.61 and 2.70, respectively (Table 3 and Fig. 2)

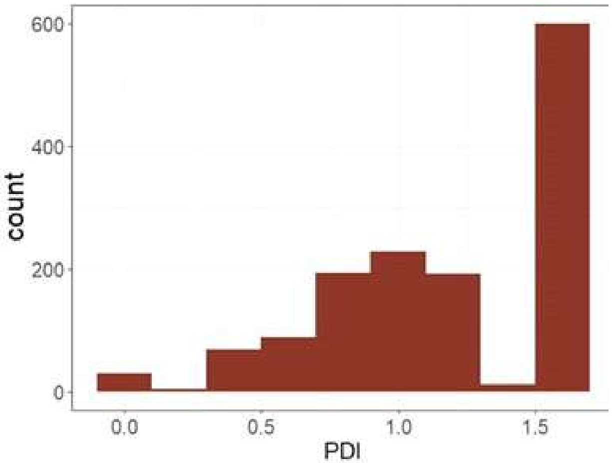
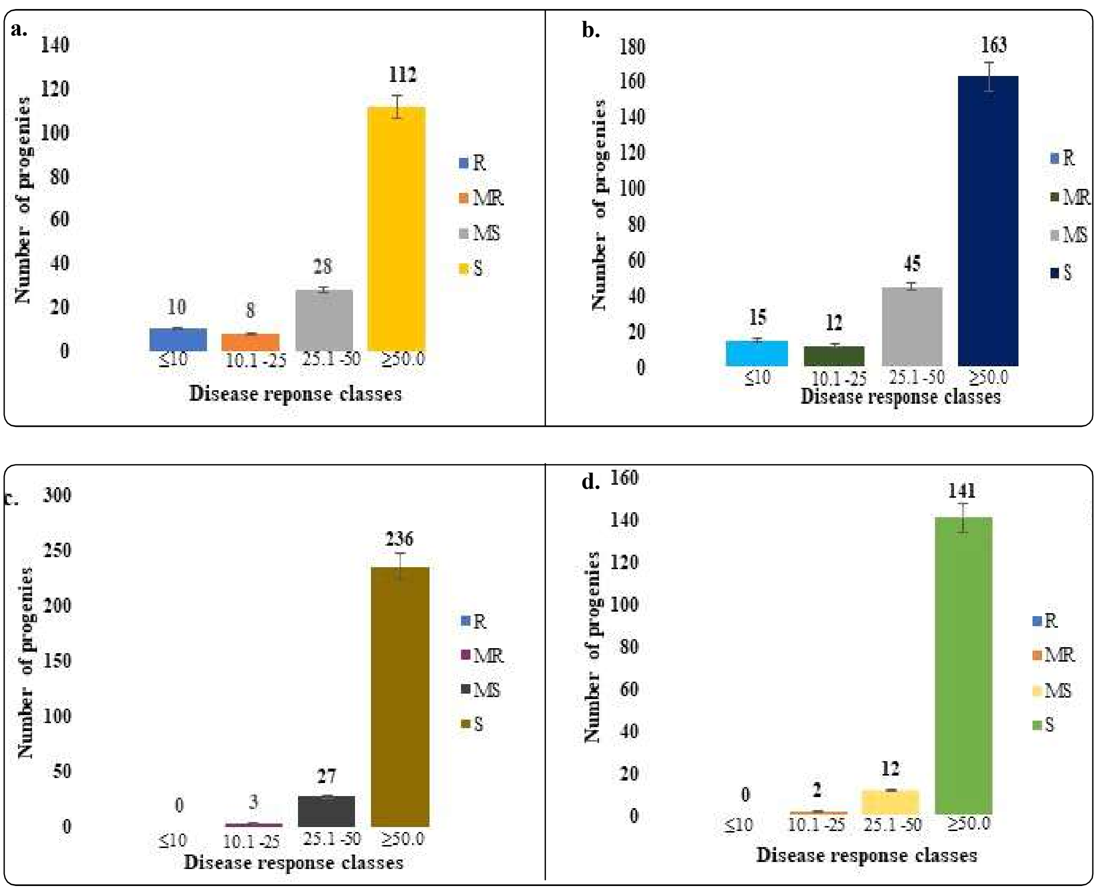
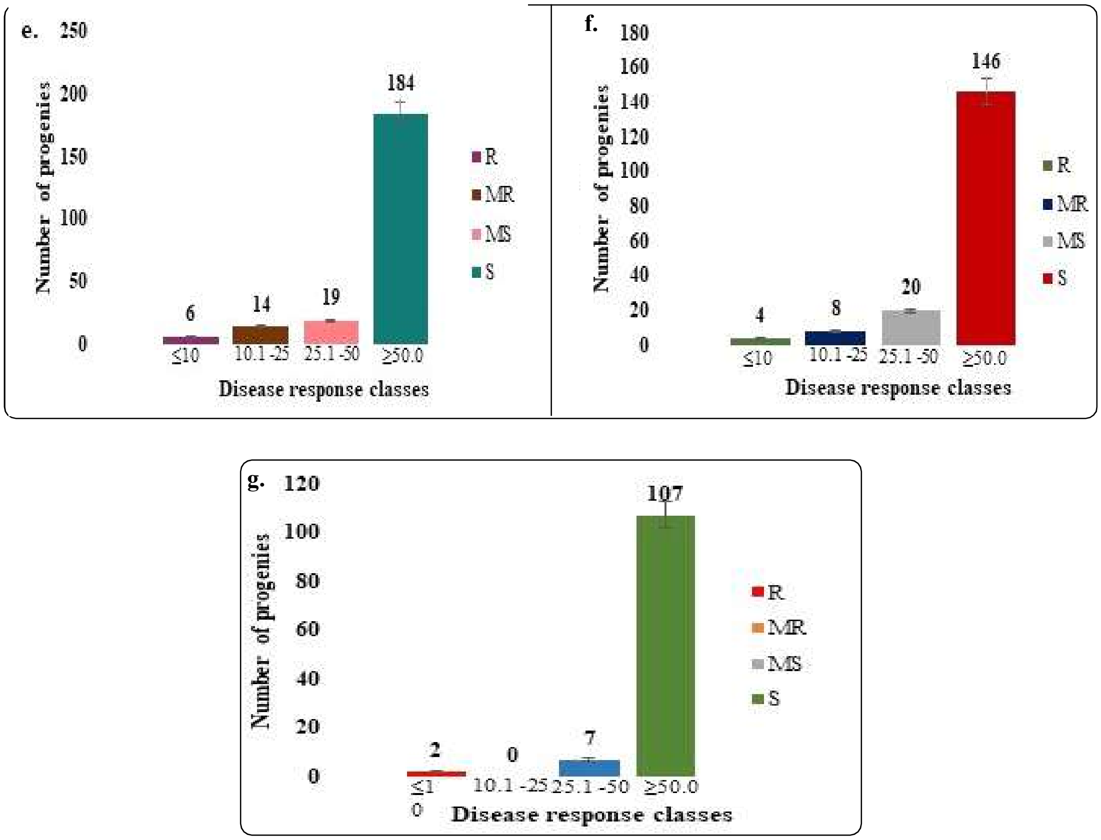


Fig. 2 : Frequency distribution of per cent disease incidence in Multiparent advanced generation inter cross derived recombinant inbred lines into different disease response classes

indicating the presence of polygenes with duplicate gene interaction in regulating the disease resistance. The possible reason for obtaining a negatively skewed distribution for disease response would be that out of eight founder parents used, only one parental genotype (SKV50) was resistant to SDM which might cause the distribution to skew towards susceptibility.

The presence of duplicate gene action indicates the presence of predominantly dispersed alleles at the interacting loci, suggesting the effectiveness of breeding methods for exploiting the non-additive component of gene action (Singh *et al*., 2019). Similar findings were obtained by Jhadhav *et al*. (2019). The phenomenon of duplicate epistasis is unfavourable from the breeder's point of view as the presence of duplicate epistasis would be detrimental to rapid genetic progress. It is difficult to fix genotypes with an increased level of trait expression because the positive effects of one parameter would be cancelled out by the negative effects of another, whereas a complementary type of epistasis has favourable effect in breeding programme (Gunasekar *et al*., 2018).





R - Resistant; MR - Moderately Resistant; MS - Moderately Susceptible and S - Susceptible

Fig. 3 : Response of individual eight-way crosses to (a-first; b-second; c-third; d-fourth; e-fifth; f-sixth and g- seventh eight way cross) disease response

Distribution of different Phenotypic Classes within the Population

The second eight way cross had a greater number of resistant progenies (15) followed by the first (10), fifth (6), sixth (4) and seventh (2) eight-way crosses and the remaining two eight-way crosses did not yield any resistant phenotypes (Fig. 3).

Identification of Lines with Resistance to Sorghum Downy Mildew

Host plant resistance serves as an economic way to mitigate the yield losses due to diseases, because of its durability. Out of 1331 MAGIC RILs evaluated for the response to sorghum downy mildew, 37 were found to be resistant, 47 were moderately resistant, 158 of them were moderately susceptible and 1089 of them showed a susceptible reaction. The increased proportion of susceptible progenies compared to other disease response classes, could be attributed to the parental contribution as out of the eight founder parents used, only one parent SKV 50 is known to be resistant to sorghum downy mildew. The identified resistant lines have to be used in the development of the high yielding hybrids with resistance to sorghum downy mildew.

Higher estimates of phenotypic and genotypic coefficients of variations and heritability with high genetic advance were observed for disease response to sorghum downy mildew in the MAGIC RILs. It suggests the scope for identification and selection of resistant lines. The skewness and kurtosis values indicated the involvement of polygenes with duplicate gene interaction implying the need for few cycles of recombination.

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Mysore J. Agric. Sci., 58 (4) : 338-348 (2024)

Population Structure, Diversity and Composition of Tree Stand in Nandi Hill Forest Ecosystem

T. S. Sumanth[1], R. Krishnamurthy[2], R. Srinivasan[3], M. Mahadeva Murthy[4],
A. S. Devakumar[5] and K. Pushpa[6]

[1,4&5]Dept. of Forestry and Environmental Science, [2]Dept. of Soil Science & Agricultural Chemistry, [6]Dept. of Agronomy, CoA, UAS, GKVK, Bengaluru - 560 065, [3]NBSS & LUP, Regional Centre, Hebbal, Bengaluru - 560 024
e-Mail : suman64logia@gmail.com

Authors Contribution

T. S. Sumanth :
Conceptualization, investigation, data analysis and manuscript drafting;

R. Krishnamurthy :
Analytical approaches, interpretation of the obtained results and supervision;

R. Srinivasan :
M. Mahadeva Murthy :
A. S. Devakumar &
K. Pushpa :
Conceptualization and analytical approaches and guidance

Corresponding Author :
T. S. Sumanth

Received : September 2024
Accepted : September 2024

Abstract

Forests are one of the main components of the terrestrial ecosystems and documenting their diversity is a necessary tool for forest conservation and land-use planning. Hence, this study was conducted to investigate the floristic composition and population structure of the Nandi Hill Forest ecosystem. Vegetation analysis was conducted by laying 0.1-hectare plots randomly. A total of 28 species from 17 families belonging to 16 orders of woody plants were recorded from the study area. A Shannon-Weinner index value of 1.507 was obtained suggesting a moderate diversity of species in the Nandi Hill Forest. Concentration of dominance value of 0.46 and the evenness index value of 0.45 suggests that the study area is dominated by a few species and the distribution of trees is uneven. The density and basal area for the whole forest was 120.71 ± 15 stems ha^{-1} and 62.46 m^2ha^{-1} respectively. *Eucalyptus tereticornis* Sm. was the most frequently occurring with the highest density and the largest contributor to the overall basal area. The DBH class distribution showed an inverse-J pattern with most individuals in the lower DBH classes, suggesting active regeneration and recruitment of new individuals. The height class distribution showed that 32.54 per cent of the individuals had a height between 15-21m. Based on the importance value index the *Eucalyptus tereticornis* Sm. was found to be the most ecologically significant tree species in the Nandi Hill Forest ecosystem.

Keywords : Forest ecosystem, Diversity, Population structure, Regeneration

Forests are one of the main components of the terrestrial biosphere and are critical for mediating the global carbon balance and mitigating global climate change. They are highly productive and intricate terrestrial ecosystems that contain almost 80 per cent above ground carbon. They play a critical role in maintaining the carbon balance and are essential for mitigating climate change (Streck & Scholz, 2006 and Whitehead, 2011). Forests account for more than one-third of the habitable land area, which is around one-quarter of the total land area (both habitable and uninhabitable) (Ritchie and Roser, 2024). According to the United Nations, forests cover 31 per cent of the world's land surface and absorb roughly 15.6 billion tons of carbon dioxide every year. Trees are the dominant vegetation in forest ecosystems and form basic structural components (Haq *et al.,* 2019). Understanding the diversity, distribution and regeneration status of trees offers valuable insights into the health of a forest eco system and the flow of ecosystem services and helps in forecasting forest dynamics (Negi *et al.,* 2019). Therefore, quantitative information on the diversity and distribution of tree species in forest ecosystems is critical for understanding the community structure and developing actionable conservation strategies.

Documenting vegetation is a necessary tool for forest conservation, landscape mapping and land-use planning (Haq *et al.,* 2017) and is a great method of summarizing our knowledge of vegetation structures and patterns (MacKenzie *et al.,* 2019). Vegetation diversity and distribution data are useful not only for understanding the architecture, species richness and spatial association patterns of an ecosystem but also for providing valuable insights into the habitat requirements of a species for successful restoration and conservation (Wasseige *et al.,* 2014).

According to Saima *et al.* (2018) hill forests exhibit intricate variations in community structure, diversity and distribution that are influenced by factors such as elevation, slope and forest productivity. Nandi Hills is one such hilly forest ecosystem and one of the most eco sensitive areas which is adversely affected by overcrowding and vehicular pollution due to excessive tourism. Therefore, it is clear that the ecosystem in and around the Nandi Hills area should be protected and managed. Monitoring and recording tree diversity and distribution of this valuable forest is essential for understanding the processes related to carbon emissions originating from deforestation and forest degradation. The present study is an attempt to provide baseline data on the diversity and tree population structure of the Nandi Hills for future conservation and better management of forest resources. The objective of this study was to address the questions: *viz* (i) what are the quantitative dissimilarities in tree species diversity and distribution in the Nandi Hill Forest ecosystem and (ii) what is the population structure of tree species in the study site?

MATERIAL AND METHODS

Study Area

Nandi Hill also known as Nandidurga is situated in the Chikkaballapur District, 10 km from Chickballapur Town and approximately 60 km from Bengaluru at an altitudinal range of 1000-1473 MASL (Fig. 1). It covers an area of 2,837 hectares. The Hilly

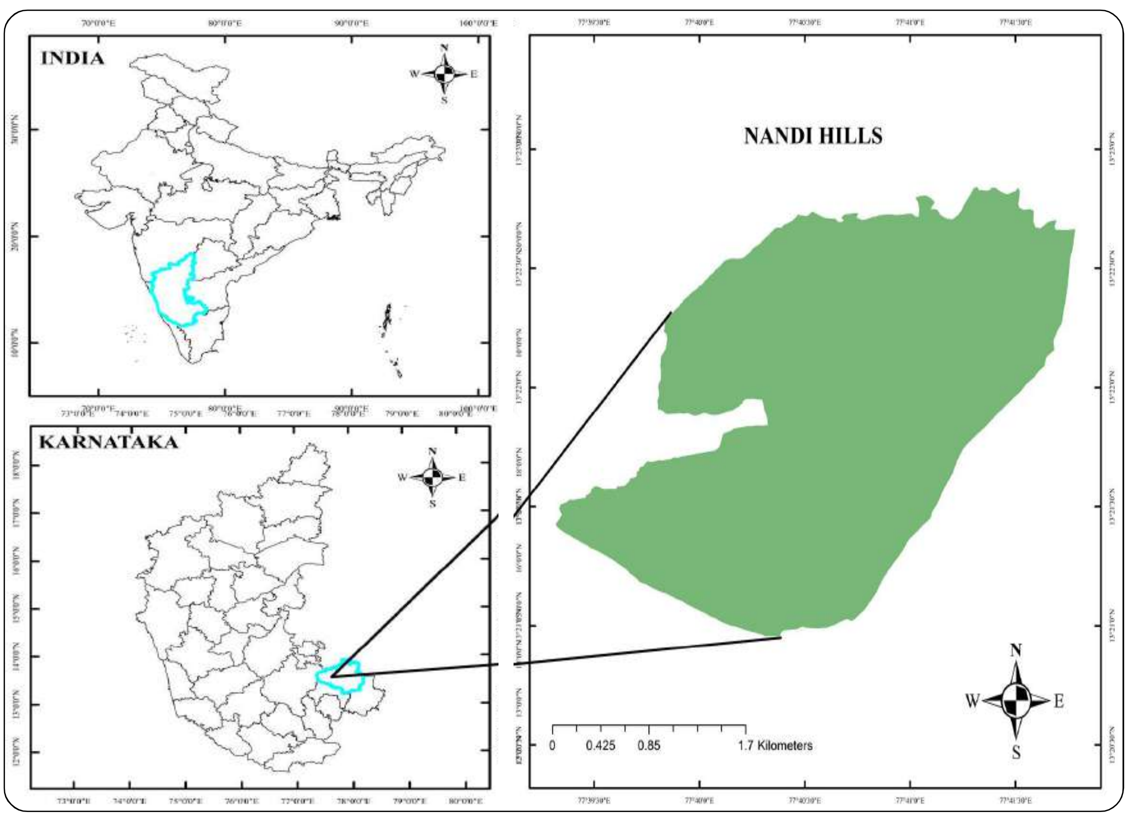

Fig. 1 : Map of the study area

landscape is craggy and rugged. The terrain of Nandi Hills is mostly rocky and consists of slopes covered with scrubs and sparse vegetation. There are six rivers that are monsoon-dependent and are not perennial.

Sampling Design and Collection of Data

Sampling of the tree species was carried out to asses diversity and population structure. Tree species composition was studied by random sampling using the quadrat method, as this method is less biased and most popularly followed (Bhatta *et al.,* 2012). A 0.1-hectare plot (Phillips *et al.,* 2003) was laid at each selected site for tree enumeration. Individuals with a girth of more than 20cm were considered for sampling and their girth and canopy height were measured. All individuals were identified up to the species level using local flora and further authentication was performed at Mahatma Ghandhi Botanical Garden, University of Agricultural Sciences, GKVK, Bangalore. The correct nomenclature, family and order of each identified tree species were assigned using the Plants of the World Online database.

Quantitative Analysis

Vegetation data were compiled and summarized using Microsoft Excel 2021. Shannon diversity index (H') was determined using $H = -\sum_{i=1}^{N} P_i \ln P_i$, where $p_i = n_i/N$; n_i is the number of individual trees present for species i and N is the total number of individuals (Magurran, 2004) and Concentration of Dominance (Cd) was determined using $Cd = \Sigma(n_i/N)^2$, where n_i = the total number of individuals of particular species and N = the total number of individuals of all species. The indices used in this study assume that individuals are randomly selected from an infinitely large population and the sample includes all species present in the community (Yemata and Haregewoien, 2022). The evenness index (J') was calculated using $J' = H'/H'_{max,}$ where $H'_{max} = \ln S$ (S=Total number of species). An estimate of the evenness with which the individuals are divided among the species in any sample, we may take the ratio of the observed diversity to the maximum possible for the same number of species (Pielou, 1966).

The Population structure was analyzed by considering key factors such as stem density, frequency, basal area, relative density, relative frequency, relative dominance, diameter class distribution (16 classes, *i.e.* 1:30-60, 2:60-90, 3:90-120, 4:120-150, 5:150-180, 6:180-210, 7:210-240, 8:240-270, 9:270-300, 10:300-330, 11:330-360, 12:360-390, 13:390-420, 14:420-450, 15:450-480, 16:>480 cm), height class distribution (11 classes, *i.e.* 1: <3, 2: 3-6, 3: 6-9, 4: 9-12, 5: 12-15, 6: 15-18, 7: 18-21, 8: 21-24, 9: 24-27, 10:27-30, 11:>30 m) and Importance Value Index (Kent and Coker, 1992).

The importance value index (IVI) is an indicator of the ecological significance of a species. It often reflects the extent of dominance, occurrence and abundance of a given species in relation to other associated species in an area (Kent and Coker, 1992). Relative Frequency, Relative dominance and Relative Density were calculated using the formula,

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a species}}{\text{Total Frequency of all species}} \times 100$$

$$\text{Relative dominance (RDo)} = \frac{\text{Total basal area of the species in all quadrats}}{\text{Total number basal area of the species in all quadrats}} \times 100$$

$$\text{Relative Density (RD)} = \frac{\text{Number of quadrats in which species is studied}}{\text{Total number of quadrats studied}} \times 100$$

$$IVI = RD + RF + RDo$$

Results and Discussion

Population Structure

Floristic Composition and Tree Species Diversity : A total of 28 tree species, spanning across 17 different families and encompassing 16 orders were documented from the sample plots (Table 1). Half of the total floristic composition was represented by members of five families. Among the families

TABLE 1

Floristic composition in the Nandi Hill Forest ecosystem

Identified Species	List of Families	List of Orders
Acacia auriculiformis A.Cunn. ex Benth.	Myrtaceae	Myrtales
Actinodaphne wightiana (Kuntze) Noltie	Fabaceae	Fabales
Albizia amara (Roxb.) Boivin	Proteaceae	Proteales
Anacardium occidentale L	Moraceae	Rosales
Araucaria bidwillii Hook.	Phyllanthaceae	Malpighiales
Bridelia retusa (L.) A.Juss.	Bignoniaceae	Lamiales
Cordia myxa L.	Lauraceae	Laurales
Delonix regia (Bojer ex Hook.) Raf.	Euphorbiaceae	Malvales
Eucalyptus tereticornis Sm.	Malvaceae	Sapindales
Ficus benghalensis L.	Anacardiaceae	Gentianales
Grevillea robusta A.Cunn. ex R.Br.	Rhamnaceae	Santalales
Grewia tiliifolia Vahl	Rubiaceae	Boraginales
Leucaena leucocephala (Lam.) de Wit	Santalaceae	Proteaceae
Mallotus philippensis (Lam.) Müll.Arg.	Boraginaceae	Solanales
Mangifera indica L.	Solanaceae	Pinales
Mimusops elengi L.	Araucariaceae	Ericales
Pongamia pinnata (L.) Pierre	Sapotaceae	
Santalum album L.		
Senegalia chundra (Roxb. ex Rottler) Maslin		
Senna corymbosa (Lam.) H.S.Irwin & Barneby		
Senna siamea (Lam.) H.S.Irwin & Barneby		
Senna spectabilis (DC.) H.S.Irwin & Barneby		
Solanum chrysotrichum Schltdl.		
Syzygium cumini (L.) Skeels		
Tabebuia aurea (Silva Manso) Benth. & Hook.f. ex S.Moore		
Vachellia nilotica (L.) P.J.H.Hurter & Mabb.		
Wendlandia thyrsoidea (Roth) Steud.		
Ziziphus rugosa Lam.		

surveyed, Fabaceae was the most dominant, with a total of 10 species, accounting for 35.71 per cent of the species diversity, reflecting the family's wide-ranging presence and significance in the ecosystem. Thakur (2015) reported similar observations in the dry deciduous forests of Madhya Pradesh where Fabaceae is the dominant family. Additionally, Myrtaceae and Anacar diaceae demonstrated considerable presence with two unique species each, contributing 7.14 per cent each to the overall diversity (Fig. 2). The diverse representation of these families highlights their richness and variety within the studied ecosystem (Table 1 & Fig. 2). The number of families of tree species found in Nandi Hill was lower than that reported by Gopalakrishna *et al.,* 2015 in the dry forest of Bannerghatta which is nearby. This may be because of the anthropo genic disturbances in the study area due to tourism and plantation activities in contrast to the dry forest of Bannerghatta which is protected by the law, safeguarding it from similar disturbances.

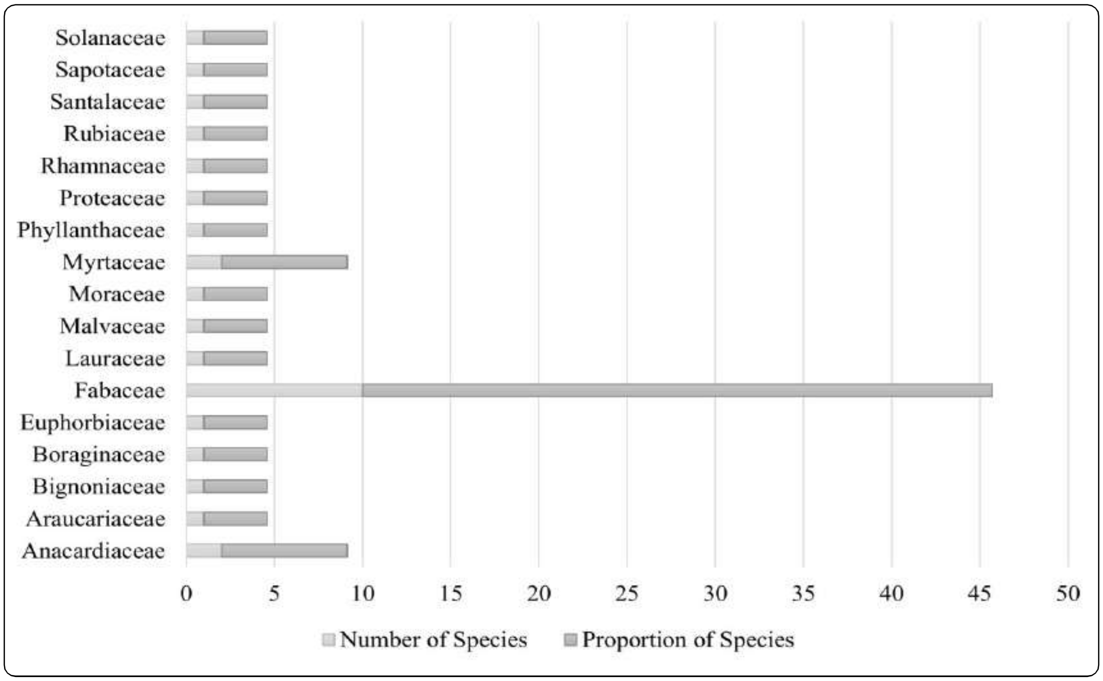

Fig. 2 : Familywise representation of species distribution

TABLE 2

Diversity and Population structure of the study area (S: Number of species; F: Number of Families; O: Number of Orders; *H´*: Shannon Index Cd: Concentration of Dominance; J': Evenness Index; BA: Basal Area (m^2ha^{-1}); d= density (stems ha^{-1}))

S	F	O	*H´*	Cd	J'	BA	d
28	17	16	1.507	0.46	0.45	62.46 ± 4.79	120.71 ± 15

The entire Nandi Hill state forest exhibited a Shannon Diversity index value of 1.507 indicating that the study area is moderately diverse (Table 2). The *H´* value in the current study is within the range (0.83-4.1) reported for forests of the Indian subcontinent (Pandey, 2000 and Pitchairamu *et al.,* 2008). The concentration of dominance (Cd) analysis is presented in Table 2; it shows that the Nandi Hill Forest ecosystem is moderately diverse and is dominated by a few species. The evenness index values indicated that the forest was unevenly distributed and few species dominated the ecosystem (J´ = 0.45) (Table 2). These results were due to the presence of *Eucalyptus tereticornis* Sm. which is an introduced species in the ecosystem and this species dominates the Nandi Hill Forest. The moderate diversity may be due to high levels of anthropogenic disturbance, mainly tourism and the more disturbed dry deciduous forests contain low species diversity when compared to less disturbed forests Murthy *et al.* (2016). The diversity is lower compared to nearby Western ghats (Sundarapandian and Swamy, 2000) and Eastern ghats (Naidu & Kumar, 2016 and Tarakeswara *et al.,* 2018), which may be because the forest receives relatively less rainfall and places that receive less rainfall exhibit lower species diversity.

Stem Density and Frequency

The study area recorded a stem density of 120.71 ± 15 (stems ha^{-1}) (Table 2). *Eucalyptus tereticornis* Sm. Showed the highest density with the 80.36 stems ha^{-1} covering 66.57 per cent of the overall density

TABLE 3

Density of dominant tree species in the study area

Species	Density (stems ha^{-1})	Percentage	Cumulative %
Eucalyptus tereticornis Sm.	80.36	66.57	66.57
Syzygium cumini (L.) Skeels	14.64	12.13	78.70
Leucaena leucocephala (Lam.) de Wit	3.93	3.25	81.95
Ficus benghalensis L.	2.50	2.07	84.02
Grevillea robusta A.Cunn. ex R.Br.	2.50	2.07	86.09
Araucaria bidwillii Hook.	1.79	1.48	87.57
Albizia amara (Roxb.) Boivin	1.43	1.18	88.76
Pongamia pinnata (L.) Pierre	1.43	1.18	89.94
Acacia auriculiformis A.Cunn. ex Benth.	1.07	0.89	90.83
Mallotus philippensis (Lam.) Müll.Arg.	1.07	0.89	91.72

followed by *Syzygium cumini* (L.) Skeels accounted for 12.13 per cent of participants (Table 3). The top ten species with the highest density covered 91.72 per cent of the overall density showing their wider distribution. The stem density in the present investigation is lower than the stem density reported by Panda *et al.* (2013) in northern Eastern Ghats. Pragasan & Parthasarathy (2010) in southern Eastern Ghats, Mohandas & Davidar (2009) in tropical montane evergreen forest (shola) of the Nilgiri Mountains and by Reddy *et al.* (2011) in the Eastern Ghats of northern Andhra Pradesh which indicates that the study area contains a moderate tree diversity and is affected by various anthropogenic factors. The frequency analysis revealed that *Eucalyptus tereticornis* Sm. was the most frequently occurring species which occurred in 82.14 per cent of the quadrats followed by *Syzygium cumini* (L.) Skeels occurred in 42.86 per cent of the quadrats (Table 4). This indicates that these tree species are widespread and are dominant members of the ecosystem.

TABLE 4

Frequency of occurrence of dominant tree species in the Nandi Hill Forest ecosystem

Species	Frequency	Percentage
Eucalyptus tereticornis Sm.	23	82.14
Syzygium cumini (L.) Skeels	12	42.86
Leucaena leucocephala (Lam.) de Wit	7	25.00
Ficus benghalensis L.	5	17.86
Grevillea robusta A.Cunn. ex R.Br.	5	17.86
Senna siamea (Lam.) H.S.Irwin & Barneby	3	10.71
Albizia amara (Roxb.) Boivin	2	7.14
Araucaria bidwillii Hook.	2	7.14
Delonix regia (Bojer ex Hook.) Raf.	2	7.14
Mallotus philippensis (Lam.) Müll.Arg.	2	7.14

Basal Area and DBH Class Distribution

The forest of Nandi Hills recorded an overall basal area of 62.46 m^2/ha (Table 2). *Eucalyptus tereticornis* Sm. Dominated the study area covering 40.21 per cent of the total basal area, followed by *Syzygium cumini* (L.) Skeels which covered 11.21 per cent of the basal area (Table 5). The top 10 dominant species covered 90.76 per cent of the total basal area showing extraordinary representation of these species in the Nandi Hill state forest. This indicates that these tree species are widespread and dominant members of the Nandi Hill Forest ecosystem. The overall basal area recorded in this study was higher than that reported by Naidu and Kumar, 2016 in tropical forests in the Eastern Ghats of Andhra Pradesh. This may be because of the higher contribution of *Eucalyptus tereticornis* Sm. for the total basal area. This species is planted centuries ago

TABLE 5

Basal Area (BA) contribution by the dominant tree species in the Nandi Hill Forest ecosystem

Species	BA (m^2/ha)	Percentage	Cumulative %
Eucalyptus tereticornis Sm.	25.12	40.21	40.21
Syzygium cumini (L.) Skeels	7.00	11.21	51.42
Mangifera indica L.	5.26	8.42	59.85
Tabebuia aurea (Silva Manso) Benth. & Hook.f. ex S.Moore	4.48	7.17	67.01
Araucaria bidwillii Hook.	4.23	6.77	73.78
Delonix regia (Bojer ex Hook.) Raf.	4.03	6.45	80.23
Grevillea robusta A.Cunn. ex R.Br.	1.71	2.73	82.96
Grevillea robusta A.Cunn. ex R.Br.	1.67	2.68	85.64
Acacia auriculiformis A.Cunn. ex Benth.	1.61	2.58	88.22
Pongamia pinnata (L.) Pierre	1.59	2.55	90.76

i.e. in 1790 by Tippu Sultan, the ruler of Mysore (Shyam Sundar, 1984) and exhibits very high DBH which adds to the basal area. The DBH class distribution shows an inverse-J shaped curve (Fig. 3) indicating good forest regeneration status with high seedling recruitment. Similar regeneration status was reported in the biodiversity heritage site of GKVK campus (Sumanth & Prasanna, 2022 and Praveen *et al.,* 2024). The first four DBH classes covered 54.44 per cent of the individuals and only a few individuals were observed in the higher girth classes *i.e.* <1%. Our findings are consistent with those of Sudhakar *et al.* (2008) in the tropical forests of Mudumalai Wildlife Sanctuary. Their study similarly found that a substantial proportion of all tree species in the Mudumalai Wildlife Sanctuary forests were juveniles.

Height Class Distribution

The height class distribution analysis showed that the 21-24m height class recorded the highest number of individuals (18.93%) followed by the 18-21m

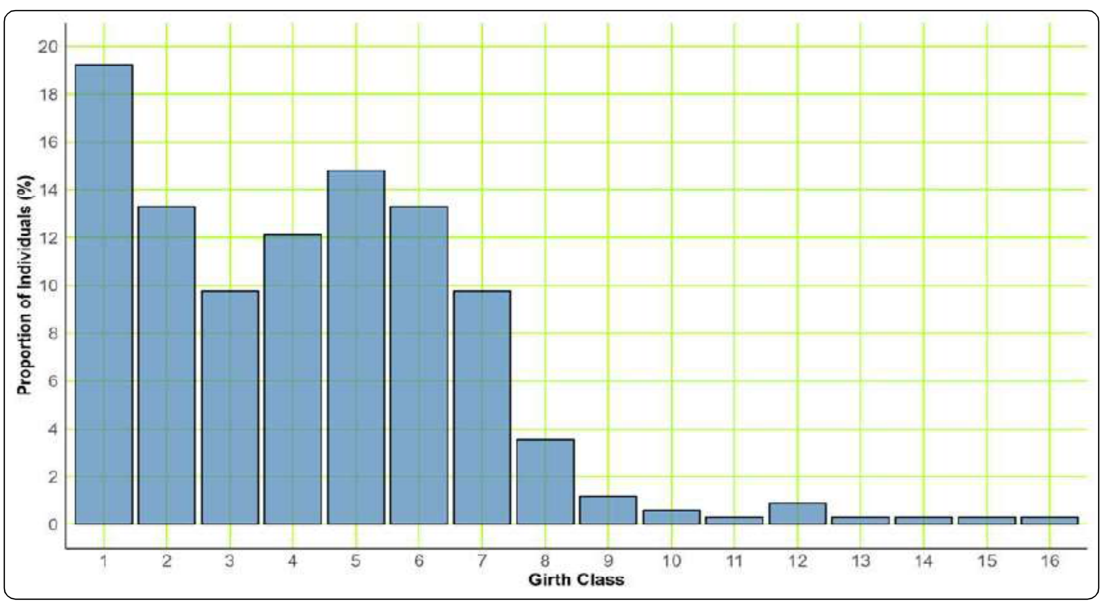

Fig. 3 : Girth class distribution of tree species in the forest of Nandi Hill

(13.61%) class and 1.18 per cent of individuals reached a height of >30m. This indicates that 32.54 per cent of woody plants in the Nandi Hill Forest were dominated by plants up to 24m in height (Table 6) suggesting that the ecosystem was dominated by medium-height trees with a successive decrease in the number of mature individuals in higher height classes.

Importance Value Index

Evaluating IVI offers an effective method for assessing the ecological significance of species within a community. Species with a higher IVI value are considered to have greater ecological importance and play a pivotal role in the overall ecological framework of the community (Lamprecht, 1989). The top ten dominant species in the study site were *Eucalyptus tereticornis* Sm., *Syzygium cumini* (L.) Skeels, *Grevillea robusta* A.Cunn. ex R.Br., *Leucaena leucocephala* (Lam.) de Wit, *Araucaria bidwillii* Hook., *Pongamia pinnata* (L.) Pierre., *Ficus benghalensis* L., *Acacia auriculiformis* A.Cunn. ex Benth., *Mangifera indica* L. and *Albizia amara* (Roxb.) Boivin. (Table 7). The top 10 dominant species covered 85.89 per cent of the IVI showing their ecological significance in the Nandi Hill Forest ecosystem. The remaining 18 species accounted for only 14.11 per cent of the IVI. Based on the IVI results the Nandi Hill Forest ecosystem can be considered as a *Eucalyptus tereticornis* Sm community (Fig. 4).

This study examined 28 species of trees belonging to 17 families and 16 orders. The study area was found to be moderately diverse and was dominated by a few tree species. *Eucalyptus tereticornis* was the most frequently occurring species with the highest density and the largest contributor to the overall basal area. The DBH class distribution showed an inverse-J curve with most individuals in the lower DBH classes

TABLE 6

Height class distribution of the tree population in the study area

Class Code	Height Class	Frequency	Proportion (%)
1	<3	11	3.25
2	3-6	45	13.31
3	6-9	45	13.31
4	9-12	23	6.80
5	12-15	35	10.36
6	15-18	37	10.95
7	18-21	46	13.61
8	21-24	64	18.93
9	24-27	17	5.03
10	27-30	11	3.25
11	>30	4	1.18

TABLE 7

Importance Value Index (IVI) of top ten dominant tree species in the Nandi Hill Forest ecosystem (RF: Relative Frequency; RD: Relative Density; RDo: Relative Dominance)

Species	RF	RD	RDo	IVI
Eucalyptus tereticornis Sm.	26.54	66.57	79.35	172.46
Syzygiumcumini (L.) Skeels	8.93	12.13	11.55	32.61
Grevillearobusta A.Cunn. ex R.Br.	4.72	2.37	1.39	8.49
Leucaenaleucocephala (Lam.) de Wit	3.89	3.25	0.95	8.10
Araucariabidwillii Hook.	4.72	1.48	1.16	7.36
Pongamiapinnata (L.) Pierre	5.66	1.18	0.22	7.06
Ficusbenghalensis L.	3.30	2.07	0.58	5.95
Acaciaauriculiformis A.Cunn. ex Benth.	4.25	0.89	0.22	5.36
Mangiferaindica L.	2.83	0.89	1.45	5.16
Albiziaamara (Roxb.) Boivin	3.77	1.18	0.16	5.12

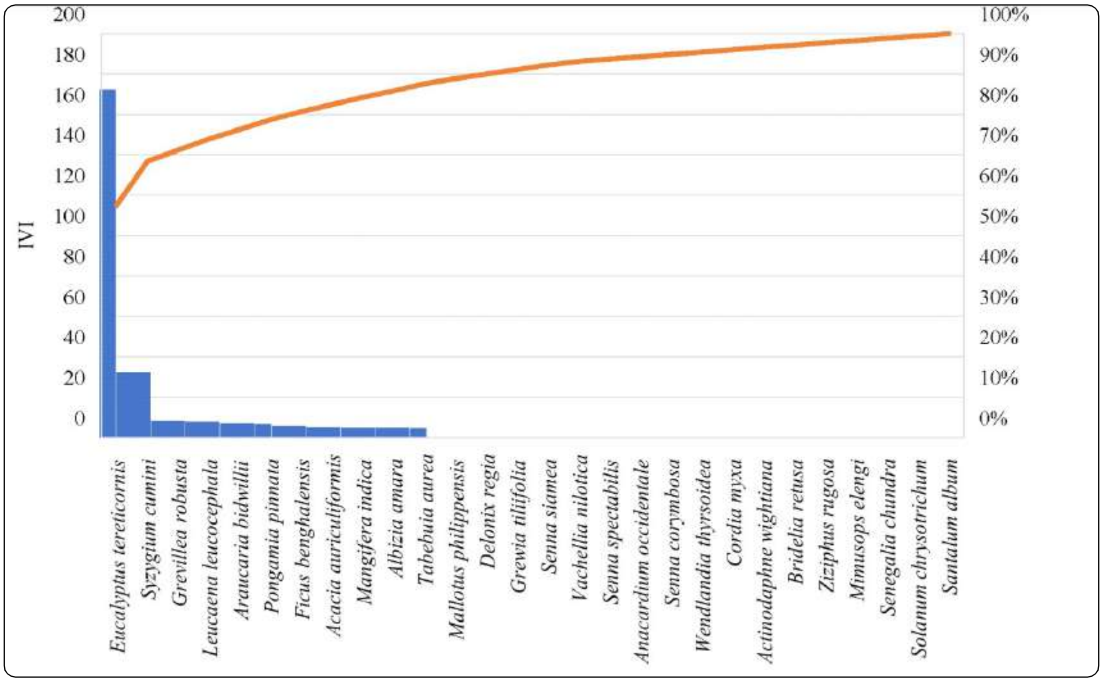

Fig. 4 : Species-wise IVI Distribution

suggesting that it is a healthy forest ecosystem with active regeneration and recruitment of new individuals. We can infer that the Nandi Hill Forest ecosystem is *Eucalyptus tereticornis* Sm. community based on IVI analysis. This study calls for the conservation of this valuable Hilly ecosystem and a proper management strategy to protect it from increasing anthropogenic activities.

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Genotype × Environmental Interaction for Growth and Yield Parameters of Elite Mulberry Hybrids in Different Seasons

C. Sushmitha[1], Chikkalingaiah[2], N. Marappa[3] and K. Murali[4]

[1&2]Department of Sericulture, [3]Department of Genetics & Plant Breeding, [4]Department of Agronomy,
College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : sushmithac113@gmail.com

Authors Contribution

C. Sushmitha ; Chikkalingaiah & K. Murali :
Conceptualization, design, curation and analysis of data and tabulation of results, original manuscript draft writing and editing;

N. Marappa :
Conceptualization, designing of the experiment and Supervision

Corresponding Author :
C. Sushmitha

Received : May 2024
Accepted : June 2024

Abstract

The investigation was carried out to study genotype × environmental interaction for growth and yield parameters of mulberry hybrids in different seasons during 2022-23 at the Department of Sericulture, UAS, GKVK, Bengaluru-65. The study comprised of eight mulberry hybrids and two check varieties. Analysis of variance for growth and yield parameters of mulberry hybrids in different seasons indicated highly significant mean sum of squares due to season for shoot height (cm), number of branches per plant, number of leaves per plant, single leaf area (cm^2), leaf moisture content (%) at harvest, leaf moisture retention capacity at 6, 9 and 12 hrs after harvest and leaf yield per plant (g). The mean squares due to seasons was significant for shoot length, number of branches per plant, number of leaves per plant, leaf moisture content, leaf moisture retention capacity at 6 and 9 hours after harvest of leaf and leaf yield per plant and non-significant for internodal distance (cm). The selection indices of mulberry hybrids revealed that rainy season (S-4) of 2023 was found more favourable for mulberry hybrids for good expression of shoot length, number of branches per plant, number of leaves per plant, single leaf area, leaf moisture content, leaf moisture retention capacity at 6 and 9 hours after harvest of leaf and leaf yield per plant. On the other hand S2-Summer season 2023 was found more favourable for mulberry hybrids for good expression of internodal distance (cm). Among the genotypes studied, no single genotype was stable across the season for all the traits. The mean performance of different mulberry hybrids in each season overall and the mean values of each genotype were computed and rankings were assigned. Among the different mulberry hybrids, ME-65 × V1 ranked first and found stable over the seasons for most of the traits *viz.*, shoot length(cm), number of branches per plant, internodal distance, single leaf area (cm^2), leaf moisture content (%), moisture retention capacity at 6, 9 hrs after leaf harvest and leaf yield per plant (g), followed by MI-79 ×MI-66.

Keywords : Mulberry hybrids, Regression coefficient, Deviation from Regression, Different seasons

The productivity of a genotype is the function of its adaptability to a particular environment. Stability of a genotype depends on the ability to retain certain morphological and physiological characters along with its production efficiency steadily allowing others to vary, resulting in predictable G×E interactions for yield. An improved population can adjust its genotypic and phenotypic states in response to environmental fluctuations in such a way that it can give high and stable yield. The study of yield or individual yield components under certain conditions can lead to simplification in genetic explanation and determination of environmental effects.

Mulberry (*Morus* spp.) is the sole host plant for silkworm (*Bombyx mori* L.). The leaf of this plant is fed to the silkworm during its larval stage. It is a perennial plant and is cultivated by the farmers in a particular field at least for 10-12 years for the production of quality leaves (Susheelamma *et al*., 2006).This plant is cultivated under various environmental conditions like tropical dry, tropical humid and sub-tropical regions. The yield stability in mulberry over a wide range of environments is one of the most desirable parameters to be considered for selecting mulberry for large scale cultivation. Sarkar *et al.* (1986) and Bari *et al*. (1990) have emphasized that a knowledge of the nature and relative magnitude of the genotype-environment interaction has great importance for selecting superior genotypes to be used commercially in diverse environmental conditions. Stable materials are therefore required to obtain least variability in leaf production per unit area over different locations.

G×E interaction is a phenomenon that phenotypes respond to genotypes differently according to different environmental factors. It is an important parameter for plant breeding programme to identify the stable genotypes/hybrids that are widely adapted to unique environment and also affects the gains, recommendation & selection of cultivars with wider adaptability (Lal *et al*., 2019). Leaf yield of mulberry fluctuates with the seasons due to sensitivity of the genotypes in different growing conditions. A G×E interaction exists where relative performance of the cultivar's changes from one environment to other environment. So, exploitation of Genotype× Environmental interaction may prove useful in identifying stable genotypes for various environmental conditions.

The present study has been undertaken to know the impact of genotype x season interaction for growth and yield parameters of mulberry hybrids in different seasons.

Material and Methods

The experiment was carried out during the year 2022-23 in Department of Sericulture, University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bengaluru. The experimental material for the present study comprised of eight mulberry hybrids and two check varieties (Table 1). The hybrids were developed by Line × Tester mating design during 2019. Among them eight elite mulberry hybrids were selected for the study based on their per se performance. These hybrids were planted in three rows with four plants in each row, with a spacing of 3 ft × 3 ft in the field in RCBD design with three replications. These mulberry hybrids maintained as bush with a crown height of two and half feet from the ground level. The experimental plot was maintained as per the recommended package of practices for rain-fed mulberry (Dandin and Giridhar, 2014). Five competitive plants are selected per replication to take observations were selected randomly from each replication for recording growth and yield parameters. The elite mulberry hybrids were evaluated on 60th day after pruning for different growth and yield parameters during rainy, winter and summer seasons of 2022-2023. The mean data of each hybrid for each season were subjected to analysis of variance in order to study the genotype×environment interaction and hybrids stability following the Eberhart and Russell model (1966) by using linear regression model.

Table 1

List of mulberry hybrids used in study

Mulberry hybrids	
MI-47	(*M. indica*) × MI-66 (*M. indica*)
MI-79	(*M. laevigata*) × MI-66 (*M. indica*)
ME-03	(*M. cathyana*) × MI-66 (*M. indica*)
ME-146	(*M. indica*) × MI-66 (*M. indica*)
ME-65	(*M. alba*) × V1(*M. indica*)
ME-67	(*M. alba*) × V1(*M. indica*)
ME-02	(*M. cathyana*) × MI-66 (*M. indica*)
ME-95	(*M. rotandifolia*) x V1(*M. indica*)
V1	(Check variety)
S36	(Check variety)

Results and Discussion

Analysis of variance indicated high significance of mean sum of squares due to season for shoot length, number of branches per plant, internodal distance, number of leaves per branch, single leaf area, leaf moisture content, leaf yield per plant and moisture retention capacity at 6 and 9 hrs after harvest. Analysis of variance for mean sum of squares due to genotype × season was non-significant for all the characters. Further, it could be observed that variance due to seasons (linear) were highly significant for shoot length, number of branches per plant, number of leaves per branch, single leaf area, leaf moisture content, leaf yield per plant and moisture retention capacity at 6 and 9 hrs after harvest. Whereas non-significant for internodal distance. Variance due to G x S (linear) were significant for single leaf area, leaf yield per plant and moisture retention capacity at 6 and 9 hrs after harvest of leaf. Whereas variance due to G x S (linear) was non-significant for shoot length, number of branches, internodal distance, number of leaves per plant, moisture content (Table 2). Similarly, the present results are in concurrence with the findings of earlier reports. Chakraborty *et al.*, 2012, opined that varieties significantly interacted with additive environment for all the growth characters and leaf yield which was also reported by Ahalya and Chikkalingaiah, 2022.

Determination of Genotype × Environmental Interaction for Growth and Yield Parameters of elite Mulberry Hybrids in Different Seasons

Shoot Length (cm)

Shoot length per plant in different hybrids differed from season to season as indicated by varying environmental indices (-42.88 to 35.00). The highest environment index and mean was recorded in S4 (35.00 and 174.00) and the same was minimum in S2 (-42.88 and 96.81) respectively. When considered overall mean ME-65 × V1 had recorded highest shoot height per plant (152.86 cm) followed by V1 (151.87cm) and MI-47 × MI-66 (146.48 cm).

Table 2

Analysis of variance for leaf yield and its contributing traits of elite mulberry hybrids in different seasons

Source of variations	d.f	Mean sum of squares due to								
		Shoot length (cm)	No. of branches /Plant	Internodal distance (cm)	No. of leaves/ branch	Single leaf area (cm^2)	Leaf moisture content (%)	LMRC at 6 hours (%)	LMRC at 9 hours (%)	Leaf yield / plant (g)
Replication with in season	11	49.587	0.905	0.106	3.205	72.652	2.103	8.541 **	4.277	7375.5Z *
Genotypes (G)	9	473.758 **	2.244 *	0.851 **	66.831 **	2320.785 **	28.728 **	11.074 **	28.875 **	224659.00 **
Seasons+ (G × S)	30	129.077 **	6.030 **	0.160	20.246 *	740.101 **	14.390 **	31.950 **	26.807 **	55041.720 **
Seasons	3	10366.080 **	54.829 **	0.636 **	119.055 **	5767.770 **	110.766 **	282.368 **	204.280 **	500608.00 **
G × S	27	102.743	0.608	0.107	9.267	181.471 *	3.682	4.125	7.087	5534.350
Seasons (Lin)	1	1098.250 **	164.487 **	1.907	357.165 **	17303.310 **	332.297 **	847.103 **	612.840 **	1501824.000 **
G × S (Lin)	9	119.835	0.289	0.097	10.242	351.367 **	7.500	8.361 **	11.744 *	10116.780 **
Pooled deviation	20	84.778 **	0.690 **	0.104 **	7.901 **	86.870 **	1.595	1.807	4.283 **	2918.821
Pooled Error	72	17.652	0.250	0.027	2.627	21.55	1.385	1.207	1.160	3274.553

*Significant@ 5%, ** Significant@1%, LMRC: Leaf Moisture Retention

The mean performance of shoot length in different mulberry hybrids was more than the grand mean in ME-65 × V1, V1, MI-47 × MI-66, ME-05 × MI-66, S36 and ME-03 × MI-66 and non-significant regression co-efficient indicated below average stability. Hence, these genotypes are specially adapted to favourable environments. The deviation from regression was highly significant which indicated unpredictable performance over the environments. The mean performance of ME-65 × V1 was more than the grand mean and significant regression co-efficient found average stability, hence it is well adapted to all the environmental conditions. On the other hand, the deviation from regression was highly significant by indicating unpredictable performance across the environment. However, the mean performance of ME-95 × V1, ME-146 × MI-66 and ME-67 × V1 was less than the grand mean with non-significant regression co-efficient and were grouped under above average stability. Hence, these genotypes were specially adapted to unfavourable environments. The genotype ME-67 × V1 recorded lowest mean performance than the grand mean with non-significant regression co-efficient indicating average stability and the deviation from regression was highly significant by indicating unpredictable performance across the environment (Table 3).

The present results are corroborated with the findings of earlier workers, Masilamani, 2005, who studied plant height in different environments like spring, summer and rainy seasons. The plant height in spring season and mean values of plant height in all the genotypes were on par with each other. Chakraborty *et al.*, 2012, studied mean performance of different mulberry varieties for plant height in different environments. The mean performance of plant height was varied with different environment and highest plant height (181.68 cm) was recorded in E2 (rainy season). Doss *et al.*, 2012, who reported that, plant height of the hybrids CT-9, CT-15 and CT-159, had bi (regression co-efficient) around unity but CT-9 and CT-159 showed minimum S^2di (deviation from linear regression) owing to their above average stability for the parameters and its ability to perform well in unfavorable environment also. In CT-44 the bi was less than unity (0.59) with less S^2di (deviation from linear regression). Raksha, 2015, also reported plant height in different genotypes and reported that none of the genotypes were stable across the seasons. The plant height of two mulberry genotypes *viz*., MI-79 (286.04) and C-763 (292.35) has more than the grand mean and regression co-efficient indicating below average stability; hence these genotypes are better adapted to favourable environments.

Number of Branches Per Plant

The number of branches per plant in ten mulberry hybrids vary from season to season as indicated by varying environmental indices (-2.391 to 3.09). The environment means and index was maximum at S4 (10.52 and 3.09) respectively and was minimum in S2 (-2.39 and 8.66) respectively. When considered overall mean ME-65 × V1 recorded more number of branches per plant (8.15) followed by V1 (8.14) and MI-79 × MI-66 (7.98) (Table 4).

The present results are corroborated with the findings of Raksha, 2015, who reported that, the environmental mean and index was more in rainy season indicating rainy season was an ideal environment for expression of number of branches per plant. The minimum environmental mean and index observed in winter season indicated the unsuitability for the expression of number of branches per plant. Ahalya *et al.* (2020) recorded the environment means and index was maximum at S6 (14.90 and 3.47) respectively and was minimum in S2 7.97 and -3.44) respectively. When considered overall mean V1 recorded more number of branches per plant (13.40) followed by M5 (12.53) and MI-79 (11.76). The mean performance of number of branches per plant of ME-65 × V1 was more than the grand mean with non-significant regression co-efficient and its value is equal to one indicating average stability; hence these hybrids are specially adapted to all environments. Whereas the deviation from regression was non-significant by indicating predictable performance over environment. The mean performance of ME-146 × MI-66, ME-95 × V1 and MI-79 × MI-66 was lesser than the grand mean having non-significant regression co-efficient and it is equal

TABLE 3

Mean performance of ten elite mulberry hybrids in four seasons and their stability parameters for shoot length (cm)

Mulberry Hybrids	S1	Rank	S2	Rank	S3	Rank	S4	Rank	Mean	Overall Rank	b*i*	S²d*i*
MI-47 × MI-66	142.33	5	115.21	1	146.36	5	182.03	4	146.48	3	0.82	56.51 *
MI-79 × MI-66	137.19	6	88.38	8	133.38	7	177.27	5	134.06	7	1.12	1.22
ME-03× MI-66	157.64	3	100.67	4	142.61	6	173.28	6	143.55	6	0.95	20.55
ME-146 × MI-66	134.63	8	90.61	5	118.85	9	153.59	10	124.42	9	0.81	13.57
ME-65 × V1	177.66	1	87.23	9	155.16	3	191.42	1	152.86	1	1.39 **	170.14 **
ME-67 × V1	132.76	7	86.38	10	118.13	10	157.40	9	123.63	10	0.91	9.46 **
ME-05 x MI-66	148.18	4	110.70	2	155.53	2	170.92	8	146.33	4	0.77	24.20
ME-95x V1	129.13	10	90.17	6	128.59	9	171.30	7	129.80	8	0.01	34.82
V1	170.82	2	93.32	7	158.18	1	185.15	2	151.87	2	1.22	113.62 **
S36	132.63	9	105.59	3	153.05	4	184.70	3	143.99	5	0.96	195.19 ***
Mean	146.29		96.81		140.98		174.70		139.70			
Environmental index	6.59		-42.88		1.28		35.00					
C.V.	5.966		5.83		4.45		4.59					
S.Em±	7.12		4.61		5.12		6.55					
CD @ P=0.05	14.97		9.68		10.76		13.76					
CD @ P=0.01	20.51		13.27		14.74		18.86					

*Significant@ 0.05 level ** Significant@ 0.01 level, bi=regression co-efficient, S²di=Deviation from regressionS1=2022 Rainy season (June-August), S2=2022 Winter season (Nov-Jan), S3=2023 Summer season (March-May),S4=2023 Rainy season (July- Sept)

TABLE 4

Mean performance of ten elite mulberry hybrids in four seasons and their stability parameters for number of branches per plant

Mulberry Hybrids	S1	Rank	S2	Rank	S3	Rank	S4	Rank	Mean	Overall Rank	b*i*	S²d*i*
MI-47 × MI-66	8.30	4	4.22	9	6.60	5	9.00	10	6.96	7	0.82	0.53
MI-79 × MI-66	8.16	5	5.13	4	7.16	3	11.46	1	5.92	9	1.12	-0.23
ME-03× MI-66	7.13	7	4.76	5	6.06	6	10.33	6	7.00	6	0.95	-0.29
ME-146 × MI-66	6.56	9	5.00	6	5.56	8	11.00	5	7.03	5	1.12	0.41
ME-65 × V1	8.56	3	5.83	2	6.83	4	11.40	2	8.15	1	1.03	-0.26
ME-67 × V1	5.36	10	4.73	7	4.36	9	9.40	9	5.96	8	0.91	0.94 *
ME-05 x MI-66	9.63	1	5.13	4	6.06	6	10.20	8	7.75	4	0.98	1.35 **
ME-95x V1	6.50	9	4.40	8	5.93	7	11.30	3	7.03	5	1.24	0.27
V1	8.13	6	5.96	1	7.26	2	11.20	4	8.14	2	0.94	-0.25
S36	9.4	2	5.16	3	8.30	1	10.26	7	7.98	3	0.48	1.24 **
Grand Mean	7.75		5.03		6.41		10.52		7.43			
Environmental index	0.32		-2.39		-1.01		3.09					
C.V.	12.52		8.66		15.14		9.13					
S.Em±	0.79		0.35		0.79		0.78					
CD @ P=0.05	1.66		0.74		1.66		1.64					
CD @ P=0.01	2.28		1.02		2.28		2.26					

*Significant@ 0.05 level ** Significant@ 0.01 level, bi=regression co-efficient, S²di=Deviation from regression
S1=2022 Rainy season (June-August), S2=2022 Winter season (Nov-Jan), S3=2023 Summer season (March-May), S4=2023 Rainy season(July- Sep)

to one with average stability indicating these hybrids are poorly adapted to all environments. The mean performance of ME-03 × MI-66, MI-47 × MI-66 and ME-67 × V1 was lesser than the grand mean having non-significant regression co-efficient and it is less than one with above average stability indicating these hybrids are specifically adapted to unfavourable environments and the deviation from regression was highly significant for ME-67 × V1, ME-05 × MI-66 and S36 indicating unpredictable performance across the environment (Table 4).

Similar findings were obtained by Raksha, 2015, who reported that number of branches per plant and reported different genotypes *viz*., MI-142 (25.24), MI-79 (37.87), C-763 (29.73), SB-21 (27.64), S-36 (26.77) and S-13 (28.77) possessed mean performance was more than the grand mean and significant regression co-efficient having below average stability. Hence these genotypes are specifically adapted to favorable environmental conditions.

Internodal Distance (cm)

Internodal distance in different mulberry hybrids vary from season to season, as indicated by varying environmental indices (-0.27 to 0.26). The environment mean and index was maximum at S2 (6.20 and 0.26) and the same was minimum in S1 (5.66 & -0.27) respectively. When considered overall mean ME-67 × V1 had highest internodal distance (6.89cm) followed by ME-03 × MI-66 (6.51 cm) and ME-05 × MI-66 (6.11 cm). Whereas lowest internodal distance (5.32 cm) was recorded in ME-65 × V1 followed by ME-146 × MI-66 (5.67 cm) (Table 5).

The mean performance of internodal distance of ME-67 × V1 and ME-03 × MI-66 was more than the grand mean with non-significant regression co-efficient and its value was equal to one indicating average stability hence these hybrids are specially adapted to all environments. Whereas the deviation from regression was non-significant by indicating predictable performance over environment. The mean performance of ME-146 × MI-66, ME-65 × V1 and MI-95 × V1 and V1 was lesser than the grand mean having non-significant regression co-efficient and it is equal to one with average stability indicating these hybrids are poorly adapted to all environments. The mean performance of MI-47 × MI-66 and S-36 was lesser than the grand mean having non-significant regression co-efficient and it is less than one with above average stability indicating these hybrids are specifically adapted to unfavourable environments. On other hand, the deviation from regression was highly significant for ME-146 × MI-66, ME-65 × V1, ME-05 × MI-66 and V1 indicating unpredictable performance across the environment (Table 5).

Similar findings were obtained by Raksha, 2015, who reported that the genotypes *viz*., MI-142 (5.34cm) and MI-139 (6.54 cm) possessed above average stability and specifically adapted to unfavourable environment since their mean performance was lesser than the grand mean and regression coefficient less than unity. Ahalya *et al*. (2020) studied internodal distance in different genotypes. The environment mean and index were maximum at S2 (5.64 and 0.36). V1 had higher mean than the grand mean indicated average stability and well adapted to all favourable environments and possessing significant deviation from regression indicating performance across the environment.

Number of Leaves Per Plant

The number of leaves per plant in ten mulberry hybrids differed from season to season as indicated by varying environmental indices (-2.68 to 4.96). The environment mean and index was maximum at S4 (39.61 and 4.96) and the same was minimum in S2 (31.97 and -2.68 respectively. When considered overall mean ME-146 × MI-66 had recorded highest number of leaves per plant (39.12) followed by MI-47 × MI-66 (39.10.2) and ME-65 × V1 (37.13) (Table 6).

The mean performance of number of leaves per plant of ME-65 × V1 and ME-95 × V1 was more than the grand mean with non-significant regression co-efficient and its value is equal to one indicating average stability hence these hybrids are specially adapted to all environments. The mean performance of ME-05 × MI-66 and S36 was lesser than the grand

Table 5

Mean performance of ten elite mulberry hybrids in four seasons and their stability parameters for internodal distance (cm)

Mulberry Hybrids	S1	Rank	S2	Rank	S3	Rank	S4	Rank	Mean	Overall Rank	b*i*	S^2di
MI-47 × MI-66	5.43	3	5.70	3	5.40	3	6.15	7	5.67	2	0.97	0.05
MI-79 × MI-66	5.90	5	6.20	5	5.70	6	6.06	6	5.96	5	0.70	-0.01
ME-03× MI-66	6.06	7	6.70	9	6.43	7	6.85	9	6.51	7	1.23	-0.00
ME-146 × MI-66	5.33	2	6.36	6	5.53	4	5.46	1	5.67	2	1.39	0.10 *
ME-65 × V1	4.66	1	5.33	1	4.43	1	5.88	4	5.32	1	1.31	0.17 **
ME-67 × V1	6.33	9	7.60	8	6.73	9	6.90	10	6.89	8	1.92	0.03
ME-05 x MI-66	6.03	6	6.46	7	6.30	8	5.66	2	6.11	6	0.10	0.14 **
ME-95x V1	5.43	4	6.20	5	5.23	2	5.96	5	5.70	3	1.65	0.00
V1	5.33	2	5.60	2	5.53	4	6.28	8	5.67	2	1.02	0.13 *
S36	6.16	8	5.90	4	5.63	5	5.68	3	5.84	4	-0.35	
Grand Mean	5.66		6.20		5.79		6.09		5.94			
Environmental index	-0.27		0.26		-0.14		0.15					
C.V.	3.96		6.05		5.18		3.50					
S.Em±	0.18		0.30		0.24		0.17					
CD @ P=0.05	0.38		0.64		0.51		0.36					
CD @ P=0.01	0.52		0.88		0.70		0.50					

*Significant@ 0.05 level ** Significant@ 0.01 level, bi=regression co-efficient, S^2di=Deviation from regression
S1=2022 Rainy season (June-August), S2=2022 Winter season (Nov-Jan), S3=2023 Summer season (March-May), S4=2023 Rainy season (July-Sept)

TABLE 6

Mean performance of ten elite mulberry hybrids in four seasons and their stability parameters for number of leaves per plant

Mulberry Hybrids	S1	Rank	S2	Rank	S3	Rank	S4	Rank	Mean	Overall Rank	b*i*	S^2di
MI-47 × MI-66	39.13	2	38.17	1	38.73	1	40.36	3	39.10	2	0.24	-2.47
MI-79 × MI-66	36.50	4	29.84	8	36.33	4	38.62	4	35.32	6	0.79	7.64 *
ME-03× MI-66	41.43	1	31.30	7	36.16	5	37.67	8	36.64	4	0.28	22.20 ***
ME-146 × MI-66	38.43	2	35.70	2	38.63	2	43.73	1	39.12	1	0.94	-1.61
ME-65 × V1	33.60	6	34.51	3	37.16	3	43.27	2	37.13	3	1.24	-1.71
ME-67 × V1	26.00	7	24.82	10	26.70	9	31.48	9	27.25	10	0.84	-2.55
ME-05 x MI-66	21.50	10	26.98	9	26.53	10	38.09	7	28.27	9	1.84	9.89 *
ME-95x V1	29.26	8	31.74	6	35.26	7	43.73	1	35.00	7	1.76	1.39
V1	35.30	5	32.17	5	36.06	6	39.64	5	35.79	5	0.83	-0.89
S36	25.90	9	34.47	4	31.33	8	39.56	6	32.89	8	1.20	20.27
Grand Mean	32.70		31.97		34.32		39.61		34.60			
Environmental index	-1.94		-2.68		-0.33		4.96					
C.V.	5.60		6.89		9.38		9.07					
S.Em±	1.49		1.80		2.63		2.93					
CD @ P=0.05	3.14		3.78		5.52		6.16					
CD @ P=0.01	4.31		5.18		7.57		8.44					

*Significant@ 0.05 level ** Significant@ 0.01 level, bi=regression co-efficient, S^2di=Deviation from regression
S1=2022 Rainy season (June-August), S2=2022 Winter season (Nov-Jan), S3=2023 Summer season (March-May), S4=2023 Rainy season (July- Sept)

mean having non-significant regression co-efficient and is equal to one with average stability indicating these hybrids are poorly adapted to all environments. The mean performance of ME-67 × V1 was lesser than the grand mean having non-significant regression co-efficient and it is less than one with above average stability indicating these hybrids are specifically adapted to unfavourable environments. Whereas the deviation from regression was highly significant for MI-79 × MI-66, ME-03 × MI-66 and ME-05 × MI-66 indicating unpredictable performance across the environment. The deviation from regression was non-significant for MI-47 × MI-66, ME-146 × MI-66, ME-65 × V1, ME-67 × V1, V1 and S36 indicating predictable performance across the environment (Table 6). Similar findings were obtained by Raksha, 2015, who reported that, environmental index for number of leaves per plant was maximum in rainy season indicated that, rainy season was favourable environment for expression number of leaves per tree. Whereas winter season was unfavourable as it is evident by the least environmental index (-15.19). The genotypes C-20 (274.32), ME-52 (415.52), ME-012 (489.78) and SB-21 (490.04) had mean performance lesser than the grand mean with the average stability hence these genotypes are poorly adapted to all the environments.

Single Leaf Area (cm^2)

Single leaf area in different mulberry hybrids vary from season to season as indicated by varying environmental indices (-24.47 to 26.39). The environment mean and index was maximum at S4 (174.73 and 26.39) and minimum at S2 (123.87 and -24.76 respectively). When considered overall mean, ME-146 × MI-66 had highest single leaf area (192.21 cm^2) followed by V1 (171.19 cm^2) and ME-05 × MI-66 (170.62 cm^2) whereas, it is lowest (132.49 cm^2) in MI-139 (Table 7).

The mean performance of number of leaves per plant in hybrid ME-146 × MI-66 and ME-67 × V1 was more than grand mean with non-significant regression co-efficient and its value is equal to one indicating average stability, hence these hybrids are specially adapted to all environments with average stability indicating these hybrids are poorly adapted to all environments. The mean performance of hybrid ME-47 × MI-66, ME-03 × MI-66 and ME-95 × V1 was lesser than the grand mean having non-significant regression co-efficient and it is less than one with above average stability indicating these hybrids are specifically adapted to unfavourable environments. Whereas the deviation from regression was highly significant for MI-79 × MI-66, ME-03 × MI-66, ME-146 × MI-66, ME-65 × V1 and ME-67 × V1 these genotypes indicating unpredictable performance across the environment. The deviation from regression was significant for MI-47 × MI-66, ME-05 × MI-66, ME-95 × V1, V1 and S36 indicating predictable performance across the environment (Table 7).

The present results are corroborated with the findings of earlier workers, Doss *et al*., 2012, revealed that Leaf area was stable across seasons in CT-159. CT-15 had above average stability for leaf area with the ability to perform equally well during unfavourable season CT-44 had high bi (2.10) and moderate S^2di (45.10). The bi of LAI was around unity in CT-11, CT-44, CT-210 & S-1635 and their respective S^2 di were also very low, suggested the uniform development of canopy in these hybrids irrespective of seasonal influence on them. Chakraborty *et al*. (2012) studied the genotype × environment interaction and phenotypic stability of 13 mulberry varieties for plant growth and leaf yield characters. The study indicated that none of varieties showed average and above average stability for growth and leaf yield characters. TR-10 for leaf area exhibited above average linear stability. In addition, S54 was stable for leaf area were found to be promising and stable variety and also Raksha, 2015, reported single area in different genotypes and reported, among the evaluated genotypes, MI-506 (119.08 cm^2), MI-79 (149.35 cm^2), C-20 (186.12 cm^2) and ME-144 (121.29 cm^2) indicated average stability and poorly adapted to all the environmental conditions. Whereas, ME-52 (234.84 cm^2), MI-32 (202.74 cm^2), SB-21 (354.23 cm^2), ME-012 (261.23 cm^2), MI-142 (220.53 cm^2), S-36 (229.12 cm^2) and S-13 (272.51 cm^2) had below average stability with and mean performance was more than the grand mean.

TABLE 7

Mean performance of ten elite mulberry hybrids in four seasons and their stability parameters for Single leaf area (cm^2)

Mulberry Hybrids	S1	Rank	S2	Rank	S3	Rank	S4	Rank	Mean	Overall Rank	b*i*	S^2di
MI-47 × MI-66	135.80	9	103.79	8	107.58	8	153.12	9	125.07	9	0.97	-14.65
MI-79 × MI-66	166.70	6	128.10	5	117.75	7	175.85	6	147.10	7	1.12	87.35 *
ME-03× MI-66	108.69	10	104.99	7	106.25	10	131.93	10	112.96	10	0.42	57.53 *
ME-146 × MI-66	199.87	1	157.03	1	200.04	1	211.89	1	192.21	1	1.78	309.04 **
ME-65 × V1	168.34	5	94.42	10	129.70	4	182.79	5	143.81	5	1.61	94.05 *
ME-67 × V1	186.91	2	113.70	6	119.22	5	191.52	2	152.84	4	1.71	76.62 *
ME-05 x MI-66	175.28	4	153.97	2	162.58	2	190.68	3	170.62	3	0.65	-10.72
ME-95x V1	142.24	8	128.43	4	123.04	6	154.11	8	136.95	6	0.55	5.59
V1	182.48	3	153.17	3	158.76	3	190.37	4	171.19	2	0.75	-25.71
S36	154.63	7	101.08	9	101.74	9	165.07	7	130.63	8	1.39	22.92
Grand Mean	162.09		123.87		132.67		174.73		148.3			
Environment index	13.75		-24.47		-15.67		26.39					
C.V.	3.24		10.83		3.92		2.79					
S.Em±	4.28		10.95		4.25		3.98					
CD @ P=0.05	9.00		23.02		8.93		8.36					
CD @ P=0.01	12.34		31.54		12.24		11.46					

*Significant@ 0.05 level ** Significant@ 0.01 level, bi=regression co-efficient, S^2di=Deviation from regression
S1=2022 Rainy season (June-August), S2=2022 Winter season (Nov-Jan), S3=2023 Summer season (March-May), S4=2023 Rainy season (July- Sept)

TABLE 8

Mean performance of ten elite mulberry hybrids in four seasons and their stability parameters for leaf moisture content (%)

Mulberry Hybrids	S1	Rank	S2	Rank	S3	Rank	S4	Rank	Mean	Overall Rank	b*i*	S^2d*i*
MI-47 × MI-66	70.61	7	62.46	6	67.86	6	72.09	3	68.25	5	1.21	1.13
MI-79 × MI-66	71.00	5	66.19	3	70.83	4	71.00	4	69.78	4	0.68	-0.57
ME-03× MI-66	69.38	8	58.79	9	66.23	7	68.93	8	65.83	8	0.21	1.58
ME-146 × MI-66	72.12	4	65.07	4	71.26	2	71.05	6	69.87	3	0.93	-0.21
ME-65 × V1	74.56	3	72.18	1	70.70	3	72.22	2	72.41	1	1.45	-0.79
ME-67 × V1	68.56	10	61.46	8	62.30	9	64.60	10	64.23	10	0.79	3.23 *
ME-05 x MI-66	70.72	6	56.15	10	67.35	8	68.84	9	65.76	9	1.94	0.25
ME-95x V1	69.78	9	64.42	5	68.67	5	69.20	7	68.02	6	0.72	-1.15
V1	74.81	2	67.97	2	71.76	1	73.26	1	71.95	2	0.87	-1.39
S36	71.84	1	62.45	7	60.93	10	68.90	5	67.53	7	1.16	-0.70
Grand Mean	71.35		63.71		68.39		70.01		68.36			
Environment index	2.98		-4.65		0.02		1.64					
C.V.	1.60		5.06		2.61		1.86					
S. Em±	0.93		2.63		1.46		1.06					
CD @ P=0.05	1.96		5.53		3.06		2.24					
CD @ P=0.01	2.68		7.58		4.2		3.07					

*Significant@ 0.05 level ** Significant@ 0.01 level, bi=regression co-efficient, S^2di=Deviation from regression
S1=2022 Rainy season (June-August), S2=2022 Winter season (Nov-Jan), S3=2023 Summer season (March-May), S4=2023 Rainy season (July- Sept)

Hence these genotypes are specifically adapted to favourable environment.

Leaf Moisture Content (%)

Leaf moisture content of different mulberry hybrids differed from season to season as indicated by varying environmental indices (-4.65 to 2.98). The environment mean and index was maximum at S1 (71.35 and 2.98 respectively) and these were lowest in S2 (63.71 and -4.65 respectively). When considered overall mean ME-65 × V1has recorded highest moisture content of leaf (72.41%) followed by V1 (71.95%) and ME-146 × MI-66 (69.87%) whereas it is lowest (64.23%) in ME-67 × V1 (Table 8).

The mean performance of number of leaves per plant of ME-65 × V1 was more than the grand mean with non-significant regression co-efficient and its value is equal to one indicating average stability. Hence this hybrid is specially adapted to all environments. The mean performance of MI-47 × MI-66, ME-05 × MI-66 and S36 lesser than the grand mean having non-significant regression co-efficient and it equal to one with average stability indicating these hybrids are poorly adapted to all environments. The mean performance of ME-03 × MI-66, ME-67 × V1 and ME-95 × V1 was lesser than the grand mean having non-significant regression co-efficient and it is less than one with above average stability indicating these hybrids are specifically adapted to unfavourable environments. Whereas the deviation from regression was highly significant for ME-67 × V1 indicating unpredictable performance across the environment. The deviation from regression was non-significant for MI-47 × MI-66, ME-65 × V1, ME-05 × MI-66, ME-95 × V1, V1 and S36 indicating predictable performance across the environment (Table 8).

The present results are corroborated with the findings of earlier reports of Bhavyashree *et. al.* (2014) reported that the moisture content of genotype SB-21 performed uniformly well over all the seasons (Mean= 67.20, C. V= 2.56 %), on the other hand, Surat local recorded greater variation for moisture content over all the seasons (Mean = 67.20, C. V = 11.97%). Among the different seasons, *kharif* 2011 recorded uniform moisture content over all the seasons. Raksha, 2015, reported moisture content of leaf and reported that, the mulberry genotypes *viz*., ME-52 (70.45%), MI-79 (73.30%), SB-21 (70.4 0%) and S-36 (72.21%) having average stability hence these genotypes are well adapted to all the environments since, these possessed the mean performance was more than the grand mean. Ahalya *et al*. (2020) revealed that based on the stability parameters *viz*., mean, regression (bi) and deviation from regression (S^2di) of eight tree mulberry genotypes indicated, V1 yielded stable performance across the seasons for moisture content.

Moisture Retention Capacity at 6 Hours of Leaf Harvest (%)

Leaf moisture retention capacity at 6 hours of different mulberry hybrids vary from season to season as indicated by varying environmental indices (-6.95 to 5.02). The environment mean and index was maximum at S4 (67.75 and 5.02 respectively) and these were lowest at S2 (55.78 and -6.95 respectively). When considered overall mean ME-65 × V1 had highest leaf moisture retention capacity at 6 hours (65.97%) followed by V1 (64.69%) and MI-47 × MI-66 (63.34%) whereas, it is lowest (60.07%) in ME-95 × V1 (Table 9).

The mean performance of leaf moisture retention capacity at 6 hours of ME-65 × V1 and ME-67 × V1 was more than the grand mean with non-significant regression co-efficient and its value is equal to one indicating average stability. Hence these hybrids are specially adapted to all environments. The mean performance of ME-03 × MI-66, ME-05 × MI-66 and S36 lesser than the grand mean having non-significant regression co-efficient and it equal to one with average stability indicating these hybrids are poorly adapted to all environments. The mean performance of MI-79 × MI-66, ME-146 × MI-66 and ME-95 × V1 was lesser than the grand mean having non-significant regression coefficient and it is less than one with above average stability indicating these hybrids are specifically adapted to unfavourable environments. Whereas the deviation from regression

TABLE 9

Mean performance of ten elite mulberry hybrids in four seasons and their stability parameters for leaf moisture retention capacity at 6 hours of leaf harvest (%)

Mulberry Hybrids	S1	Rank	S2	Rank	S3	Rank	S4	Rank	Mean	Overall Rank	b*i*	S^2di
MI-47 × MI-66	65.92	6	61.12	8	57.06	3	69.26	2	63.34	3	0.99	-0.64
MI-79 × MI-66	66.18	4	62.44	2	52.27	8	68.18	4	62.27	6	0.65	1.08
ME-03× MI-66	66.20	3	61.86	4	52.77	7	68.20	3	62.26	7	1.28	-1.00
ME-146 × MI-66	65.60	8	61.73	7	55.73	4	67.26	6	62.58	5	0.96	-1.87
ME-65 × V1	68.14	1	63.15	1	62.47	2	70.14	1	65.97	1	1.31	0.21
ME-67 × V1	66.80	2	61.77	6	54.88	5	67.80	8	62.81	4	1.10	-1.56
ME-05 x MI-66	64.94	9	61.90	3	51.86	10	66.28	7	61.24	9	1.19	1.28
ME-95x V1	63.13	10	57.65	9	54.39	6	65.13	10	60.07	10	0.91	-0.70
V1	65.94	5	61.80	5	63.73	1	67.27	9	64.69	2	0.31	2.51
S36	65.64	7	61.90	3	52.60	9	67.98	5	62.03	8	1.26	-0.63
Grand Mean	65.85		61.53		55.78		67.75					
Environment index	3.12		-1.19		-6.95		5.02					
C.V.	2.89		3.09		3.33		2.86					
S.Em±	1.55		1.55		1.52		1.58					
CD @ P=0.05	-		3.26		3.19		3.33					
CD @ P=0.01	-		4.47		4.37		4.56					

**Significant@ 0.05 level ** Significant@ 0.01 level, bi=regression co-efficient, S^2di=Deviation from regression
S1=2022 Rainy season (June-August), S2=2022 Winter season (Nov-Jan), S3=2023 Summer season (March-May), S4=2023 Rainy season (July- Sept)

TABLE 10

Mean performance of ten elite mulberry hybrids in four seasons and their stability parameters for leaf moisture retention capacity at 9 hours of leaf harvest (%)

Mulberry Hybrids	S1	Rank	S2	Rank	S3	Rank	S4	Rank	Mean	Overall Rank	b*i*	S^2d*i*
MI-47 × MI-66	57.89	7	55.60	5	51.01	4	59.89	7	56.10	4	0.84	-1.25
MI-79 × MI-66	59.35	3	54.94	6	46.41	8	61.35	3	55.51	5	0.50	-1.32
ME-03× MI-66	56.36	9	45.59	10	47.60	7	57.70	9	51.81	10	1.13	15.00 ***
ME-146 × MI-66	58.46	6	53.88	7	48.79	5	60.46	6	55.40	6	1.15	-1.45
ME-65 × V1	61.88	1	60.32	1	58.14	2	63.55	1	60.97	1	1.46	-0.43
ME-67 × V1	57.30	8	54.88	9	46.13	9	58.64	8	54.24	8	1.20	1.68
ME-05 x MI-66	58.63	5	55.84	4	44.59	10	60.63	5	54.92	7	1.52	3.85 *
ME-95x V1	55.52	10	51.15	8	50.16	3	57.52	10	53.59	9	0.73	0.35
V1	59.49	2	56.36	3	60.34	1	61.83	2	59.50	2	0.14	5.85 **
S36	59.15	4	57.88	2	46.97	6	60.82	4	56.20	3	1.30	5.82 **
Grand Mean	58.40		54.64		50.01		60.24		55.82			
Environmental index	2.5		-1.18		-5.81		4.41					
C.V.	2.15		4.12		4.76		2.14					
S.Em±	1.02		1.83		1.94		1.03					
CD @ P=0.05	2.16		3.85		4.08		2.17					
CD @ P=0.01	2.95		5.28		5.60		2.97					

*Significant@ 0.05 level ** Significant@ 0.01 level, bi=regression co-efficient, S^2di=Deviation from regression
S1=2022 Rainy season (June-August), S2=2022 Winter season (Nov-Jan), S3=2023 Summer season (March-May), S4=2023 Rainy season (July-Sept)

was non-significant for all mulberry hybrids indicating predictable performance across the environment (Table 9).

Leaf Moisture Retention Capacity at 9 Hours of Leaf Harvest (%)

Leaf moisture retention capacity at 9 hours of different mulberry hybrids vary from season as indicated by varying environmental indices (-5.81 to 4.41). The environment mean and index was maximum at S4 (60.24 and 4.41 respectively) and minimum S3 (50.01 and -5.81 respectively). When considered overall mean ME-65 × V1 had highest leaf moisture retention capacity at 9 hours (60.97%) followed by V1 (59.50%) and S36 (56.20%). Whereas it is lowest (51.81%) in ME-03 × MI-66 (Table 10).

Similar results were reported by Ahalya *et al*., 2020, who reported that leaf moisture retention capacity at 9 hours of different genotypes vary from season to season as indicated by varying environmental indices (-6.62 to 7.42). The environment mean and index was maximum at S5 (62.44 and 7.42 respectively) and minimum S3 (48.39 and -1.78 respectively). When considered overall mean M5 had highest leaf moisture retention capacity at 9 hours (59.42%) followed by V1 (58.57%) and MI-012 (56.18%) whereas it is lowest (51.83%) in MI-21.

The mean performance of leaf moisture retention capacity at 9 hours of ME-65 × V1 and S36 was more than the grand mean with non-significant regression co-efficient and its value is equal to one indicating average stability hence these hybrids is specially adapted to all environments. The mean performance of ME-03 × MI-66, ME-146 × MI-66, ME-67 × V1 and ME-05 × MI-66 lesser than the grand mean having non-significant regression co-efficient and it equal to one with average stability indicating these hybrids are poorly adapted to all environments. The mean performance of MI-79 × MI-66, ME-95 × V1 was lesser than the grand mean having non-significant regression coefficient and it is less than one with above average stability indicating these hybrids are specifically adapted to unfavourable environments. Whereas the deviation from regression was highly significant for ME-03 × MI-66, ME-05 × MI-66, V1 and S36 indicating unpredictable performance across the environment. The deviation from regression was non-significant for MI-47 × MI-66, MI-79 × MI-66, ME-146 × MI-66, ME-65 × V1, ME-65 × V1, ME-67 × V1 and ME-95 × V1 indicating predictable performance across the environment (Table 10).

Similar results were reported by Raksha, 2015, reported the leaf moisture retention capacity at 9 hours and reported that, ME-012 (52.94%), C-763 (52.35%), SB-21 (54.08%), C-20 (49.84%) and MI-506 (54.14%) had mean performance lesser than the grand mean and regression co-efficient with above average stability indicating these genotypes are specifically adapted to unfavourable environments.

To determine the leaf moisture at six and nine hours of harvest, a composite sample of ten leaves was collected and fresh weight was taken. The leaves were kept open under laboratory condition and the weight was recorded at 6 hr after harvest. The leaves were dried thoroughly at 80 ^{0}C in the oven. Dry weight was taken, the moisture retention capacity was calculated by using the formula below (Shivashankar, 2015).

$$\text{Moisture retention capacity (\%)} = \frac{\text{(Weight after 6 hr) - (Dry weight)}}{\text{(Fresh weight) - (Dry weight)}} \times 100$$

$$\text{Moisture retention capacity (\%)} = \frac{\text{(Weight after 9 hr) - (Dry weight)}}{\text{(Fresh weight) - (Dry weight)}} \times 100$$

'Single Leaf Area', which leaf was taken for analysis as each leaf varies with its area.

4th or 5th leaves are taken for observation, yes it varies.

Leaf area was estimated by measuring the length and breadth of individual leaf from different hybrids and multiplied with factor and expressed in cm^2.

$$SLA = L \times B \times 0.69$$

Where, SLA = Single Leaf Area

L = Length (cm^2)

B = Breadth (cm^2)

0.69 = Correction factor

Leaf Yield Per Plant (g)

The leaf yield per plant in different mulberry hybrids varied from season to season as indicated by varying environmental indices (-264.42 to 231.02). The environment mean and index was highest at S4 (1063.70 and 231.02) and lowest in S2 (568.25 and -264.42) respectively. When considered the overall mean ME-65 × V1 had highest leaf yield per plant (1089.99g) followed by ME-03 × MI-66 (1082.34g) and V1 (1018.57g). Whereas it is lowest (468.93g) in ME-67 × V1 (Table 11)

The leaf yield per plant in different mulberry hybrids *viz.*, MI-79 × MI-66, ME-03 × MI-66, ME-68 × V1 and V1 was more than the grand mean with non-significant regression co-efficient and its value is equal to one indicating average stability hence these hybrids is specially adapted to all environments. The mean performance of MI-47 × MI-66, ME-146 × MI-66 and ME-95 × V1 and lesser than the grand mean having non-significant regression co-efficient and it equal to one with average stability indicating these hybrids are poorly adapted to all environments. The mean performance of ME-67 × V1, ME-05 × MI-66 was lesser than the grand mean having non-significant regression co-efficient and the value is less than one with above average stability indicating these hybrids are specifically adapted to unfavourable environments. On other hand the deviation from regression was highly significant for ME-03 × MI-66, ME-05 × MI-66, V1 and S36 indicated unpredictable performance across the environment. The deviation from regression was significant for all mulberry hybrids for leaf yield per plant indicating predictable performance across the environment (Table 11).

The present results are in concurrence with the findings of Masilamani, 2005 revealed the leaf yield performance in different seasons of spring, summer and rainy season. Among the genotypes studied the leaf yield of mulberry was highest in TR-8 during spring, summer and rainy seasons of 2002. In contrary the genotype BC-259 yielded higher leaf yield in all the seasons of 2003. Doss *et al.*, 2012 also reported that the stability analysis revealed that hybrids CT-44, CT-159, CT-11 are the most stable hybrids for leaf yield while CT-210, CT-9 and CT-210 are suitable for constrained areas while CT-94 and CT185 are good for optimal conditions. Ghosh *et al.*, 2013, evaluated leaf yield performance of 10 mulberry varieties was tested through stability analysis for different crop seasons. Variance for deviation from regression (S_{di}^2) of varieties C_{2017}, RFS_{175} and Thalaghatapura did not differ significantly from zero. However, the b_i values of only RFS_{175} out of these three is not significantly different from unity and may be considered to be a stable variety with moderate leaf yield.

While C_{2017} having b_i value significantly higher than unity is suitable for places like Berhampore, Jorhat and Imphal having positive environmental indices Thalaghatapura having b_i value significantly lower than unity is suitable for Koraput, Muluk, Ranchi and Kalimpong with negative environmental indices. Ahalya *et al*. (2020) revealed that based on the selection indices, S6-rainy season 2019 was found more favourable for mulberry genotypes for good expression of leaf yield per tree. Based on the stability parameters *viz*., mean, regression (bi) and deviation from regression (S^2di) of eight tree mulberry genotypes indicated, V1 yielded stable performance across the seasons for leaf yield per tree. Sathyanarayana and Sangannavar (2021) determined the stability analysis and genotype x environment interaction of alkali tolerant mulberry genotypes *viz*., AR-12, AR-14, AR-10, AR-08, AR-29, V1 and S34 at different alkali soils on leaf yield. The large variation in mean leaf yield/microplot, regression co-efficient (bi) and deviation from regression (S^2di) indicated the different responses of genotypes to soil reclaimed with amendments. Genotypes AR-12 and AR-14 showed high leaf yield (AR-12: 18.240 kg, AR-14: 16.15 kg), the low deviation from regression (S^2di) (AR-12: -0.04, AR-14: 0.03) and their regression coefficient values (bi) were close to unity (AR-12: 1.41, AR-14: 1.34) and could be classified as stable genotypes.

TABLE 11

Mean performance of ten elite mulberry hybrids in four seasons and their stability parameters for leaf yield per plant (g)

Mulberry Hybrids	S1	Rank	S2	Rank	S3	Rank	S4	Rank	Mean	Overall Rank	b*i*	S^2di
MI-47 × MI-66	939.56	6	513.61	6	521.66	7	1041.90	6	754.18	7	1.18	6265.52
MI-79 × MI-66	1182.36	3	713.60	5	796.00	5	1271.71	3	990.92	5	1.21	658.43
ME-03× MI-66	1254.36	2	745.23	1	995.53	2	1334.24	2	1082.34	2	1.88	-2600.99
ME-146 × MI-66	835.36	8	420.48	8	493.83	8	925.93	8	668.34	8	1.09	-284.62
ME-65 × V1	1252.60	1	740.23	2	996.63	1	1366.50	1	1089.99	1	1.11	-1771.63
ME-67 × V1	537.66	9	312.00	10	395.76	10	630.30	9	468.93	10	0.63	-3349.07
ME-05 x MI-66	511.98	10	321.38	9	496.77	9	615.42	10	486.39	9	0.50	-487.25
ME-95x V1	903.86	7	440.38	7	708.73	6	1013.73	7	766.68	6	1.24	-3002
V1	1142.56	4	731.96	4	954.03	4	1245.75	4	1018.57	3	1.00	-2844.12
S36	1080.93	5	743.61	3	987.43	3	1191.50	5	1000.87	4	0.82	-243.01
Grand Mean	964.12		568.25		734.64		1063.70		832.68			
Environmental index	131.44		-264.42		-98.04		231.02					
C.V.	14.21		4.19		0.69		13.27					
S.Em±	111.89		19.44		4.07		115.24					
CD @ P=0.05	235.07		40.85		8.55		242.12					
CD @ P=0.01	322.06		55.98		11.72		331.73					

*Significant@ 0.05 level ** Significant@ 0.01 level, bi=regression co-efficient, S^2di=Deviation from regression
S1=2022 Rainy season (June-August), S2=2022 Winter season (Nov-Jan), S3=2023 Summer season (March-May), S4=2023 Rainy season (July- Sept)

Genotype × environment interaction has great importance for selecting superior cultivars to be used commercially in diverse environmental conditions. The selection indices of mulberry hybrids revealed that rainy season (S-4) of 2023 was found more favourable for the expression of shoot length (cm), number of branches per plant, number of leaves per branch, single leaf area (cm^2), leaf yield per plant (g) at harvest and leaf moisture retention capacity at 6 and 9 hrs after harvest, respectively). Based on the stability parameters *viz*., mean (x) and regression (bi), ME-65 × V1 yielded stable performance across the seasons for the maximum number of parameters *viz*., shoot length (cm), number of branches, internodal distance (cm), leaf moisture retention capacity (%) and leaf yield per plant (g) and for single leaf area and leaf moisture content, ME-146 × MI-66 is stable.

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Vocational Interests Expressed by the Agriculture Graduates for Entrepreneurship under SRP

P. Vaishnavi[1], D. A. Nithya Shree[2] and Sunil V. Halakatti[3]

[1]Department of Agricultural Extension, School of Agricultural Sciences,
Dhanalakshmi Srinivasan University, Samayapuram - 621 112

[2&3]Department of Agricultural Extension Education, College of Agriculture, UAS, Dharwad - 580 005

e-Mail : p.vaishnavi1997@gmail.com

Authors Contribution

P. Vaishnavi :
Conceptualization, research design, data analysis and draft preparation;

D. A. Nithya Shree :
Conceptualization, supervision, editing and final approval;

Sunil V. Halakatti :
Conceptualization and editing;

Corresponding Author :
P. Vaishnavi

Received : June 2024
Accepted : June 2024

Abstract

The study was conducted across seven agricultural universities in South India to explore the vocational interests of agriculture graduates, particularly after participating in the Experiential Learning Programmes under Student Rural Entrepreneurship Awareness Development Yojana programme. A total of 350 agriculture graduates from seven universities were surveyed using personal interviews and Google Forms, employing Garrett's ranking method for comprehensive analysis. The study unveiled a spectrum of vocational interests among graduates, with a focus on entrepreneurship. Notably, mushroom cultivation emerged as the most preferred entrepreneurial venture across universities, suggesting its appeal as a sustainable and profitable agricultural pursuit. Bio-agents and bio-fertilizers followed closely, reflecting the increasing demand for organic and bio-based products in both domestic and international markets. However, beekeeping garnered the least interest, possibly due to its perceived complexity and specialized skill requirements. The comparative analysis of vocational interests among agriculture graduates from various universities revealed subtle preferences. While poultry farming ranked prominently in some institutions, others showed a preference for dairy and livestock or bio-agents and bio-fertilizers. Mushroom cultivation consistently ranked high across most universities, indicating its universal appeal among aspiring agriculture entrepreneurs. Overall, mushroom cultivation emerged as the top vocational interest, highlighting its potential as a productive entrepreneurial endeavor within the agricultural sector. The study underscores the importance of understanding vocational preferences and entrepreneurial aspirations among agriculture graduates, providing valuable insights for educational and policy interventions aimed at fostering innovation and entrepreneurship in agriculture.

Keywords : Agriculture graduates, Entrepreneurship, Experiential learning programme, Student READY programme, Vocational interests

The Indian Council of Agricultural Research (ICAR) recommended Student Rural Entrepreneurship Awareness Development Yojana (READY) Programme and it was launched by Hon'ble Prime Minister of India Shri. Narendra Modi on July 25th, 2015 in the AU's of the country (Vaishnavi and Nithya Shree, 2024). The programme has been introduced for one complete year in the last year of the degree programme for UG education in the disciplines of agriculture, agricultural engineering, biotechnology, community science, dairy technology, food technology, forestry, fisheries, horticulture and sericulture since 2016-2017 (Arundhathi *et al*., 2024). This program aims to promote final-year undergraduates with the necessary skills and knowledge to become successful entrepreneurs in the agricultural sector (Anonymous, 2017).

In this connection the vocational interests of agriculture graduates play a crucial role in shaping the future of agricultural practices and innovations. It aims enterepreneurship and awarness development among the graduates (Saba *et al.*, 2021). In a comprehensive study, the distribution of vocational preferences among graduates from various agricultural universities were analyzed, shedding light on the diverse career paths pursued by these individuals. Detailed examination of data provided in tables, enclosed preferences of graduates from different institutions. This survey not only highlighted the popularity of specific vocational interest, but also unveils trends and variations across different university cohorts. Such an investigation is pivotal in understanding the evolving landscape of agricultural education and the entrepreneurial aspirations of its graduates through READY programme (Anonymous, 2016).

Methodology

The study was conducted in seven agricultural universities of South India, *viz.,* University of Agricultural Sciences, Bengaluru (UAS-B); University of Agricultural Sciences Dharwad, (UASD); University of Agricultural Sciences, Raichur (UASR); Acharya N. G. Ranga Agricultural University (ANGRAU), Professor Jayashankar Telangana State Agricultural University (PJTSAU), Tamil Nadu Agricultural University (TNAU) and Kerala Agricultural University (KAU). From each university, one agriculture college was selected for the study. From each agriculture college 50 graduates who had passed out in the year of 2022 were selected randomly for the research. Thus the total sample size for the study was 350 agriculture graduates. These graduates expressed a diverse range of vocational interests particularly in entrepreneurship following their participation in Experiential Learning Programmes (ELP) within the Student READY Programme (SRP) intiative. The collection of data was executed through a combination of personal interviews and Google Forms, utilizing an interview schedule. The vocational interests of the agriculture graduates were measured using Garrett's ranking method for comprehensive analysis and interpretation of the gathered data.

Results and Discussion

Totally 10 vocational interests were expressed by the agriculture graduates for entrepreneurship after undergone ELP in SRP. The results revealed that, the major vocational interest preferred by UASB

Table 1

Distribution of UASB agriculture graduates according to vocational interest

(n_1 = 50)

Vocational interest	Garrett's score	Mean Garrett's score	Rank
Poultry farm	2860	57.20	I
Seed Production	2750	55.00	II
Dairy and Livestock	2731	54.62	III
Food Processing	2664	53.28	IV
Mushroom Cultivation	2634	52.68	V
Commercial Horticulture	2514	50.28	VI
Bio-agents and Bio-fertilizers	2435	48.70	VII
Sericulture	2328	46.56	VIII
Agro service / Agri business	2218	44.36	IX
Bee Keeping	2116	42.32	X

TABLE 2

Distribution of UASD agriculture graduates according to vocational interest

(n_2 = 50)

Vocational interest	Garrett's score	Mean Garrett's score	Rank
Dairy and Livestock	3099	61.98	I
Poultry farm	2839	56.78	II
Seed Production	2814	56.28	III
Mushroom Cultivation	2783	55.66	IV
Bio-agents and Bio-fertilizers	2617	52.34	V
Commercial Horticulture	2377	47.54	VI
Sericulture	2286	45.72	VII
Bee Keeping	2267	45.34	VIII
Agro service / Agri business	2155	43.1	IX
Food Processing	2013	40.26	X

(Table 1) graduates was poultry farm with Mean Garrett Score of 57.20. UASD (Table 2) graduates expressed a major vocational interest in dairy and livestock with Mean Garrett Score of 61.98. The major vocational interest preferred by UASR (Table 3) graduates was bio-agents and bio-fertilizers with Mean Garrett Score of 70.76.

Further, the results showed the major vocational interest preferred by ANGRAU (Table 4), PJTSAU (Table 5) and TNAU (Table 6) graduates was mushroom cultivation with Mean Garrett Score of 56.78, 55.18 and 55.74 respectively. KAU graduates expressed (Table 7) major vocational interest in food processing with Mean Garrett Score of 58.10.

Overall, across all universities, mushroom cultivation emerged as the major vocational interest expressed by the agriculture graduates for entrepreneurship with Mean Garrett Score of 55.99 (Table 8). This might be due to consideration of mushroom cultivation as a sustainable and profitable venture in agriculture. It requires relatively low investment, uses agricultural waste as substrate, and offers high returns, making it an attractive option for aspiring entrepreneurs. The findings are supported by Murthy *et al.*, (2019), shirur and shivalingegowda (2015).

TABLE 3

Distribution of UASR agriculture graduates according to vocational interest

(n_3 = 50)

Vocational interest	Garrett's score	Mean Garrett's score	Rank
Bio-agents and Bio-fertilizers	3538	70.76	I
Dairy and Livestock	3106	62.12	II
Poultry farm	3052	61.04	III
Commercial Horticulture	3020	60.40	IV
Seed Production	2969	59.38	V
Mushroom Cultivation	2906	58.12	VI
Food Processing	2882	57.64	VII
Sericulture	2779	55.58	VIII
Agro service / Agri business	2602	52.04	IX
Bee Keeping	2509	50.18	X

TABLE 4

Distribution of ANGRAU agriculture graduates according to vocational interest

(n_4 = 50)

Vocational interest	Garrett's score	Mean Garrett's score	Rank
Mushroom Cultivation	2839	56.78	I
Food Processing	2789	55.78	II
Commercial Horticulture	2756	55.12	III
Seed Production	2685	53.70	IV
Dairy and Livestock	2557	51.14	V
Agro service / Agri business	2468	49.36	VI
Poultry farm	2401	48.02	VII
Bio-agents and Bio-fertilizers	2389	47.78	VIII
Bee Keeping	2243	44.86	IX
Sericulture	2123	42.46	X

TABLE 5

Distribution of PJTSAU agriculture graduates according to vocational interest

(n_5 = 50)

Vocational interest	Garrett's score	Mean Garrett's score	Rank
Mushroom Cultivation	2759	55.18	I
Bio-agents and Bio-fertilizers	2746	54.92	II
Poultry farm	2741	54.82	III
Seed Production	2731	54.62	IV
Dairy and Livestock	2669	53.38	V
Commercial Horticulture	2412	48.24	VI
Food Processing	2407	48.14	VII
Sericulture	2339	46.78	VIII
Bee Keeping	2267	45.34	IX
Agro service / Agri business	2179	43.58	X

TABLE 6

Distribution of TNAU agriculture graduates according to vocational interest

(n_6 = 50)

Vocational interest	Garrett's score	Mean Garrett's score	Rank
Mushroom Cultivation	2787	55.74	I
Bio-agents and Bio-fertilizers	2764	55.28	II
Poultry farm	2728	54.56	III
Seed Production	2705	54.10	IV
Dairy and Livestock	2593	51.86	V
Commercial Horticulture	2548	50.96	VI
Food Processing	2408	48.16	VII
Sericulture	2248	44.96	VIII
Bee Keeping	2237	44.74	IX
Agro service / Agri business	2232	44.64	X

TABLE 7

Distribution of KAU agriculture graduates according to vocational interest

(n_7 = 50)

Vocational interest	Garrett's score	Mean Garrett's score	Rank
Food Processing	2905	58.10	I
Mushroom Cultivation	2891	57.82	II
Bio-agents and Bio-fertilizers	2729	54.58	III
Commercial Horticulture	2672	53.44	IV
Bee Keeping	2471	49.42	V
Seed Production	2372	47.44	VI
Dairy and Livestock	2349	46.98	VII
Agro service / Agri business	2306	46.12	VIII
Poultry farm	2297	45.94	IX
Sericulture	2258	45.16	X

TABLE 8

Overall distribution of agriculture graduates according to vocational interest

(n_8 = 350)

Vocational interest	Garrett's score	Mean Garrett's score	Rank
Mushroom Cultivation	19599	55.99	I
Bio-agents and Bio-fertilizers	19218	54.91	II
Dairy and Livestock	19104	54.58	III
Seed Production	19026	54.36	IV
Poultry farm	18918	54.05	V
Commercial Horticulture	18299	52.28	VI
Food Processing	18068	51.62	VII
Sericulture	16361	46.75	VIII
Agro service / Agri business	16160	46.17	IX
Bee Keeping	16110	46.03	X

Bio-agents and bio-fertilizers emerged as second major vocational interest expressed by the agriculture graduates for entrepreneurship with Mean Garrett Score of 54.91. It clearly states that there is a rising demand for organic and bio-based products in the agriculture sector, both in domestic and international markets. Bio-agents and bio-fertilizers are essential components of sustainable agriculture practices to minimize the use of synthetic chemicals and enhance the quality of produce. Graduates recognize this market demand and see opportunities to capitalize on it through entrepreneurship.

Further, bee keeping was the least vocational interest expressed by the agriculture graduates for entrepreneurship with Mean Garrett Score of 46.03. It was found that beekeeping requires specific knowledge, skills and expertise. Graduates may perceive it as a more complex and challenging field compared to other entrepreneurial options. They might be hesitant to venture into a less familiar area.

The comparison of vocational interest of agriculture graduates in various agricultural universities is shown in the Table 9. In UAS-B, poultry farm ranked first followed by seed production and dairy and livestock were ranked second and third, respectively. In UASD, dairy and livestock, poultry farm and seed production were in first, second and third ranks, respectively. In

TABLE 9

Comparison of agriculture graduates according to vocational interests in selected State Agricultural Universities

(n = 350)

Vocational interest	State Agricultural Universities							
	UASB (n_1 = 50)	UASD (n_2 = 0)	UASR (n_3 = 50)	ANGRAU (n_4 = 0)	PJTSAU (n_5 = 50)	TNAU (n_6 = 0)	KAU (n_7 = 0)	Overall (n=350)
	Garrett's rank							
Poultry farm	I	II	III	VII	III	III	IX	V
Seed Production	II	III	V	IV	IV	IV	VI	IV
Dairy and Livestock	III	I	II	V	V	V	VII	III
Food Processing	IV	X	VII	II	VII	VII	I	VII
Mushroom Cultivation	V	IV	VI	I	I	I	II	I
Commercial Horticulture	VI	VI	IV	III	VI	VI	IV	VI
Bio-agents and Bio-fertilizers	VII	V	I	VIII	II	II	III	II
Sericulture	VIII	VII	VIII	X	VIII	VIII	X	VIII
Agro service / Agri business	IX	IX	IX	VI	X	X	VIII	IX
Bee Keeping	X	VIII	X	IX	IX	IX	V	X

UASR, bio-agents and bio-fertilizers ranked first followed by dairy and livestock, poultry farm were ranked second and third, respectively. In ANGRAU, mushroom cultivation, food processing and commercial horticulture were in first, second and third ranks, respectively. In PJTSAU and TNAU, mushroom cultivation ranked first followed by bio-agents and bio-fertilizers and poultry farm were second and third ranks respectively. In KAU, food processing, mushroom cultivation and bio-agents and bio-fertilizers were in first, second and third ranks, respectively.

In terms of overall ranking of vocational interests across all universities, mushroom cultivation were ranked first followed by bio-agents and bio-fertilizers and dairy and livestock were ranked second and third, respectively. Further, seed production, poultry farm, commercial horticulture and food processing were ranked from fourth, fifth, sixth and seventh, ranks respectively. Sericulture, agro service/agri business and bee keeping were eighth, ninth and tenth ranks, respectively.

The study revealed fascinating insights into the vocational interests of agriculture graduates regarding entrepreneurship opportunities. Across various universities, mushroom cultivation emerged as the top choice, reflecting its perceived sustainability, profitability and relatively low investment requirements. This trend underscores the growing market for organic and bio-based products in both domestic and international agriculture sectors.

The rankings across universities provide an understanding of regional preferences, with each university showing distinct inclination towards specific entrepreneurial ventures. Overall, the findings highlight the dynamic nature of agricultural entrepreneurship, shaped by market trends, technological advancements and environmental considerations. As graduates explore diverse avenues, they contribute to the evolving landscape of sustainable and innovative agricultural practices.

Acknowledgement : The firsht author is grateful to the Indian Council of Social Science Research (ICSSR) for their full-term centrally-administered doctoral fellowship, which provided invaluable support throughout the entire process of completing this research.

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Influence of Planting Geometry and Nutrient Levels on Growth, Yield, Economics and Nutrient uptake of Field Bean

Vattem Sandeep[1], R. Jayaramaiah[2], Laxman Navi[3] and N. Umashanker[4]
[1&3]Department of Agronomy, [2]Department of of Agrometeorology, [4]Department of Agricultural Microbiology,
College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : navilaxman95@gmail.com

Authors Contribution

Vattem Sandeep :
Experiment execution, data collection, data analysis and draft preparation;

R. Jayaramaiah :
Conceptualization, framed research and draft correction;

Laxman Navi :
Data analysis and manuscript preparation;

N. Umashanker :
Conceptualization and manuscript correction

Corresponding Author :
Vattem Sandeep

Received : July 2024
Accepted : August 2024

Abstract

A field experiment was conducted to investigate performance of field bean with varying spacing and fertilizer levels at ZARS, UAS, GKVK, Bengaluru. The experiment consisted of two factors *i.e.,* spacing and fertilizer each at four different levels. Among spacing levels, growth parameters such as number of branches (6.9), number of leaves (17.5), leaf area (906.5 cm^2 $plant^{-1}$), dry matter production (31.1 g $plant^{-1}$) were recorded significantly higher in 60 cm × 30 cm spacing (S_4). Similarly yield parameters, pod length (5.4 cm), number of seeds pod^{-1} (4.2), number of pods $plant^{-1}$ (25.3), seed yield $plant^{-1}$ (16.1 g) were found significantly higher in 60 cm × 30 cm spacing whereas, higher seed yield (848.7 kg ha^{-1}) was recorded in 45 cm × 15 cm spacing (S_1). Among different fertilizer levels higher number of branches (6.8), number of leaves (16.5), leaf area (897.2 cm^2 $plant^{-1}$), dry matter production (28.6 g $plant^{-1}$) and higher yield parameters namely pod length (5.4 cm), number of seeds pod^{-1} (4.22), number of pods $plant^{-1}$ (24.7) and seed yield (764.6 kg ha^{-1}) were recorded in 150 per cent RDF application (F_4). These parameters were found on par with 125% RDF (F_3). Among the treatment combinations between spacing and fertilizer levels S_1F_4 (45 cm × 15 cm spacing and 150% RDF) recorded higher seed (918.2 kg ha^{-1}) yield. Among spacing levels higher nitrogen, phosphorus and potassium uptake was recorded (53.20, 6.78 and 48.52 kg ha^{-1}, respectively) with spacing of 45 cm × 15 cm. Among different fertilizer levels higher nitrogen, phosphorus and potassium uptake (52.36, 6.68 and 48.17 kg ha^{-1}, respectively) was recorded in application of 150% RDF level compared with other levels of application.

Keywords : Field bean, Planting geometry, Fertilizer level, Growth, Yield, Economics of field bean

Pulses form an important component in diet of major population in the world and particularly in India. India being the largest producer of pulses, is also a largest importer of pulses annually. Due to vast 1.3 billion population, meeting their nutritional requirements and low productivity from the existing pulse cultivation has led for dependence on imports for domestic requirements. Maintenance of self-sufficiency and food security is essential, especially in case of pluses for a nation like India to meet domestic requirements and to end malnutrition. Climate change also poses an immense threat to global agriculture and food security. Adaption of climate resilient crops and good management practices supported by scientific community, can enhance the productivity of pulses over a period of time. Climate hardy crops like field bean can help in mitigating climate change and its adverse effect on agriculture. Adaptability of field bean to diverse climate and soils, makes the crop to yield better even in stress conditions than general pulse crops.

Field bean (*Dolichos lablab* L.) is bushy to spreading type and belongs to family *Fabaceae*. It is commonly known as Dolichos bean, Hyacinth bean, Indian bean, Sem, Avare *etc*., Dolichos bean is cultivated widely across the world under diverse climatic conditions as high genetic diversity is noticed within crop. It is a multi-purpose crop, as around the world it is cultivated for various purposes such as for vegetable, pulse grain, fodder, as cover crop and also as green manure crop (Ramesh and Byregowda, 2016). Pulse crops like field bean which can fix atmospheric nitrogen effectively also requires starter dose of nitrogen during initial stages. Moreover, in most pulse crops reduction in nitrogen fixation is noticed at pod formation and development stages. This may be due to competition between developing pods and root nodules for available photosynthates, since N fixation is also an energy demanding process. Field bean unlike other pulses has diverse variability and varied growth habit such as multiple flushes of flowering, succulent pod at early stage and longer plant greenness after pod maturity compared to other pulses. These diverse growth habits of field bean crop need investigation under varied management practices, which can help in establishing valid recommendations. Therefore, the study was conducted to access influence of different levels of spacing and fertilizers on growth, yield, economics and nutrient uptake of field bean.

Material and Methods

The experiment was conducted at Zonal Agricultural Research Station, Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bangalore (13 07' North latitude, 77 56' East longitude and 924 m above mean sea level altitude) under Eastern Dry Zone (ACZ- V) of Karnataka. The soil of experimental site is red sandy loam in texture with slightly acidic in pH (6.20), electric conductivity of 0.18 dS m^{-1} and organic content was 0.24 per cent. The soil is low in available nitrogen and medium in phosphorus and potassium availability. The experiment was laid in RCBD (factorial design) comprising of two factors spacing and fertilizers, each at four levels. All recommended package of practices followed during experimentation were as per PoP of UAS, Bangalore. The recommended spacing is 45 cm × 15 cm and dose of fertilizer (RDF) was 25:50:20 kg N, P_2O_5 and K_2O ha^{-1}. Spacing levels comprised of S_1- 45 cm × 15 cm, S_2- 45 cm × 15 cm, S_3- 60 cm × 15 cm and S_4- 60 cm × 15 cm. Fertilizer levels comprised of F_1- 75 per cent RDF, F_2- 100 per cent RDF, F_3- 125 per cent RDF and F_4- 150 per cent RDF. Variety used was Hebbal Avare- 4 (HA- 4) which is photo-insensitive and has determinate growth. The required quantity of seeds for each treatment were sown based on the spacing and the recommended seed rate of 30 kg ha^{-1} with 45 cm x15 cm as per UAS-B PoP. Pre-calculated quantities of fertilizers doses in the form of urea, diammonium phosphate and muriate of potash were applied at once as basal dose to each treatment plot. The crop was sown in the month of August and rainfall (881.2 mm) received during the crop period was adequate for growth. Plot size used for experiment was 5.4 m × 3.3 m which varied as per respective spacing followed.

Plant height, number of branches, leaves, leaf area and dry matter production per plant at harvest stage were recorded from five randomly selected plants in each treatment plot. Yield parameters such as pod length, number of seeds per pod, pods per plant, seed yield per plant were recorded at harvest from five randomly selected plants in each plot. On the basis of seed weight obtained from net plot, seed yield was calculated and expressed in kg ha^{-1}.

The soil from each treatment were drawn after harvest of the crop and analysed for available nitrogen, phosphorus and potassium and these were determined by alkaline permanganate method as outlined by Subbiah and Asija (1956), Olsen's method using spectrophotometer and neutral normal ammonium acetate extractant using flame photometer as outlined by Jackson (1973), respectively. The plants from each treatment were collected, processed and used for nutrient uptake analysis. Nitrogen content was estimated by modified Micro-Kjeldhal's method as outlined by Jackson (1973) and expressed in per cent. The data obtained was subjected to statistical analysis by analysis of variance (ANOVA) to test the significance of difference among the treatments by 'F' test and a conclusion was drawn at 5 per cent probability level.

Results and Discussion

Growth Parameters of Field Bean as Influenced by Spacing and Fertilizer Levels

Growth parameters of field bean as influenced by different spacing and fertilizer levels is presented in Table 1.

Plant Height (cm)

At harvest stage, different spacing levels had significant influence on plant height. Significantly higher plant height (85.61 cm) was recorded in 45 cm × 15 cm spacing. Higher plant height under closer spacing (S_1) might be attributed due to higher plant population per unit area and close encounter by plants in terms of spatial interaction with each other, which has resulted in an increased plant height in order to intercept solar radiation for photosynthesis. Similar results were reported by Sabar (2021).

Significantly higher plant height at harvest (85.38 cm) was observed in 150 per cent RDF (F_4) level. Increase

Table 1

Effect of spacing and fertilizer levels on growth parameters of field bean at harvest

Treatments	Plant height (cm)	No. of branches plant^{-1}	No. of leaves plant^{-1}	Leaf area (cm^2 plant^{-1})	Dry matter (g plant^{-1})
Spacing levels (S)					
S_1: 45 cm × 15 cm	85.61	5.97	12.50	673.25	21.33
S_2: 45 cm × 30 cm	79.88	6.52	14.36	847.07	29.19
S_3: 60 cm × 15 cm	83.22	6.25	13.17	818.36	25.76
S_4: 60 cm × 30 cm	77.80	6.91	17.58	906.54	31.14
S.Em ±	1.62	0.16	0.64	50.76	1.28
C.D. at 5%	5.40	0.55	2.12	169.29	4.45
Fertilizer levels (F)					
F_1:75% RDF	78.29	5.88	12.63	681.71	25.16
F_2:100% RDF	79.98	6.22	13.44	784.70	26.28
F_3:125% RDF	82.86	6.66	15.02	881.52	27.34
F_4:150% RDF	85.38	6.89	16.53	897.28	28.65
S.Em ±	1.62	0.16	0.64	50.76	1.28
C.D. at 5%	4.68	0.47	1.83	146.61	3.69
Interactions (S × F)					
$S_1 F_1$	81.78	5.27	11.37	545.73	19.41
$S_1 F_2$	83.82	5.93	11.43	611.11	20.9
$S_1 F_3$	87.70	6.27	12.73	796.90	22.00
$S_1 F_4$	89.13	6.43	14.50	739.27	23.01
$S_2 F_1$	76.76	6.07	12.93	731.59	27.50
$S_2 F_2$	78.58	6.33	13.87	747.17	28.66

Continued....

TABLE 1 Continued....

Treatments	Plant height (cm)	No. of branches plant^{-1}	No. of leaves plant^{-1}	Leaf area (cm^2 plant^{-1})	Dry matter (g plant^{-1})
S_2 F_3	80.93	6.6	14.64	910.30	29.55
S_2 F_4	83.26	7.07	16.01	884.37	31.08
S_3 F_1	79.76	5.73	12.50	659.74	23.58
S_3 F_2	81.77	5.86	12.73	852.22	24.40
S_3 F_3	84.76	6.67	13.30	939.87	26.55
S_3 F_4	86.60	6.73	14.15	936.45	28.50
S_4 F_1	74.89	6.47	13.73	789.78	30.15
S_4 F_2	75.74	6.74	15.73	928.30	31.15
S_4 F_3	78.05	7.10	19.40	943.03	31.25
S_4 F_4	82.52	7.38	21.45	965.03	32.00
S.Em ±	3.24	0.33	1.27	101.52	2.56
C.D. at 5%	NS	NS	NS	NS	NS

in plant height with higher levels of fertilizer application (F_4) might be due to higher availability of major nutrients such as nitrogen, phosphorus and potassium which resulted in pronounced meristematic growth of the plants and might have resulted in higher plant height. Similar results were reported by Nimbargi (2005) and Jaisankar and Manivannan (2018). Interaction between spacing and fertilizer levels was found to be non-significant. However, higher plant height (89.13 cm) was recorded in S_1F_4.

Number of Branches Plant^{-1}

Significantly higher number of branches plant^{-1} (6.91) were noticed in 60 cm × 30 cm spacing (S_4) at harvest. This may be due to lower plant population (55,555 plants ha^{-1}) at wider spacing which had resulted in higher number of branches plant^{-1}. Increase in number of branches at wider spacing might be due to availability of space for lateral growth. These findings are in conformity with Sabar (2021) and Venugopala *et al*. (2014).

Significantly higher number of branches plant^{-1} (6.89) were observed in 150 per cent RDF level (F_4) at harvest stage. These observations were found on par (6.66 cm) with 125 per cent RDF level (F_3) at harvest. The higher doses of nutrients application might have helped in maintaining overall growth of the plant in terms of assimilation of nutrients to all parts of plant and would have resulted in higher number of branches plant^{-1}. Interaction between spacing and fertilizer levels was found to have non-significant influence, however, higher number of branches plant^{-1} (7.38) were recorded in S_4F_4.

Number of Leaves Plant^{-1}

Significantly higher (17.5) number of leaves plant^{-1} were recorded in plant spacing (S_4) with 60 cm × 30 cm at harvest. Whereas, lower number of leaves plant^{-1} (12.5) were recorded with spacing (S_1) 45 cm × 15 cm. The higher number of leaves plant^{-1} were found in wider spacing S_4 (60 × 30 cm) might be due to availability of adequate resources under wider spacing and more number of branches where less plant population (55,555 plants ha^{-1}) was existing.

Significant influence by different levels of fertilizer application was observed on number of leaves plant^{-1}. Higher number of leaves plant^{-1} (16.53) were observed in 150 per cent RDF level (F_4) and was followed by 125 per cent RDF application (15.02) as compared to other levels of fertilizer at harvest stage.

This might be mainly attributed to availability of major nutrients N, P and K which play an important role in early vegetative growth which resulted in increased number of leaves per plant. Similar findings were reported by Jagadale *et al*. (2017) and Jaisankar and Manivannan (2018). Interaction between spacing and fertilizer levels was found to be non-significant. However, higher number of leaves plant^{-1} (21.4) were recorded in S_4F_4.

Leaf Area (cm^2) Plant^{-1}

Significantly higher leaf area plant^{-1} (906.54 cm^2 plant^{-1}) was recorded in plant spacing of 60 cm × 30 cm (S_4) at harvest stage as compared to other spacings. Whereas, lower leaf area plant^{-1} (673.25 cm^2 plant^{-1}) was recorded in 45 cm × 15 cm plant spacing at harvest stage. The increase in leaf area per plant, in wider spacing might be due to promoted growth of individual plants as they were accommodated under low density per unit area.

Significant influence of fertilizer levels was found on leaf area plant^{-1}. Significantly higher leaf area (897.28 cm^2 plant^{-1}) was found in 150% RDF application (F_4) and followed by 125% RDF level (881.52 cm^2 plant^{-1}) compared to other fertilizer levels at harvest. The increase in leaf area with higher nutrient levels might be due to increased availability of nitrogen and phosphorus nutrients which would have promoted metabolic activities of plant such as cell division, differentiation and in turn higher leaf area of plant. These results are in accordance with findings of Shrikanth *et al.* (2008) and Vyas and Jamliya (2017). Interaction between spacing and fertilizer levels was found to have non-significant influence on leaf area plant^{-1}. However, higher leaf area plant^{-1} (965.03 cm^2 plant^{-1}) were recorded in S_4F_4.

Dry Matter Production (g plant^{-1})

Dry matter production (g plant^{-1}) was found statistically higher (31.14 g plant^{-1}) in spacing (S_4) 60 cm × 30 cm at harvest. Whereas, lower value of dry matter production (21.33 g plant^{-1}) was recorded with spacing 45 cm × 15 cm (S_1). Higher dry matter production per plant was recorded at wider spacing (60 cm × 30 cm) which may be attributed due to pronounced vegetative growth of plant in terms of branches and leaf area of field bean. These results are in accordance with findings of Joshi and Rahevar (2015).

Different fertilizer levels had significant influence on dry matter production in field bean. Significantly higher dry matter production (28.65 g plant^{-1}) was recorded in 150% RDF level (F_4) at harvest stage and was followed by 125% RDF application (F_3) (27.34 g plant^{-1}). Whereas, lower dry matter production (25.16 g plant^{-1}) was recorded in 75% RDF application. Optimum availability of nutrients to plants under higher levels of RDF application would have resulted in higher uptake. This further might have enhanced the vegetative growth and photosynthetic efficiency of plant and might have resulted in higher dry matter production per plant. These results are in conformity with Jaisankar and Manivannan (2018). Interaction between spacing and fertilizer levels was found to have non-significant influence on dry matter plant^{-1}. However, higher dry matter plant^{-1} (32.0 g) were recorded in S_4F_4.

Yield Parameters of Field Bean as Influenced by Spacing and Fertilizer Levels

Yield parameters of field bean as influenced by different spacing and fertilizer levels are presented in Table 2.

Pod Length (cm)

Spacing at different plant populations had significant influence on pod length. Among different spacings significantly higher pod length (5.45 cm) was recorded in spacing (S_4) with 60 cm × 30 cm. Whereas, lower pod length (4.82 cm) was recorded in spacing at 45 cm × 15 cm. These increase in pod length with wider spacing was may be due to enhanced vegetative growth of plant under wider spacing in terms of number of branches and leaf area, would have improved the source potential. This might have resulted in partitioning of photosynthates adequately to developing pods.

Significantly higher pod length (5.44 cm) was recorded in 150% RDF level (F_4). Whereas, lower pod length (4.68 cm) was recorded in fertilizer

TABLE 2

Yield parameters of field bean as influenced by spacing and fertilizer level

Treatments	Pod length (cm)	Number of seeds pod^{-1}	Number pods $plant^{-1}$	Seed yield (g $plant^{-1}$)
Spacing levels (S)				
S_1: 45 cm × 15 cm	4.82	3.68	20.65	12.17
S_2: 45 cm × 30 cm	5.00	3.96	23.81	14.18
S_3: 60 cm × 15 cm	4.83	3.83	21.46	13.68
S_4: 60 cm × 30 cm	5.45	4.26	25.35	16.19
S.Em ±	0.08	0.12	0.74	0.58
C.D. at 5%	0.28	0.43	2.57	2.03
Fertilizer levels (F)				
F_1:75% RDF	4.68	3.68	21.05	12.72
F_2:100% RDF	4.85	3.82	21.90	13.14
F_3:125% RDF	5.12	3.97	23.55	14.28
F_4:150% RDF	5.44	4.22	24.78	16.08
S.Em ±	0.08	0.12	0.74	0.58
C.D. at 5%	0.23	0.36	2.13	1.69
Interactions (S × F)				
$S_1 F_1$	4.67	3.36	18.97	10.67
$S_1 F_2$	4.81	3.49	20.3	11.79
$S_1 F_3$	4.85	3.68	21.25	12.12
$S_1 F_4$	4.99	4.19	22.10	14.11
$S_2 F_1$	4.69	3.75	22.45	13.30
$S_2 F_2$	4.92	3.82	22.86	13.39
$S_2 F_3$	4.95	4.09	24.32	14.35
$S_2 F_4$	5.44	4.16	25.6	15.67
$S_3 F_1$	4.52	3.50	20.42	12.77
$S_3 F_2$	4.63	3.86	20.82	12.89
$S_3 F_3$	4.93	3.90	21.35	13.75
$S_3 F_4$	5.19	4.05	23.25	15.32
$S_4 F_1$	4.86	3.97	22.36	14.13
$S_4 F_2$	5.06	4.23	23.6	14.52
$S_4 F_3$	5.75	4.22	27.27	16.89
$S_4 F_4$	6.14	4.61	28.17	19.22
S.Em ±	0.16	0.25	1.48	1.17
C.D. at 5%	NS	NS	NS	NS

application at 75% RDF level (F_1). Optimum levels of nutrients in plant, enhances effective translocation of photosynthates to developing pods which is catalysed by mineral nutrients. The above results are in validation with Dalai *et al.* (2020) and Chaudary (2020). Interaction effect between spacing and fertilizer levels was non-significant with respect to pod length. However, higher pod length (6.14 cm) was recorded under treatment combination $S_4 F_4$ (spacing at 60 cm × 30 cm and 150% RDF fertilizer level).

Number of Seeds Pod^{-1}

Within different spacing levels, significantly higher number of seeds pod^{-1} (4.26) was recorded in 60 cm × 30 cm spacing (S_4). Whereas, lower number of seeds pod^{-1} was recorded in spacing 45 cm × 15 cm (3.68) as compared to different spacing levels. Under wider spacing optimum availability of space per plant might have ultimately enhanced availability of nutrients, moisture and light consequently better development and increased number of seeds per pod. The increased number of seeds per pod are in accordance with findings of Murade *et al*. 2014. Among different fertilizer levels imposed, significantly higher number of seeds pod^{-1} (4.22) was recorded in 150% RDF level (F_4), which is on par with 125% RDF level (3.97) compared with other fertilizer levels.

Number of Pods Plant^{-1}

Different spacings had significant influence on number of pods plant^{-1}. Among different spacings followed, spacing with 60 cm × 30 cm (S_4) had resulted in significantly higher number of pods plant^{-1} (25.35). Whereas, lower number of pods plant^{-1} were observed in spacing 45 cm × 15 cm (20.65). Increased number of pods plant^{-1} recorded in wider spacing (S_4), was may be due to higher number of branches and access to available resources to plants under wider spacing would have resulted in establishing greater source potential of plant.

Fertilizer levels also had significant influence on number of pods plant^{-1}. Among different levels of fertilizers applied, significantly higher number of pods plant^{-1} (24.78) were recorded at 150% RDF level (F_4), which were on par with 125% RDF (F_3) application (23.55). Whereas, lower number of pods plant^{-1} (21.05) were recorded in 75% RDF application. Increased availability of nutrients with higher levels of fertilizer application would have augmented the morphological and metabolic changes in terms of growth and differentiation, ultimately resulting in higher number of pods plant^{-1}. The above findings are in conformation with the findings of Dalai *et al.* (2021) and Chaudary (2020).

Seed Yield (g) Plant^{-1}

There was significant effect of different spacing levels on seed yield per plant. Spacing at 60 cm × 30 cm (S_4) resulted in significantly higher seed yield plant^{-1} (16.19 g) compared to other spacings. Whereas, lower seed yield plant^{-1} (12.17 g) was recorded in spacing at 45 cm × 15 cm (S_1). This might be due to less competition for existing resources such as moisture, light and nutrients with wider spacing (S_4) which has favoured in producing more reproductive parts compared to higher plant density S_1 (45 cm × 15 cm). The above findings are in accordance with Joshi & Rahevar (2015) and Damoar *et al.* (2020).

Significantly higher seed yield plant^{-1} (16.08 g) was recorded in fertilizer level of 150% RDF (F_4) compared with other levels of fertilizer application, which was on par with 125% RDF level (14.28 g plant^{-1}). Whereas, lower seed yield plant^{-1} (12.72 g) was recorded in 75% RDF level of fertilizer application. Higher seed yield plant^{-1} in higher fertilizer dose which might be due to increased photosynthetic efficiency of plants in higher level of nitrogen, phosphorus and potassium availability which resulted in increased seed yield per plant. Similar results are reported by Desai *et al*. (2021) and Sabar (2021).

Yield of Field Bean as Influenced by Spacing and Fertilizer Levels

Yield of field bean as influenced by different spacing and fertilizer levels is presented in Table 3.

Seed Yield (kg ha^{-1})

Different levels of spacing imposed in field bean crop found to have significant influence on seed yield. Among the different spacings followed, significantly higher seed yield (848.70 kg ha^{-1}) was recorded in 45 cm × 15 cm spacing (S_1) as compared to other spacing levels. However, lower seed yield (568.16 kg ha^{-1}) was recorded in 60 cm × 30 cm spacing (S_4). The increased seed yield (kg ha^{-1}) in closer spacing S_1 (45 cm × 15 cm) may be due to establishment of optimum balance between source and sink aspects of individual plants and overall performance per unit area

TABLE 3

Seed, haulm yield and harvest index of field bean as influenced by spacing and fertilizer levels

Treatments	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Harvest index
Spacing levels (S)			
S_1: 45 × 15 cm	848.70	1495.24	0.36
S_2: 45 × 30 cm	683.41	1683.83	0.34
S_3: 60 × 15 cm	787.54	1829.22	0.31
S_4: 60 × 30 cm	568.16	1291.83	0.33
S.Em ±	15.69	55.73	0.02
C.D. at 5%	52.33	193.99	0.01
Fertilizer levels (F)			
F_1:75% RDF	657.34	1405.81	0.33
F_2:100% RDF	717.34	1517.89	0.34
F_3:125% RDF	748.53	1616.08	0.34
F_4:150% RDF	764.61	1760.34	0.33
S.Em ±	15.69	55.73	0.01
C.D. at 5%	45.32	160.97	NS
Interactions (S × F)			
$S_1 F_1$	712.03	1369.91	0.34
$S_1 F_2$	861.86	1424.23	0.36
$S_1 F_3$	902.63	1547.67	0.37
$S_1 F_4$	918.28	1639.16	0.37
$S_2 F_1$	650.87	1438.67	0.34
$S_2 F_2$	685.87	1626.67	0.34
$S_2 F_3$	691.63	1736.66	0.34
$S_2 F_4$	705.28	1933.33	0.33
$S_3 F_1$	721.05	1636.89	0.31
$S_3 F_2$	764.18	1768.89	0.31
$S_3 F_3$	821.10	1866.66	0.32
$S_3 F_4$	843.85	2044.44	0.31
$S_4 F_1$	545.40	1177.78	0.34
$S_4 F_2$	551.71	1251.78	0.34
$S_4 F_3$	584.50	1313.33	0.32
$S_4 F_4$	591.02	1424.44	0.31
S.Em ±	31.38	114.72	0.01
C.D. at 5%	NS	NS	NS

of land. In case of wider spacing S_4 (60 cm × 30 cm), though superior yield parameters were reported, this phenomenon did not compensate the reduced plant population per unit area (Shrikanth *et al.,* 2008) and (Nath *et al*., 2023).

Different fertilizer levels had significance influence on seed yield of field bean. Among different levels of nutrients applied, application of 150% RDF (F_4) has resulted in significantly higher seed yield (764.61 kg ha^{-1}) compared to other levels, which was on par (748.53 kg ha^{-1}) with 125% RDF level (F_3). Whereas, lower seed yield (657.34 kg ha^{-1}) was obtained in 75% RDF level of application as compared with other levels. This can be attributed to better growth of plants in terms of number of leaves, branches and dry matter production per plant under higher doses of fertilizer application, which in turn improved the photosynthesis and photosynthates assimilation for development of sink. The above results were in line with findings of Dalai *et al.* (2020). The interaction effect between different spacing and fertilizer levels recorded non-significant influence on seed yield per ha. However, higher seed yield (918.28 kg ha^{-1}) was recorded in treatment combination $S_1 F_4$ (spacing at 45 cm × 15 cm and 150% RDF level).

Haulm Yield (kg ha^{-1})

Among different spacings followed, significantly higher haulm yield was recorded (1829.22 kg ha^{-1}) in 60 cm × 15 cm spacing. Whereas, lower haulm yield was recorded (1291.83 kg ha^{-1}) in spacing 60 cm × 30 cm compared to other spacings. This might be due to effective utilization of available growth resources such as interception of solar radiation, moisture and nutrient uptake.

Different fertilizers levels had significant influence on haulm yield of field bean. Application of 150% RDF level has recorded (1760.34 kg ha^{-1}) significantly higher haulm yield, which was on par with (1616.08 kg ha^{-1}) application of 125% RDF level. Whereas, lower haulm yield was (1405.81 kg ha^{-1}) recorded in 75% RDF application level when compared to other levels of fertilizers application. The increased haulm yield under 150% RDF might be due to optimum availability of major nutrients which increased both vegetative and root growth of plant. Further, this could be due to enhanced vegetative growth as a complimentary effect due to adequate and balanced availability of necessary nutrients during the crop growth period (Suresh *et al*. 2021) and (Nath *et al*., 2023). Interaction between spacing and fertilizer levels recorded non-significant effect on haulm yield in field bean. Among different treatment combinations, higher haulm yield (2044.44 kg ha^{-1}) was recorded in treatment combination S_3 F_4 (spacing at 60 cm × 15 cm and 150% RDF level).

Harvest Index

Significantly higher harvest index (0.36) was recorded in spacing 45 cm × 15 cm (S_1) compared to other spacing levels. Whereas, lower harvest index (0.31) was observed in spacing at 60 cm × 15 cm among other spacing levels. This may be due to varied response of plant growth, in terms of seed, straw yield and overall biomass production. Harvest index, which is proportion between seed yield and total biomass, both components were found varied with different spacings. Similar results were reported by Nagamani *et al.* (2020) and Patel *et al.* (2018).

Different levels of fertilizer application had non-significant influence upon harvest index in field bean. Higher harvest index (0.34) was recorded in 125% RDF level (F_3). Among different treatment combinations between spacing and fertilizer levels higher harvest index (0.37) was recorded in treatment combination S_1 F_4 (spacing at 45 cm × 15 cm and 150% RDF level).

Economics of Field Bean as Influenced by Spacing and Fertilizer Levels

Economics of field bean as influenced by different spacing and fertilizer levels was presented in Table 4.

Gross Returns, Net Returns and B:C Ratio of Field Bean

Higher gross returns, net returns and B:C ratio were observed (Rs.61784 ha^{-1}, Rs.61784 ha^{-1} and 2.99) with 45 cm × 15 cm spacing (S_1), which has higher plant

Table 4

Economics of field bean as influenced by spacing and fertilizer levels

Treatments	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio
Spacing levels (S)			
S_1: 45 × 15 cm	61784	41090	2.99
S_2: 45 × 30 cm	50094	30900	2.61
S_3: 60 × 15 cm	57774	37829	2.90
S_4: 60 × 30 cm	41708	22889	2.22
S.Em ±	-	-	-
C.D. at 5%	-	-	-
Fertilizer levels (F)			
F_1:75% RDF	48126	29677	2.61
F_2:100% RDF	52499	33241	2.72
F_3:125% RDF	54727	34659	2.73
F_4: 150% RDF	56008	35130	2.68
S.Em ±	-	-	-
C.D. at 5%	-	-	-
Interactions (S × F)			
S_1 F_1	51999	32520	2.67
S_1 F_2	62620	42330	3.09
S_1 F_3	65639	44539	3.11
S_1 F_4	66879	44970	3.05
S_2 F_1	47631	29651	2.65
S_2 F_2	50185	31395	2.67
S_2 F_3	50735	31136	2.59
S_2 F_4	51828	31418	2.54
S_3 F_1	52928	34199	2.83
S_3 F_2	56145	36606	2.87
S_3 F_3	60201	39852	2.96
S_3 F_4	61820	40660	2.92
S_4 F_1	39944	22082	2.27
S_4 F_2	40497	22340	2.20
S_4 F_3	42885	23660	2.23
S_4 F_4	43507	23473	2.17
S.Em ±	-	-	-
C.D. at 5%	-	-	-

population per unit area and resulted in higher seed yield. In case of different levels of fertilizer application, higher gross returns, net returns and B:C ratio (Rs.56008 ha^{-1}, Rs.35130 ha^{-1} and 2.73) were recorded in 150% RDF level (F_4). Higher gross returns, net returns and B:C ratio were recorded (Rs.66879 ha^{-1}, Rs.44970 ha^{-1} and 3.11) in treatment combination $S_1 F_4$ (spacing at 45 cm × 15 cm and 150% RDF level). This might be due to ideal combination of planting geometry and fertilizers application would have enhanced crop growth in terms of both vegetative and yield attributes relatively, with specific combination of inputs used. Similarly, these factors combination might be efficient in utilizing available growth resources which has enhanced formation of higher number of fruit bearing branches and pods, which ultimately contributed in the final yield. Higher yield per unit area and inputs applied finally resulted in higher B:C ratio. These results are in validation with findings of Shrikanth (2008) and Dalai *et al.* (2021) in field bean.

Available Nutrient Status in Soil (kg ha^{-1}) after the Harvest of Field Bean as Influenced by Spacing and Fertilizer Levels

Available nutrient status in soil (kg ha^{-1}) after the harvest of field bean as influenced by different spacing and fertilizer levels is presented in Table 5.

Available Nitrogen, Phosphorus and Potassium (kg ha^{-1})

Available nitrogen, phosphorus and potassium after the harvest of field bean crop was not affected significantly by different levels of spacing. However, higher available nitrogen, phosphorus and potassium (194.64, 38.15 and 213.07 kg ha^{-1}, respectively) after the harvest of field bean crop was observed in spacing 60 cm × 30 cm and lower available nitrogen, phosphorus and potassium (184.53, 33.07 and 203.77 kg ha^{-1}, respectively) after the harvest of field bean crop was observed in spacing 45 cm × 15 cm.

Different levels of fertilizer application had significant influence on available nitrogen, phosphorus and potassium status after the harvest

Table 5

Available nutrient status in soil after the harvest of field bean as influenced by spacing and fertilizer levels

Treatments	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})
Spacing levels (S)			
S1: 45 cm × 15 cm	184.53	33.07	203.77
S2: 45 cm × 30 cm	185.55	34.47	204.71
S3: 60 cm × 15 cm	190.82	37.30	209.55
S4: 60 cm × 30 cm	194.64	38.15	213.07
S.Em ±	4.65	1.17	3.03
C.D. at 5%	NS	NS	NS
Fertilizer levels (F)			
F1:75% RDF	175.97	31.45	195.89
F2:100% RDF	185.22	35.61	205.44
F3:125% RDF	192.66	36.70	210.21
F4: 150% RDF	201.69	39.23	219.55
S.Em ±	4.65	1.17	3.03
C.D. at 5%	13.43	3.39	8.74
Interactions (S × F)			
S1 F1	172.11	30.73	192.64
S1 F2	176.36	32.67	196.25
S1 F3	192.30	33.82	210.92
S1 F4	197.02	35.05	215.26
S2 F1	177.00	32.51	196.84
S2 F2	180.82	33.14	200.36
S2 F3	185.36	34.39	204.53
S2 F4	199.03	37.84	217.11
S3 F1	172.44	31.69	192.34
S3 F2	188.07	37.68	207.03
S3 F3	194.57	37.76	213.01
S3 F4	198.52	40.09	220.83
S4 F1	182.33	30.89	201.74
S4 F2	195.62	38.94	213.97
S4 F3	198.42	40.82	216.55
S4 F4	202.19	41.95	225.01
S.Em ±	9.30	2.35	6.05
C.D. at 5%	NS	NS	NS

of field bean crop. Significantly higher available nitrogen, phosphorus and potassium status after the harvest (201.69, 39.23 and 219.55 kg ha^{-1}, respectively) was recorded in fertilizer application at 150% RDF, followed by (192.66, 36.70 and 210.21 kg ha^{-1}, respectively) 125% RDF application level and lower available nitrogen, phosphorus and potassium status (175.97, 31.45 and 195.89 kg ha^{-1}, respectively) after harvest, was observed in 75% RDF level of nutrient application.

Different treatment combinations were found to have non-significant influence on the available nitrogen, phosphorus and potassium status after the harvest of field bean. However, higher available nitrogen, phosphorus and potassium (202.19, 41.95 and 225.01 kg ha^{-1}, respectively) was found in treatment S_4 F_4 (spacing at 60 cm × 30 cm and 150% RDF level) and lower available nitrogen, phosphorus and potassium (172.11, 30.73 and 192.64 kg ha^{-1}, respectively) was recorded in treatment combination S_1 F_1 (spacing at 45 cm × 15 cm and 75% RDF level).

Higher soil available status of N, P and K after the harvest were resulted in F_4 even though higher uptake of nutrients in this level of fertilizer application was recorded. This may be due to excess of nutrients after accommodating crop growth requirements, that might have eventually resulted in higher available status of N, P and K. Field bean being a legume crop, higher levels of available nutrient with increased levels of nutrients application, might have reached optimum crop need during initial growth and pod development stages, when biological nitrogen fixation was considerably low. Further, higher levels of fertilizer application would have resulted in enhanced growth and simultaneous biological phenomenon of crop due to optimum availability of nutrients ultimately resulting in higher uptake and available status of N, P and K after the harvest of the crop. These results are in validation with Walchand (2016), Vyas and Kushwaha (2015) in soybean, Sabar (2021) in rice bean, Siddaram (2012) and Babubhai (2017) in field bean.

Nutrient Uptake of Field Bean as Influenced by Spacing and Fertilizer Levels

Nutrient uptake by field bean as influenced by different spacing and fertilizer levels is presented in Table 6.

Nitrogen, Phosphorus and Potassium uptake (kg ha^{-1})

Nitrogen, phosphorus and potassium uptake was significantly influenced by different levels of spacings. Among different spacings followed, significantly higher nitrogen, phosphorus and potassium uptake was recorded (53.20, 6.78 and 48.52 kg ha^{-1}, respectively) with spacing of 45 cm × 15 cm, which was on par (52.05, 6.64 and 47.89 kg ha^{-1}, respectively) with 60 cm × 15 cm spacing. Whereas, significantly lower nitrogen, phosphorus and potassium uptake (37.95, 4.84 and 34.91 kg ha^{-1}, respectively) was recorded with spacing 60 cm × 30 cm.

Different levels of fertilizer application had significant influence on nitrogen, phosphorus and potassium uptake of field bean. Significantly higher nitrogen, phosphorus and potassium uptake (52.36, 6.68 and 48.17 kg ha^{-1}, respectively) was recorded in application of 150% RDF level compared with other levels of application, followed by (48.73, 6.21 and 44.83 kg ha^{-1}, respectively) with 125% RDF application. Whereas, lower nitrogen, phosphorus and potassium uptake (40.77, 5.20 and 37.09 kg ha^{-1}, respectively) was observed in 75% RDF level of application.

Different treatment combinations were found to have non-significant influence upon nitrogen, phosphorus and potassium uptake by field bean. However, higher nitrogen, phosphorus and potassium uptake (62.11, 7.92 and 57.14 kg ha^{-1}, respectively) was found in treatment S_1 F_4 (spacing at 45 cm × 15 cm and 150% RDF level) and lower nitrogen, phosphorus and potassium uptake (33.74, 4.30 and 31.05 kg ha^{-1}) was recorded in treatment combination S_4 F_1 (spacing at 60 cm × 30 cm and 75% RDF level).

Increase in nutrient uptake of N, P and K in closer spacing levels (S_1 and S_3) might be due to optimum

Table 6

Nutrient uptake of field bean as influenced by spacing and fertilizer levels

Treatments	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})
Spacing levels (S)			
S1: 45 cm × 15 cm	53.20	6.78	48.52
S2: 45 cm × 30 cm	44.80	5.71	41.21
S3: 60 cm × 15 cm	52.05	6.64	47.89
S4: 60 cm × 30 cm	37.95	4.84	34.91
S.Em ±	1.10	0.14	1.02
C.D. at 5%	3.68	0.47	3.39
Fertilizer levels (F)			
F1:75% RDF	40.77	5.20	37.09
F2:100% RDF	46.13	5.88	42.44
F3:125% RDF	48.73	6.21	44.83
F4: 150% RDF	52.36	6.68	48.17
S.Em ±	1.10	0.14	1.02
C.D. at 5%	3.19	0.41	2.94
Interactions (S × F)			
S1 F1	40.51	5.21	38.37
S1 F2	50.75	6.47	46.69
S1 F3	56.41	7.19	51.89
S1 F4	62.11	7.92	57.14
S2 F1	41.17	5.25	37.88
S2 F2	43.78	5.58	40.28
S2 F3	45.91	5.85	42.24
S2 F4	48.33	6.16	44.46
S3 F1	44.65	5.69	41.08
S3 F2	51.37	6.55	47.26
S3 F3	54.91	7.00	50.52
S3 F4	57.28	7.30	52.69
S4 F1	33.74	4.30	31.05
S4 F2	36.48	4.65	33.57
S4 F3	39.83	5.08	36.64
S4 F4	41.73	5.32	38.39
S.Em ±	2.21	0.28	2.03
C.D. at 5%	NS	NS	NS

growth of the plants under ideal spacing which might have resulted in maximum exploitation of available above and below ground resources. Plant biomass production and nutrient uptake being complimentary in nature, higher plant population (1,48,048 and 1,11,111 plants ha^{-1}, respectively) in close spacing might have increased biomass production per unit area further increasing nutrient uptake. Similar findings were reported by Kishor (2020) in chia, Devaraj (2020) in pigeon pea and Shrikanth (2008) in field bean.

Increased uptake of N, P and K by field bean were reported in application of 150% RDF compared to other levels. This might be due to optimum availability of nutrients under increased levels enhanced the uptake of nutrients. Further, phosphorus which plays an important role in root growth and proliferation, would have resulted in better absorption of moisture and nutrients with higher levels of nutrient application. These results are in validation with findings of Gupta (2007) in black gram, Vyas and Kushwaha (2015) in soybean, Suresh *et al.* (2021) in pigeon pea and Sabar (2021) in rice bean.

The study revealed that both spacing and fertilizer levels significantly influenced the growth and yield parameters of field bean. Closer spacing (45 cm × 15 cm) resulted in higher plant height and seed yield per hectare, attributed to optimized resource utilization by the optimum plant density. Wider spacing (60 cm × 30 cm) improved the number of branches, leaves, leaf area and dry matter production per plant due to reduced competition. Higher fertilizer application (150% RDF) consistently enhanced plant growth, yield attributes and nutrient uptake. The combination of closer spacing and higher fertilizer levels (S_1F_4) provided the best results for maximizing seed yield and economic returns, indicating the importance of optimal spacing and nutrient management in field bean cultivation.

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Mysore J. Agric. Sci., 58 (4) : 389-397 (2024)

Development and Nutritional Assessment of Functional Food with Agathi (*Sesbania grandiflora*) Flowers

P. Yasaswini[1], K. G. Vijayalaxmi[2], and K. N. Srinivasappa[3]
[1&2]Department of Food Science and Nutrition, [3]Department of Horticulture,
College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : Yasaswini.pavuluri789@gmail.com

Authors Contribution

P. Yasaswini :
Conceptualization, carried out research work, data analysis and manuscript preparation;

K. G. Vijayalaxmi :
Conceptualization, framed research proposal, supervision and corrected manuscript;

K. N. Srinivasappa :
Provided research guidance and corrected manuscript

Corresponding Author :
P. Yasaswini

Received : September 2024
Accepted : September 2024

Abstract

Agathi (*Sesbania grandiflora*) flowers are known for their rich nutritional and bioactive compounds making them an ideal ingredient for developing functional foods. The study was undertaken to develop and evaluate agathi flower-based sandwich fillings. Three formulations of agathi sandwich fillings (FSH1, FSH2, FSH3) were prepared substituting tomato with agathi flowers at 40, 50 and 60 per cent levels respectively, along with a control filling (VSH) containing capsicum, tomato and carrot. The results showed that the FSH3 formulation was best accepted with higher sensory scores for colour (8.57), appearance (8.52), flavour (8.38), taste (8.47), texture (8.66) and overall acceptability (8.61), respectively than the control and other formulations. Proximate analysis revealed that FSH3 has significantly higher moisture (69.85 g), protein (1.6g), ash (2.04g), crude fibre (2.53g), but lower fat (7.25g), carbohydrates (16.71g) and energy (139 Kcal) per 100g compared to control (VSH) sandwich filling. Shelf-life studies were conducted for VSH and FSH3, by analysing changes in moisture content, sensory properties and microbial load (total bacterial count and total mold count) every twelve hours at room temperature. FSH3 demonstrated superior sensory scores and maintained acceptable microbial levels till 24 hours of storage period. Cost analysis indicated the economic feasibility of sandwich filling with agathi flowers. These findings highlighted the potential of agathi flowers to enhance the nutritional profile and sensory attributes of functional foods, supporting their inclusion in health-promoting diets.

Keywords : *Sesbania grandiflora,* Agathi flowers, Sandwich filling, Functional food, Sensory evaluation, Nutritional analysis, Shelf-life

In recent years, the demand for functional foods has increased as consumers become more aware of the link between diet and health. These foods provide health benefits beyond basic nutrition and can help reduce the risk of various diseases (Hasler, 2000). Originating in Japan in the 1980s, the concept has since gained global popularity (Mellentin and Heasman, 2014).

Sesbania grandiflora, commonly known as agathi, is a fast-growing, medium-sized tree that can reach a height of 10-15 meters and a diameter of up to 30 cm (Kashyap & Mishra, 2012 and Dwivedi *et al*., 2014). This versatile plant has various medicinal properties, with all its parts being beneficial. Agathi flowers have traditionally been used in various culinary applications with a range of health protective properties. The large, butterfly-shaped flowers are a prominent feature of the tree, hanging at the leaf base in clusters of 2-5. These flowers can be white, yellowish, rose pink or red, measuring 5-10 cm in length and about 30 mm wide before opening (Wagh *et al*., 2009). Agathi flowers have demonstrated significant antioxidant activity, reversing oxidative stress markers in the kidneys due to phenolic compounds and anthocyanins (Kumaravel *et al.*, 2011). Agathi flowers also exhibit anti-diabetic potential by inhibiting alpha-amylase, thereby regulating blood sugar levels and reducing blood glucose levels while enhancing antioxidant enzyme activity in diabetic rats (Kothari *et al.*, 2017 and Veerabhadrapppa & Raveendra Reddy, 2017). Furthermore, neuroprotective effects were also observed, as the flowers protect brain tissue from oxidative damage induced by chronic cigarette smoke exposure (Ramesh *et al.*, 2015). The flowers also demonstrated hepatoprotective properties, improving liver function and antioxidant levels in rats (Pari & Uma, 2003).

These diverse health benefits underscore the potential of agathi flowers as a functional food ingredient aimed at promoting health and preventing diseases. Despite their known benefits, the integration of agathi flowers into modern functional food products remains relatively unexplored. This study intended to bridge this gap by developing and evaluating sandwich fillings with fresh agathi flowers, thereby creating a novel functional food product.

The objective of this study is to formulate sandwich fillings with varying proportions of agathi flowers, assess their sensory evaluation, analyse the proximate composition of the best-accepted formulation and evaluate their shelf-life stability and economic feasibility.

Material and Methods

The present research was carried out in the Department of Food Science and Nutrition, University of Agricultural Sciences, GKVK, Bengaluru, India. The study was conducted during the academic year 2023-2024.

Procurement of Raw Materials

Agathi (*Sesbania grandiflora*) flowers were collected from the horticulture garden, UAS, GKVK, Bangalore. Petals were separated from the flowers and washed. Additional raw materials needed for the product were procured from local vendors of Bangalore, India.

Standardization of Sandwich Filling with Fresh Agathi Flowers

The control sandwich filling was prepared with capsicum, tomato and carrot. Three formulations of sandwich fillings were prepared using different proportions of agathi flowers *i.e.,* F1 (40%), F2 (50%), F3 (60%) by substituting the tomato and keep other ingredients at constant level (Table 1). The preparation process followed for making all formulations of sandwich fillings is given in Fig. 1 and the final output of products are shown in plate 1.

Sensory Evaluation of Developed Functional Foods

The sensory attributes of the formulated *Sesbania grandiflora* incorporated functional food products were analysed by 30 semi-trained panel members using a 9-point hedonic scale at the Food Science and Nutrition Department, UAS, GKVK, Bangalore. The panel members were asked to score sensory characteristics according to their importance in evaluating the acceptability of different treatments.

Table 1

Composition of Sandwich Filling Formulations

Ingredients	VSH (g)	FSH1 (g)	FSH2 (g)	FSH3 (g)
Flowers	-	40	50	60
Tomato	30	30	20	10
Capsicum	30	-	-	-
Carrot	10	-	-	-
Onion	10	10	10	10
Fresh coconut	5	5	5	5
Green chilli	1.5	1.5	1.5	1.5
Curry leaves	2	2	2	2
Ginger garlic paste	1.5	1.5	1.5	1.5
Red chilli powder	1.5	1.5	1.5	1.5
Turmeric	0.5	0.5	0.5	0.5
Salt	2	2	2	2
Seasonings	1	1	1	1
Oil	5	5	5	5

Note : VSH- Vegetable Sandwich; FSH1- Sandwich filling with 40% agathi flowers; FSH2- Sandwich filling with 50% agathi flowers; FSH3- Sandwich filling with 60% agathi flowers

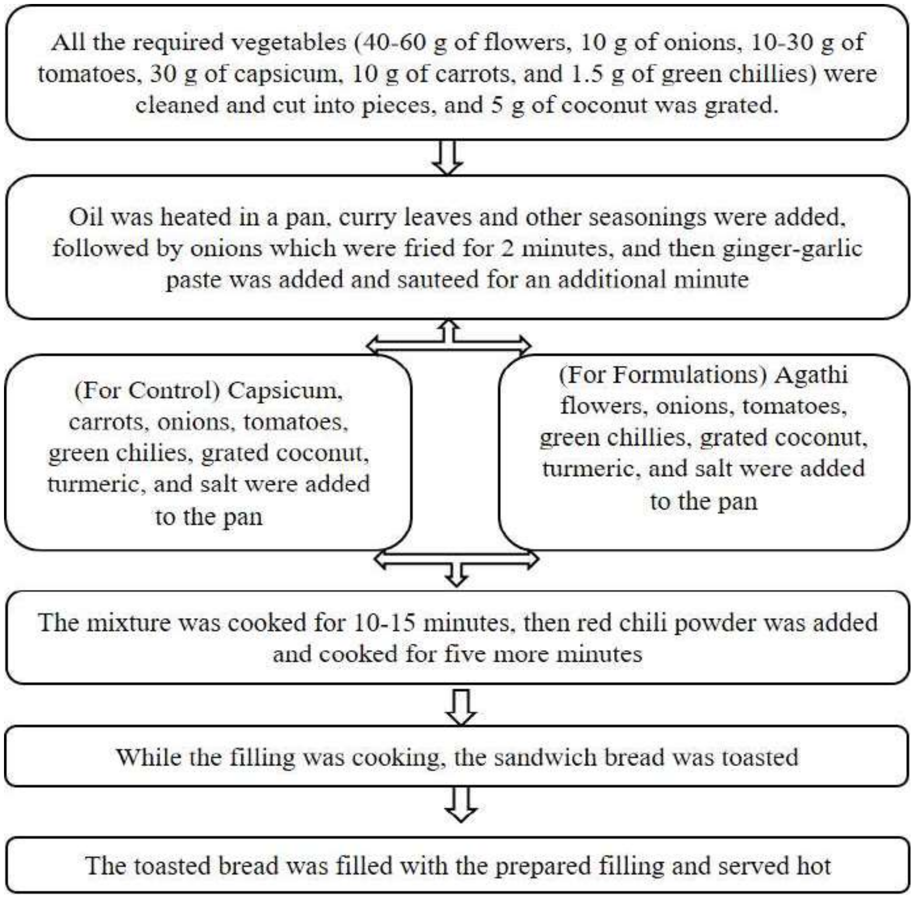

Fig. 1 : Flow chart for the preparation of sandwich filling formulations

Plate 1 : Formulations of sandwich fillings

For the sensory evaluation, the sandwich fillings were served with toasted bread to simulate actual consumption conditions and the core research focuses on the development and evaluation of the sandwich fillings. The mean scores for all characteristics were obtained and statistically analyzed.

Nutritional Analysis : Standardised Association of Official Agricultural Chemists (AOAC, 2005) protocols were used for analysing nutritional parameters such as moisture, protein, fat, as hand crude fibre. The carbohydrate content of the samples was determined utilizing the difference method. Additionally, the energy content was computed using the factorial method.

Shelf-life Study of best Accepted Products : The best accepted product by the sensory panel and the control were stored in steel boxes at room temperature. The changes in moisture content, sensory characteristics and microbial load were studied every 12 hours. Microbial analysis of the products was carried out as per the standard method by using Nutrient Agar (NA) for total bacterial count (TBC) and rose bengal agar for total mold count (TMC) (Tambekar *et al*., 2009).

Calculation of Production Costs

The cost calculation for both control and the best accepted functional food products entailed a thorough evaluation. The production cost was calculated by including the expenses of raw materials, processing costs, overhead charges which cover both operational and indirect expenses, labour costs, machinery operation costs and the addition of a profit margin.

Statistical Analysis

All the results were presented as mean ± standard deviation (SD). Independent samples t-tests were used for two-group comparisons and ANOVA with Duncan's multiple range test (DMRT) for multiple group comparisons (Rao, 2018). Statistical analyses were performed using SPSS 20.0 (IBM, USA).

Results and Discussion

Evaluation of Sensory Scores

The sensory evaluation of sandwich fillings with different levels of agathi flowers (FSH1, FSH2, FSH3) along with control sandwich filling (VSH) revealed significant differences in sensory attributes. Table 2 and Fig. 2, represent the sensory scores for colour, appearance, flavour, taste, texture and overall acceptability of different formulations.

A significant difference was observed in the sensory scores of colour ($p \leq 0.01$), appearance ($p \leq 0.01$), taste ($p \leq 0.01$), texture ($p \leq 0.01$) and overall acceptability ($p \leq 0.01$) among the different formulations, while no

Table 2

Sensory scores of sandwich fillings

Treatments	Colour	Appearance	Flavour	Taste	Texture	Overall Acceptability
VSH	8.19 ± 0.51 ^{ab}	8.09 ± 0.57 ^{ab}	8.14 ± 0.79 ^{a}	7.57 ± 0.59 ^{a}	7.66 ± 0.79 ^{a}	7.95 ± 0.58 ^{a}
FSH1	7.95 ± 0.80 ^{a}	8.00 ± 0.63 ^{a}	8.04 ± 0.80 ^{a}	8.09 ± 0.83 ^{ab}	7.90 ± 0.87 ^{a}	8.00 ± 0.77 ^{a}
FSH2	8.33 ± 0.73 ^{ab}	8.28 ± 0.56 ^{ab}	8.14 ± 0.35 ^{a}	8.23 ± 0.62 ^{b}	8.19 ± 0.67 ^{ab}	8.14 ± 0.57 ^{ab}
FSH3	8.57 ± 0.59 ^{c}	8.52 ± 0.51 ^{c}	8.38 ± 0.49 ^{a}	8.47 ± 0.67 ^{c}	8.66 ± 0.48 ^{c}	8.61 ± 0.52 ^{c}
F-value	3.23 **	3.54 **	1.02 ^{NS}	6.48 **	8.54**	5.11 **
SE (m)	0.14	0.12	0.14	0.15	0.14	0.13
CD	0.41	0.34	N/A	0.42	0.41	0.38

Note : VSH- Vegetable Sandwich; FSH1- Sandwich filling with 40% agathi flowers; FSH2- Sandwich filling with 50% agathi flowers; FSH3- Sandwich filling with 60% agathi flowers. Values are expressed as mean ± SD. Values having different superscripts in the same columns are statistically significant (p d" 0.01), ** Significant at p d" 0.01 level; NS- Non-significant; N/A- Not available

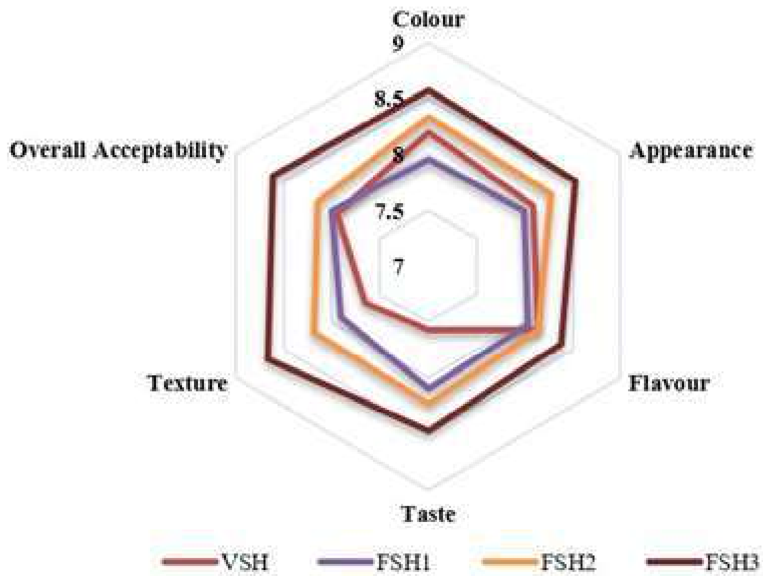

Fig. 2 : Sensory scores of sandwich fillings with different proportions of agathi flowers

significant difference was found in flavour (NS). Specifically, FSH3, the sandwich filling with 60 per cent agathi flowers, achieved the highest scores in all sensory attributes: colour (8.57), appearance (8.52), flavour (8.38), taste (8.47), texture (8.66) and overall acceptability (8.61). This indicates a strong preference for the FSH3 formulation over control and other formulations, may be due to the balanced enhancement of visual appeal, taste and texture provided by the higher proportion of agathi flowers. Comments in the sensory score card revealed that the FSH3 formulation had good sensory scores compared to other formulations because as the proportion of flowers increased, the crunchiness and palatability improved.

The control filling (VSH), which consisted of capsicum, tomato and carrot, received lower scores in comparison to FSH3 but remained moderately accepted with an overall acceptability score of 7.95. FSH1 and FSH2, with 40 and 50 per cent agathi flower incorporation received intermediate scores (8.00 and 8.14 respectively), reflecting a gradual increase in sensory appeal with higher agathi flower content.

The observed trend aligns with previous studies on functional foods, where higher incorporation of nutrient-dense ingredients such as agathi flowers tends to improve sensory attributes and overall acceptability. For instance, studies on quinoa incorporation in nachos showed that by increasing the level of functional ingredients, sensory properties such as colour, texture and overall acceptability were enhanced (Patiballa and Ravindra, 2022).

Proximate Composition of Sandwich Fillings

The proximate composition revealed that agathi flowers sandwich (FSH3) significantly influenced the nutritional profile compared to the control filling (VSH). Table 3, represented the proximate composition of the sandwich fillings.

Notably, FSH3, the formulation with the highest agathi flower content (60%), exhibited a statistically significant increase ($p \leq 0.01$) in moisture (69.85g/100g), protein (1.60g/100g), crude fiber (2.53g/100g) compared to the control (VSH). Ash content (2.04g/100g) in FSH3 also showed a significant difference ($p \leq 0.05$) compared to VSH. Conversely, FSH3 displayed a statistically significant decrease ($p \leq 0.01$) in fat content (7.25g/100g), carbohydrates (16.71g/100g) and energy (139 kcal/100g) than the control filling. These results demonstrated the nutritional enhancement achieved by incorporating agathi flowers into the sandwich fillings. These findings aligned with studies on

TABLE 3

Proximate composition of sandwich fillings

Treatments	Moisture	Protein	Fat	Ash	Crude fibre	CHO#	Energy##
VSH	65.79 ± 0.34	1.35 ± 0.03	7.44 ± 0.08	1.70 ± 0.15	2.42 ± 0.02	21.27 ± 0.42	158 ± 0.97
FSH3	69.85 ± 0.23	1.60 ± 0.02	7.25 ± 0.02	2.04 ± 0.02	2.53 ± 0.03	16.71 ± 0.20	139 ± 1.04
t-value	16.92 **	10.15 **	3.98 **	3.74 *	4.37 **	16.65 **	23.02 **

Note : VSH- Vegetable sandwich filling; FSH3- Sandwich filling with 60% agathi flowers. Values expressed as mean ±standard deviation of three determinations. CHO- Carbohydrates. #- Calculated by difference method.
##- Determined by computation.** - Significant at 0.01 per cent level, *- Significant at 0.05 per cent

composite flour mixes, where the addition of nutrient-rich ingredients enhanced the nutritional profile (Rani and Jamuna, 2023).

Shelf-life Study

Effect of Storage on Moisture Content

The moisture content of the sandwich fillings was significantly affected by storage time, as illustrated in Table 4. FSH3, which had 60 per cent agathi flowers, exhibited a higher initial moisture content (69.85 g/100 g) compared to the control filling (VSH) with 65.79 g/100 g. Over the storage period, the moisture content increased in both formulations, with FSH3 increased to 71.54 g/100 g and VSH to 67.23 g/100 g after 24 hours. The increase in moisture content was statistically significant (p≤0.01) at each time point for both formulations. The increase in moisture content during storage may be attributed to the absorption of moisture from the surrounding environment during storage.

TABLE 4

Effect of storage on moisture content of sandwich fillings

Storage time	Moisture content (%)	
	VSH	FSH3
0th hour	65.79 ^{a} ± 0.34	69.85 ^{a} ± 0.23
12th hour	66.49 ^{b} ± 0.06	70.62 ^{b} ± 0.03
24th hour	67.23 ^{c} ± 0.52	71.54 ^{c} ± 0.09
F-value	37.88 **	98.53 **
SE (m)	0.11	0.08
CD	0.41	0.30

Note : VSH- Control Vegetable sandwich filling, FSH3- Sandwich filling with 60% agathi flowers. Values expressed as mean ±standard deviation of three determinations.Values having different superscripts in the same columns are statistically significant (p ≤ 0.01). ** - Significant at 0.01 per cent level

Effect of Storage on Sensory Properties

The sensory properties of sandwich fillings with agathi flowers (FSH3) and the control vegetable filling (VSH) were evaluated over a storage period of 24 hours (Table 5).

For the control vegetable sandwich filling (VSH), significant changes in sensory properties were observed throughout the storage period. Colour scores declined drastically from 8.19 at 0 hours to 4.28 at 24 hours (p≤0.01), indicating a clear deterioration in the visual appeal of the product. Similarly, appearance scores dropped from 8.09 to 4.09 (p≤0.01), and flavour scores decreased from 8.14 to 3.23 (p≤0.01). Texture also exhibited notable reductions, with scores declining from 7.66 to 4.04 (p≤0.01). Overall acceptability significantly reduced from 7.95 at 0 hours to 3.61 at 24 hours (p≤0.01). However, taste scores were only evaluated up to 12 hours due to safety concerns, as the microbial load crossed the permissible limits after that point.

The sandwich filling with 60 per cent agathi flowers (FSH3) followed a similar trend in sensory scores over the storage period. Colour scores decreased from 8.57 at 0 hours to 3.76 at 24 hours (p≤0.01), while appearance scores dropped from 8.52 to 3.38 (p≤ 0.01). Flavour scores declined from

TABLE 5

Effect of storage on sensory properties of sandwich fillings

VSH - Storage hours	Colour	Appearance	Flavour	Taste	Texture	Overall Acceptability
0th hour	8.19 ± 0.51	8.09 ± 0.53	8.14 ± 0.79	7.57 ± 0.59	7.66 ± 0.79	7.95 ± 0.58
12th hour	7.04 ± 0.58	6.90 ± 0.43	6.66 ± 0.57	6.80 ± 0.51	6.76 ± 0.43	6.90 ± 0.62
24th hour	4.28 ± 0.46	4.09 ± 0.62	3.23 ± 0.70	-	4.04 ± 0.38	3.61 ± 0.66
F-value	308.20 **	304.97 **	274.65 **	19.69 **	230.04 **	271.60 **
SE (m)	0.11	0.11	0.15	0.12	0.12	0.13
C.D	0.32	0.33	0.43	0.34	0.35	0.38
FSH3- Storage hours	**Colour**	**Appearance**	**Flavour**	**Taste**	**Texture**	**Overall Acceptability**
0th hour	8.57 ± 0.59	8.52 ± 0.51	8.38 ± 0.49	8.47 ± 0.67	8.66 ± 0.48	8.61 ± 0.49
12th hour	6.80 ± 0.40	6.76 ± 0.43	6.19 ± 0.74	6.61 ± 0.49	6.85 ± 0.35	6.57 ± 0.50
24th hour	3.76 ± 0.70	3.28 ± 0.46	3.38 ± 0.49-		3.19 ± 0.40	3.23 ± 0.43
F-value	369.48 **	671.35 **	374.36 **	102.08 **	936.27 **	668.42 **
SE (m)	0.12	0.10	0.13	0.13	0.09	0.10
C.D	0.35	0.29	0.36	0.37	0.25	0.29

Note : VSH- Control Vegetable sandwich filling, FSH3- Sandwich filling with 60 per cent agathi flowers. Values expressed as mean ± standard deviation.** - Significant at 0.01 per cent level

8.38 to 3.38 ($p \leq 0.01$). Texture and overall accept ability also showed significant reductions, with texture scores decreasing from 8.66 to 3.23 and overall acceptability dropping from 8.61 to 3.23 ($p \leq 0.01$). As with VSH, taste scores were only evaluated up to 12 hours due to safety concerns, as the microbial load exceeded permissible limits beyond this point.

Despite showing an overall decline in sensory qualities, FSH3 generally maintained better scores than VSH in the earlier stages of storage (0 to 12 hours). However, by 24 hours, the control filling (VSH) scored higher in attributes such as appearance, taste, texture and overall acceptability compared to FSH3, indicating that the control filling retained better sensory qualities at the later stage of storage.

Effect of Storage on Microbial Population

The microbial population in vegetable sandwich filling (VSH) and sandwich filling with 60 per cent agathi flowers (FSH3) was monitored at 0, 12 and 24 hours, with both Total Bacterial Count (TBC) and Total Mold Count (TMC) recorded (Table 6).

TABLE 6

Effect of storage on microbial population of sandwich fillings

Storage hours	VSH		FSH3		Safety status
	TBC ($\times 10^2$cfu/g)	TMC ($\times 10^2$cfu/g)	TBC ($\times 10^2$cfu/g)	TMC ($\times 10^2$cfu/g)	
0 hours	0.00	0.00	0.00	0.00	Safe
12 hours	6.60 ± 0.52	0.50 ± 0.40	8.54 ± 0.98	0.65 ± 0.71	Safe
24 hours	52.3 ± 1.25	1.60 ± 0.72	66.8 ± 1.52	2.40 ± 1.05	Unsafe

Note : VSH- Control Vegetable sandwich filling; FSH3- Sandwich filling with 60% agathi flower; TBC- Total Bacterial Count; TMC- Total Mold Count

At 0 hours, no microbial growth was detected in either formulation, confirming the initial safety of the sandwich fillings. Both the VSH and FSH3 fillings were free from microbial contamination immediately after preparation, indicating that the ingredients and preparation methods were microbiologically safe. By 12 hours, there was a notable increase in microbial population. VSH exhibited a TBC of 6.60 × 10^2 cfu/g and a TMC of 0.50 × 10^2 cfu/g, while FSH3 showed slightly higher values, with a TBC of 8.54 × 10^2 cfu/g and a TMC of 0.65 × 10^2 cfu/g. Despite this increase, the microbial counts for both formulations remained within the permissible limits set by the Food Safety and Standards Authority of India (FSSAI) for thermally processed foods (TBC: 1 × 10^3 cfu/g, TMC : 1 × 10^2 cfu/g) (Anonymous, 2018). Therefore, both sandwich fillings were considered micro biologically safe at the 12-hour mark.

Production Cost of Sandwich Fillings

The total raw material cost for the control filling (VSH) is INR 5.27, while for the FSH3 filling, it is INR 9.07 (as shown in Table 7).

Including processing costs at 20 per cent, overhead charges at 30 per cent and a profit margin of 15 per cent, the total production cost for 100g of control filling comes to INR 9, whereas the FSH3 filling costs INR 15. The slightly higher cost of FSH3 is primarily due to the inclusion of 60g of agathi flowers, priced

TABLE 7

Production cost of sandwich fillings

Ingredients (g)	Rate/Kg (Rs.)	VSH		FSH3	
		Quantity used (g)	Cost (Rs.)	Quantity used (g)	Cost (Rs.)
Flowers	100	100	-	60	6
Tomato	30	30	30	10	0.3
Capsicum	50	50	30	-	-
Carrot	30	30	10	-	-
Onion	83	50	10	10	0.5
Fresh coconut	50	50	5	5	0.25
Green chilli	40	40	1.5	1.5	0.06
Curry leaves	100	100	2	2	0.2
Ginger garlic paste	80	80	1.5	1.5	0.12
Red chilli powder	200	200	1.5	1.5	0.3
Turmeric	150	150	0.5	0.5	0.07
Salt	10	10	2	2	0.02
Seasonings	-	-	1	1	0.5
Oil	150	150	5	5	0.75
Total	5.27	9.07			
Processing cost (20%)	1.05	1.81			
Overhead charges (30%)	1.58	2.72			
Profit (15%)	0.79	1.36			
Cost of product	8.69	14.96			
Round off to	Rs. 9/-	Rs. 15/-			

Note : VSH- Vegetable sandwich filling; FSH3- Sandwich filling with 60% agathi flowers at INR 4, contributing to the increased total cost compared to the control.

The FSH3 formulation, which contained 60 per cent agathi flowers, not only enhanced the nutritional profile by significantly increasing protein, crude fiber, carbohydrates and energy content, but also maintained superior sensory qualities over time compared to the control filling. Despite a slight increase in production cost, the enhanced nutritional and sensory attributes justify the value. The study also recommends the development of such food formulations as an inclusion in healthy food basket. Thus, the study exhibited the significant potential of incorporating agathi (*Sesbania grandiflora*) flowers into sandwich fillings as a functional food ingredient.

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Examining the Physiological Basis of Thermo Tolerance Using RIL's of Finger Millet

I. Akhila Anil and Y.A. Nanja Reddy
Department of Crop Physiology, College of Agriculture, UAS, GKVK, Bengaluru

In climate change scenario, high temperature and drought occur simultaneously affecting the plant growth and productivity worldwide. Among these two, the increasing temperature is difficult to overcome by management practices. Under such situations, selection of tolerant finger millet genotypes from recombinant inbred lines (RIL's) would have a great significance. Therefore, 451 and 220 RIL's of F_6 generation were evaluated under field and laboratory conditions, respectively. The field study conducted in two dates of sowing (January-D_1) and (February-D_2) with relatively higher temperature. Field study revealed the existence of large genetic variability in physiological and yield contributing traits. Employing path coefficient analysis and multiple regression analysis, mean ear-head weight, productive tillers and threshing percentage were identified as most contributing traits towards yield. Based on the heat susceptibility index for grain yield at whole plant level, the RIL's 6.5.9, 6.12.24, 6.12.8, 6.5.10 and 6.17.9 were identified as tolerant and 6.19.4, 6.12.5, 6.2.23, 6.12.7 and 6.4.2 were identified as susceptible. Further, at seedling level, based on the cellular level tolerance of RIL's to temperature induction response (TIR), the seedlings with higher survival (>92.9%) and lesser per cent reduction in recovery growth (<43.1%) , RIL's 6.1.11, 6.2.4, 6.5.10, 6.12.5, 6.13.8, 6.17.8b, 6.18.6, 6.18.22, 6.19.12 and 6.20.24 were identified as tolerant, and with lower seedling survival (<78.6%) and higher reduction in recovery growth (>70.5%), the RIL's 6.3.2, 6.4.12, 6.7.2, 6.10.5, 6.10.14,6.13.15, 6.17.10, 6.17.8a, 6.21.11 and 6.21.24 were identified as susceptible. The performance of RIL's at cellular level and whole plant level are not related to each other. Therefore, the study highlights the importance of both constitutive traits at whole plant level and acquired traits at seedling level are necessary to achieve thermotolerance in finger millet.

Analysis of Nitrogen Containing Bioactive Compounds at Different Levels of Applied Nitrogen in Mulberry

Kamatham Neeharika and M. Savitha
Department of Crop Physiology, College of Agriculture, UAS, GKVK, Bengaluru

Nitrogen is essential for growth and development of plants, as it is a key component of primary bioactive chlorophyll, amino acids, proteins, polyamines and secondary metabolites such as alkaloids. Studying nitrogen metabolism helps in understanding the plant functional processes. This study was focused on mulberry, a unique host plant of the beneficial silk worms, also essential for conserving soil and biodiversity, air quality improvement, aesthetics, medicinal purpose and cultural significance. Understanding how mulberry utilize and process nitrogen helps in optimizing fertilization strategies, enhancing crop growth and yield. Tree mulberry (Victory-1) with wider spacing (8 x 3 feet) treated with different levels of nitrogen (control, 25%, 50% and 100% RDN recommended dosage of nitrogen of bush mulberry) was evaluated for physiological traits, growth parameters, enzymatic and non-enzymatic biochemical parameters at 60 days after pruning (DAP). Nitrogen metabolizing nitrate reductase (NR) and nitrite reductase (NiR) enzyme activities, petiole protein content and leaf amino acid content were found to be significantly high at 100% RD of nitrogen. Compared to stem and petiole protein content (10-15%), leaf protein content on dry weight basis was significantly higher (35-40%). The alkaloid content was highest at 50% RD of nitrogen. The 100% RD of nitrogen (bush mulberry recommendation) increased leaf yield as compared to control in tree mulberry as well. Increased number of branches accounted for increased leaf yield. Correlation and path analysis among all the parameters, revealed that yield is directly enhanced by LAI and SLW. This experiment not only ensures the basis behind the recommended nitrogen dosage of a mulberry tree, but also provides insights into the nitrogen metabolism.

Validating the Relevance of Drought Adaptive Traits in Traits Pyramided Doubled Haploid (DH) Rice Lines under Water Limited Condition

A.S. Sandeep and B. Mohan Raju
Department of Crop Physiology, College of Agriculture, UAS, GKVK, Bengaluru

With rising population, urbanization and limited resources, boosting rice productivity per unit area is inevitable to meet the increasing food demand. However, with depleting water resources, increasing the rice productivity is a big challenge. In this scenario, it has been suggested that, pyramiding relevant drought adaptive traits would improve drought adaptation besides sustaining productivity. Pyramiding traits through conventional breeding takes longer time while, the doubled haploids (DH) technology shortens the breeding cycle. In this regard, previously the doubled haploid rice lines were developed using anthers of F1 plants of a cross between trait donor lines (epicuticular waxes, WUE, root characteristics, CLT) and characterized for the traits and identified the DH lines with pyramided traits. In the present study, presence of the pyramided drought adaptive traits and their relevance was examined by growing them under stress condition. The data highlights considerable variability in stress tolerance among the DH lines. Notably, the DH lines with all the three pyramided traits displayed superior drought tolerance, maintaining their yield even under stress conditions. Conversely, DH lines with no pyramided traits experienced a more significant reduction in yield under stress compared to those with one/two and three pyramided traits. Furthermore, the three-traits pyramided DH lines exhibited enhanced root characteristics, including greater root length, volume and weight. Molecular characterization with root and WUE markers confirmed the presence of both WUE and root traits in the traits pyramided DH lines. In conclusion, this study underscores the significance of DH technology for hastening the breeding process to pyramid the traits of interest and also signifies the relevance of the drought adaptive traits under conditions of water limitation.

Endophyte-Mediated Trait Activation Associated with Growth in Pigeonpea

A.B. Anu and N. Nataraja Karaba
Department of Crop Physiology, College of Agriculture, UAS, GKVK, Bengaluru

Endophytes are symbiotic microorganisms that mainly reside in the apoplast region within plants. Their significance is increasing due to their role in enhancing specific plant traits. Among nine initially screened fungal endophytes, eight successfully colonized the pigeonpea seedlings, confirmed by re-isolation, except the strain, P-37. Among colonized endophytes, SF-5 and K-23 exhibited increased seedling growth compared to the control. Molecular characterization identified SF-5 as *Fusarium equiseti*, K-23 as *Fusarium incarnatum* and N-14 as *Fusarium* sp. Evaluation of their role at the whole plant level under greenhouse conditions substantiated that plants inoculated with SF-5 and K-23 demonstrated significant improvements in plant height (90.4 and 80.8 cm), number of leaves and branches (25.4, 9.6 and 22.2, 9.2), total dry matter (216 and 188 g), leaf area (2427.06 and 1826.72 cm^2), chlorophyll content (2.07 and 2.09 mg/g FW), photosynthetic rate (28.04 and 26.72 $\mu mol/m^2/s$) and yield (78.79 and 71.45 g). Additionally, a significant reduction in flower drop was observed compared to N-14 (check) and the control. Under field conditions, K-23 and SF-5-treated plants demonstrated rapid growth compared to N-14, G-yellow, IIIPRR3 and the control. Hormone profiling by LCMS/MS analysis indicated that SF-5-treated plants exhibited a higher per cent increase in growth-regulating hormones Indole-3-acetic acid and salicylic acid compared to N-14, while N-14-treated plants showed a greater per cent increase in negative regulators abscisic acid and 1-aminocyclopropane-1-carboxylic acid (ACC, ethylene precursor) compared to SF-5-treated plants over control. This research highlights the potential of utilizing habitat-adapted endophytes to enhance the growth of an important pulse crop, pigeonpea.

Effect of Arbuscular Mycorrhizal Interaction with Bacterial Endophytes on Growth Promotion and Drought Tolerance in Maize (*Zea mays* L.)

NAKUL KALE AND N. EARANNA
Department of Agricultural Microbiology, College of Agriculture, UAS, GKVK, Bengaluru

EXPLORING interaction effect of bacterial endophytes with arbuscular mycorrhiza (AM) is essential to improve crop yield during drought condition. Symbiotic association of the fungus (AM) and beneficial bacteria in plant can provide more impetus to plant growth during drought. In this study, 54 bacterial endophytes were isolated from 10 drought adapted grass species and screened for drought tolerance using Poly Ethanol Glycol (PEG-800) at different concentrations. Of which 5 isolates *viz.,* P7L1, P2L2, P6R1, P7R1 and P3L2 showed drought stress tolerance up to 20 per cent PEG. These bacteria were identified as *Pseudomonas tolaasii* (P7L1), *Staphylococcus equorum* (P2L2), *Bacillus tropicus* (P6R1), *Staphylococcus saccharolyticus* (P7R1) and *Citrobacter amalonaticus* (P3L2) by 16S rRNA gene sequences. Among the five drought tolerant bacteria, *Pseudomonas tolaasii* and *Citrobacter amalonaticus* showed more efficiency than other three in drought tolerance. Therefore, the two bacteria with *Glomus mosseae* (AM) were used to understand interaction effect on drought tolerance and growth improvement in maize under greenhouse conditions. The inoculated plants subjected to drought stress during critical crop growth period (45-65 days) showed improved growth and yield of maize. But the plants exposed to prolonged drought (throughout crop period) drastically reduced plant growth and did not produce tassels suggesting that the prolonged drought is detrimental despite inoculation. Further, dual inoculation resulted in increased relative water content (RWC), photosynthetic pigments and root colonization in drought-imposed plants at critical growth stage. The co-inoculated plants also showed production of higher osmolytes, plant hormones and drought related enzymes (SOD, PPO, GPX and catalase). Thus, this study suggests that the interaction of *Glomus mosseae* with *Pseudomonas tolaasii* or *Citrobacter amalonaticus* is imperative to overcome oxidative stress at critical period of maize growth.

Characterization and Role of Gut Microflora Associated with Selected Recent Invasive Insect Pests

B. AMEER PASHA AND R. MUTHURAJU
Department of Agricultural Microbiology, College of Agriculture, UAS, GKVK, Bengaluru

STUDIES were conducted to know the host fitness attributes of invasive insect pests of coconut rugos spiralling white fly *Aleurodicus rugioperculatus* Martin and fall army worm *Spodoptera frugiperda* J.E. Smith which were reported in India recently. Gut endosymbionts associated with the above invasive insect pest which are collected from different geographical locations were assessed for the molecular identification and further the isolated gut endosymbionts were assessed for amylase, cellulase, pectinase, lipase, protease, glutathione-S-transferase and carboxylesterase activity. Among them the results of *Bacillus cereus* (MRSW01) exhibited amylase activity (1.840 μ mol/min/ml), *Proteaus vulgarius* (MRSW05) had the highest cellulase activity (5.630 μ mol/min/ml). Whereas with respect to pectinase activity, *Bacillus cereus* (MRSW01) had the highest (0.0046 μ mol/min/ml), highest lipase activity (0.260 μ mol/min/ml) which was exhibited by *Proteaus vulgarius* (MRSW05), *Psuedomons helleri* (CHRSW028) revealed highest protease activity (0.340 μ mol/min/ml). The studies also showed that the *Proteus vulgaris* CHRSW02 had the highest chitinolytic activity (0.430 nmol/min/ml) and *Pseudomonas helleri* CHRSW028 had the lowest chitinolytic activity (0.023 μ mol/min/ml). Further, the pesticide degrading activity studied for detoxification through glulathione-S-transferase and carboxylesterase at different concentration with *Proteas vulgaris* (CHRSW02) displayed the highest glulathione-S-transferase at 400 ppm, with *Bacillus subtilis* (CS033) exhibited the highest carboxylesterase activity at the same concentration. These findings shed light on the enzymatic diversity of bacterial isolates, potentially benefits applications in bioremediation and biotechnology through further research in needed to fully leverage their potential.

Effect of Arsenic Resistant Fungal Endophytes on Growth Promotion and Metal Stress Tolerance of Rice (*Oryza sativa* L.) under Arsenic-Metal Stressed Condition

K.R. Abhinandana and K. Nagaraju
Department of Agricultural Microbiology, College of Agriculture, UAS, GKVK, Bengaluru

Arsenic contamination in soil poses a serious threat to sustainable agriculture and human health. The conventional methods are used for remediation of contaminated soils and these methods pose environmental threats and are costly. There is a need for most economical, efficient and promising solution. Therefore, attempted to get arsenic tolerant fungal endophytes (83) from the plants of arsenic-contaminated regions of Karnataka. The eight endophytes could efficiently endure metal stress upto 2000 ppm with tolerance index >0.5. These eight isolates were subsequently evaluated for *in vitro* arsenic removal potential under 100 ppm arsenic concentration. The isolate S3P1S1 exhibited significantly higher bioaccumulation, biosorption and arsenic removal from the medium followed by S4P2L2, while the highest biovolatilization was observed with isolate S3P1S1 followed by S1P1R1. All the eight endophytes exhibited plant growth promoting activities; remarkably S4P2L2 and S3P1S1 yielded significant higher levels of indole acetic acid, siderophores and exhibited phosphate solubilization. These two isolates S3P1S1 and S4P2L2 were molecularly characterized and identified as *Fusarium nygamai* and *Penicillium crustosum,* respectively. They were further assessed for arsenic tolerance and growth promotion of rice under arsenic stress (50 and 75 mg /kg) under greenhouse condition. The endophytic colonization of rice resulted in the recovery of chlorophyll pigments, significantly improved water use efficiency, growth and physiological attributes compared to control. Additionally, endophytic association decreased the contents of methylglyoxal and malondialdehyde by improving the activity of enzymes involved in glyoxalase pathway, leading to increased plant tolerance to arsenic toxicity. Moreover, fungal endophytes inoculated rice plants exhibited reduced arsenic accumulation in rice grains compared to the respective control under both 50 and 75 mg /kg arsenic stress. Therefore, the study concludes that tested endophytes have the potential to improve arsenic tolerance in rice and can be used as efficient inoculants to substitute existing conventional methods.

Effect of Microbial Inoculants and *Jeevamrutha* on Growth and Yield of Cowpea (*Vigna unguiculata* L.)

S. Lavanya and R.N. Lakshmipathi
Department of Agricultural Microbiology, College of Agriculture, UAS, GKVK, Bengaluru

The field experiment was carried out to evaluate the effect of microbial inoculants and *jeevamrutha* on growth and yield of cowpea (*Vigna unguiculata* L.) under organic production system at RIOF, University of Agricultural Sciences, GKVK, Bengaluru. It included eight treatments and three replication plotted under Randomized Complete Block Design (RCBD). The study was conducted to maximize the production of cowpea using KBC-9 variety through the application of microbial inoculants and *jeevamrutha*. Based on Duncan's Multiple Range Test, T_8 inoculated with *Rhizobium leguminosarum* + *Aspergillus awamori* + *Jeevamrutha* outperformed the other treatments which recorded significant plant height (39.83 cm), number of branches/plant (8.57), number of leaves/plant (23.19), seed yield (8.38 q ha^{-1}), haulm yield (21.42 q ha^{-1}), number of pods / plant (14.86), number of kernels / pod (15.29), nodule weight / plant (0.57 g), effective nodules (61.12). Soil enzyme activity *i.e*., soil dehydrogenase (43.33 µg TPF g^{-1} hr^{-1}) and soil urease (33.17 µg NH_4^+ N hr^{-1}) and significant microbial population *viz*., bacteria (86.26 x 10^6 CFU/g soil), fungi (23.25 x 10^3 CFU/g soil), actinomycetes (21.90 x 10^2 CFU/g soil), free living N_2 fixers (38.16 x 10^6 CFU/g soil), PO_4 solubilizers (21.84 x 10^3 CFU/g soil), *Rhizobium leguminosarum* (32.39 x 10^6 CFU/g soil) was found significant in T_8 than the rest of the treatments. Absolute control recorded the lowest growth, yield and microbial population. Hence, we can conclude that T_8 proven to be effective to improve the overall growth, yield, nutrient uptake and soil microbial activity in cowpea.

Genome Analysis and Development of Formulations of Antagonistic *Bacillus subtilis* against Phytopathogens

K.S. Ankitha and T.K. Radha
Department of Agricultural Microbiology College of Agriculture, UAS, GKVK, Bengaluru

Bacillus subtilis, an endospore forming bacterium known for its antagonistic attributes against phytopathogens through production of secondary metabolites, including lipopeptides. In the present study, we investigated antagonistic potential of *B. subtilis* strain BSWG1 against *Sclerotium rolfsii* and *Rhizoctonia solani*. BSWG1 exhibited 55.50 and 100 per cent inhibition of *S. rolfsii*in dual and volatiome bioassay, respectively and 100 per cent inhibition of *R. solani* in volatiome bioassay. Poison food technique demonstrated inhibitory effect with 100 per cent reduction in both *S. rolfsii* and *R. solani* growth, when exposed to lipopeptide at concentration 100 µL/mL. Moreover, pot experiments revealed promising 76 per cent reduction in disease incidence in Tomato. We further characterised genomic makeup of BSWG1 by sequencing its genome using Illumina NextSeq500 platform. Biosurfactant genes, responsible for surfactin (*SrfAA*, *SrfAC*, *SrfAD*, *SrfP*), fengycin (*PpsE*, *PpsD*, *PpsC*, *PpsB*) and putisolvin (*DnaK*) production were identified using Blast X diamond tool. Furthermore, liquid chromatography-mass spectrometry (LC-MS) was employed to characterize lipopeptides produced by BSWG1, revealing presence of surfactin (eight peaks), fengycin (five peaks), iturin (four peaks) and novel lipopeptides. Additionally, antiSMASH analysis was done utilizing whole genome data of BSWG1 which validated LC-MS findings by identifying gene clusters with 100 per cent similarity for fengycin, bacilaene, bacillibactin, subtilosin A, bacilysin and 82 per cent similarity for surfactin synthesis genes. Further biosynthetic gene cluster (BGC) of zwitteremicin A *viz*., *Zwa5A*, *Zwa6*, *Zwa5A* and *Zwa5A* were also identified. Efficient formulations of BSWG1 (capsule, liquid, talc) were developed. Bioassays, whole genome sequencing, LC-MS analysis demonstrated strain efficacy which facilitated development of efficient formulation.

Influence of ACC Deaminase Positive Phosphate Solubilizing Bacteria and Arbuscular Mycorrhizal Fungi on Growth and Yield of Soybean [*Glycine max* (L.) Merr.] under Different Moisture Deficit Regimes

Athira Sreenivasan and K. Tamil Vendan
Department of Agricultural Microbiology, College of Agriculture, UAS, GKVK, Bengaluru

Drought causes significant reductions in growth and yield of several important crops. Overcoming drought by crop plants involves a complex phenomenon, where plants find ways mainly through physiological adaptation. However, in nature, the plants also rely on microbes to mitigate the hazardous drought effects. The 1-aminocyclopropane-1-carboxylate (ACC) deaminase-producing PGPR offers drought stress tolerance by regulating plant ethylene levels. Arbuscular mycorrhizal fungi (AMF) and phosphate solubilizing bacteria (PSB) could interact synergistically because PSB solubilizes sparingly available phosphorous into soluble compounds that AMF can absorb and transport to the host plant. Little is known about the interactions between these two groups in terms of promoting soybean plant growth [*Glycine max* (L.) Merr.], which is widely planted by the local farmers. The present study was conducted to isolate and characterize ACC deaminase positive PSB and investigate the inoculation effects of PSB and AMF on the growth and yield of soybean under different moisture deficit regimes (40, 60 and 80% FC). The dual inoculation of pre-eminent phosphobacterial isolate, *Klebsiella variicola* (PAR03), selected by principal component analysis and AMF-*Glomus* sp., in combination with a higher level of rock phosphate (45 g), showed the significant increase in plant growth parameters compared toboth uninoculated and solely inoculated treatments in pot culture under different moisture deficit regimes. Also, an elevated production of cellular osmolytes, leaf chlorophyll content, plant phosphorus content and yield were observed in consortium treatment. This consortium could be an effective bio-inoculant for crop improvement in drought-affected agricultural fields.

Effect of Lipo-Chitooligosaccharide on Arbuscular Mycorrhizal Association in Tomato (*Solanum lycopersicum* L.)

Sachin Kenchannavar and R.N. Lakshmipathi
Department of Agricultural Microbiology, College of Agriculture, UAS, GKVK, Bengaluru

The study investigated the impact of Lipo-Chitooligosaccharide (LCO) fortified Arbuscular Mycorrhizal fungi (AMF) on the growth and yield of *Solanum lycopersicum* L. (Tomato). Conducted over the period of 2022-2023, the research employed ICAR-IIHR variety *Arka Rakshak* at L-block, IFS demo unit, ZARS, GKVK, Bengaluru. Employing a randomized complete block design (RCBD) with nine treatments and four replications, the study aimed to understand the influence of LCO fortification on AM association and soil microbial properties. With the application of LCO done twice at 10 and 40 days after transplanting, the data collection involved plant parameters at 30, 60 and 90 days after treatment (DAT) and soil samples at different stages for microbial and soil nutrient analysis. The results revealed that treatment T_8 (100 % RDF + AM + LCO @ 10 kg/ha) exhibited the highest plant growth parameters, earliest flowering (38 DAT), picking times (69 DAT) and superior yield parameters. Moreover, T_8 demonstrated increased microbial populations, enzymatic activities, mycorrhizal colonization (78.26 %) and phosphorus uptake, ultimately leading to enhanced tomato yield (51931 kg/ha) and improved soil quality. Statistically, T_8 was significantly superior, closely followed by T_9 (75 % RDF + AM + LCO @ 10 kg/ha). In conclusion, the application of AMF combined with LCO @ 10 kg/ha and 100% RDF presents a good approach to maximizing tomato growth and yield while simultaneously enhancing soil quality. The study emphasizes the potential of biofertilizers as effective alternatives to chemical fertilizers, paving the way for sustainable and eco-friendly agricultural practices.

Development of Transgenic Ridge Gourd [*Luffa acutangula* (L.) Roxb] against *Tomato Leaf Curl New Delhi Virus* (Geminiviridae:Begomovirus)

Ananya and N. Nagesha
Department of Plant Biotechnology, College of Agriculture, UAS, GKVK, Bengaluru

Ridge gourd is a very popular vegetable crop of cucurbitaceae family. At present, one of the major constraints in ridge gourd production is the yellow mosaic disease caused by ToLCNDV. At present, the research study was performed as preliminary work for the development of transgenic ridge gourd which may confer resistance against ToLCNDV. The strategy employed two genes namely, *CP* and *Rep* to develop the disease resistant plants. On the basis of the morphological symptoms, the infected samples were collected and the total DNA was isolated. The two genes were amplified using respective gene specific primers with the amplicon size of 771bp for *CP* and 1085 bp for *Rep* gene. The purified *CP* and *Rep* genes were cloned to pTZ57R/T vector. Further, *CP* and *Rep* genes were moved into plant expression vector pBI121 and pB4NU, respectively. Both the vectors having respective gene construct were transformed into *Agrobacterium tumefaciens* strain GV3101, respectively. *CP* gene was agroinfiltered into tobacco for the transient expression of the coat protein. Further, *in planta* transformation of the *CP* gene construct was done in the ridge gourd seeds. PCR analysis and SDS PAGE analysis showed the presence of gene and a distinct protein band of size 30.5 kDa in tobacco and ridge gourd plants. Further, *in silico* studies on *CP* and *Rep* gene were also done to compare these genes in the other strains of ToLCNDV and check the domain of these proteins responsible for infectivity.

Computational Analysis of Receptor Binding Domain (RBD) in Spike Glycoprotein of SARS-Cov-2 Variants to Evaluate their Binding Potential to the Receptor Angiotensin-Converting Enzyme 2 (ACE2)

NISHAD SULTANA AND S. NAGESHA
Department of Plant Biotechnology, College of Agriculture, UAS, GKVK, Bengaluru

THE emergence of the novel coronavirus SARS-CoV-2 gave rise to the unprecedented global health crisis of the COVID-19 pandemic, accompanied by the proliferation of numerous variants, some of which have raised concerns. In this study, we harnessed computational techniques to scrutinize these Variants of Concern (VOCs), including various Omicron subvariants. Our approach involved the utilization of protein structure prediction algorithms and molecular docking to explore the impact of mutations within the Receptor Binding Domain (RBD) of SARS-CoV-2 and its interactions with the human angiotensin-converting enzyme 2 (hACE-2) receptor. The prediction of RBD structures for naturally occurring SARS-CoV-2 variants was performed using the tr-Rosetta algorithm. Subsequent docking and binding analysis employing HADDOCK and PRODIGY illuminated crucial interactions occurring at the Receptor-Binding Motif (RBM). Our findings revealed a hierarchy of increased binding affinity between the human ACE2 receptor and the various RBDs, with the order as follows: wild type (Wuhan-strain) < Beta < Alpha < Gamma < Omicron-B.1.1.529 < Delta < Omicron-BA.2.12.1 < Omicron-BA.5.2.1 < Omicron-BA.1.1. Notably, Omicron-BA.1.1 demonstrated the highest binding affinity of -17.4 kcal mol^{-1} to the hACE2 receptor among all the mutant complexes. Moreover, our analysis revealed that when active RBD residues underwent mutations, binding affinity and intermolecular interactions were consistently enhanced across all mutant complexes. By investigating the distinctions among different variants, this study lays a robust foundation for structure-based drug design targeting the RBD region of SARS-CoV-2, particularly pertinent to emerging variants.

Understanding the Molecular Basis of Differences in Finger Number in Finger Millet (*Eleusine coracana*)

H.S. HEMASHREE AND GEETHA GOVIND
Department of Plant Biotechnology, College of Agriculture, UAS, GKVK, Bengaluru

FINGER MILLET (Nutri-cereals), is highly nutritious, grown in marginal soils with least inputs that contributes to food and nutritional security of Karnataka. It is important to increase the grain yield to meet the increasing demand. Grains in cereals are formed from fertilized florets in inflorescence. Increasing floret number per spikelet or spikelet's per plant and regulating floret fertility or abortion rate are promising strategies to improve grain yield. Molecular mechanism underlying inflorescence meristem (IM) identification, maintenance and differentiation is obscure in finger millet, but relatively well elucidated in rice, maize, wheat, barley and foxtail millet. These plants have led in identification of signalling network Clavata-Wuschel (CLV-WUS) pathway, knotted 1-like homeodomian proteins, G-protein that regulate stem cell maintenance and IM initiation. The MADS-Rice Centroradialis (RCN) pathway, Ramosa (RA), frizzy panicle (FZP), TCP transcription factor and others mediate inflorescence branching, meristem identity and inflorescence architecture. In this study attempt was made to understand the molecular mechanism regulating IM development or finger number in finger millet, which has aunique spike architecture using genotypes contrasting for finger number- HF (High finger number) and LF (Low finger number). The development of the IM was delayed in response to drought stress in both the LF and HF genotypes. The HF types-maintained finger length under drought stress similar to plants under control condition. The Expression of five different genes *viz., APO1, FZP, MADS5, RCN4* and *WUS* was studied for its role in IM development under drought and control condition. The reduction in finger number and finger length correlated with the expression pattern of key genes (*APO1, FZP, RCN4, MADS5* and *WUS*) of IM development.

Morphological and Molecular Screening of Tomato (*Solanum lycopersicum* L.) Accessions for Fruit Shape and Yield

K.R. VINUTHA AND S. SHYAMALAMMA
Department of Plant Biotechnology, College of Agriculture, UAS, GKVK, Bengaluru

TOMATO is important vegetable crop grown and consumed worldwide. It is regarded as a productive and protective food and its consumption strengthens the immune system and is protective against infectious and degenerative diseases. The present study involved screening of sixty one tomato accessions for fruit shape and yield. Genetic variability components showed higher magnitude of variation for all the traits studied and was evident through values of range and mean performance. Correlation studies indicated a positive and significant association of yield with number of fruits per cluster (0.492**) and number of fruits per plant (0.524**), while path coefficient analysis revealed higher positive direct effects *viz.,* fruits per plant (0.538), fruit diameter (0.364) and number of fruits per cluster (0.314) on yield per plant. Genetic divergence analysis based on morpho-phenological and productivity traits, grouped all accessions in three clusters, out of which cluster 1 being largest with 57 accessions. Higher intra cluster distance was observed in Cluster 2 (423.04), followed by Cluster I (401.88). Based on the cluster means, the accessions with superior yield and yield attributing traits were found to be grouped in Cluster 1 hence, while choosing the accessions for further use in crop breeding programme one may find useful accessions from Cluster 1. The identified accessions from cluster 1 are EC-162516, EC-620489, EC-632944, EC-620508, EC-631359, EC-620484, EC-631406, EC-631371, EC-620425, EC-631378 and EC-620552. The fruit shape specific InDel markers were used for molecular analysis of 61 accessions. Among the 15 InDel markers used sli2384 and sli565 have shown higher PIC (0.41) values. The higher gene diversity was observed in sli1147 (0.49) followed by sli2384 (0.48). The selected accessions can be further screened by conducting multilocation trials for pest and disease resistance as well as for their suitability for culinary and processing purpose.

Machine Learning Approach for Pesticide Resistance Prediction Using Sequence Activity Relationship in Cytochrome P450

AKASH M. HOSAMANI AND P.S. BENHERLAL
Department of Plant Biotechnology, College of Agriculture, UAS, GKVK, Bengaluru

INSECT pests significantly impact Indian agriculture with the overuse of pesticides leading to the development of pesticide resistance among these pests. Insect pests are evolving metabolic resistance by producing specific enzymes like cytochrome P450 to detoxify pesticides. This study explores the use of machine learning techniques to predict the enzyme activity of cytochrome P450 monooxygenase. The study aims to establish a quantitative relationship between the protein sequence and the enzyme activity, measured by the substrate dissociation constant (K˜ value). Protein sequence and activity data were retrieved from biological databases such as NCBI, UniProt and BRENDA. The protein sequences were numerically encoded using 57 selected features from the amino acid index database and were then transformed into the frequency domain using the fast fourier transformation, revealing hidden periodicities and patterns in the protein sequences. The sum of the FFT values for each protein is then correlated with the K_m value using linear regression analysis. This has showed that different substrate categories of cytochrome P450 monooxygenase exhibit different patterns and relationships. Numerical encoding schemes based on alpha-NH chemical shifts, normalized frequency of C-terminal beta-sheet, beta-strand indices for beta-proteins and hydrophobic parameter pi resulted in R^2 value of 0.44, 0.51, 0.99, 0.79, respectively for the datasets coenzyme, unsaturated fatty acids, flavonoid, steroids as substrate class.

Phytosynthesized Silver Nanoparticles in Groundnut Production: Effect of SW-AgNPs on Biotic and Abiotic Stress Tolerance

S. SATHISH AND VEENA S. ANIL
Department of Plant Biotechnology, College of Agriculture, UAS, GKVK, Bengaluru

THE current research demonstrates that application of phytosynthesized silver nanoparticles (AgNPs) in Groundnut (*Arachis hypogaea* L.) can significantly mitigate biotic and abiotic stresses and enhance yield. The scaled-up procedure of phytosynthesis involved the reduction of Ag^{+} to Ag^{o} nanoparticles using sandalwood leaf extract. SEM, FTIR, AFM, XRD, TEM and catalytic dye degradation assays were used to characterize and determine the shelf-life of scaled-up phytosynthesized AgNPs. The AgNPs remained stable and maintained the spherical shape and particle size 20-30 nm over six months. In addition, AgNPs degraded the dyes CBB, MBB and BB with comparable efficiency over six months, proving the stability and catalytic activity of AgNPs over long term room temperature storage. The pot and field experiments carried out in this study confirmed the benefit of application of phytosynthesized AgNPs as a seed treatment and foliar sprays. The pot experiment involving the imposition of drought stress to AgNPs treated plants reveals that phytosynthesized AgNPs have positive impact on drought stress tolerance and GC-MS analysis shows that treated plants produce antimicrobial, anti-inflammatory, anti-stress related compounds. The biochemical analysis of treated plants indicates enhanced antioxidant enzyme activities (SOD, POX), proline content and total phenolic and flavonoids that can contribute drought stress tolerance. The field experiment confirmed that application of phytosynthesized AgNPs to groundnut crop significantly increased the chlorophyll levels (control-1.34 mg/ g FW and ST + 2 sprays of AgNPs (2 months and 5 months old) + RF- 2.27 mg/ g FW), and resulted in yield enhancement of 26.55 over control and 14.86 per cent over the fungicide treatment and helped manage late leave spot disease. The GC-MS analysis revealed unique metabolites which are induced due to AgNPs treatment.

Evaluation of Microbial Consortia Developed from Compost Tea for Enhancing Production under Organic Cultivation of Groundnut (*Arachis hypogaea* L.): Biochemical Evaluation of Induced Systemic Resistance and Tolerance towards Biotic and Abiotic Stresses

P.G. HEMASHREE AND VEENA S. ANIL
Department of Plant Biotechnology, College of Agriculture, UAS, GKVK, Bengaluru

THIS study investigates eco-friendly alternatives to address environmental and health concerns associated with widespread agrochemical use in modern agriculture, focusing on groundnut cultivation. The experiments were conducted at Research Institute on Organic Farming during 2022 *kharif* season to evaluate the efficacy of compost tea derived microbial consortia *viz.,* NPF (UASB_CT1) consortium. The results show significant improvements in plant height (30.6 cm), fresh weight (44.47 g), chlorophyll content (4.81 mg/g), POX (213.49 µg/min/mg protein) and SOD (29.88 µg/min/mg protein for 50 per cent inhibition) activities, leading to higher yields and disease resistance in NPF treatment compared to control. Greenhouse experiments in 2023 summer demonstrated the consortium's effectiveness in mitigating drought stress with NPF treatment showing lower reductions in chlorophyll content (3.05%) and relative water content (24.89%) compared to controls. GC-MS analysis from both field and pot experiments revealed unique metabolites triggered by compost tea and consortium treatments, potentially contributing to plant growth, development and drought tolerance. The shelf-life evaluation indicated the stability of the liquid microbial consortium during storage with observed increases in IAA, GA and cytokinins levels in microbial consortium NPF (UASB_CT1) throughout that period. This research highlights the potential of compost tea-derived microbial consortium, particularly NPF (UASB_CT1), as a simple, eco-friendly and cost-effective solution for enhancing organic groundnut cultivation. The findings offer a valuable contribution to organic agronomic practices, providing farmers with an effective and environmentally friendly approach to groundnut production.

Studies on Morphological, Molecular and Phytochemical Contents in Cluster Bean [*Cyamopsis tetragonoloba* (L.) Taub.] Accessions

Gond Pallavi Pradeep and S. Shyamalamma
Department of Plant Biotechnology, College of Agriculture, UAS, GKVK, Bengaluru

Cluster bean is an important self-pollinated, restorative leguminous vegetable crop. It is a multipurpose crop and serves as vegetable, animal feed, fodder as source of phytochemicals and galactomannan gum for industrial use. The present investigation was carried out to screen cluster bean accessions for pod and seed quality traits, through morphological and molecular methods. The analysis of variance revealed significant difference among the accessions for all the morphological quantitative traits, indicating the presence of sufficient genetic variability. Correlation analysis indicated a positive and significant association of pod yield with number of pods per plant (0.78) and seed yield with plant height (0.43). Genetic divergence based on morphological and productivity traits revealed four clusters with maximum number of 17 accessions in cluster IV. Highest intra cluster distance was observed in cluster III (5.51). IC41089, IC8831, IC41063, IC41061, IC 41078 found superior for important pod and seed yield traits like green pod yield per plant, number of pods per plant, number of seeds per pod, seed yield per plant which need to be further screened. Molecular characterization was carried out using fifteen SSR markers for diversity analysis. The dendrogram obtained from molecular data analysis grouped the accessions into two clusters, cluster I (5 accessions) and cluster II (28 accessions with check variety Pusa Navbahar). Polymorphic Information Content (PIC) value ranged from 0.00 to 0.35 with the mean of 0.06. GC-MS analysis of cluster bean accessions showed the presence of different phytochemicals in the methanolic and ethylacetate extract of pod and seed samples. The major phytochemicals identified in the methanolic extract includes cis-vaccenic acid, hexadecanoic acid, methyl ester, 5-Amino-2-methoxyphenol, glycerin while ethyl acetate extract included propanoic acid, ethane,1-decanol,1-nonadecene, 13-docosenamide. Oleic acid and phytol were common in both the extracts. Identification of these phytochemicals validates the medicinal value of cluster bean.

Homology Modelling of Vegetability Controlling Proteins in Vegetable Soybean in Comparison with Grain Soybean (*Glycine max* M.)

Shivaraj Ganigi and Mohan Chavan
Department of Plant Biotechnology, College of Agriculture, UAS, GKVK, Bengaluru

This research aims to uncover the molecular and genetic basis for distinctions between vegetable and grain soybeans, focusing on proteins associated with vegetability traits mainly flavour, tissue softness and sweetness. Using raw protein sequences, BLASTP analysis was conducted with the soybean cv William 82 assembly as the reference genome against Glyma Fiskeby III (vegetable soybean) and Glyma Lee (grain soybean) assemblies. Results were clustered and filtered based on identity percentage, mismatches, gap opens, query length and percentage query coverage. Protein structures were predicted using SWISS-MODEL tool and quality was assessed using GMQE and QSQE scores. Structural variations were visualised and superimposed using PyMol. RMSD values above 1.2 Å and TM-score values > 0.5 revealed dissimilarities among protein structures. The proteins that showed variation which could contribute to trait flavour are Glyma.04G10451, Glyma.06G268700, Glyma.06G213600, Glyma.08G087100, Glyma.11G037100, Glyma.15G41040 and Glyma.18G47780. Similarly for tissue softness include Glyma.05G160000, Glyma.12G017600, Glyma.13G126000 and for the trait sweetness are Glyma.07G065500, Glyma.09G021900, Glyma.09G042200, Glyma.09G076600, Glyma.15G184300 and Glyma.20G028800. A heatmap analysis showed amino acid composition differences between vegetable and grain soybean for flavour-contributing proteins. Notably, flavour-contributing proteins displayed significant variations in alanine, aspartate and glutamate amino acid levels, potentially influencing soybean flavour profiles, while proteins related to tissue softness and sweetness displayed minimal distinctions. The study contributes insights into genetic and molecular variations, offering potential applications in vegetable soybean breeding and crop improvement.

Testing the Efficacy of Plant Leaf Extracts from Jackfruit (*Artocarpus heterophyllus* Lam.), Guava (*Psidium guajava* Linn.) and Tulsi (*Ocimum sanctum* Linn.) on Postharvest Diseases in Fruits

Mohammed Rabban and K.M. Harinikumar
Department of Plant Biotechnology, College of Agriculture, UAS, GKVK, Bengaluru

Grapes and guava are very important fruits in India. Due to their perishable nature they are prone to postharvest diseases. The soft rot in grapes (*Aspergillus* spp) and fruit rot in guava (*Alternaria* spp) are the threatening postharvest diseases effecting the fruit quality and storage. The isolated post-harvest pathogen from the grapes and guava were characterized as *Aspergillus niger* and *Alternaria tenuissima* by using ITS (Internal Transcribed Spacer region) primers. Guava, jackfruit and tulsi extracts were prepared using methanol and water as solvents. Antifungal activity of the plant extracts was tested against *Aspergillus niger* and *Alternaria tenuissima* using poison food technique. In *A. niger* and *A. tenuissima,* combination of jackfruit, guava and tulsi methanol leaf extract showed 93.61 per cent and 91.22 per cent and in aqueous extracts 85.05 per cent and 89.53 per cent mycelia inhibition, respectively. Grapes and guava fruits that were sprayed in the orchard with plant extracts extended their shelf life. Combination of jackfruit, guava and tulsi methanol leaf extract at 8000ppm showed minimum of 3.49 per cent and 4.63 per cent and in aqueous leaf extracts 6.25 per cent and 5.63 per cent of weight loss, less TSS accumulation was in methanol leaf extracts 16.24 per cent and 7.32 per cent was recorded. In aqueous leaf extracts 16.82 per cent and 7.27 per cent was reported. Shelf life was extended upto 16 and 14 days in methanol leaf extract and 12 and 13 days in aqueous leaf extract in grapes and guava, respectively. The qualitative phytochemical screening of selected plant extracts showed the presence of various phytochemicals like tannins, phenols, flavonoids, terpenoids, saponins and alkaloids. All these findings implied the availability of various phytochemicals might be a source of antifungal agent for inhibition of pathogens and to improve the postharvest quality of fruits.

Identification of Quantitative Trait Loci, Prediction of Genomic Estimated Breeding Values and their Cross-Validation for Resistance to Southern Rust (*Puccinia polysora* Underw.) in Maize (*Zea mays* L.)

Noor E. Mujjassim and H.C. Lohithaswa
Department of Genetics and Plant Breeding, College of Agriculture, UAS, GKVK, Bengaluru

Southern corn rust disease (SCR) caused by *Puccinia polysora*, is emerging as a potential production constraint in maize. To effectively manage the disease, development and deployment of resistant cultivars to SCR is crucial with minimal effects on the environment. Under these premises, QTL for resistance to southern corn rust were detected by using mean disease severity data under artificial epiphytotic condition across three locations from three doubled haploid (DH) populations *viz.,* PL#09× PL#07, PL#08× PL#07 and PL#08× PL#15. The Linkage map was constructed using the genotyping data of 109, 127 and 102 polymorphic SNP markers. In population 1 (PL#09× PL#07), three QTL were detected on chromosomes 2 and 4 (qSCR-2-2, qSCR-2-1 and qSCR-4-1). Among these QTL, one major QTL on chromosomes 2 (qSCR-2-2) was found to be consistent across three locations. Five QTL regions conferring resistance to SCR were mapped onto chromosome 1,2,3 and 10 in population 2 (PL#08× PL#07) and only one major QTL (qSCR-10-1) was detected in population 3 (PL#08× PL#15). The five DH populations *viz*., PL#09× PL#07, PL#08× PL#07, PL#08× PL#15, PL#09× PL#15 and PL#18× PL#15 were used for predicting and validating GEBVs for SCR resistance. The accuracy of predicted GEBVs was marginally less in five-fold cross validation approach compared to leave-one-out-cross validation approach (LOOCV) in all the five populations. In population 1 and 2 prediction accuracy was ranged from 0.2-0.7 and in population 3, 4 and 5 the prediction accuracy was ranged from 0.1 to 0.47. In cross-population validation of genomic estimated breeding values (GEBVs) three DH populations were pooled and used as training set and predictions were calibrated in population 2 (PL#08× PL#07) and population 5 (PL#18× PL#15), the predictive accuracy was more in population 5 (0.49) followed by population 2 (0.44).

Genetics of Resistance to Chilli Leaf Curl Virus Disease, Fruit Yield and Quality Traits in Chilli (*Capsicum annuum* L.)

BALARAJU SUSMITHA AND A. MOHAN RAO
Department of Genetics and Plant Breeding, College of Agriculture, UAS, GKVK, Bengaluru

CHILLI leaf curl virus disease (*ChiLCVD*), major threat to chilli cultivation has potential to cause 100 per cent yield losses. To combat *ChiLCVD*, genetically resistant chilli cultivars offer an economical and eco-friendly solution. Stable resistant sources and reliable knowledge on genetic basis of resistance are quintessential for *ChiLCV* resistance breeding. Under this premise, thirty-two genotypes were evaluated for responses to *ChiLCVD* under natural epiphytotics and viruliferous-whitefly-mediated challenge inoculation conditions during summer 2020 and 2021, respectively. Genotypes S343 and Bhoot Jolokia were found consistently resistant to *ChiLCVD* infection under both regimes, rendering them as potential resistant sources. Further, four F_2 and back cross populations including three intra-*C. annuum* and one interspecies were developed involving resistant sources; S343, LTL7 and Bhoot Jolokia to decipher genetics of *ChiLCVD* resistance. F_2 and backcross generations of these crosses were evaluated for responses to *ChiLCVD* infection. Among intra-*C. annuum* crosses, resistance was found to be governed by single dominant gene, while in inter-species cross, two recessive genetic loci interacting in duplicate epistasis contributed to resistance. Genetics of fruit yield and its component traits were under the influence of both additive and dominant genes with duplicate epistasis among four crosses as deciphered through six generation mean analysis. While, carotenoids were predominantly under the influence of additive genetic loci. Furthermore, SSR alleles at five marker loci (AVRDC PP1, AVRDC MD 782, GPMS 185, AVRDC_PP74 and AVRDC_PP79) were identified as unique to *ChiLCVD* resistant genotypes. Further, two markers, AVRDC MD 782 and GPMS 185 were predicted to have putative function in viral defence mechanism. In yet another study, crosses involving both parents resistant to *ChiLCVD* was ideal to develop F_1 hybrids with satisfactory resistance. Additionally, breeding populations derived from Aparna × S343 and ADL4 × S343 were identified as potential based on rank sum method across productivity traits.

Identification and Confirmation of QTLs Governing Late Leaf Spot Disease Resistance and Pod Yield and its Related Traits in RIL Population of Groundnut (*Arachis hypogaea* L.) Using SSR Markers

N. SHILPA AND N. MARAPPA
Department of Genetics and Plant Breeding, College of Agriculture, UAS, GKVK, Bengaluru

GROUNDNUT is one of the important leguminous oilseed crops. Prime objective of groundnut breeding lies in development of Late leaf spot (LLS) disease resistance cultivars with higher productivity as LLS is one of the most devastating disease in groundnut. Identification of molecular markers associated with LLS disease resistance is beneficial in the development of LLS disease resistance cultivars. Based on these premises, present investigation was carried out to detect QTLs controlling LLS disease resistance, pod yield and its related traits in 94 RIL mapping population developed from the cross TMV 2 × GPBD 4. RILs were phenotyped during *kharif* 2022 under three environments and were screened for LLS disease reaction, pod yield and its related traits. Linkage map was constructed using 121 polymorphic SSR markers with total length of 3186.32 cM and average inter-marker distance of 22.22 cM. A total of 60 QTLs (minor and major QTLs) were identified for LLS disease resistance, pod yield and its related traits across three locations of which 34 QTLs were identified for LLS disease resistance and 26 QTLs were detected for pod yield and its related traits. One common/stable QTL each (*q60PDI-5-1, q90PDI-8-1, q105PDI-11-1, qNPP-4-1* and *qPW-9*-1) was detected for all the traits under consideration except for LLS disease resistance at 75 DAS and shelling per cent. Six QTLs were confirmed from F_2 mapping population of same cross and from earlier reported QTLs for LLS disease resistance. RILs *viz*., RIL 9, RIL 45 RIL 67 and RIL 88 were stable for disease resistance and also had higher pod yield. The identified QTLs can be utilised in marker assisted backcross breeding after validation. The performance was these RILs should be confirmed by evaluating them under multi-locations/ years and can be exploited in future groundnut breeding programs.

Assessment of Genetic Variability and Identification of Potential Vegetable Pigeonpea [*Cajanus cajan* (L.) Millsp.] Genotypes for Fresh Pod Yield and Quality Traits

M. MONISHA AND H.C. LOHITHASWA
Department of Genetics and Plant Breeding, College of Agriculture, UAS, GKVK, Bengaluru

IN the present study, a set of 28 vegetable pigeonpea genotypes was evaluated in Randomized Complete Block Design with three replications during *kharif* 2022 at the Zonal Agricultural Research Station (ZARS), University of Agricultural Sciences, GKVK, Bengaluru to assess the genetic variability and to identify potential genotypes for fresh pod yield and quality traits. Analysis of variance indicated significant genotypic differences for all the traits. Genetic variability parameters like PCV and GCV were found to be high for fresh pod yield and majority of the yield attributing traits. High heritability coupled with high genetic advance as *per cent* of mean indicated the influence of additive genes in controlling the traits. The association of fresh pod yield with other traits in the study showed significant positive correlation with number of pods plant^{-1}, number of seeds pod^{-1}, pod length, number of secondary branches and test weight, which also exhibited the high positive direct effect. The genotypes in the study were grouped into four clusters following K-mean clustering. Maximum number of (9) genotypes were grouped in cluster IV. The highest inter cluster distance was observed between clusters I and III (6.53), indicating the presence of maximum genetic diversity between genotypes of these clusters. Most of the high yielding genotypes were present in cluster III and low yielding genotypes were grouped in cluster I. The genotypes IPAV20-9, IPAV16-15-B and IPA16-16-B1-2 exhibited high fresh pod yield, better nutritional and low antinutritional contents compared to other genotypes. These genotypes could be evaluated extensively to identify the suitable genotypes and used as parents in hybridization programmes.

Haplo-Pheno Analysis of Candidate Gene Linked to Glycemic Index in Rice

DODDAPANENI MANISHA AND H.B. MAHESH
Department of Genetics and Plant Breeding, College of Agriculture, V.C. Farm, Mandya

RICE is the most widely eaten staple food crop in the world and it is the main source of caloric intake for large population. Rice induces relatively higher glycemic response and associated with impaired glucose tolerance. By keeping in view of increasing prevalence of diabetes, research was formulated to identify low GI rice cultivars by analyzing resistant starch trait. Resistant starch is the type of starch which possess inverse relationship with GI and it is an important dietary component that offers several health benefits to humans. Resistant starch content among 175 landraces of rice were estimated and it ranged from 0.34 to 10.06 (%). The genotypes *viz.,* GP105, GP094, GP211, GP100, GP109, GP055, GP007, GP098, GP200, GP209 are having high RS whereas, GP134, GP148, GP224, GP136, GP188, GP016, GP085, GP031, GP088 and GP008 were having less RS content. By using the biochemical data and 43,835 SNPs, marker-trait correlation was established. Among them six SNPs were located on chromosomes 12,10 and 3. Highly significant SNP was detected on chromosome 12 (S12_21104517) which codes for retrotransposon Ty3-gypsy subclass protein. Another significant SNP (S10_13330825) which codes for Cellulose synthase protein. The candidate genes implicated with high RS will be an invaluable resource for future functional characterization and marker assisted breeding to get low GI rice genotypes.

Identification of Promising Germplasm Accessions for Grain Yield and a Stable Source of Resistance for Powdery Mildew in Black Gram [*Vigna mungo* (L.) Hepper]

D. Meenaskshi Monika and J. Shanthala
Department of Genetics and Plant Breeding, College of Agriculture, UAS, GKVK, Bengaluru

Powdery nildew disease caused by *Erysiphe polygoni* is one of the most destructive diseases in black gram causing yield losses. Genetic interventions are considered a substantial approach to minimize losses caused by the disease. As a step forward, an investigation was carried out to identify powdery milder-resistant black gram accessions in high-yielding genetic backgrounds. The major constraint in developing a superior cultivar is the lack of genetic variability. This can be overcome by selection for which the variability present in the germplasm accessions has to be assessed. Two sets of 100 germplasm accessions were evaluated separately for grain yield and response to powdery mildew disease infestation under natural conditions following alpha lattice design during 2022-2023 at the experimental plots of K block, University of Agricultural Sciences, GKVK, Bengaluru followed by screening germplasm accessions under natural conditions, those that were resistant and highly resistant were further confirmed for resistance by artificial screening. In the investigation done polymorphism for qualitative traits was observed. The germplasm accessions such as IC- 436773, MBG-20-16, MBG-20-23, and VBN-9 were promising for multiple quantitative traits. The gremplams accessions such as LBG-402, KUG-216, and IC-436604 show greater pod yield and seed yild. In the set evaluated for responses to powdery mildew disease under natural conitions, out of 100 germplasm accessions, three were highly resistant and eight accessions were resistant. These lines were further cinfirmed for resistance by artificial screening. Under greenhouse conditions, three germplasm were highly resistance and seven germplam were resistant. Accessions such as RFV-13-30, M-414, Ru-13-02, LBG-752, IC-281977 and KU-12-35 show low *per cent* disease incidence coupled with high seed yeld and pod yield. The se germplasm accessions can be used as parent material in further hybridization programme and can be evaluated in different locations.

Prospecting of Tomato Germplasm Accessions (*Solanum* spp.) for *Tomato Leaf Curl Virus* Resistance

K.V. Varshitha and N. Marappa
Department of Genetics and Plant Breeding, College of Agriculture, UAS, GKVK, Bengaluru

Tomato is a self-pollinated crop (2n=24). It is one of the important vegetables consumed worldwide. Its production is limited by destructive tomato leaf curl disease (ToLCD). In the present study, 51 germplasm accessions belonging to *Solanum lycopersicum*, *S. esculentum* var. *cerasiforme*, *S. peruvianum*, *S. pimpinellifolium, S. arcanum*, *S. habrochaites* and *S. cheesmanii* with three checks were used to study genetic variability for fruit yield and its attributing traits and to identify resistant source for ToLCD using natural, artificial screening and validation with gene specific markers. Substantial variation among the germplasm accessions was observed for fruit yield and its attributing traits. In natural screening, five highly resistant (EC 582629, EC 771603, EC 771609, EC 771608, LA 1264) and eight resistant accessions were identified. Accession EC 771608 (*S. peruvianum*) was highly resistant and five accessions *viz.,*EC 771603 (*S. peruvianum*), EC 771609(*S. peruvianum*), LA 2152 (*S. arcanum*), LA 1346 (*S. arcanum*), LA 1264 (*S. habrochaites*) were resistant in artificial screening. Validation study indicated that none of the accessions carried *Ty-1/Ty-3* and *Ty-6* genes. Accessions EC 771608, LA 1264, LA 2152 and LA 1346 showed the presence of *Ty-2*gene and accessions EC 771608, EC 771603, EC 771609, LA 1346,EC 677078, L-02846, EC 677068, EC 676796, EC 677075 and EC 68698 exhibited the presence of*Ty-3* gene. The accession EC 771608 displayed highly resistantreactions in both natural and artificial screening along with the presence of *Ty-2* and *Ty-3* genes which can be used as valuable source of resistance against ToLCD.

Breeding Potential of Selected Inbred Lines Based on their Testcross Performance in Sweetcorn (*Zea mays* var. *saccharata*)

N.M. Prathima and T.M. Ramanappa
Department of Genetics and Plant Breeding, College of Agriculture, UAS, GKVK, Bengaluru

The present investigation was carried out in sweetcorn to carry out the combining ability analysis and to understand nature of gene action for yield and its component traits. Combining ability of 15 inbred lines were assessed using five testers in line × tester mating design. Seventy-five sweetcorn hybrids, their twenty parents and five checks were evaluated during summer, 2023 for twelve quantitative traits. ANOVA for combining ability analysis in line × tester cross revealed variances due to lines was significant for majority of the traits except cob length, cob diameter, kernel rows per cob, kernels per row and moisture content emphasizing importance of GCA in the inheritance of characters under investigation. Variance due to line × tester interaction was significant for all the traits. The inbred lines namely, MAI-102, 1861, Ch-2020130 and MAI-286 were found good general combiners for most of the productivity traits and these inbred lines can be utilized in developing the promising hybrids. Among the testers 40224, 1882 and BNG-3 exhibited a higher positive significant GCA effect. Estimates of SCA variance were found to be higher than the estimates of GCA variances, indicating predominant role of dominance or non-additive gene action in the inheritance of fresh cob yield per plant and its component traits. The hybrid combinations, Ch-2020100 × BNG-3, Ch-21105661 × 1882 and MAI-283 × BNG-3 registered highest significant SCA effects for fresh cob yield per plant and hence, these hybrid combinations can be released for commercial cultivation after evaluation in multilocation trials.

Predicting Breeding Potential of Horse Gram [*Macrotyloma uniflorum* (Lam.) Verdc.] Crosses Based on Transgressive Segregation and Usefulness Indices

Sanganagouda Y. Arahunasi and J. Shanthala
Department of Genetics and Plant Breeding, College of Agriculture, UAS, GKVK, Bengaluru

Horse gram being predominantly self-pollinated crop, pure-lines are the only probable cultivar options. Pedigree selection of desirable recombinant inbred lines (RILs) for use as pure-line cultivars is the most widely used breeding methodology in horse gram. Assessment of variability and predicting breeding potential of crosses helps in discarding inferior crosses and thus enhancing pace and efficiency of breeding programme in horse gram. The combination of high quantitative traits (QTs) mean, absolute range (AR), standardized range (SR), absolute phenotypic variance (σ^2_p), phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), transgressive segregation index (TSI) and usefulness index (U_I) estimated in F_4 generations was used as the criterion to assess and identify crosses with high breeding potential to recover high frequency of RILs with desirable traits *viz.,* pods plant^{-1}, pod weight plant^{-1} (g) and grain weight plant^{-1} (g). Presence/absence of significant differences in QTs mean, AR, SR, σ^2_p, PCV, GCV, TSI and $U_I$between the crosses were considered as evidence for the presence/absence of variability. Based on these criteria, the crosses HPKM-320 × CRIDA-18-R and IC 361290 × PALEM 1 were variable for pods plant^{-1}, pod weight plant^{-1} (g) and grain weight plant^{-1} (g) traits suggesting that crosses could be affected in any direction in horse gram. The breeding potential varied with the trait and the statistics used. Based on TSI, the cross IC361290 × PALEM1 showed better breeding potential than HPKM320 × CRIDA 18R for all three QTs. Based on trait means and U_I, the cross HPKM-320 × CRIDA-18-R showed better breeding potential than IC361290 × PALEM1 for all three QTs. Hence, U_I (predicted genetic gain), which is based on mean, variance and heritability could be used as an objective tool for selecting segregating populations with better breeding potential to derive superior RILs for use as pure-line cultivars.

Mapping and Confirmation of GENE/QTL Controlling Growth Habit, Flowering Time and Grain Yield in Dolichosbean [*Lablab purpureus* (L.) Sweet]

M. Kemparaju and S. Ramesh
Department of Genetics and Plant Breeding, College of Agriculture, UAS, GKVK, Bengaluru

To maximize dolichos bean productivity, it is necessary to develop and deploy high yielding cultivars with desired growth habit (GH) and days to flowering (DF) that match prevailing crop growth season in the environments to which they are targeted. Dependable knowledge on genetic basis of grain yield, GH and DF enables the use of the most appropriate selection strategy to breed cultivars with desired combination of traits. Genetic basis of grain yield, GH and DF was unraveled by detecting QTL using SSR markers in F_2 population. The effectiveness of selective genotyping strategy (SGS) and entire mapping population genotyping strategy (EGS) were compared to detect QTL controlling DF. The results suggest that alleles at two SSR markers (LPD 25 and LPD 37) are linked to QTL controlling DF in both strategy, thus providing adequate evidence for comparable statistical power of SGS relative to EGS. Among 97 polymorphic SSR markers, LPD19 was found linked in coupling phase to genes controlling GH in F_2 population derived from HA 10-8 × HA 5. LPD 19 was also found linked to GH loci in F_2 and RIL mapping populations and near isogenic lines derived from HA 4 × HA 5. A total of seven and five main effect QTLs were detected in $F_{2:3}$ mapping population derived from HA 10-8 × HA 5 based on two season data. Two main effect QTL were common across two seasons. The markers which were found linked to QTL controlling grain yield were confirmed in F_6 RILs derived from HA 4 × HA 5.

Diversity of Natural Enemies of Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) and their Susceptibility to Selected Insecticides

G.T. Shruthi and A.N. Shylesha
Department of Agricultural Entomology, College of Agriculture, UAS, GKVK, Bengaluru

In order to know the natural enemy complex associated with *Spodoptera frugiperda* (J. E. Smith) which has posed a major threat to maize cultivation since its invasion to India, roving surveys were conducted in southern districts of Karnataka during 2019 to 2022 in maize ecosystem. A total of 25 natural enemies were recorded of which egg parasitoids *viz.*, *Trichogramma* sp. and *Telenomus* sp. were predominant, accounting for 25.86 per cent parasitism and other parasitoids are *Chelonus* sp., *Chelonus formosanus* Sonan, *Cotesia* sp., *Glyptapanteles creatonoti* (Viereck), *Phanerotoma* sp. and *Coccygidium transcaspicum* (Kokujev), *Campoletis chlorideae* Uchida, *Eriborus* sp., *Exoristaxanthaspis* (Wiedemann) and *Drino* sp. and ichneumonids. Besides parasitoids, generalist predators *viz.*, *Coccinella septempunctata* Linnaeus,*Cheilomenes sexmaculata* (Fabricius), *Eocanthecona furcellata* Wolff, *Andrallus spinidens* (Fabricius), *Forficula* sp., *Paederus* sp., ants and predatory spiders were also found to attack on *S. frugiperda,* apart from macro-natural enemies, three entomopathogens *viz.*, *Metarhizium rileyi* (Farlow), *SpfrNPV* and *Pseudomonas fluorescens* (Migula) were also recorded on *S. frugiperda*. Molecular characterization was done using COI gene with the product range of 612 to 658 bp and sequences were submitted to Genbank, NCBI. Some insecticides commonly used in maize were evaluated for susceptibility of Braconids (*Chelonus* sp., *Chelonus formosanus* & *Habrobracon hebetor* (Say)) by leaf dip method and egg parasitoids (*Trichogramma chilonis* Ishii, *Trichogramma pretiosum* Riley & *Telenomusremus* Nixon) by glass vial method under laboratory conditions. Spinosad and spinetoram were highly toxic (100% mortality) and while emamectin benzoate, chlorantraniliprole, imidacloprid and thiamethoxam+ lambda-cyhalothrin were found to be relatively safer (<50%) to Braconids and slightly to moderately harmful (53.33-94.66%) to egg parasitoids. However, azardirachtin was relatively safest for all the parasitoids tested, indicating that azardirachtin could be utilized in IPM programme to manage *S. frugiperda* along with parasitoids; however, spinosad and spinetoram should be avoided when parasitoids are active.

Studies on CRISPR/Cas9 Mediated Genome Editing in Eggplant Shoot and Fruit Borer, *Leucinodes orbonalis* Guenee, Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) and Oriental Fruit Fly, *Bactrocera dorsalis* (Hendel)

C.N. BHARGAVA AND R. ASOKAN
Department of Agricultural Entomology, College of Agriculture, UAS, GKVK, Bengaluru

CRISPR/Cas9,originally a bacterial defence mechanism, has become a potent gene-editing tool in diverse organisms. Its potential extends to managing insect pests through Precision-Guided Sterile Insect Technique (pgSIT). This approach necessitates validating specific genes, such as those involved in sex determination and spermatogenesis. The current study employed ribonucleoprotien (RNP) complex to functionally validate the spermatogenesis related genes as a target for pgSIT, along with marker genes in *Leucinodes orbonalis, Spodoptera frugiperda* and *Bactrocera dorsalis.* In *L. orbonalis*, editing of eye colour gene, *tryptophan 2, 3-dioxygenase* was established for the first time, where the mutant moths exhibited a reddish-brown eye phenotype. With respect to *S. frugiperda*, the *SfSxl* gene was edited using RNP complex. Conserved region of all five documented splice variants was targeted which resulted in various INDELs at the target site. Consequently, there was a notable decrease in both overall fecundity and the hatching rate of eggs, emphasizing the crucial role of *SfSxl* gene in maintaining fertility in both sexes. In *B. dorsalis*, the eye colour gene, *white* (*wh*) was targeted, resulting in INDEL mutations with a complete loss of eye pigmentation. A homozygous white eye mutant ($wh^{-/-}$) with a four-base pair deletion was generated, revealing effects on various biological attributes. $wh^{-/-}$ individuals exhibited reduced reproductive fitness, decreased overall body size and prolonged developmental duration. Another gene *Bdtektin1* having its significance in spermatogenesis was also mutated. Mutant males showed a marked reduction in sperm viability, with a higher proportion of non-viable sperms compared to the control group. This underscores the pivotal roleof *Bdtektin1* gene in maintaining the male fertility. With this RNP-mediated editing system in place, key genes involved in sex determination and spermatogenesis can be validated for developing a pgSIT system Top of Form.

Studies on Whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae); Genetic Diversity, Associated Viruses and Endosymbionts, *in Silico* Interactions of Whitefly-Virus-Endosymbiont Proteins and Whole Genome Sequencing

KOPPARTHI AMRUTHA VALLI SINDHURA AND K.M. SRINIVAS REDDY
Department of Agricultural Entomology, College of Agriculture, UAS, GKVK, Bengaluru

THE whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae) is posing significant threat to vegetable production in India, jeopardizing agriculture. Being considered as a cryptic species complex, it is a challenge to manage the population due to endosymbionts harboured and viruses transmitted. To address this, we conducted an extensive survey to analyse the genetic diversity of *B. tabaci* cryptic species complex along with its virome and endosymbionts diversity in the vegetable ecosystems covering 85 locations across 11 districts of Karnataka and 10 districts of Andhra Pradesh. Genetic diversity analysis using mitochondrial cytochrome oxidase subunit gene I (*mtCOI*) sequence revealed, six cryptic species (Asia I, Asia II-2, Asia II-5, Asia II-7, Asia II-8 and MEAM1) associated with vegetable crops belonging to *Solanaceae*, *Malvaceae*, *Cucurbitaceae* and *Brassicaceae*. Begomoviruses *viz.,* chilli leaf curl virus (ChiLCV), eggplant leaf curl Chhattisgarh virus (EgLCuChV) and tomato leaf curl New Delhi virus (ToLCNDV) were detected in whitefly population using group specific primers. Next generation sequencing (NGS) identified 34 plant viruses in *B. tabaci,* revealing the diverse viral landscape. Further, endosymbionts including Gammaproteobacteria, Bacilli, Actinomycetes and Sphingobacteria were isolated and characterized. Primary and secondary endosymbionts associated with *B. tabaci* were identified across the surveyed locations. Molecular docking studies of *B. tabaci* proteins with viral coat proteins and associated endosymbiont GroEL proteins, identified Chloride intracellular channel exc-4 (CIC exc-4) protein as potential target. Virtual screening of 2,486 phytochemicals against CIC exc-4 identified promising compounds like Psychotridine, Staphidine and Quadrigemine A. For the first time in India, whole genome sequencing of *B. tabaci* cryptic species was carried out. It yielded 8094 genes which would aid in understanding the tripartite relationship of host-vector-virus. Our investigations provide insights aiding in the management of whitefly and whitefly-vectored plant viral infections and emphasizing the use of natural plant-based products for sustainable agricultural practices.

Studies on the Biology of Shoot and Fruit Borer, *Diaphania caesalis* (Walker) (Lepidoptera: Pyralidae) and Screening of Selected Genotypes of Jackfruit (*Artocarpus heterophyllus* Lamk.) for Resistance

MANJULA AND N. SUMITHRAMMA
Department of Agricultural Entomology, College of Agriculture, UAS, GKVK, Bengaluru

THE *Diaphania caesalis*, is a globally economic important insect pest of jackfruit. Current study focused on the biology of *D. caesalis* and screening of selected jackfruit genotypes for its resistance during 2022-23. The infestation of *D. caesalis* on shoots peaked on the second week of January (26.91%) and decreased thereafter and reappeared on the first week of July (0.28%). Fruit infestation started on second week of January (17.92%), gradually decreased on third week of August (0.46%). The incidence showed negative correlation with maximum and minimum temperatures, relative humidity and rainfall but a positive correlation with sunshine hours. The developmental period of *D. caesalis* for I, II, III, IV and Vth instar larvae were 2.75±0.08, 2.5±0.14, 2.78±0.09, 3.30±0.13 and 3.46±0.11 days, respectively. Average larval and pre-pupal periods were 14.81±0.26 and 3.96±0.25 days, respectively. The mean pupal period and adult longevity of male was 9.63±0.20, 7.63±0.34 days and female was 10.4±0.20, 8.07±0.36 days, respectively. The mean parasitization by larval parasitoid, *Apanteles* sp. was 31.29 per cent. Twelve genotypes screened against *D. caesalis* infestation, Malaysia Jack and Kalashri were resistant to shoot and tolerant to fruit infestation. The genotypes TBT-3, Ramachandra, Lalbag Madhura and Ashok Orange were tolerant to shoot and fruit infestation and Swarna and Byarachandra were susceptible. Morpho-biochemical studies shows that infestation was negatively correlated with leaf colour and leaf apex shape, fruit shape and positively correlated with entry points of *D. caesalis* and infestation showed negative association with total phenols, tannins, flavonoids, antioxidant activity and positive association with total sugars.

Studies on Influence of Major Biochemical Components of Guava Fruits on Infestation of Fruit Fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae)

B. ANILKUMAR AND G. KESHAVAREDDY
Department of Agricultural Entomology, College of Agriculture, UAS, GKVK, Bengaluru

FRUIT fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) is a major and serious pest of guava, which causes immense economic damage and loss to the farmers. The screening studies of different guava varieties against fruit fly revealed that the varieties Taiwan pink and Seedless varieties were found highly susceptible to the fruit fly infestation and had the highest mean number of maggots per fruit. Allahabad safeda was found to be less susceptible to fruit fly infestation and had less number of maggots per fruit under unprotected conditions in the field. The preferential responseof fruit fly on different guava varieties fruits under laboratory conditions indicated that Allahabad safeda was the least preferred variety for oviposition and had least mean number of maggot when compared to other guava varieties. The Taiwan pink variety was highly preferred by fruit fly for oviposition and had the highest number of maggots in choice test. In no-choice test, all the varieties were equally preferred by the fruit fly for oviposition which could be due to population pressure. The morphological parameter the fruit rind thickness had a significant negative correlation with fruit fly infestation. The biochemical parameters like TSS and proteins in both fruit rind and pulp had a significant positive correlation with per cent fruit infestation, whereas, the per cent fruit infestation had a significant negative correlation with total phenols, tannins and ascorbic acid in fruit rind and pulp.

Floral Biology, Abundance and Diversity of Flower Visitors in Jackfruit, (*Artocarpus heterophyllus* Lam.)

D.S. Chaitra and N. Sumithramma
Department of Agricultural Entomology, College of Agriculture, UAS, GKVK, Bengaluru

Studies on floral biology, abundance and diversity of flower visitors in jackfruit were carried out at the Centre for Jackfruit, Department of Biotechnology, UAS, GKVK, Bengaluru during 2022 and 2023. Flowering of jackfruit observed from November to May in 2022-2023 and peak flowering occurred from December to April. Floral bud development ranged from 32.20 to 64.80 days, with spikes opening at intervals of 14.00 to 28.20 days. Genotype Angadi Hebbanna had the highest spikes on footstalks (8:7) and Thailand Pink had the highest number of male spikes on a leafy shoot (8 male spikes). The highest per cent of inflorescence exposed to the east direction (60.73 %) and the least was found towards north direction (3.41 %). Pollen availability on male spikes lasted for 4.60 to 6.80 days, female stigmatic receptivity lasted for 18.40 to 26.00 days and anther dehiscence peaked from 2 p.m. to 4 p.m . Stigmatic receptivity allowed for pollen transfer within 33.00 to 38.00 hours. Among 8497 inflorescences observed, *Oecophylla smaragdina* Fabricius (37.02 %) was the most abundant species, followed by *Ochyromera artocarpi* Pascoe (34.93 %), *Cecidomyia artocarpi* Felt (15.21 %) and *Drosophila* sp. Fallen (12.29 %), which visited more flowers, indicating their possible involvement in pollen transfer. The highest diversity and evenness of flower visitors occurred from 9 a.m. to 12 p.m. Brushing of pollen from male to female flowers increased fruit size, weight and seed set more than other methods *viz.,* open pollination, net bagging and cloth bagging. Complete cloth bagging of female inflorescences without pollination resulted in seedless jackfruit, possibly due to parthenocarpy.

Reaction of Local Land Races of Paddy against Yellow Stem Borer, *Scirpophaga incertulas* (Walker) (Lepidoptera: Crambidae) and its Management through New Insecticides

Pooja A. Vaidya and B.S. Basavaraju
Department of Agricultural Entomology, College of Agriculture, V.C. Farm, Mandya

The investigations on reaction of local land races of paddy against yellow stem borer (*Scirpophaga incertulas)* and its management through new insecticides were carried out at College of Agriculture, V.C. Farm, Mandya, Karnataka during *kharif* and *summer* seasons of 2022-23. During *kharif* 2022, the highest infestation of dead heart (24.22%) and white ears (22.36%) was observed during second week of October (vegetative stage) and November (reproductive stage), respectively along with a significant positive association with rainfall. During *summer* 2023, the highest infestation of dead heart (29.26%) and white ears (29.02%) was observed during 4^{th} week of April (vegetative stage) and May (reproductive stage), respectively along with a significant positive association with minimum temperature, afternoon relative humidity and rainfall. The field evaluation of 115 local land races of rice against yellow stem borer resulted in identifying eight resistant rice varieties like Tai jasmine, Bangara sanna-2, Doddi batta, BR 2655, Gamnada batta, Jeerigesanna, Kundi pullan and Kari kagga. Among the morphological characters, plant height, flag leaf length and panicle length showed significant negative association, while flag leaf width, width of second leaf, peduncle length and stem diameter showed significant positive association. Likewise, the total phenols, tannins and amino acids found negative association with stem borer while, sugars and crude proteins found positive association. Among ten new insecticides evaluated bifenthrin 10EC, fipronil 5EC and chlorantraniliprole 18.5SC were found effective against rice yellow stem borer. However, bifenthrin 10 EC was found superior by recording higher grain yield, net return and B:C ratio compared to other treatments.

Impact of Brown Planthopper (*Nilaparvata lugens*) Feeding on Popular Rice Cultivars of Cauvery Command Area

A. SOUMYA AND L. VIJAY KUMAR
Department of Agricultural Entomology, College of Agriculture, V.C. Farm, Mandya

THE present investigation was carried out in the glasshouse at the Department of Agricultural Entomology, College of Agriculture, V.C. Farm, Mandya during 2022-23. The studies on tolerance level of ten popular cultivars BR 2655, IR 64, Rajamudi, MSN 99, Tanu, MTU 1010, MTU 1001, Gangavathi Sona, Jaya and Jyothy with different level of resistance including two resistant checks RP 2608-18-3-5 and PTB 33 by conducting various tests. The results indicated that higher number of probing marks, lower area of honeydew, prolonged nymphal duration, lower nymphal survival percentage, lower growth index, lower adult longevity and lower functional plant loss index were recorded in resistant checks and moderately resistant cultivars BR 2655, IR 64, Rajamudi and MSN 99 compared to highly susceptible cultivars Jaya and Jyothy. The impact of BPH feeding on nutritional aspects of five selected rice cultivars indicated that with increasing BPH population per plant there was a rapid and significant reduction of dry weight, moisture content, crude protein content, total chlorophyll (chla+b) and starch content was noticed in highly susceptible and susceptible cultivars after 5, 7 and 14 days of BPH release. In case of moderately resistant cultivars there was a gradual decrease of nutritional aspects after 7 and 14 days of BPH release. Further in all the selected cultivars total free amino acids increased with increasing BPH population per plant. The infestation with different densities of BPH per plant of BR 2655 and Jaya at different critical growth stages such as tillering stage, panicle initiation stage, heading stage, flowering stage, milking stage and dough stage indicated that infestation at tillering and panicle initiation stage resulted in significant reduction of yield attributes such as per cent panicle emergence, panicle length, panicle weight and number of grains per panicle compared to other growth stages.

Reaction of Local Landraces of Rice, Mechanism of Resistance, Biotype Status and Management of Asian Rice Gall Midge, *Orseolia oryzae* (Wood-Mason) in Cauvery Command Area

VEENA CHULAKI AND L. VIJAY KUMAR
Department of Agricultural Entomology, College of Agriculture, V.C. Farm, Mandya

THE investigations on the reaction of local landraces of rice, mechanism of resistance, biotype status and management of Asian rice gall midge, *Orseolia oryzae* (Wood-Mason) in Cauvery command area were carried out at 'A' block, College of Agriculture, V.C. Farm, Mandya, Karnataka during *rabi* season of 2022-2023. The field evaluation of 252 local land races against gallmidge resulted in identifying 5 resistant, 29 moderately resistant, 61 moderately susceptible and 157 land races as susceptible. Among biochemical constituents total soluble sugars, total reducing sugars, crude proteins, nitrogen and magnesium were found positive association with midge infestation while, total phenols, total free aminoacids, tannins, phosphorous, potassium, calcium and sulphur were found negative. The reaction pattern of 16 standard rice gene differentials under four groups tested against local population of gallmidge indicated R-R-R-S reaction and this confirmed the existence of homogenous population of biotype-1 in Cauvery command area. Among different locations under 3 districts in southern parts of Karnataka surveyed for the incidence of rice gallmidge during *rabi* 2022, the highest per cent silver shoot (11.36%) was recorded in Mandya followed by Kabini command area of Chamarajanagara (10.26%) and the least per cent silver shoot (6.78%) was observed in Mysore. Among 9 insecticides evaluated, fiproni l5 SC@2.00 mlL^{-1}, carbosulfan 25 EC@ 1.75 mlL^{-1} and thiamethoxam 25 WG @ 0.25 gL^{-1} was found effective against gallmidge. However, fipronil 5 SC@2.00 mlL^{-1} was found to be superior in recording higher grain yield, net return and C:B ratio (1:2.91) compared to other treatments.

Characterization of *Xanthomonas oryzae* pv. *oryzae* Isolates and Improving Bacterial Leaf Blight Resistance in Rice through Sweet Gene Editing

NAMBURI KARUNAKAR REDDY AND M.K. PRASANNAKUMAR
Department of Plant Pathology, College of Agriculture, UAS, GKVK, Bengaluru

RICE (*Oryza sativa* L.) is the most important staple commodity, providing food for nearly half the global population. The bacterial leaf blight (BLB) caused by *Xanthomonas oryzae* pv. *oryzae* (*Xoo*) is one of the most destructive diseases afflicting rice fields. Seventy-four isolates were obtained as pure culture and subjected to leaf clip inoculation, confirming their pathogenicity on TN-1 rice plants in a glass house. Typical BB symptoms were observed as early as the 3rd day post-inoculation. The morphological and pathogenicity characteristics of 74 isolates from various rice-growing regions in India were used to differentiate them. The pathogenicity assay determined that all isolates were virulent on the susceptible variety TN-1, with the KPXoo19 isolate producing significantly more lesion length, xanthomonadin and exopolysaccharide. Molecular confirmation using 16S rRNA sequencing identified 39 isolates as *Xanthomonas oryzae* pv. *oryzae* and 35 as *Pantoea ananitis*. The latter was reported as a rice pathogen for the first time in Karnataka, India. Pathotype analysis with 22 near-isogenic lines (NILs) identified nine distinct pathotypes within 39 *Xoo* isolates, with pathotypes IV and VIII being the most prevalent (36%). The resistance genes *Xa21, xa13,* and *xa8* exhibited broad spectrum resistance against these diverse pathotypes. Pathotype analysis classified 35 *P. ananitis* isolates into five major pathotypes and the resistance genes *xa13, Xa21* and *Xa11* were effective against these diverse pathotypes. MLST analysis of 33 *Xoo* isolates revealed a high degree of genetic diversity while the isolate, KPXoo8, displayed distinct genetic characteristics. Gene-specific diversity analysis indicated varying degrees of genetic variation among housekeeping genes, with *dnaK* (Chaperone protein) showing the most variability. Genome-wide association analyses using various models identified SNPs associated with bacterial blight resistance linked to candidate SWEET genes namely, *OsSWEET2b, OsSWEET11* and *OsSWEET15*. Using plants expressing *OsSWEET11:13-gRNA* and *OsSWEET14-gRNA* the *OsSWEET11, OsSWEET13* and *OsSWEET14* genes were characterised using the CRISPR Cas9 gene editing technology. Gene editing was confirmed in the transgenic plant, IR-64 revealed significant changes in the SWEET genes, particularly a decrease in the expression of *OsSWEET14*, *OsSWEET11* and *OsSWEET13* by 5-fold, 1.5-fold and 3-fold, respectively.

Understanding the Mechanisms Involved in Cucumber Mosaic Virus (CMV) Pathogenesis in Multiple Hosts Belonging to Diverse Taxonomic Groups

P.S. POOJA AND C.N. LAKSHMINARAYANA REDDY
Department of Plant Pathology, College of Agriculture, UAS, GKVK, Bengaluru

CUCUMBER mosaic virus (CMV) is the most predominant and destructive virus posing serious threat on economically important agricultural and ornamental crops. The dynamics of interactions of CMV with its hosts is pivotal in establishing successful infection, but the knowledge regarding its pathogenesis in multiple hosts is limited. In this regard, an attempt was made to explore the previously available CMV-chilli interactive transcriptome and metabolome data for their functional annotation, an *in silico* interaction prediction followed by experimental validation. Among the differentially expressed genes (DEG's), 23 genes with functional annotation were analysed for their reactivity and stability through domain prediction, physicochemical characterization, secondary and tertiary structure prediction using bioinformatics tools. Further, to identify common/unique pathways involved during CMV infection, functionally annotated chilli analogous proteins were mined from other hosts like tomato, cucumber and banana using NCBI BLAST and subjected for three dimensional structure modeling. *In silico* molecular docking analysis of interaction between CMV and host proteins unveiled chlorophyll a-b binding protein 3C (CAB 3C), chlorophyll a-b binding protein 4 (CAB 4), chlorophyll a-b binding protein 13 (CAB 13) and probable aquaporin PIP proteins (PIP) as the top four host proteins that showed highest binding affinity with CMV 2b followed by 1a and 2a proteins. Gene cloning and molecular characterization of CMV along with selected host proteins *viz*., CAB 3C, CAB 4, CAB 13 and PIP were carried out and confirmed the homology between retrieved and obtained sequences. *In vitro* validation of interaction between CMV and top four host proteins revealed CMV 2b protein as an interacting partner of CAB 13 protein in both chilli and tomato but not in cucumber and banana in an yeast two-hybrid system. This study provides initial insights in understanding the molecular mechanisms of symptom production by CMV in different host plants.

Identification and Bio-Management of Root-Knot Nematode (*Meloidogyne enterolobii*) in Guava (*Psidium guajava* L.)

M. VARSHA AND T.R. KAVITHA
Department of Plant Pathology, College of Agriculture, UAS, GKVK, Bengaluru

MELOIDOGYNE ENTEROLOBII is an emerging and most serious pest of guava in Southern India. Biological control method is an effective strategy in management of root knot nematodes ensuring soil fertility and environmental health. The goal of our study is to evaluate the distribution and severity of *M. enterolobii* on guava in Southern Karnataka and find an effective combination of bioagents for root knot nematode (RKN) management. Survey conducted in a total of 10 guava orchards from four districts of Southern Karnataka, the major guava cultivating areas revealed the incidence of *M. enterolobii* in all the places. Visual evaluation of infested roots by galling index (RKI) recorded the highest distribution and severity of RKN in Ramanagara district (RKI-4.00) followed by Bengaluru (RKI-3.00) and Bengaluru rural (RKI-2.00). The identity of the nematode isolates was confirmed by a combination of morphological and molecular methods. The cuticular modifications at the posterior region of the female nematode were consistent with the perineal patterns of *M. enterolobii*. Further, molecular characterization of isolate GBN-1, by sequencing of 18S-rRNA region confirmed the nematode as *M. enterolobii*. Among various combination of bioagents tested under field conditions revealed that the treatment T5 [*Trichoderma asperellum*+*Bacillus subtilis*+neemcake+African Marigold (30mL+30mL+100g/plant)] imposed at monthly interval was effective in reducing the nematode population in soil (746.67/200 cc) and roots (149.33/5g root), maximum reduction of galls (13.67/5g root), egg masses (17.67/5g root) and over control (1248.11/200 cc, 284.33/5g root, 36.00/5g root, 41.33/5g root) of the nematodes, respectively.

Molecular Detection of Begomoviruses Infecting Pole Bean, Weed Hosts and its Management through Biomolecules

ANNAPURNESHWARI S. SHRIGAN AND B. MANJUNATH
Department of Plant Pathology, College of Agriculture, UAS, GKVK, Bengaluru

YELLOW mosaic disease (YMD) caused by begomovirus is an important constraint in pole bean production. The survey conducted in five districts of Southern Karnataka which revealed the occurrence of YMD ranging from 10 to 70 per cent. Chikkaballapura district had highest mean disease incidence (72.50 %). Among the collected samples, 17 samples showed amplification for HgYMV-CP and four samples showed amplification for MYMV-CP. Phylogenetic analysis revealed that the samples collected from Chikkaballapura district exhibited the highest nucleotide identity with HgYMV Chittor Tirupati isolate for HgYMV-CP region. Conversely, samples collected from Kolar showed the highest nucleotide identity with HgYMV Fb2 Bangalore isolate. Among the weed samples, it was observed that the symptomatic weeds such as *Parthenium hysterophorus, Solanum nigrum* and *Amaranthus* spp. and as ymptomatic *Euphorbia geniculata* samples tested positive for Deng primer, whereas *Solanum nigrum* and *Amaranthus* spp. tested positive for HgYMV-CP alone. Sequencing results revealed that *Solanum nigrum* showed 98 per cent nucleotide identity with Tomato leaf curl virus strain MPT [Coimbatore; Tamil Nadu] and *Amaranthus* spp. showed 98 per cent nucleotide identity with Ageratum yellow vein Sri Lanka virus. Among eight treatments, sea weed extract treatment (LBD46@1.5ml/L) was found to be significantly superior over the untreated control as it effectively suppressed the pole bean yellow mosaic virus disease by recording the average lowest disease incidence during *kharif* 2022 (5.50%) and summer 2023 (7.71%).

Characterization and Management of *Uromyces setariae-italicae* Causing Rust Disease in Foxtail Millet [*Setaria italica* (L.) Beav.]

TANUJA SHIRAGAPPAGOL AND K.B. PALANNA
Department of Plant Pathology, College of Agriculture, UAS, GKVK, Bengaluru

FOXTAIL millet (*Setaria italica*) is the second most cultivated millet globally with the high nutritional content. Despite its hardiness, its growth is challenged by many biotic and abiotic stresses. Among the biotic, rust is one of the major constraints causing significant yield loss. A total of 12 samples were distinguished by the presence of light brown to dark pustules and identified as *Uromyces setariae-italicae* based on morphological characteristics like cinnamon brown colour and single celled uredospores. Significant variation was observed among the isolates with respect to spore size which ranged between 22.98-38.20 x 18.33-28.64 µm. Out of 94 genotypes evaluated for rust resistance at Bengaluru, nine were resistant, nine were moderately resistant, 24 were susceptible, 52 were highly susceptible and none indicated a highly resistant reaction against rust. While in Mandya, seven were resistant, 12 were moderately resistant, 24 were susceptible and 51 genotypes were found highly susceptible and none of the genotypes indicated a highly resistant reaction for rust. The avoidable grain yield and fodder yield loss was accounted for 17.45 per cent and 18.15 per cent, respectively. Among the 15 fungicides tested under *in vitro* condition, mancozeb (95.37 %), tebuconazole (96.83 %) and tricyclazole + mancozeb (97.80 %) were proven effective in inhibiting spore germination. Among the bioagents and botanicals tested *Trichoderma viride* (TV2) and tulasi (92.78 %) were proven effective in control of rust on foxtail millet. The information generated in the present investigation can be further utilised for field evaluation under integrated management of foxtail millet rust.

Screening of Pigeonpea Genotypes to Pigeonpea Sterility Mosaic Virus Disease and Identification of the Pigeonpea Sterility Mosaic Virus (PPSMV) Strain Prevalent in Bengaluru

ARIF AND A.S. PADMAJA
Department of Plant Pathology, College of Agriculture, UAS, GKVK, Bengaluru

PIGEONPEA, a important legume crop susceptible to a range of phytopathogens. Among them, pigeonpea sterility mosaic virus disease (PPSMD) caused by pigeonpea sterility mosaic virus (PPSMV) stands out as a major constraint resulting in substantial yield loss. Ninety three pigeonpea genotypes was screened for sterility mosaic disease was evaluated in *kharif* season of 2022 at ZARS, GKVK, Bengaluru. Out of the 93 genotypes tested, 88 were found to be susceptible, four genotypes exhibited moderate resistance, one genotype showed resistance and the local resistant check BRG-3 remained symptom-free throughout the crop growth period. The PPSMV-infected genotypes showed a range of mosaic symptoms, including yellowing, mottling, stunting and sterility, leading to lack of flower and pod formation. In contrast, the resistant genotype BRG-3 continued to produce flowers, pods and healthy seeds. Molecular analysis revealed the prevailing strain as PPSMV-II, with a 96.4 per cent nucleotide similarity to the reference sequence of PPSMV II in NCBI Database. The impact of PPSMV-II on physiological and biochemical parameters of pigeonpea plants revealed that, susceptible and resistant genotypes exhibited variations in chlorophyll content, sugars, phenols, proteins and nutrient levels, suggesting that the virus manipulates these host compounds for its survival. The virus infection significantly affected physiological parameters in susceptible plants compared to resistant ones, impacting photosynthesis, transpiration and stomatal conductance. Furthermore, both resistant and susceptible pigeonpea genotypes showed variations in the levels of growth hormones and defense related signaling molecules, indicating that the virus might influence the host plant through these alterations for its pathogen.

Development of Protocols for the Extraction of Metabolites from Potential Endophytes and their *In-vitro* Assessment against Fungal Plant Pathogens

Anil Annappa Gudimani and C.R. Jahir Basha
Department of Plant Pathology, College of Agriculture, UAS, GKVK, Bengaluru

Standardized protocols for extracting secondary metabolites by using two potential endophytes, HI2 and PHR3 isolates of *Trichoderma asperellum*, using four solvents (ethyl acetate, methanol, chloroform and acetone) were developed to determine the efficiency of these solvents in extracting secondary metabolites and the extracted metabolites were evaluated against the fungal pathogens *viz*., *Pyricularia setariae*, *Bipolaris oryzae* and *Curvularia lunata* under *in-vitro* conditions. Endophytes and plant pathogens were confirmed through molecular and morphological studies, respectively. Further, secondary metabolites were successfully extracted using ethyl acetate, chloroform and acetone solvents excluding methanol solvent due to its miscibility with the extraction media. Extracted metabolites were subjected to Liquid Chromatography Mass Spectrometry (LC-MS/MS) analysis and a substantial number of bioactive compounds were identified. Ethyl acetate extracts yielded 154 compounds, chloroform extracts yielded 527 compounds and acetone extracts yielded 176 compounds from fungal endophyte HI2. Similarly, ethyl acetate extracts from fungal endophyte PHR3 yielded 161 compounds, chloroform extracts yielded 319 compounds and acetone extracts yielded 140 compounds. Further, the efficiency of secondary metabolites extracted using ethyl acetate, chloroform and acetone was evaluated *in-vitro* through standard poisoned food technique and disc diffusion assay. Chloroform and acetone derived extracts of the fungal endophytes HI2 and PHR3, respectively, significantly inhibited the pathogen *C. lunata* in poisoned food technique. However, chloroform derived extracts from the HI2 fungal endophyte significantly suppressed the pathogen *C. lunata* under disc diffusion assay.

Discovery of Novel Viruses Associated with Tomato in Natural Ecosystem and Development of Diagnostic Protocols for their Detection

S.S. Kavya and C.N. Lakshminarayana Reddy
Department of Plant Pathology, College of Agriculture, UAS, GKVK, Bengaluru

The field of plant virology has been significantly impacted by the onset of advancements in high-throughput sequencing. The emergence of Next Generation Sequencing has enabled the detection, identification and unraveling of novel viruses and previously reported viruses in an unbiased manner. Tomato is a widely consumed vegetable. To profile the tomato virome, sixty viral-infected leaf samples were collected based on symptomatology by a roving survey in the year 2022-2023. Total RNA was isolated through phenol-chloroform Lithium chloride extraction protocol which yields high-quality RNA as reflected by intact and clear bands in gel electrophoresis. The total RNA was pooled based on equimolar concentration and subjected to rRNA depletion. The library was then constructed for whole transcriptome sequencing using the Illumina NOVASEQ 6000 platform. The whole transcriptome analysis revealed the presence of cucumber mosaic virus (CMV), tomato leaf curl New Delhi virus (ToLCND), chilli veinal mottle virus (ChiVMV), tomato chlorosis virus (ToCV), southern tomato virus (STV) and watermelon bud necrosis virus (WBNV). From the virus-associated contigs, the complete genome for CMV, ToLCND, ChiVMV and partial or near-complete genome for ToCV, STV and WBNV were reconstructed. Pairwise identity analysis revealed that all the identified viruses showed >90 per cent nucleotide identity with their respective reference isolates available in the NCBI database. Further, neighbour network analysis revealed reticulate topologies indicating potential recombination events among putative recombination in the genomes. RT-PCR and RT-LAMP based validation was performed for ToLCND and CMV.

Discovery of Novel Viruses Associated with Papaya (*Carica papaya* L.) in Natural Ecosystem and Development of Diagnostic Protocols for their Detection

K.P. Lavanya and C.N. Lakshminarayana Reddy
Department of Plant Pathology, College of Agriculture, UAS, GKVK, Bengaluru

Viruses are the major bottleneck in papaya cultivation in India. In the current scenario, identification of viruses became more difficult due to mixed infection of known and unknown viruses in plants using biased traditional detection methods. Next-generation sequencing (NGS) technology helps in the unbiased revealing of viruses including known and unknown ones. A total of 60 different virus-infected leaf samples from papaya plants showing mosaic, mottling, shoestring, leaf curl, blistering, yellowing and distortion of leaves were collected during the year 2022-2023. The average viral disease incidence ranged from 50 to 97.5 per cent in the surveyed districts. The total RNA isolated from 60 different leaf samples was pooled and sequenced through NGS. Pre-processed data was used for *de novo* assembly. The assembled contigs were subjected to standalone MEGABLAST analysis against the viral reference sequences, which revealed the presence of three viruses *i.e.,* papaya ringspot virus (PRSV), cucumber mosaic virus (CMV)-RNA3 segment and Wuhan aphid virus 1 (WhAV-1) from total RNAome. From the virus associated contigs, complete genome for PRSV and partial genome for CMV and WhAV-1 was reconstructed. Taxonomic position of identified viruses was elucidated based on phylogenetic analysis and ICTV threshold criteria for species demarcation. Further, recombination breakpoint analysis detected two unique recombination breakpoint events in PRSV. Molecular tools *i.e.,* RT-PCR and RT-LAMP were optimized for rapid detection of PRSV. Infection of CMV and WhAV-1 in papaya is the first report from current study in India, suggesting that mixed viral infections were associated with papaya under natural field conditions.

Virome Profiling in Muskmelon and Bitter Gourd by Using Next Generation Sequencing (NGS)

K.S. Uday Durga Prasad and V. Venkataravanappa
Department of Plant Pathology, College of Agriculture, UAS, GKVK, Bengaluru

In current scenario, identification of viruses is complicated due to mixed infection of known and unknown viruses in plants using traditional detection methods. NGS has enabled the detection, identification and unravelling diversity of known and unknown viruses. Virome analysis of muskmelon and bitter gourd by NGS led to the identification of known and novel viruses. A roving survey was conducted in different districts in southern Karnataka, revealed average disease incidence of 54.6 to 88.9 per cent in muskmelon and 59.3 to 88.9 per cent in bitter gourd, respectively. A total of 50 viral infected leaf samples of bitter gourd and 25 samples of muskmelon, exhibiting diverse symptoms were collected. Total RNA was isolated from all samples separately and subjected to mRNAome sequencing. Pre-processed data was subjected to *de-novo* assembly. Standalone MEGABLAST analysis identified four viruses melon yellow spot virus, watermelon bud necrosis virus, sukawa aphid-borne yellow virus and tomato leaf curl New Delhi virus with complete genome and five of chilliveinal mottle virus, papaya ring spot virus, zucchini tigre mosaic virus, zucchini yellow mosaic virus and cucumber mosaic virus with near-complete genomes from bitter gourd. Similarly, from muskmelon two viral complete genomes, melon yellow spot virus and watermelon bud necrosis virus and two partial genomes, melon partiti virus and cucumis melo endorna virus were recovered. The data identified viruses in both crops were validated by RT-PCR and RT-LAMP assays confirming their presence in the collected samples. Further recombination analysis showed potential recombinant events, contributing to viral variation.

Evaluation of Jasmine [*Jasminum sambac* (L.) Aiton] under Open and Polyhouse Condition for Induction of Off-Season Flowering under Bengaluru Condition

V.G. NAVYA AND K.S. NIRMALA
Department of Horticulture, College of Agriculture, UAS, GKVK, Bengaluru

AN experiment was conducted at the Department of Horticulture, UAS, GKVK, Bengaluru during 2022-2023 to analyse the effect of pruning time and growth regulators on 'off season' flower production in *Jasminum sambac* (L.) Aiton both under open and polyhouse condition. Three pruning treatments were imposed during the second fortnight of August (P_1), October (P_2) and December (control). Growth regulators *viz*., GA_3 at 100 (G_1), 150 (G_2) and 200 ppm (G_3), Cycocel at 500 (G_4), 750 (G_5) and 1000 ppm (G_6) and double distilled water (Control, G_7) were sprayed at 15 days after pruning. Under both open and polyhouse condition, October pruning with GA_3 at 200 ppm (P_2G_3) recorded maximum plant height (86.00 and 105.67cm) and plant spread {E-W (80.33 and 94.33 cm) and N-S (62.00 and 90.00 cm)}. Higher number of secondary branches per plant (18.67 and 19.33) and higher chlorophyll content during vegetative (52.00 and 57.00) and flowering period (53.17 and 58.25) were recorded in October pruning with Cycocel at 1000 ppm (P_2G_6). The same treatment recorded better flower characteristics *viz.,* days to bud initiation (38.67 and 34.67 days), first flowering (50.33 and 47.00 days), 50 per cent flowering (73.67 and 70.33 days) and total duration of flowering (250 and 268.33 days). Similarly, quality parameters such as bud diameter (1.20 and 1.35 cm) and 100 bud weight (31.56 and 46.57 g), corolla tube length (1.22 and 1.28 cm), bud length (1.48 and 1.40 cm) and flower diameter (1.20 and 1.35 cm) were higher in the October pruning with GA_3 at 200 ppm (P_2G_3). P_2G_6 showed significantly increased off-season flower yield per plant (0.285 and 0.366 kg) and per ha (1.259 and 1.628 t) both under open and polyhouse condition. Earliness of flowering, quality and yield 48 per cent were higher under polyhouse as compared to open condition.

Evaluation on Plant Density and Nutrition for Growth, Yield and Quality of Broccoli (*Brassica oleracea* var. *italica*)

H.L. SOUNDARYA AND K.N. SRINIVASAPPA
Department of Horticulture, College of Agriculture, UAS, GKVK, Bengaluru

THE open field and polyhouse experiments were conducted in the Factorial Randomized Complete Block Design consisting of twelve treatments replicated thrice, to study the effect of different levels of plant spacing, major nutrients and micronutrient combinations on growth, yield and quality parameters of broccoli (*Brassica oleracea* var. *italica*) at Department of Horticulture, University of Agricultural Sciences, GKVK, Bengaluru during *rabi*, 2022. The study revealed that maximum plant height (67.25 and 93.17 cm), number of leaves (27.18 and 27.33), leaf area (19865 and 24178 cm^2), chlorophyll content (82.15 and 89.20), head length (20.08 and 21.61 cm), fresh weight of head (553.62 and 602.99 g), head compactness (24.20 and 27.29 g cm^{-3}), total soluble sugars (9.91 and 9.69 p Brix), minimum days to head initiation (38.88 and 41.15) and minimum days to first harvest (51.53 and 51.37) were observed in the treatment (T_{12}) comprising of 45 cm x 60 cm spacing with 150:100:75 kg NPK per hectare and 0.40 % Boric acid + 0.60% $ZnSO_4$ + 0.30 % $MnSO_4$ nutrient combination in open field and polyhouse conditions, respectively. Whereas maximum yield per hectare (239.52 and 263.90 q ha^{-1}) and B:C ratio (2.38 and 4.21) were recorded in the treatment (T_8) consisting of 45 cm x 45 cm spacing with 150:100:75 kg NPK per hectare and 0.40 % Boric acid + 0.60 % $ZnSO_4$ + 0.30 % $MnSO_4$ nutrient combination in open field and polyhouse conditions, respectively.

Evaluation of Cluster Bean (*Cyamopsis tetragonoloba* L.) Genotypes for Growth, Yield and Quality Traits

IRANNA RAMAPPA MARADI AND M. SHALINI
Department of Horticulture, College of Agriculture, UAS, GKVK, Bengaluru

THE present study was carried out at Department of Horticulture, College of Agriculture, UAS, GKVK, Bengaluru during Summer 2023. The experimental treatments consisted of twenty-seven genotypes including one check variety were evaluated by following Randomised Block Design to generate and interpret the information on mean performance for various parameters, variability, heritability and genetic advance. According to mean performance, the genotypes IC-11501 (146.54 q/ha), IC-41170 (140.46 q/ha), IC-11376 (134.81 q/ha) and Bidar Local (134.78 q/ha) recorded higher yields, genotypes IC-41177 (21.36 %), Bellary Local (19.99 %), IC-11427 (19.85 %) and Mysore Local (19.81%) recorded highest crude protein content. Genotypes Bidar Local, Bellary Local and Kodagu Local have more than 8 days of shelf life. These results indicates that such genotypes can be used in trait-specific breeding programs. In present study, high PCV and GCV were observed for number of branches per plant (70.57 %; 70.38 %), ten pod weight (57.94 %; 57.27 %), number of pods per plant (42.30 %; 41.03 %), number of clusters per plant (41.22 %; 40.88 %) and pod yield per plant (33.15 %; 32.93 %) indicating wide range of variability among the genotypes. The characters like plant height, stem girth, number of nodes on main stem, number of branches per plant, number of clusters per plant, number of pods per plant, pod length, pod width, ten pod weight and pod yield per plant have recorded high heritability combined with a high genetic advance as per cent of the mean demonstrating a predominance of additive gene component. This shows that there is plenty of opportunity for improving the characters by direct selection.

Effect of Seaweed Extract on Growth, Yield and Quality of French Bean (*Phaseolus vulgaris* L.)

JAGADISH MANUR AND NAGAPPA DESAI
Department of Horticulture, College of Agriculture, UAS, GKVK, Bengaluru

THE experiment entitled 'Effect of seaweed extract on growth, yield and quality of French bean (*Phaseolus vulgaris* L.)' was conducted at Department of Horticulture, University of Agricultural Sciences, GKVK campus, Bengaluru-65 during late *rabi* season of 2022-23 under polyhouse conditions. The experiment was laid out in Randomized Complete Block Design with nine treatments replicated thrice.The seaweed extracts used were *Sargassum wightii* and *Ascophyllum nodosum* both at four levels of concentration *i.e.*, 0.5, 1.0, 1.5, 2.0 ml/litre of water. Foliar sprays of these seaweed extracts were taken at 30 and 45 days after sowing. Experimental findings revealed that maximum plant height (393.20cm), number of leaves per plant (326.73) and number of branches per plant (10.99) were recorded with the foliar application of *Ascophyllum nodosum* @ 2ml/ litre, whereas, foliar application of *Sargassum wightii*at 2.0 ml/litre exhibited maximum number of pods per cluster (6.89), number of pods per plant (177.11), highest fruit set per cent age (92.74%), highest yield per plant (2.18 kg), yield per plot (28.32 kg) and yield per ha (40.3 t). Among quality parameters, foliar application of *Sargassum wightii*at 2.0 ml/litre resulted in highest ascorbic acid (30.75 mg/100gm) and protein (24.52%) content of fresh pods along with highest benefit cost ratio (2.56) compared to control treatment.

Studies on Combining Ability and Heterosis for Yield and Yield Attributing Traits in Bitter Gourd (*Momordica charantia* L.)

R. Tejaswini and Kavita Kandpal
Department of Horticulture, College of Agriculture, UAS, GKVK, Bengaluru

An experiment entitled 'Studies on combining ability and heterosis for yield and yield attributing traits in bitter gourd (*Momordica charantia* L.)' was carried out during the year 2022-23 at Department of Horticulture, University of Agricultural Sciences, GKVK, Bengaluru. A total of 49 F_1 hybrids were developed through the utilization of line × tester mating design. The parents and developed hybrids along with standard check (Pusa Hybrid 6) were evaluated in RCBD and Alpha lattice design, respectively for yielda and yield attributing traits. The combining ability analysis revealed that among 14 parents, Pusa Rasdar, Pusa Do Mausami, Pusa Vishesh, Hirkani and Pant Karela 4 were identified as best general combiners for most of the studied traits. The estimates of heterosis revealed that the hybrids, Konkan Karali × Pant Karela 4 (45.45%), Konkan Tara × Pusa Do Mausami (23.48%), Pusa Rasdar × Phule Green Gold (126.87%) and Hirkani × Pusa Do Mausami (46.20%) were top performing hybrids over standard check for fruit length, diameter, average weight and number of fruits per vine, respectively. Similarly, Pusa Rasdar × Pant Karela 4 (127.06%), Priya × Pusa Do Mausami (101.05%), Punjab 14 × Pusa Do Mausami (100.53%) and Pusa Rasdar × Pant Karela 3 (97.61%) were top performing hybrids over standard check for yield per vine. These hybrids also recorded highest significant SCA effects hence, considered as good specific combiners. These hybrids can be forwarded to F_2 generation to validate their stability.

An Economic Analysis of Farmers' Livelihood vis-à-vis Human Wildlife Conflict in Central Western Ghats of Karnataka

M.S. Ramu and K.B. Umesh
Department of Agricultural Economics, College of Agriculture, UAS, GKVK, Bengaluru

Rapid urbanization, industrialization and technological progress have brought in both prosperity and challenges. As human population expanded, the conflicts with wildlife emerged due to encroachments on habitats for agriculture and resource extraction. This study focuses on Human-Wildlife Conflict (HWC) in the Central Western Ghats of Karnataka, specifically in the Sakleshpur and Mudigere ranges of the Hassan and Chikkamagalur forest divisions respectively. Primary data were collected from 200 respondents through personal interview related to 2022-23 and the secondary data (2013-14 to 2022-23) was gathered from the department of forest. Data were analysed using compound annual growth rate (CAGR), regression, land useland cover (LULC) and Probit function. Over the past decade, Karnataka reported 3,03,081 HWC cases, predominantly driven by crop raiding (89.44%). The cases of HWC increased at 2.98 per cent, with higher growth in Chikkamagalur division (7.15%) compared to Hassan (0.68%). Elephant (*Elephas maximus*), Indian gaur (*Bos gaurus*) and Wild boar (*Sus scrofa*) were identified as significant crop raiders. Per household economic loss due to HWC was Rs. 96,101 per year with higher loss in Sakleshpur (Rs. 1,14,393 per year) compared to Mudigere (Rs. 77,809 per year) region. The HWC results in 9.89 per cent reduction in agricultural income and 8.02 per cent reduction in overall household income in the study area. Adoption of mitigation measures decreased with distance from the forest and increased with the number of crops and higher household income. Elephant-proof trenches emerged as the most effective mitigation measure. Ex-gratia payments did not cover the lifetime economic loss of perennial crops. Constraints in receiving ex-gratia includes high transaction costs and delayed payments. The study recommends effective strategies such as habitat conservation, improved food sources for wildlife, expert advisory services and streamlined ex-gratia processes to mitigate HWC losses.

Price Behaviour and Trade Performance of Indian Silk and Silk Products: An Econometric Analysis

JOYCY RANI DASARI AND M.N. VENKATARAMANA
Department of Agricultural Economics, College of Agriculture, UAS, GKVK, Bengaluru

THE present study examines the price behaviour and trade performance of Indian silk and silk products using both primary and secondary data. The cointegration analysis of daily prices during 2017 to 2022 indicated that Ramanagara, Kolar and Sidlaghatta markets were highly correlated for both bivoltine and cross breed cocoons. The bivoltine cocoon prices prevailing in Ramanagara market influenced the Kollegala, Kanakapura and Kolar markets. For cross breed cocoon prices, bidirectional causality was found between Sidlaghatta and Kolar markets only. The Johansen's cointegration test revealed that there exists cointegration between Chinese silk prices and Indian silk prices at 5 per cent level of significance. The Compound Annual Growth Rateshowed decreasing trend of 5.27 per cent in the exports of silk products from India during 2011-12 to 2021-22, which was largely attributed to the highly negative Residual Competitiveness effect followed by the World Demand effect. However, both Commodity Composition effect and Market distribution effect were found to be positive. USA was one of the most stable markets among the major importers as reflected by the higher probability of retention at 0.751.The values of NPC, DRC, EPC were higher than one which implies that Indian silk was unprotected by the policy frame work, not competitive in the world market and hence not worth exporting**.** As the size of GDP of importing countries increases, the greater is possibility to enhance the trade from India. The domestic demand of silk is high and rises with the increasing affordability, there by decreasing the international trade. There is need to raise the production and maintain international quality standards to compete in world market.

Profitability of Cool Season Vegetables Production and Marketing in Idukki District of Kerala

ALAIDA TOMY AND G.M. GADDI
Department of Agricultural Economics, College of Agriculture, UAS, GKVK, Bengaluru

THE present study on assessing profitability of cool season vegetables in Idukki district of Kerala used primary data from 80 farmers (40 each for garlic and carrot) and 20 market intermediaries. The secondary data on area under vegetables revealed 1.6 per cent growth rate but was not significant. The Cuddy-Della Valle Index revealed low instability in area, production and productivity for most of the crops in the study area however, cardamom and pepper showed medium instability. The transitional probability matrix indicated continuous shift in area under different crops during the study period and tea showed the highest retention. With the total costs of Rs.80,420.41/ac and Rs.71,971.51/ac, garlic and carrot growers realized a yield of 18.60 q/ac and 73.48 q/ac respectively. Despite attractive profitability from garlic (1.34) and carrot (1.52) cultivation as indicated by returns per rupee of expenditure, the resource use efficiency analysis highlighted the potentiality to increase the usage of some of the inputs like planting material, FYM, fertilizer and plant protection chemical to optimize returns. Majority of garlic growers preferred Channel-I (Producer→Commission agent→Wholesaler→Retailer→ Consumer) over Channel II and Channel III despite higher PSCR (66.53%) and marketing efficiency index (1.96) in Channel III (Producer→Horticorp→Consumer) due to its limited absorption capacity. The majority of carrot growers also preferred Channel-I (Producer→Commission agent→Wholesaler→Retailer→Consumer) over Channel II despite better PSCR (62.00%) and marketing efficiency index (1.68) found in Channel II (Producer→Horticorp→Consumer). The need of the hour is to minimize post-harvest losses and ensure stable prices through creation of suitable infrastructures for efficient post-harvest handling.

An Economic Impact of Root Grub Infestation on Sugarcane in Vijayapura District of Karnataka State

SHREESHAIL RAJASHEKHAR HANJAGI AND K.R. NETHRAYINI
Department of Agricultural Economics, College of Agriculture, UAS, GKVK, Bengaluru

SUGARCANE is identified as an important commercial crop and in recent times its production has been hampered due to root grub infestation. The overall objective of the study was to analyses the economic impact of root grub infestation on sugarcane in Vijayapura district of Karnataka. Purposive multi stage random sampling technique was employed for the selection of respondents. Two taluks namely, Sindagi and Indi were selected which experienced heavy root grub infestation. The primary data collected from sugarcane growers before (2020-21) and after (2021-22) the root grub infestation were analysed using descriptive statistics, two sample t-test, partial budgeting technique and Garrett ranking techniques were employed. The results revealed that the cost of cultivation of sugarcane after infestation was higher (Rs.80,310/acre) as compared to before (Rs.77,336/acre), the yield before infestation was high (51.51 metric tons/acre) compared to after infestation (Rs.36.90 metric tons/acre). Returns per rupee of expenditure dropped by 31.02 per cent (1.96 to 1.36). Economic effectiveness of integrated method approach is more beneficial as compared to the adoption of individual methods to control root grub. Scarcity of labour and pest and disease occurrence, Non-availability of resistant varieties and lack of awareness about IPM. IPM were major constraints in root grub management. To combat the negative economic impact of root grub infestation in sugarcane a comprehensive policy approach encompassing IPM practices, training and raising public awareness for sustainable sugarcane production assumes importance.

Production and Marketing Strategies for Groundnut in Central Dry Zone of Karnataka : An Economic Analysis

R. SHREEDEVI AND H. LOKESHA
Department of Agricultural Economics, College of Agriculture, UAS, GKVK, Bengaluru

THE present study was carried out in Chitradurga and Tumakuru districts of Karnataka with the objective of identifying the strategies for enhancing production and marketing of groundnut. A sample size of 120 farmers belongs to both Chitradurga (60) and Tumakuru (60) districts were selected for the study. In Karnataka, the groundnut area exhibited a negative CAGR of 2.76 per cent from 2000-01 to 2021-22 and productivity showed a positive growth of 1.39 per cent. The combined effect resulted in a negative production CAGR of 1.29 per cent. The production growth of groundnut in both Chitradurga and Tumakuru is declining with rate of 2.23 and 3.82 per cent respectively. The cost of cultivation of groundnut in Tumakuru was higher with Rs. 47,737 per acre compared to Chitradurga (Rs. 44,401/acre). The average yield obtained in Tumakuru (6.37 q/acre) was more than Chitradurga district (4.96 q/acre). The returns per rupee of expenditure in Chitradurga and Tumakuru districts were Rs. 0.87 and 1.01 respectively. The mean economic efficiency of groundnut production in Chitradurga and Tumakuru was 0.52 and 0.54 respectively. Granger causality test confirmed that Challakere and Bellary were the key groundnut markets influencing the prices of all other markets. Supply of quality seeds of drought tolerant variety along with seed treatment with *Trichoderma* and application of gypsum identified as important production strategies. Selling of cleaned and dried groundnut and avoiding borrowing linked sale of produce to commission agents identified as important marketing strategies in enhancing the income of the farmers.

Production and Preference for Hassan Cucumber: An Economic Analysis

S.N. RAMYA AND N. MALLIKARJUNA SWAMY
Department of Agricultural Economics, College of Agriculture, UAS, GKVK, Bengaluru

THE present study was undertaken in Hassan district of Karnataka, as Hassan stands first in the area and production of cucumber. The objectives of the study were to estimate the growth in area, production and productivity of cucumber, to estimate the economics of cucumber production, to examine the resource use efficiency and to examine the factors determining producers and consumers preference. The analytical tools used for analysis were CAGR, descriptive statistics, cobb-douglas production function and conjoint analysis. The growth rates in area, production and productivity of cucumber were 1.55, 2.15 and 0.57 per cent, respectively and are significant at one per cent probability level. The average total cost of cultivation per acre was Rs.59,193. The total variable cost and fixed cost constituted about 88.63 and 11.37 per cent, respectively. The returns realised per rupee of expenditure was found to be 1.44. Efficiency analysis revealed that the MVP/ MFC ratio exceeded unity for expenditure on fertilisers (5.02) indicating underutilization of resources. Conversely, the MVP/ MFC ratio for seeds (0.83), human labour (0.23) and machine labour (0.57) was less than unity, indicating the overutilization of resources. The farmers prefer the variety of cucumber which gives higher fruit count per plant having more resistant to diseases. The fresh appearance of the cucumber followed by taste, price and colour of the produce were the main attributes that affect the consumers preference for cucumber. The results of this research study helps the concerned farmers and developmental departments to take the necessary measures in the production of Hassan cucumber.

Impact of Shri Kshetra Dharmasthala Rural Development Project on the Livelihood Security of Farmers of Karnataka State

N.R. CHAITHRA AND Y.N. SHIVALINGAIAH
Department of Agricultural Extension, College of Agriculture, UAS, GKVK, Bengaluru

THE present study was carried out in Dakshina Kannda and Kolar district to analyse the impact of Shri Kshethra Dharmasthala Rural Development Project (SKDRDP) on the livelihood security of farmers of Karnataka state during 2022-23. Purposive Random sampling design was employed and primary data were collected using well-structured interview schedule from a total of 260 farmers, from four taluks namely Beltangady, Puttur, Kolar and Bangarpet consisting of 180 beneficiaries and 80 non- beneficiaries in Karnataka state. From each taluk 45 beneficiaries, 20 non- beneficiaries were selected. The results revealed that most prevalent purpose to join SKDRDP was to avail credit by 19.44 per cent of the beneficiaries. The livelihood security was found better by 33.89 per cent to average (33.33%). With respect to satisfaction level of total beneficiaries exactly two-fifth (40.00%) of them belonged to satisfied category followed by highly satisfied (31.67%). SKDRDP beneficiaries have better farm machinery possession than non-beneficiaries, more water availability and better access to cooking facilities with respect to green energy usage. The social impact was found that beneficiaries have better social cohesiveness, involvement in different social organizations and also the recognition in comparison to non-beneficiaries. The overall income was higher by Rs. 97,697 per farmer from 2019 as a base year due to SKDRDP interventions. Cropping intensity of coastal zone beneficiaries (121.50%) is more in comparison to non-beneficiaries (111.07%). In case of eastern dry zone the cropping intensity of beneficiaries (138.03%) are higher than non-beneficiaries (119.69%). Major constraints expressed by beneficiaries towards SKDRDP were non suitability of training timings, lack of timely access to the interventions. Farmers suggested that repayment of the loans should be made biweekly/ monthly, marketing facilities need to be concentrated more.

Attracting and Retaining of Youth in Agriculture (ARYA) Project on Livelihood Security of Youths in Karnataka: An Analysis

C.M. Rajesh and S.V. Suresha
Department of Agricultural Extension, College of Agriculture, UAS, GKVK, Bengaluru

To emphasize and empower the youths in agriculture, ICAR came out with the ARYA project, which is the core of the present study, conducted in the state of Karnataka during the year 2022-23 in the following districts of Bangalore rural, Uttara Kannada and Shivamogga. The total of 180 samples collected comprising of 60 samples from each district were collected. The results revealed that in Shivamogga, nearly half (46.67%) of respondents reported an average level of livelihood status. In Uttara Kannada, nearly three-fourths (73.33%), enjoyed an average to better level of livelihood status. Similarly, in Bangalore Rural, more than three-fourth (76.67%) of youth respondents experienced average to better livelihood status. Overall in Karnataka, nearly three-fourth (72.22%) of youths reported average to better livelihood status. Among the respondents 31.11 per cent of the youths displayed a low level of entrepreneurial behavior, 35.00 per cent exhibited a medium level and 33.89 per cent demonstrated a high level of entrepreneurial behavior.The variables, including education, annual income, family occupation, exposure to mass media, participation in extension programs, extension contact, marketing orientation, independence, mental activity, socio-political participation, landholding and self-confidence exhibited a statistically significant relationship with livelihood security. Major constraints encountered by youths for practicing agriculture were fluctuating weather conditions, labor shortage during peak times, non-availability of quality inputs at correct time, inconsistent and limited power supply disrupts operations, high cost of inputs, lack of capital/resources, market price instability, distress sales occur due to urgent financial needs. Providing good quality inputs, timely supply of necessary inputs, establishment of local market, timely provision of subsidy/credit were the major suggestions expressed by the youths to overcome the constraints for practicing agriculture.

Impact of FPOs on Socio-Economic Status of Member Farmers in Karnataka

Veera Anusha and R. Vinay Kumar
Department of Agricultural Extension, College of Agriculture, UAS, GKVK, Bengaluru

Collectivization of the farmers into Farmer Producer Organisations (FPOs) is considered as the most effective way to address present day challenges faced by small and marginal farmers in agriculture. Hence, the study throws light on the impact of FPOs on the socio-economic status of its members and their attitude towards FPOs. The study was conducted in two taluks of Kolar district *viz.*, Kolar and Srinivaspura in Karnataka state. Two FPOs from each taluk and 30 members from each FPO were selected randomly. Thus, a total of 120 respondents formed the sample for the study. The study revealed that two fifth (40.00%) of the members had favourable attitude towards their organisations. The results indicated a considerable shift in the socio-economic status of the members after joining the FPOs, that is, in FPO 1, FPO 2, FPO 3 and FPO 4 there was a shift from low and medium category of 83.33 per cent, 80.00 per cent, 80.00 per cent and 80.00 per cent to medium and high category of 83.33 per cent, 83.33 per cent, 83.33 per cent and 76.67 per cent, respectively. Majority of the members (62.50%) felt that getting lower price for their produce was the major constraint faced by them. To overcome the above constraint, major suggestion given by the members (45.83%) was to provide regular market awareness at every crop season by FPOs. Hence, organizing farmers into groups increases small and marginal farmers' risk-taking ability and their access to sufficient and timely finance, modern technology and expanded markets.

Performance Analysis of Sugarcane Growers in Vijayapura District

GAJANAND SHANTAPPA BHAIRAGOND AND G. NAGESHA
Department of Agricultural Extension, College of Agriculture, UAS, GKVK, Bengaluru

THE present investigation was carried out to assess the performance analysis of sugarcane growers in Vijayapura district. One hundred and twenty sugarcane growers were randomly selected from Indi and Sindagi taluk of Vijayapura district. The findings of the study revealed that, more than two fifth (48.34%) of the big farmers had medium level of production performance. Whereas, in case of small farmers, more than half (51.67 %) of the respondents had medium level of production performance. More than two fifth (45.00%) of big farmers had medium level of economic performance and 45.00 per cent of small farmers had low level of economic performance. Two fifth of the small farmers had low level of social performance. Whereas, in case of big farmers, more than two fifth of respondents (41.66%) had medium level of social performance. Regarding overall performance, half of the big farmers and more than two fifth (43.34%) of small farmers had medium and low level of overall performance, respectively. Nearly three fifth (58.34%) of the small farmers had high level of yield gap. Whereas, 58.53 per cent of big farmers had medium level of yield gap. The major constraints expressed by sugarcane growers were low price for sugarcane crop, delay in payment by sugarcane factories and high cost of plant protection chemicals, fertilizers and equipments. Timely payment by sugarcane factories and providing subsidies for purchase of plant protection chemicals fertilizes and equipments were the major suggestions put forth by the sugarcane growers.

An Analysis of Technological Gap, Yield Gap and Marketing Behaviour of Coconut Growers in Tumkur District of Karnataka

K. MOHITH AND C. NARAYANASWAMY
Department of Agricultural Extension, College of Agriculture, UAS, GKVK, Bengaluru

THE present study on technological gap, yield gap and marketing behaviour of randomly selected 120 coconut growers from Tiptur, Turuvekere, Chikkanayakanahalli and Sirataluks of Tumkur district was conducted during the year 2022-23. Results revealed that among overall coconut growers, 42.50 per cent of them had medium level of technological gap. Overall it was found that major technological gaps among coconut growers were found in disease management, pest management, chemical fertilizer application, micronutrient application, mulching and intercropping. Among the overall coconut growers, more than two-fifth of them (46.67%) belonged to medium level of yield gap. Among the overall coconut growers, slightly more than two-fifth of them (40.83%) come under medium level of marketing behaviour. The data was subjected to 'Kruskal-Wallis One-way ANOVA' and results indicated that there was a significant difference in the technological gaps, yield gaps and marketing behaviour of coconut growers among the taluks. Major constraints expressed by coconut growers were pest and diseases attack, high cost of inputs and poor irrigation facilities. Providing good market prices, educating and make available cost-effective simple technologies for pest and disease management and educating about labour saving technologies like mulching, coconut climbing machineries were the most important suggestions expressed bycoconut growers.

Farmer's Participation in FPO Ecosystem in Eastern Dry Zone of Karnataka

R. SHALINI AND S. GANESAMOORTHI
Department of Agricultural Extension, College of Agriculture, UAS, GKVK, Bengaluru

THE study was conducted in Bangalore Rural and Chikkaballapur district of Karnataka in the year 2022-23 to study the extent of members participation in FPO activities. Fifty-five FPO members were selected randomly from each district Bangalore Rural and Chikkaballapur. Thus, making a total sample size of one hundred and ten. The findings of the study revealed that, more than two-fifth (47.00 %) of the members belonged to moderate followed by poor (31.00 %) and better (22.00 %) level of participation. Under overall assessment of FPO Ecosystem, FPOs in Chikkaballapur district scored 52.10 per cent whereas FPOs in Bangalore Rural district scored 34.73 per cent. This is a clear indication that FPOs in Chikkaballapur district have favourable and congenial ecosystem to build sustainable FPOs and to extend their business wing. The results revealed that, seeking technical guidance from all the professional organizations (Rank-I) was the main reason perceived by the members for the success of the FPOs followed by Economic benefits for FPO members (Rank-II), Lower marketing cost due to pooled marketing (Rank-III), Enabled leadership in the FPO (Rank-IV) and Democracy in selection by office bearers (Rank-V). The major constraints expressed by the FPO members were lack of time under personal constraints, lack of proper training hall under infrastructural constraints, Lack of knowledge on technical practices under operational constraints, lack of sufficient finance for carrying FPO selected activities under economic constraints, low price for produce and distress sale under marketing constraints and lack of trained manpower in village/nearby under social constraints.

Performance and Perception of Grape Growers towards Scientific Production Technologies in Vijayapura District of Karnataka

SANGANAGOUDA BIRADAR AND D. RAGHUPATHI
Department of Agricultural Extension, College of Agriculture, UAS, GKVK, Bengaluru

THE research study was conducted in Vijayapura district of Karnataka during the year 2022-2023 with main objective to analyse the performance and perception of grape growers towards scientific production technologies. Sixty each small and bigfarmers were selected by simple random sampling technique from Vijayapura and Indi taluks. Thus, making the total sample size of 120. The findings revealed that more than two-fifth (40.83%) of the growers had high level of knowledge performance, nearly two-fifth (38.33 %) of the growers belonged to medium level of adoption performance, nearly two-fifth (37.50 %) of the growers belonged to medium level yield performance, more than one-third (35.00 %) of growers had low level economic performance and more than one-third (36.67 %) of the growers had medium level social performance. Regarding overall performance, more than one-third (35.83 %) of growers had medium level of performance. Nearly two-fifth (37.50 %) of growers had medium level perception towards scientific production technologies. The independent variables education, extension contact, extension participation, economic motivation, achievement motivation, management orientation, risk bearing ability and scientific orientation were found to have significant relation with the dependent variables of growers' performance and perception level. The major constraints expressed by growers were there were no resistant varieties for prevailing pest and diseases, scarcity of skilled labour during lean time, delayed cash payment by buying agencies and market price fluctuation. Developing pest and disease resistant varieties, availability of skilled labours in lean time, necessity of small-scale farm mechanization, timely payment by buying agencies, remunerative price for the grape were the important suggestions expressed by growers to increase the yield and income from grape cultivation.

A Study on Market Potential of Organic Food Products in Bengaluru City, Karnataka

K.M. Suman and Siddayya
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

THE study aimed to assess the market potential, consumer behavior and brand image of organic food products in Bengaluru City, Karnataka. Primary data was collected from 40 firms/ retailers and 120 consumers. Results indicated that 62.50 per cent of stores offered certified organic products and 80.00 per cent offering natural products. Regarding delivery methods, 90.00 per cent provided door delivery, while 37.50 per cent offered online delivery. 'Word-of-Mouth' ranked as the most influential source of information. Fruits and vegetables accounted for 33.58 per cent of market share followed by oils (30.67 %), milk and milk products (13.58 %), cereals (10.14 %), millets and pulses (6.22 % each). The Herfindahl-Hirschman Index of 0.238 suggested moderate market concentration. Consumers were segmented into 'Late Adopters', 'Seasoned Enthusiasts' and 'Organic Lifestyle Veterans' based on consumption duration. The majority (80.83 %) preferred specialty stores, followed by online (10.83 %) and malls/ supermarkets (8.36 %) for purchasing organic food products. Buying behavior of consumers indicated that 81.67 per cent preferred to buy certified organic food products. Although 75.00 per cent believed organic products were priced high 85.00 per cent were willing to pay more. Of these, 56.67 per cent expressed willingness to pay a premium of 1-10 per cent, showing a positive attitude towards organic products. Confirmatory factor analysis assessed brand image, revealing excellent model fits for Grami Super Food Organics, Pro Nature and Akashayakalpa Organics. Well be showed acceptable fit, while Pro Nature for pulses had a moderate fit. Overall, the study offers actionable insights to retailers, producers and policy makers to further develop and enhance the organic food market in the region. As consumer awareness and demand continue to grow, there is substantial potential for further expansion and improvement within the organic food sector in Bengaluru.

An Analysis of Market Structure and Profitability of Hydroponic Firms in Bengaluru

K.V. Chaithra and G. Ranganath
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

THIS study was undertaken to assess the market structure and profitability of hydroponicfirms in Bengaluru (urban and rural districts) during 2022-23 using both primary and secondary data. Primary data was collected from 93 respondents which comprises of 23 hydroponic firms, 20 hydroponic retailers and 50 consumers. The results of the study revealed the market concentration, competitiveness, market share and financial viability of hydroponic firms growing lettuce, spinach, celery, basil. The market structure was analyzed using Herfindahl-Hirschman Index which revealed a competitive market for hydroponic firms with less market concentration. Financial viability of the hydroponic units ranging from 5000 square feet to 2 acres was assessed. The hydroponic firms gross returns varied depending on its size, from Rs.13.53 lakhs to Rs. 141 lakhs. The total annual expenses ranged from Rs.6.76 Lakhs to Rs.73.21 lakhs. The net returns were in the range of Rs.6.76 Lakhs to Rs.68.16 lakhs. The NPV at10.50 per cent of discountrate, demonstrated positively across all firm sizes. The highest B:C ratio was found in case of 43,560 sq. ft hydroponic firms (1.77) and lowest in 5000 sq.ft firms (1.21). The hydroponic firms, with 43,560 sq.ft. of area had the highest Internal Rate of Return (30%), while the 5,000 square feet firms had the lowest Internal Rate of Return (17%). These findings clearly demonstrated that investment on any scale of hydroponic firms was financially viable. Superior quality of hydroponics and limited range of hydroponic products were identified as the major strength and weakness, respectively. Similarly, growing demand for hydroponic produces and higher pricing were identified as the major opportunity and challenge, respectively. Provision of financial assistance under a separate credit line with low interest rates is one of the major policy implication from the study.

An Economic Analysis of Production and Marketing of Arecanut in Chitradurga District of Karnataka

G.R. PRIYANKA AND MAMATHAGIRISH
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

THE study focused on economic analysis of production and marketing of Arecanut in Chitradurga district of Karnataka. The primary data was collected from 30 growers and 17 market intermediaries and the secondary data on area and production of arecanut was sourced from publications of Directorate of Economics and Statistics. Compound Annual Growth Rate (CAGR), Capital Budgeting Technique, Acharya's Method and Garrett's Ranking Techniques were used to analyse the data. The area under arecanut cultivation in Karnataka and Chitradurga grew at five per cent and seven per cent per annum, respectively during the reference period (2005-06 to 2021-22). The arecanut production in Karnataka and Chitradurga depicted a positive growth at 8.32 per cent and 10.41 per cent, respectively. The total cost of arecanut cultivation was Rs.2,35,361/- per acre per annum fetching a gross return of Rs.4,92,375/- and a net return of Rs.2,57,014. Three marketing channels prevailed in Chitradurga *viz.,*Channel-I: Producer - Village trader - Primary wholesaler - Processor - Secondary wholesaler - Retailers - Consumers, Channel-II: Producer - Co-operative Societies - Secondary Wholesaler - Retailers - Consumers, Channel-III: Producer - Pre-harvest Contractors - Village traders - Primary wholesaler - Processor - Secondary wholesaler - Retailers - Consumers. The processors are the main actors in value chain adding value to arecanut. Inadequate finance and high intervention of marketing middlemen are the production and marketing constraints faced by arecanut farmers. The vulnerability of arecanut growers to market price fluctuations can be overcome through Cooperative Societies and Farmer Producer Organizations.

Consumer Preference and Buying Behaviour of Branded Ready to Use Spices

M. ZANITH CHANGAPPA AND M.S. GANAPATHY
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

THE present study was conducted in Bengaluru city to examine the consumer preference and buying behaviour of branded ready to use spices. The primary data was collected from 120 branded ready to use spice consumers using pre-tested structured schedule and the data was analysed using Descriptive Statistics, Factor Analysis and Garrett's Ranking Technique. The major brands of spices available in the city were MTR, Everest, Eastern, Sakthi, Sparsh, Aachi, MDH and Catch. Among them, MTR was the most popular spice brand preferred by majority (50.83 %) of the consumers. The study revealed that 49.17 per cent of the consumers purchased branded spices on a monthly basis and 34.16 per cent of them found Supermarkets as the most convenient point of purchase.The purchases made by consumers were found to be both planned and unplanned (63.33 %). Good taste and better quality were the major reasons for particular brand preference in ready to use spices. The important factors influencing the purchase of branded spices by consumers were time saving, household income, high quality, readily available, family size, taste, health benefits, brand image, price and keeping quality. Television was the major source of information regarding promotional offers on spices for 57 per cent of the households. TV advertisement was ranked first among the promotional strategies influencing the purchase of branded spices. 57.50 per cent and 67.50 per cent of the consumers were influenced by celebrity endorsements and advertisements respectively, while purchasing branded spices. Extra quantity (93.33 %) was the major pricing strategy attracting branded spice consumers in Bengaluru city.

Marketing Strategy of Nutri-Cereal Product Firms in Bengaluru Urban and Bengaluru Rural Districts - An Exploratory Study

B.U. Kavya and G. Ranganath
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

The present study delves into exploring the marketing strategies of nutri-cereal product firms in Bengaluru Urban and Bengaluru Rural districts during 2022-23. With the aim of examining firm profiles, analyzing marketing mix and assessing brand image, a sample of 15 nutri-cereal product firms were selected using purposive and snowball sampling methods. Marketing mix data was collected through personal interview which comprised 30 consumers each from the major five firms and five consumers each from the remaining ten firms which accounted for a total of 200 sample consumers. Primary data related to brand image was collected exclusively from 30 consumers each from the major five firms accounting to a total of 150 sample consumers. The results of the study from the marketing mix analysis, utilizing Structural Equation Model, revealed a robust reliability and validity of data. Product and place mix elements exhibited significant effects on customer satisfaction, as indicated by critical ratios of 9.829 and 2.441 respectively having the probability values less than 0.05. The study employed ordinal logistic regression to assess brand image, uncovering variations among firms. Cafe Natural and Amruthabindu Millet Foods demonstrated strong model fit in explaining customer satisfaction with brand image, while others exhibited weaker relationships. The identified weaker relationships suggested opportunities for firms like Siridhanya Speciality Foods, The Millet Store, and Shubh Enterprise to enhance brand image by emulating the marketing and branding strategies of Cafe Natural and Amruthabindu Millet Foods like online presence, continuous innovation and catering to diverse tastes and preferences. The findings provide actionable insights for firms aiming to optimize marketing strategies by consistently delivering on product quality and customer satisfaction.

An Analysis of Consumer Preference for Honey – A Study in Bengaluru City

S. Sharmila and M.R. Girish
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

The present study made an attempt to analyse the brand preference of consumers of honey, factors influencing the purchase of honey by consumers, purchase behaviour of consumers of honey and the brand loyalty as well as the store loyalty of consumers of honey in Bengaluru city. For the study, data were elicited from 120 consumers drawn purposively from the city. Dabur was the most popular honey brand preferred by majority (40.83 %) of the sample consumers. Television was one of the major sources of information about various honey brands for all the sample consumers as it is the most popular mass media among people. The health benefits of honey and honey as a sugar substitute were the most important factors which influenced the consumers to purchase honey. Majority (47.50 %) of the sample consumers preferred to purchase less than 500 g of honey per visit. Majority (61.67 %) of the consumers purchased honey occasionally due to its limited usage. In most of the families, all the members consumed honey due to its established benefits in terms of its anti-bacterial, anti-microbial and anti-inflammatory properties. The purchasing decisions of most consumers were both planned and unplanned, as their approach to buying honey varied depending on their circumstances and needs. Majority (84.17 %) of the consumers were influenced by advertisements with regard to purchase of honey. About 93 per cent of the sample consumers purchased honey from super markets as it provides a wide range of honey brands under one roof. The brand loyalty of the consumers was mainly influenced by quality as it is quite obvious that quality honey is associated with better taste and flavour. For majority of the sample consumers, convenience of shopping was the major factor which influenced their store loyalty.

Value Chain Analysis of Arabica Coffee – A Study in Hassan District of Karnataka

K.R. YASHASWINI AND K.B. VEDAMURTHY
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

THE present study aimed to analyze the Arabica coffee value chain in Hassan district, Karnataka, focusing on primary data from 60 Arabica coffee growers, 5 traders, 5 curers, 5 roasters cum retailers and 5 exporters. Key actors identified in the value chain included the Coffee Board, input suppliers, labour contractors, coffee growers, traders, multinational companies, hullers and curers, roasters, Indian Coffee Trade Association, exporters, retailers and consumers. The results showed that 86.67 per cent of arabica coffee growers sold parchment coffee, while 13.33 per cent sold cherry coffee. 68.33 per cent of arabica coffee growers traded through channel I (Growers → Traders → Curing units → Exporters), 18.33 per cent in channel III (Growers → Curing units → Exporters), 15.00 per cent in channel II (Growers → Traders → Curing units → Roasters cum retailers → Consumers) and 10.00 per cent in channel IV (Growers → Curing units → Roasters cum retailers → Consumers). Channel II exhibited higher price spreads (Rs.403.93 and Rs.372.26) for both parchment and cherry coffee. Market efficiency, measured through Acharya's and Shepherd's method was highest in channel III for both parchment (2.51 and 3.51) and cherry coffee (1.34 and 2.31). Arabica coffee growers faced production constraints from sudden weather changes, while price fluctuations were a significant marketing challenge. Traders, on the other hand, encountered inadequate labor availability as a major constraint.

An Exploratory Study on Consumption and Trade of Plant Protection Chemicals in India

V. YASHWANTH KUMAR AND M. ARUN
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

PLANT protection chemicals (PPCs) are predominantly used in agriculture, many a times, indiscriminately and injudiciously causing damage to ecosystem and possible loss of biodiversity. The study analyzed PPC usage across the states of India considering both absolute quantities and per hectare use; categorized indigenous and imported PPC active ingredients by hazard levels, usage analysis by crop category and changes in India's trade pattern of PPC. For the study, secondary data pertaining to the period 2012 to 2022 was analyzed using Compound Annual Growth Rate and Markov Chain Analysis. At all India level, the PPC use grew from 45 to 64 million metric tonnes during 2012 to 2022, accounting for an annual growth of 2.42 per cent. The PPC use intensity was highest in Jammu and Kashmir (>3.5 kg/ha). India primarily relies on domestic pesticides (85%) for its consumption needs. The consumption of moderately hazardous chemical pesticides was predominant (>40%).Among crop categories, the overall PPC usage stood highest among cereals (33-39%) while in terms of per hectare consumption, vegetables (475 g/ha) took the top position. India imported PPCs from about 98 countries (1.49 lakh tonnes, valuing USD 1.8 billion in 2021),with China accounting for half the total, both by value and volume. India exported PPCs to about 192 countries (6.34 lakh tonnes, valuing USD 4.5 billion in 2021), with Brazil (20%) and USA (15%) topping the list. On an average, India's exports earned relatively lesser per unit ($7.09 thousand/tonne) through exports than it spent ($12.38 thousand/tonne) on imports in 2021. In the case of trade dynamics, Vietnam (63.37% retention) and Brazil (10.26% retention) were found to be consistent importers of Indian pesticides. China (74% retention) and Germany (55.52% retention) were the most stable PPCs exporters to India during 2012 to 2021 in terms of quantity.

Global Trends in Consumption and Trade of Plant Protection Chemicals

PANDIT REENA THANUJA AND M. ARUN
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

PLANT protection chemicals (PPCs) are the intellectual products invented with increasing market recognition. With MNC production facilities being located across the globe, its consumption takes place worldwide despite damage to ecosystems and human health. This research explores possible patterns and trends in consumption and trade of pesticides using the annual PPC consumption across different countries from 1990 to 2020, using secondary data (FAOSTAT). Data was analysed by using statistical tools like exponential growth rate analysis and pivot tables for aggregation, percentage and ranks were called upon. To depict PPC use intensity, per hectare consumption (179 Countries) is also computed. Herbicides (10.7 lakh tonnes, 51.8%) followed by fungicides & bactericides (5.17 lakh tonnes, 25.06%) were most used globally. Insecticides (4.57 lakh tonnes) accounted for 22.15 per cent of chemical use, while the rodenticides (0.18 lakh tonnes,0.88%) was used the least. The top 10 countries (USA, Brazil, China, Argentina,Canada, France, Australia, India, Italy and Turkey) collectively used over 1 million tonnes of pesticides in 1990, which rose to over 1.6 million tonnes by 2020. Brazil has significantly increased pesticide usage from 50,000 tonnes in 1990 to over 3.75 lakh tonnes in 2020. Growth in global pesticide exports by value, evidenced a five-fold increase from around USD 8 billion in 1990 to over USD 40 billion by 2020. Analyzing global trends in PPC consumption and trade has identified regions with surging pesticide use. Considering its impact on ecosystems, biodiversity and human health the study highlighted alarming levels of PPC use among certain countries. The need for stricter PPC use regulations or alternative pest management approaches is to be considered.

An Empirical Analysis of Consumer Behaviour towards Value Added Products of Millets in Bengaluru Urban District

PRASANNA AND K.B. VEDAMURTHY
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

THE study investigates consumer behaviour towards millet value-added products in the Bengaluru urban district, employing multiple regression, conjoint analysis, van westendorp price sensitivity meter and garrett's ranking techniques on data from 120 consumers across the four zones of Bengaluru city. The study finds that key factors such as age, income and postgraduate education are statistically significant among eight factors that influence the purchase of value added products of millets. Majority of consumers preferred millet cookies (68.33 %), followed by millet flour (61.67 %), malt powder (55.83 %) and idli/ dosa mix (54.17 %). Consumers emphasized specific attributes in their preferences, focusing on extending a product's quality through shelf life (35.34 %). Other considerations include packaging (17.34 %), nutritional value (16.84 %), a wide range of products (16.11 %) and taste (14.36 %). Consumers were willing to spend more on specific products, expressing readiness to pay Rs.5/- extra (6.2%) for Siri's 200g millet cookies and Rs.9/- additional (4.16%) for Jeeni millet health mix powder. Additionally, consumers were willing to pay a 12 per cent premium (Rs.15/-) for Indira's Ragi Dosa Mix. The research highlighted that the inadequate availability of value added products of millets was one of the major constraints faced by the consumers, followed by a lack of promotion of nutri-cereals products, lack of well-known brands, different preferences among family members and distance from home. The new millet ventures should focus on the above factors and increase their sales to reach the target consumers.

Value Chain Analysis of Rice in Sindhanur Taluk of Raichur District, Karnataka

M. Lakshmi Prasanna and Mamatha Girish
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

The present study was aimed at value chain analysis of rice in Sindhanur taluk of Raichur district of Karnataka. The trends in area and production of paddy, the cost, returns and degree of value addition of paddy processing into rice and puffed ricewere analysed. Production, processing and marketing constraints of paddy were also analysed. Primary data was collected from 10 rice millers and 30 paddy growers. The results revealed that growth rate of area, production and productivity of rice in Raichur district depicted an increasing trend at 2.44 per cent, 3.64 per cent and 1.14 per cent, respectively. Rice millers earned Rs.453.82 lakhs annually, with a net return of Rs.11,797/- per tonne with B-C ratio of 1.36 depicting profitability of paddy processing. Puffed rice production by millers generated an income of Rs.1,94,882/- and a net return of Rs.509/- per quintal and a B-C ratio of 1.18. The highest degree of value addition for both - paddy to rice and puffed rice was done at the processors stage. Farmers faced production constraints with pest and diseases as the primary issue, followed by high input costs and unfair produce prices. Marketing challenges included price fluctuations, delayed payments and high transportation costs. Paddy processing hurdles involved high electricity costs, inefficient rice mill use and challenges related to procurement costs and raw material availability. Direct marketing of rice through their own brand would enable thehigher income generation by rice mill owners.

Production and Marketing of Catla Fish in Birbhum District of West Bengal

Soumyajit Biswas and M.S. Ganapathy
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

The study focused on growth in area, production and productivity of catla fish in Birbhum district, cost and returns in catla fish production, marketing channels and consumer preference. The area, production and productivity of catla fish respectively, recorded a CAGR of 6.16, 6.85 and 0.65 per cent during 2010-2022 period. Most of the farmers (75%) found to have very small sized water body and a smaller percentage farmers (25%) found to have large amount of water bodies. The annual total cost for catla farming was found to be Rs.4,76,643 / ha for small-scale farmer and Rs.5,19,754 / ha for large-scale farmers. The profit for catla cultivation was found to be Rs.2,43,356 / ha for small-scale farmers and Rs.5,60,245/ha for large-scale farmers. The productivity was 4000 kg / ha and 6000 kg / ha per year. About 48 per cent of farmers traded through channel-III (Producer →Wholesaler → Retailer → Consumer), 32 per cent in channel-II (Producer → Retailer → Consumer) and 20 per cent in channel-I (Producer → Consumer). Producer's share in consumer's rupees was found to be highest in channel-I (97.63%) followed by channel-II (79.4%) and lowest in channel-III (79.00%). Consumers were preferring catla fish mainly due to its taste and nutritive value. SWOC analysis revealed that higher market price throughout the year was major strength, perishability of catla fish was major weakness, suitability for polyculture and gradual-harvesting were major opportunities, unavailability of quality fingerlings was found to be major challenges in catla fish farming.

A Study on Consumer Preference for Value Added Rice Products in Bengaluru City

Shailaja and Mahin Sharif
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

Rice is one of the most staple food crops, feeding more than 60 per cent of India's population. The popularity of value-added rice products among consumers has dramatically increased due to urban families and dual-income earning people of the households opting for rice products offers a multitude of benefits that cater to both taste and health. The study was conducted with the objective of documenting different types of value added rice products available in the market, to analyze the determinants of consumer preference for value added rice products and to undertake the SWOC analysis of value added rice products. The study was conducted in Bengaluru city with a sample of 75 respondents. The results of the study revealed that MTR, ID, Tata Sampann, Elite, GITS and Double Horse etc., were the major brands of value added rice products in retail outlets. Examining socio-economic characteristics of consumers revealed that the majority of consumers age fell between 31 to 45 and majority of consumers with 43.33 per cent were employed in the private sector. The analysis of monthly income, family type and food habits through multiple linear regression demonstrated significant positive correlations with monthly expenditure on value-added rice products Notably, the R-squared value of 81.56 per cent indicated a good fit. Availability of wide range of rice products and low shelf life of value-added rice products were identified as the major strength and weakness, respectively. Retailers are offering online services to reach a wider customer base and changing dietary trends as the major opportunity and challenge, respectively. Therefore, the food processing companies, public institutions like CFTRI, IICPT can design and develop new products to cater the need of the consumers was one of the major policy implications from the study.

An Economic Analysis of Milk Producers' Cooperative Societies – A Study in Bengaluru Rural District

Varsha K. Patil and M.R. Girish
Institute of Agribusiness Management, College of Agriculture, UAS, GKVK, Bengaluru

The present study was conducted in Bengaluru Rural district covering Doddaballapur taluk. The study analysed inputs supplied by MPCSs; Milk procurement pattern of MPCSs; Financial performance of MPCSs; Women participation in functioning of MPCSs; constraints faced by MPCSs and Dairy farmers. The primary data was collected from four sample MPCSs and from each sample MPCS, 15 dairy farmers were randomly selected. The inputs provided by MPCSs to members were balanced cattle feed, mineral mixture, rubber mats, mineral blocks, deworming tablets and fodder seeds and feed supplements, while the services rendered were animal insurance, artificial insemination services, and veterinary services. The quality parameters such as fat, SNF and Corrected Lactometer Reading were used by MPCSs to determine the price of milk. The tasks such as milk measurement (according to standards) and procurement were exclusively handled by men with a 100 per cent male participation rate. In the case of billing and maintaining records, the involvement of men and women was to the tune of 75 and 25 per cent, respectively. All the sample MPCSs had current ratio and net capital ratio of more than one indicating that all the societies had liquidity and were solvent, while thequick ratio and equity value ratio wereless than one indicating financial risk to societies.The collection of milk by middlemen from dairy farmers at their doorsteps was the major constraint faced by MPCSs while lack of timely access to veterinary services was the major production constraint faced by dairy farmers.

Study of Spatio-Temporal Price Behavior of Tomato in Selected Markets of India

K. Lekhana and T.L. Mohan Kumar
Department of Agricultural Statistics, Applied Mathematics and Computer Science,
College of Agriculture, UAS, GKVK, Bengaluru

In the present study, analysis of the trend in prices of tomato of selected markets *viz*., Bengaluru, Chintamani, Kolar, Pimpalgaon, Indore and Azadpur were studied using secondary data on monthly prices of tomato collected from the Krishimarata Vahini website from January 2002 to December 2022. Linear models (Straight line, Quadratic and Cubic) and Nonlinear models (Exponential and Logistic) were fitted to analyze the trends in prices of tomato. RMSE and R^2 values were considered to choose the best models. The linear model was best fitted for all the markets except Bengaluru market for which exponential model was found to be best fitted. The prices of tomato have shown an increasing trend in the selected markets. The ratio to moving average method was used to calculate the seasonal indices of prices of tomato. All the markets showed low prices during the peak period of harvest *i.e.,* from December -Febrauary and highest prices during the off-season *i.e.,* from August-October Co-integration between selected markets was analyzed using Johansen's co-integration test, the pairwise causality between markets was analyzed using the Granger causality test for the weekly price data from 2021 to 2022. Results indicated that Chintamani, Kolar, Pimpalgaon, markets had significant long-term effects on the prices of other markets. Pimpalgaon market previous week's prices had short-term effects on prices of Bengaluru, Kolar, Indore and Azadpur markets. Kolar, Pimpalgaon market prices had short-term effects from the previous week's prices of the Chintamani market. The different forecasting models (Holt's-Winter, SARIMA, ARCH-GARCH and ANN) were employed to forecast prices of tomato in the selected markets. ANN model performed better on both training and testing data with the lowest RMSE as compared with others. Hence, the ANN model was used for forecasting the in all the selected markets.

Statistical Analysis on Land Use Pattern of Area, Production and Productivity of Selected Cereal Crops in Karnataka

Akshay Kalyani and H.S. Surendra
Department of Agricultural Statistics, Applied Mathematics and Computer Science,
College of Agriculture, UAS, GKVK, Bengaluru

An effort was made to analyse the compound growth rate,instability and relative contribution of area and productivity in the production of major cereal crops in Karnataka, for this particular study the time series data of 30 years (1991-2020) on area, production and productivity was collected. The exponential modelused to compute the CAGR,Coefficient of variation (CV %), Cuddy-Della Valle instability index,Coppock's Instability Index (CII%) were used to analyse instabilityand decomposition analysis method was usedto compute the relative contribution of area, productivityin the increased production of cereal crops. The exponential modelbased compound growth depicted that there was positive growth rate for production for the cereal crops considered under study except Jowar. However, there was a negative growth rate for area of all cereal crops except Maize. The decomposition analysis of both rice and bajra concludes that the area expansion effect could be the major reason for positive change in production pattern, whereas increase in productivity was the major reason for increase in production in case of maize and jowar crops. The study on instability analysis for these crops indicated that, the pattern of area and production was stable for rice crop in Bellary district, whereas the maize was consistent in Haveri district for area and production. Further Jowar crop showed stable production in Raichur with respect to area and production. However, bajra crop showed consistent in all parameters under Kalburgi district. The identified growth rate in individual cereal crop provides chronological background of how the cultivation of cereal crops persuade the life of farmers either in negative or positive way.

Statistical Analysis of Area and Production of Tobacco in Gujarat

GADHAVI HIMANSHU ARJUNSINH AND M. GOPINATH RAO
Department of Agricultural Statistics, Applied Mathematics and Computer Science,
College of Agriculture, UAS, GKVK, Bengaluru

This study employs a 21-year longitudinal dataset spanning from 1999 to 2019 to meticulously scrutinize the trajectory of tobacco cultivation within three carefully selected districts in Gujarat, namely Mehsana, Anand and Kheda. To undertake this comprehensive analysis, a diverse array of mathematical models, including linear, quadratic, Generalized Additive Model (GAM), exponential and monomolecular models were thoughtfully employed for trend assessment. An exhaustive evaluation, grounded in the determination of Minimum Mean Absolute Percentage Error (MAPE) values, distinctly underscored that the Generalized Additive Model (GAM) was unequivocally the most apt choice across all three districts for modelling both the production and area of tobacco crops. Of particular significance was the prodigious accuracy demonstrated by the GAM in the districts of Mehsana, Anand, and Kheda. Furthermore, the study extended its purview by leveraging the GAM model to proffer a prognostication of tobacco crop production over a forthcoming six-year period. The forecasts unequivocally signalled an upward trajectory for Mehsana and Anand, while Kheda, in stark contrast, registered a noticeable decline. Notably, structural shifts in the tobacco crop landscape were acutely discerned post-2000 within all three districts, thus accentuating the pivotal significance of this investigation. These findings hold the potential to serve as a guiding compass for policymakers and stakeholders alike, offering strategic guidance for the promotion of sustainable agricultural development within the region.

Brown Manuring : An Effective Technique for Yield Sustainability and Weed Management in Aerobic Rice - Rice Bean Cropping System

JYOTI JADIPUJARI AND B.S. LALITHA
Department of Agronomy, College of Agriculture, UAS, GKVK, Bengaluru

A field experiment on 'Brown manuring : An effective technique for yield sustainability and weed management in aerobic rice - rice bean cropping system' was conducted during summer and *kharif* seasons of 2022 and 2023 at Agronomy field unit, Zonal Agricultural Research Station, UAS-B, GKVK, Bengaluru. The experiment was composed of three factors *viz.,* factor I: Brown manuring (C_1-Rice and C_2-Rice + Sunhemp), factor II: RDF levels (N_1- 75% RDF, N_2-100% RDF and N_3- 125% RDF) and factor III: Herbicides [H_1- No herbicide, H_2- Pendimethalin (1000 g *a.i.* ha^{-1}) PE *fb* Pyrazosulfuron (25 g *a.i.* ha^{-1}) (POE at 25 DAS) and H_3-Bensulfuron methyl + Pretilachlor 6.6 % G (660 g *a.i.* ha^{-1}) PE *fb* Bispyribac sodium (25 g *a.i.* ha^{-1}) 25-30 DAS] with 18 treatment combinations replicated thrice in randomized complete block design with factorial concept. In the pooled (2022 and 2023) data results revealed that combination of rice + sunhemp with 125% RDF along with Bensulfuron methyl + Pretilachlor *fb* Bispyribac sodium recorded significantly higher plant height (80.92 cm), leaf area index (2.38), dry matter production (99.62 g plant^{-1}), number of panicles (20.68 plant^{-1}), grain yield (4774 kg ha^{-1}), straw yield (6747 kg ha^{-1}), uptake of nitrogen (118.58 kg ha^{-1}), phosphorous (36.82 kg ha^{-1}) and potassium (131.03 kg ha^{-1}). Rice + sunhemp with 100% RDF along with Bensulfuron methyl + Pretilachlor *fb* Bispyribac sodium recorded significantly higher net returns (Rs.55094 ha^{-1}) and B-C ratio (2.06). In rice - rice bean cropping system, residual rice bean recorded higher plant height (44.45 cm), dry matter production (26.39 g plant^{-1}), seed yield (1283 kg ha^{-1}) and haulm yield (2893 kg ha^{-1}) under rice + sunhemp with 125% RDF along with Bensulfuron methyl + Pretilachlor *fb* Bispyribac sodium.

Studies on Sowing Window, Planting Geometry and Weed Management Practices on Growth and Yield of Pigeonpea [*Cajanus cajan* (L.) Millsp]

SWATI DASH AND K. MURALI
Department of Agronomy, College of Agriculture, UAS, GKVK, Bengaluru

FIELD experiments were conducted during *kharif* 2021 and 2022 at K-block, UAS, GKVK, Bengaluru. First experiment was conducted on sowing windows, planting geometry and varieties to assess its effect on growth and yield of pigeonpea. Significantly higher growth and yield parameters were recorded during the first fortnight of May sowing. Higher plant height (191.53cm), number of branches (36.71), number of pods per plant (87.45), pod weight per plant (65.32g), grain weight per plant (33.55g) leading to higher grain yield (1945 kg ha^{-1}) and stalk yield (8373 kg ha^{-1}) was recorded with May 1^{st} fortnight sowing. In case of planting methods paired row system of planting (60/120 cm x 30cm) resulted in significantly higher pigeonpea grain yield (1203 kg ha^{-1}) compared to normal row spacing (120 cm x 30 cm) with the grain yield of 1029 kg ha^{-1}. Among the varieties BRG-3 recorded significantly higher grain yield (1164 kg ha^{-1}) than BRG-4 (1068 kg ha^{-1}). The higher B:C ratio was recorded for sowing window of first fortnight of May (3.51), paired row planting (1.98) and BRG-3 (2.10) compared to other treatments. Second experiment was conducted on weed management practices to assess its effect on growth and yield of pigeonpea. It was observed that by application of Diclosulum 84%WDG @ 22g a.i/ha (PE) *fb*Fluazifop -p-butyl 11.1% + fomesafen 11.1%SL @ 250 g a.i/ha (PoE) resulted in significantly higher weed control as observed by lower total weed count (3.33), dry weight (2.14g) and higher weed control efficiency (95.25 %) at 30 DAS and lower total weed count (3.53) and dry weight (1.65g) at 60 DAS and higher weed control efficiency (98.03%) compared to other herbicides, which led to higher grain yield (1623 kg ha^{-1}) and B:C ratio (3.29).

Studies on Response of Finger Millet to Nano-N and Nano-Zn for Enhancing Productivity and Nutrient Use Efficiency

M.A. SNEHA AND MUDALAGIRIYAPPA
Department of Agronomy, College of Agriculture, UAS, GKVK, Bengaluru

THE field and pot experiments were conducted at Dryland Agriculture Project, UAS, GKVK, Bengaluru during *kharif* 2021 and 2022 to evaluate the studies on response of finger millet to nano-N and nano-Zn for enhancing productivity and nutrient use efficiency. The field experiment comprised of two factors *viz.,* Factor I: Nitrogen levels (A_1: No nitrogen, A_2: 50% RDN, A_3: 75% RDN and A_4: 100% RDN), Factor II: Method of fertilizer application (B_1: Soil application of zinc @ 12.5 kg ha^{-1}, B_2: Foliar application of nano-N, B_3: Foliar application of nano-Zn and B_4: Foliar application of nano-N and nano-Zn) with 16 treatment combinations along with two control (C-1: Recommended PK, C-2: Recommended NPK) replicated thrice in randomized complete block design with factorial concept. The pooled data revealed that combined application of 100% RDN along with spraying of nano-N and nano-Zn at 35 and 55 DAS @ 2 ml per litre of water registered significantly higher plant height (100.49 cm), leaf area (1446 cm^2 $hill^{-1}$), total dry matter production (61.05 g $hill^{-1}$), number of productive tillers (12.89 $hill^{-1}$), ear length (7.41 cm), grain yield (3535 kg ha^{-1}), straw yield (5048 kg ha^{-1}), total uptake of nitrogen (54.30 kg ha^{-1}), phosphorus (12.64 kg ha^{-1}) and potassium (50.91 kg ha^{-1}) and was on par with the application of 75% RDN with spraying of nano-N and nano-Zn twice. Higher net returns (Rs.73768 ha^{-1}), BC-ratio (2.59) and nitrogen use efficiency were also recorded with the application of 75% RDN along with spraying of nano-N and nano-Zn twice. The results of pot experiment with 10 treatments replicated thrice showed significantly higher anti-oxidant enzyme activity, chlorophyll content, relative water content and grain yield with application of 100% RDN along with spraying of nano-N and nano-Z twice at 35 and 55 DAS @ 2 ml per litre of water.

Studies on Bio-Efficacy of Granular Biofertilizer with Different Levels of Nitrogen and Phosphorus on Productivity and Quality of Groundnut (*Arachis hypogaea* L.)

ANILKUMAR AND H.S. LATHA
Department of Agronomy, College of Agriculture, UAS, GKVK, Bengaluru

A field experiment entitled 'Studies on bio-efficacy of granular biofertilizer with different levels of nitrogen and phosphorus on productivity and quality of groundnut (*Arachis hypogaea* L.)' was conducted during *kharif* 2022 at AICRP for Dryland Agriculture, UAS, GKVK, Bengaluru. There were ten treatments replicated thrice in Randomized Complete Block Design. Among the different treatments, the treatment which received 100% NPK+ GR-Bio @ 7.5 kg ha^{-1} recorded significantly higher growth parameters at harvest *viz.,*plant height, number of branches and total dry matter accumulation (49.81 cm, 6.75 and 33.68 g plant^{-1}), pod and haulm yield (2637 and 4648 kg ha^{-1}, respectively), oil and protein yield (944 and 493 kg ha^{-1}, respectively) nutrient uptake (226.13, 28.39 and 108.23 kg ha^{-1} of nitrogen, phosphorus and potassium, respectively), available nutrient in soil (296.58, 83.99 and 215.22 kg ha^{-1} of nitrogen, phosphorus and potassium, respectively), soil microbial population (33.51 x 10^6 and 40.41 x 10^6 CFU g^{-1} soil of nitrogen fixers and PSB, respectively), net returns (Rs.53,528 ha^{-1}) and benefit cost ratio (2.23). Further from the results, it could be concluded that, 100% NPK coupled with the soil application of 7.5 kg ha^{-1}of granular biofertilizer enhanced pod and haulm yield to an extent of 6.76 and 6.26 per cent, respectively over 100% NPK+ *Rhizobium* and PSB (T_3) and also it enhanced the yield and quality of groundnut which showed positive influence on maintenance of soil health.

Performance of LCO - Fortified Biofertilizers and Nano Nitrogen in Paddy

TARUN V. NAIK AND D.C. HANUMANTHAPPA
Department of Agronomy, College of Agriculture, UAS, GKVK, Bengaluru

A field experiment was conducted at the University of Agricultural Sciences, GKVK, Bengaluru during *kharif* 2022 to study the performance of LCO - fortified biofertilizers and nano nitrogen in paddy. The experiment was laid out in a Randomized Complete Block Design with seven treatments replicated thrice. The treatments consisted of different combinations of lipo-chito oligosaccharides (LCO) fortified biofertilizer, nano urea and mycorrhizae along with different rates (100 and 75%) of the recommended dose of fertilizers and control. Results revealed that, the application of 100 % Rec. NPK + LCO-fortified biofertilizer @ 10 kg ha^{-1} + Foliar spray of nano urea @ 0.2 % at 30 and 60 DAT recorded significantly higher leaf area (1912 cm^2 plant^{-1} at 90 DAT), leaf area index (6.37 at 90DAT), plant height (77.1 cm), number of tillers plant^{-1} (35.8), number of leaves plant^{-1} (71.5) and total dry matter accumulation (46.06 g plant^{-1}) at harvest which resulted in increased yield attributes such as number of productive tillers (589 m^{-2}), number of panicles (584 m^{-2}), grain weight (3.86 g panicle^{-1}), number of grains panicle^{-1} (176.7) and grain yield (7056 kg ha^{-1}), straw yield (7556 kg ha^{-1}) and harvest index (0.48). Significantly higher plant nutrient uptake of nitrogen, phosphorus and potassium (95.99, 36.54 and 83.25 kg ha^{-1}, respectively), gross returns (Rs.1,69,144 ha^{-1}), net returns (Rs.1,12,447 ha^{-1}) and B:C ratio (2.98) were higher in the same treatment.

Influence of Foliar Nutrition on Seed Yield and Quality of Pigeonpea [*Cajanus cajan* (L.) Millsp.]

S. DAYANANDANAIK AND H.M. ATHEEKUR REHMAN
Department of Agronomy, College of Agriculture, UAS, GKVK, Bengaluru

THE field experiment entitled 'Influence of foliar nutrition on seed yield and quality of pigeonpea [*Cajanus cajan* (L.) Millsp.]' was conducted during *kharif* 2022 at 'K' Block, Zonal Agricultural Research Station, University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bengaluru. The experiment consisted of foliar application of two types of nutrients (19:19:19 and Pulse magic), two growth promoters (NAA and N - Triacontanol) and their combinations at flowering and pod formation stages, totally there were eight treatments replicated thrice in randomized complete block design. The growth and yield attributes were varied significantly and RDF + foliar application of one per cent pulse magic at flowering and pod formation stage recorded higher plant height (144.6 cm), number of branches (16.8 plant^{1}), leaf area (3218 cm^2 plant^{-1}), leaf area index (2.38) and total dry matter accumulation (135.5 g plant^{-1}) as compared to control (122.2 cm, 12.9, 2421 cm^2 plant^{-1} and 89.4 g plant^{-1}, respectively) at harvest. Higher seed yield (1590 kg ha^{-1}), crude protein content (21.1%), crude protein yield (335.5 kg ha^{1}), net returns (Rs.52570 ha^{-1}) and B:C ratio (2.33) recorded with the application of RDF + foliar application of one per cent pulse magic at flowering and pod formation stage which increased the yield by 30.56 per cent compared to control and lower seed yield, net returns and B:C ratio (1104 kg ha^{-1}, Rs.27322 ha^{-1} and 1.74, respectively) was recorded with control treatment.

Response of Cowpea (*Vigna unguiculata* L.) to Integrated Nutrient Management

S.D. SHILPA AND K.N. KALYANA MURTHY
Department of Agronomy, College of Agriculture, UAS, GKVK, Bengaluru

A field experiment entitled 'Response of cowpea (*Vigna unguiculata* L.) to integrated nutrient management' was conducted during *kharif* 2022 at K-block of AICRP on Arid Legumes, GKVK, UAS, Bangalore. The experiment consisted of ten treatments which were replicated thrice in Randomized Complete Block Design. Among the different treatments, application of 100% RDF + seed treatment with microbial consortia and soil application of microbial consortia recorded significantly higher seed and haulm yield (1394 kg ha^{-1} and 3238 kg ha^{-1}, respectively), growth and yield parameters *viz.* plant height (46.2 cm), number of branches (8.9), leaf area (1098 cm^{2}plant^{-1}), total dry matter accumulation (25.4 g plant^{-1}), number of root nodules (38.2), number of pods plant^{-1} (23.6), pod length (17.7 cm) and number of seeds pod^{-1} (17.2). Further, significantly higher nutrient uptake (55.7, 16.8 and 51.8 kg ha^{-1} of nitrogen, phosphorus and potassium, respectively), soil organic carbon (0.42 %), nutrient availability (274.2, 44.4 and 267.2 kg ha^{-1}of nitrogen, phosphorus and potassium, respectively), soil microbial count (44.8 × 10^6, 21.4 × 10^4, 23.5 × 10^3, 29.7× 10^5 and 24.3 × 10^5 CFU g^{-1} soil of bacteria, fungi, actinomycetes, free living N_2-fixers and PSB, respectively) and higher net returns (Rs.60556 ha^{-1}) and benefit cost ratio (3.23) were observed with the treatment which received 100% RDF + seed treatment with microbial consortia and soil application of microbial consortia. Hence, it can be concluded that response of cowpea is found to be better with the application of 100% RDF + seed treatment with microbial consortia and soil application of microbial consortia.

Response of Sulphur Oxidizing Bacteria Inoculum on Growth, Yield and Quality of Sunflower (*Helianthus annuus* L.)

H.V. BABYBAI AND P. PRAKASH
Department of Agronomy, College of Agriculture, UAS, GKVK, Bengaluru

A field experiment was conducted to know the response of sulphur oxidizing bacteria inoculum in sunflower during late *kharif*,2022 at ZARS, AICRP on Sunflower, UAS, GKVK, Bengaluru. The experiment was laid out in RCBD with seven treatments replicated thrice. The treatment consisted of RDF + Sulphur @ 20 kg ha^{-1} + SOB as seed treatment @ 1.0 kg ha^{-1}+ SOB as soil application @ 2.0 kg ha^{-1} recorded significantly higher plant height (174 cm at harvest), number of leaves $plant^{-1}$ (17.90 at 90 DAS), leaf area (2585 at 45 DAS cm^2 $plant^{-1}$), LAI (1.44 at 45 DAS), stem girth (7.56 cm at harvest), dry matter production (68.35 g $plant^{-1}$ at harvest), chlorophyll content (92.2 at harvest), ear head diameter (19.1 cm), head weight (298.57 g), yield $plant^{-1}$ (30.05 g), test weight (6.89 g), seed yield (2184 kg ha^{-1}), stalk yield (2490 kg ha^{-1}), harvest index (0.47), uptake of nitrogen, phosphorus, potassium, sulphur (117.46, 32.41, 79.68 kg ha^{-1} and 313.75 g ha^{-1}), oil content (38.50%), oil yield (841 kg ha^{-1}), available soil nutrient status *viz*., available nitrogen, phosphorus, potassium, sulphur (277.73, 26.88,158.25 kg ha^{-1} and 13.53 mg kg^{-1}), respectively. Increased sulphur content over initial (37.63%), soil microbial population (fungi 27.62 x 10^4 CFU g^{-1}, bacteria 57.45 x 10^6 CFU g^{-1}, actinomycetes 25.69 x 10^2 CFU g^{-1} and SOB 4.57 × 10^2 CFU g^{-1}), cost of cultivation (Rs.58,336 ha^{-1}), gross returns (Rs.1,37,592 ha^{-1}), net returns (Rs.79,256 ha^{-1}) and B:C ratio (2.36).

Efficacy of Pre and Post Emergent Herbicides on Weed Flora, Growth and Yield of Soybean (*Glycine max* L. Merrill.)

B.V. VIKAS ACHARI AND S. KAMALA BAI
Department of Agronomy, College of Agriculture, UAS, GKVK, Bengaluru

A field investigation was conducted during *kharif* 2022 at J-block, AICRP on weed management, UAS, GKVK, Bengaluru. The experiment was laid out in RCBD with eleven treatments replicated thrice. The treatments consisted of five pre-emergent herbicides (Pendimethalin, diclosulam, pendimethalin + imazethapyr, sulfentrazone + clomazone, diclosulam + pendimethalin) and four post-emergent herbicides (fluazifop -p- butyl + fomesafen, bentazone, sodium acifluorfen + clodinafop propargyl, imazethapyr + propaquizafop), compared with two hand weedings at 20 and 40 DAS and unweeded check. Among the pre emergent herbicide treatments, application of sulfentrazone 28 % + clomazone 30 % WP (RM) @ 725 g *a.i.* ha^{-1} recorded lower total weed density (4.67 no. m^{-2}), weed dry weight (7.47 g m^{-2}), higher weed control efficiency (81.20 %) at 40 DAS and lower weed index (1.2) with higher seed yield (1912 kg ha^{-1}). In the post emergent herbicide treatments, fluazifop -p- butyl 11.1 % + fomesafen 11.1 % SL @ 250 g *a.i.* ha^{-1} recorded lesser total weed density (15.33 no. m^{-2}), total weed dry weight (12.20 g m^{-2}), weed index (2.0) and higher weed control efficiency (69.32 %) at 40 DAS with higher seed yield (1897 kg ha^{-1}) and B:C ratio (3.37). Considering the high cost and non-availability of labour at the right time, the use of pre and post emergent herbicides found effective in controlling weeds and resulted in increased yield with higher returns.

Investigation on Insect Pollinator Profile of Lucerne, *Medicago sativa* L.

SHREYA R. PATIL AND G. ESWARAPPA
Department of Apiculture, College of Agriculture, UAS, GKVK, Bengaluru

A field experiment on 'Investigation on insect pollinator profile of Lucerne, *Medicago sativa* L.' was carried out at the Research Farm of ICAR- National Bureau of Agricultural Insect Resources (NBAIR), Attur, Yelahanka, Bengaluru during 2022-23. Totally 36 floral visitors belonging to four insect orders were documented of which Hymenopterans were most abundant, followed by Lepidoptera, Diptera and Hemiptera. The composition of *Apis cerana* F. was maximum followed by *A. florea* F. and *Lampides boeticus* L.during different bloom phases of lucerne. Anther dehiscence was observed after 1 to 72 hr of the anthesis in lucerne. The pollens were viable from 1 to 120 hr after anthesis and the stigma receptivity was observed 54 hr before anthesis and continued upto 96 hr after anthesis. Among the different modes of pollination imposed to evaluate their effect on pod set and seed yield parameters, the plots subjected to open pollination had maximum pod set, pods per inflorescence, seeds per pod, seeds per inflorescence, seed weight per inflorescence and germination per cent as compared to that of plot enclosed with a colony of *A. cerana* pollination and pollinator exclusion plot. Effective tripping of the flowers by floral visitors resulted in varied pod set and yield parameters.

Morphological and Molecular Characterisation of Thai Sac Brood Virus Affecting Indian Honey Bee, *Apis cerana* F.

CHETAN VEERANAGOUDA MARIGOUDAR AND A.N. SHYLESHA
Department of Apiculture, College of Agriculture, UAS, GKVK, Bengaluru

THIS study investigates Thai Sac Brood Virus (TSBV) infection in Indian honeybee species *A. cerana* F. in Karnataka, employing a comprehensive approach that examines both morphological and molecular aspects to understand the impact of TSBV infection on the host honeybee population. Monitoring honeybee health in Karnataka is crucial due to TSBV's persistent impact on *A. cerana* colonies, thereby supporting beekeeping. Key findings encompass a wide range of disease infection per colony (0-100%) and per apiary (0-60%) across various locations in Karnataka. Seasonal incidence patterns reveal peak infection rates with 100 per cent infection in affected colonies during the survey period. Weather parameters demonstrate varying associations with disease incidence, where temperature exhibited a non-significant negative relationship with disease incidence, while relative humidity showed a non-significant but positive relationship with disease incidence in all three districts. Morphological examinations, including Transmission Electron Microscope (TEM) for the virus (31.81nm in diameter) and Scanning Electron Microscope (SEM) for understanding the virus's effect on the cuticle of bee larvae, along with genomic analysis, highlight TSBV's RNA composition. The data include genome size (8859 bp), GC content and functional annotations. Phylogenetic analysis places TSBV NBAIR A1 within the same clade as the Karnataka and Tamilnadu strains, underscoring its position within the AcSBV subgroup. PCR amplification (497 bp) confirms the presence of TSBV, while Recombinase Polymerase Amplification (610 bp) and Loop-Mediated Isothermal Amplification (LAMP) assays were efficient and sensitive methods for TSBV detection, surpassing traditional RT-PCR in terms of speed (30 min), lower temperature requirements (39°C) and reduced cost of detection. These findings can be used to develop holistic approaches for disease management and sustainable beekeeping practices, ensuring the continued health and viability of *A. cerana* bee colonies in Karnataka.

Processing, Development and Evaluation of Value Added Food Products from Lotus (*Nelumbo nucifera*)

S. Ashoka and M.L. Revanna
Department of Food Science and Nutrition, College of Agriculture, UAS, GKVK, Bengaluru

The study explores the untapped nutritional and functional potential of the culturally revered lotus plant, focusing on its various parts such as seeds, rhizomes and flowers. Hence, the present study was undertaken to standardize the process of dehydration and to develop value added products from the lotus flower, seeds and stem flour. Through processing techniques, the study demonstrates the transformation of lotus into a diverse range of value-added food products as functional ingredients. Comprehensive evaluations of the physical characteristics, drying methods, color changes and chemical compositions of lotus-based products are conducted. The nutritional analysis reveals richness of lotus flower, seed and stem flours in essential nutrients, minerals and amino acids, showcasing their potential as functional food ingredients. The study also delves into antioxidant and polyphenol content, demonstrating the health-promoting benefits of lotus products. Sensory evaluations of lotus-based muffins, biscuits and cookies highlight consumer acceptability. Moreover, the research includes glycemic index studies, indicating the potential of lotus seed and stem incorporation in chapati to regulate blood glucose levels. Cost estimations for the developed products underscore their economic viability. The findings collectively emphasize lotus as a promising source for developing nutritious, natural and sustainable food choices. The study's comprehensive approach, from processing techniques to consumer acceptability and health benefits, lotus as a valuable crop with diverse applications in the food industry. Overall, the research contributes valuable insights into harnessing the nutritional and functional potential of lotus, promoting its cultivation and encouraging the development of innovative food products to enhance global nutritional well-being. However, the comprehensive findings underscore the transformative potential of lotus in creating diverse, nutrient-rich and sustainable food choices, promoting nutritional well-being and fostering agricultural practices that align with evolving consumer preferences.

Nutritional Evaluation of Value-Added Tamarind (*Tamarindus indica*) Products

Thallapalli Divya and S. Shamshad Begum
Department of Food Science and Nutrition, College of Agriculture, UAS, GKVK, Bengaluru

Tamarind (*Tamarindus indica*) belongs to the family 'Fabaceae' with its genus tamarindus and it is derived from the arabic word- 'Tamr-Hindi', which means 'Date of India'. The present study was undertaken to develop value-added products, to assess the sensory parameters, analyse the nutrient composition, shelf life, consumer acceptability and cost analysis. Tamarind *rasam* concentrate (TRC) from chintamani local and Tamarind *chigali* (TC) from Gorur selection were scored best with respect to all sensory parameters. TRC and TC had protein (11.7 g and 3.78 g), ash (8.2 g and 7.40g), crude fibre (12.6 g and 9.30g), carbohydrate (6.83g and 67.02g) and energy (278 and 299 Kcal) per 100g. Analysis of mineral composition showed that Phosphorus (353 mg), Magnesium (200 mg), Zinc (2.89 mg), Calcium (430 mg), Iron (13 mg) and Potassium (850 mg) per 100g respectively, were highest in TRC. The sensory profile of TRC and TC indicated good acceptability. However, as the storage period increased, the sensory scores were found to be decreased but the products were acceptable till 180 days. The peroxide value and free fatty acid value were found to be within permissible limits for both products until end of storage period. The consumer study indicated TRC and TC to be acceptable. The cost of production was lower for these products than the similar products available in the market. Hence, Tamarind based products are cost effective and good alternative to boost health along with nutritional benefits and it also as good potential for value addition in convenience foods.

Development and Quality Evaluation of Lemongrass Incorporated Products

JEEVITA KUSAGUR AND BHARATHI C. MIRAJKAR
Department of Food Science and Nutrition, College of Agriculture, UAS, GKVK, Bengaluru

LEMONGRASS belonging to the family Poaceae is native to tropical regions of Asia and the Indian subcontinent. It is underutilized grass rich in minerals, fiber, flavonoids and polyphenolic compounds. Hence, the present study was undertaken for development and quality assessment of value added food products by incorporating dehydrated plant powder. Plants subjected to steam blanching for three mins and tray dried at 65^0C was selected for further studies based on appearance. The nutritional composition revealed that plant had 63.40 g carbohydrates, 7.16 g protein, 4.70 g fat, 9.17 g crude fibre, Total ash 7.03 g per 100 g of sample. The bioactive components like antioxidant activity (2601.44 mg AAE/100g), total polyphenols (369.91 mg GAE/100g) and flavonoids (158.22 mgRE/100 g) were recorded. Value added products such as butter biscuits, custard powder, muffins and crackers were developed by incorporating dehydrated plant powder at varying per cents. Among the variations, one per cent in butter biscuits and muffins, three per cent in crackers and 1.5 per cent in custard powder had higher scores for overall acceptability. The shelf life of lemongrass incorporated products was studied for 30 (Butter biscuits and Crackers), 45 (Custard powder) and 7 (Muffins) days, respectively. The sensory parameters of products diminished with longer storage period. The consumer acceptability was good for all the sensory attributes. The cost of production of butter biscuits, custard powder, muffins and crackers were Rs.20, Rs.35, Rs.35 and Rs.27 per 100 g, respectively. Hence, processing and value addition of lemongrass will pave way to explore development of nutritious products from underutilized herbs.

Studies on Development of Low-Calorie Foods Using Stevia (*Stevia rebaudiana* L.)

G.C. YASHASWINI AND SAVITA S. MANGANAVAR
Department of Food Science and Nutrition, College of Agriculture, UAS, GKVK, Bengaluru

STEVIA REBAUDIANA, a perennial shrub is the sweetest plant belonging to the Asteraceae family. Stevia leaves are an excellent source of diterpene glycosides which are responsible for sweetness and is being utilized commercially for sugar substitution in foods, beverages and medicines. Hence, the present study was undertaken for development of low-calorie foods using stevia green leaves powder (SGLP) and processed white stevia powder (PWSP). The study revealed that SGLP contained nutritional composition of 11.09 per cent moisture, 12.08 g of protein, 8.86 g of total ash, 14.8 g of crude fibre, 2.94 g of fat, 64.19 g of carbohydrates, 275.70 kcal of energy, 15.26 mg of vitamin C and 370 µg of β-carotene per 100g of sample, whereas the PWSP exhibited reduced levels of nutrients as compared to SGLP. The mineral content in SGLP is significantly higher than that of PWSP. The SGLP exhibited the highest levels of total antioxidant activity and bioactive components with antioxidant activity of 2744.06 µAAE/100g, total polyphenols of 1397.19 µGAE/100g and flavonoids of 92 µRE/100g, whereas the PWSP registered comparatively lower values for bioactive compounds. White finger millet products such as biscuits, cookies and rusks were developed by incorporating two stevia powders to an extent of 1, 1.25 and 1.5 per cent. Among the variations, 1.25 per cent SGLP based products and one per cent PWSP based products had higher scores for overall acceptability. The storage period and packaging material tangibly affected moisture, free fatty acid, peroxide value and microbial load but all the levels were within the permissible limit. The consumer acceptability of stevia based products revealed that, 80 to 95 per cent of consumers accepted the stevia based bakery products. Thus, the study demonstrated that stevia powders can be used as the best alternative to sugar in bakery products.

Nutritional Evaluation of Tomato (*Solanum lycopersicum*) Based Value Added Products

T. Akhil Kumar and S. Shamshad Begum
Department of Food Science and Nutrition, College of Agriculture, UAS, GKVK, Bengaluru

Tomato (*Solanum lycopersicum*) is known as the most important and popular fruit crop that is generally treated as a vegetable, originating from Western South America and Central America that is valued for its nutritional value. The present study was undertaken to standardize the process of dehydration to develop value added and shelf stable products from dehydrated tomato powder and to evaluate its nutritional content. Fresh tomatoes were subjected with different pre-treatments and dried at three different drying temperatures (at 40°C, 50°C and 60°C) in a tray drier. The moisture content, yield per cent and colour varied significantly among the pre-treatments. However, tomatoes drying at 50°C without blanching was considered best for further process. Dehydrated tomato powder was analysed for physico-chemical, functional and nutrient analysis. Different value added products were developed by incorporating dehydrated tomato powder at different levels. Sensory acceptability of developed products was in the range of liked moderately to liked extremely on a nine-point hedonic scale. Tomato powder incorporated masala biscuits (T_3-10 %), cookies (T_1-4 %), tomato chutney and tomato sauce made with var. Sahoo was preferred over Var. Arka Abhed, tomato jam prepared from Var. Arka Abhed was best accepted. Micronutrient was improved significantly upon tomato powder incorporation into the products. The microbial load was well within safe and permissible limits till 30th dayof the storage study. In essence, the transformation of tomatoes into dehydrated powder, tomato chutney, tomato jam and tomato sauce not only enhances their usability but also minimizes wastage, making it a sustainable and resourceful practice.

Formulation and Evaluation of Millet Based Edible Cutleries

M. Sahana and M.L. Revanna
Department of Food Science and Nutrition, College of Agriculture, UAS, GKVK, Bengaluru

Millets are small seeded grains, taxonomically belonging to family Poaceae, considered as crop of food security because of the sustainability in adverse agro climatic conditions. Millets are good source of energy, dietary fiber, gluten free, slowly digestible starch and thus provide sustained release of glucose and thereby satiety. Plastic is a great threat to the entire ecosystem so, there is a considerable need to replace plastic cutlery with better alternatives like edible cutlery as it is generally recognized as EBO (eco-friendly, biodegradable and organic). Millet based edible cutleries will 'create a market force' for the local farmers by bringing back demand for millets. On the other hand, consumable containers cum ready to eat food are becoming a hot trend globally. Therefore, the study entitled "Formulation and evaluation of millet based edible cutleries" was conducted with the objectives to develop and analyse the physico-chemical, functional and storage stability of developed edible cutleries with functional ingredients for best accepted standardized products in the proportion of refined wheat flour(40g), white finger millet flour (40g), little millet flour (40g), foxtail millet flour (40g), whole wheat flour (20g), sugar (12g), margarine (2g), corn starch (2.5g), xanthan gum (2g), milk powder (4.5g), sorghum flour (15g), salt (0.5g) and vanilla essence (0.5g). Sensory acceptability of developed cutleries was in the range of moderately to like extremely on a nine-point hedonic scale. The standardized millet based edible cutleries were found to be nutritionally superior in terms of fiber, protein, carbohydrates, energy, calcium and iron. Significant differences were observed in sensory scores, moisture, free fatty acid of millet based edible cutleries stored in metallized polyester polyethylene compared to that stored in aluminium silver foil packaging materials. Changes in microbial counts were within permissible limits in samples stored in both packaging materials. The developed millet based edible cutleries were nutritious with good storage stability.

Influence of Pre-Harvest Spraying of Insecticides and Botanicals on Pulse Beetle and Storability of Seeds in Field Bean (*Labalab purpureus* L.)

ANAND AND B. BASAVARAJA
Department of Seed Science and Technology, College of Agriculture, UAS, GKVK, Bengaluru

THE field experiment was conducted at Agriculture Research Station, Madenur, Hassan during *rabi* 2022 to know the influence of pre-harvest spraying of insecticides and botanicals on pulse beetle and storability of seeds in field bean (*Labalab purpureus* L.) var. HA-4. Freshly harvested seeds were collected and graded seeds were evaluated for their quality parameters in the laboratory. Among different pre-harvest sprays, spinosad 45 SC @ 0.04 ml/l recorded highest seed quality parameters such as 100 seed weight (19.30 g), seed germination (91.25 %), seedling vigour index-I (3728), seedling vigour index -II (6862), electrical conductivity (239.25 μScm^{-1}) and no seed infestation (zero number of eggs laid and zero number of egg hatch) were recorded and control recorded lowest seed quality parameters. Further, these seeds were stored in cloth bag under ambient condition up to six months and seed quality parameters were recorded at monthly intervals. The results revealed that among the different pre harvest sprays after six months of seed storability, spinosad 45 SC @ 0.04 ml/l had highest seed quality parameters such as 100 seed weight (19.02 g), seed germination (82.89 %), seedling vigour index-I (2520), seedling vigour index -II (4038) and lowest electrical conductivity (400.08 μScm^{-1}) and seed infestation (3.97 %). Emamectin benzoate and deltamethrin showed on par results with each other in all seed quality parameters and control recorded lowest seed quality parameters. This study concluded that, in field bean var. HA-4, preharvest spray of spinosad 45 SC @ 0.04 ml/l can control the bruchid infestation and maintain the seed quality parameters above IMSCS up to six months of storage period.

Studies on Standardization of Seed Testing Protocol and Dormancy Breaking Methods in Quinoa (*Chenopodium quinoa* Willd.)

H.K. KIRAN KUMAR AND A.B. NARAYANAREDDY
Department of Seed Science and Technology, College of Agriculture, UAS, GKVK, Bengaluru

A laboratory study was conducted to standardize the germination testing protocol of quinoa in the Department of Seed Science and Technology, College of Agriculture, University of Agricultural Sciences, GKVK, Bengaluru during 2022-23. Quinoa seeds were subjected to germination test at different temperatures (20°C, 25°C, 30°C, 20/25°C and 25/30°C) with different substrata (top of paper, between paper and sand). Among substrata, the highest germination (82.5 %), mean seedling length (10.83 cm), mean seedling dry weight (16.08 mg), speed of germination (38.50), seedling vigour index-I (897) and seedling vigour index-II (1331) were observed in between paper method and lowest (66.6 %, 10.12 cm, 15.22 mg, 20.78, 678 and 1018, respectively) were observed in sand method. Among temperatures, highest germination (78.2 %), mean seedling length (12.40 cm), mean seedling dry weight (18.08 mg), seedling vigour index-I (973) and seedling vigour index-II (1416) were observed at alternative temperature of 25°C/30°C and lowest (71.0 %, 8.33 cm, 13.24 mg, 594 and 943, respectively) were observed at 20°C. Speed of germination was maximum (35.23) at 30°C and minimum (23.90) at 20°C. Further, freshly harvested seeds of quinoa were subjected to dormancy breaking treatments. Among different treatments, the highest germination (85.67 %), mean seedling length (13.83 cm), mean seedling dry weight (18.23 mg), seedling vigour index-I (1185), seedling vigour index-II (1562) were recorded in seed treated with KNO_3 @ 1.5 % for 12 hr and lowest (16.33 %, 8.00 cm, 13.30 mg, 131 and 217, respectively) were recorded in untreated seeds. Therefore, it is concluded that germination test of quinoa could be conducted alternative temperature of 25/30°C using between paper as a substratum and treating the seeds with KNO_3 @ 1.5 % for 12 hours break the dormancy of quinoa seeds.

Morphological, Physiological and Biochemical Characterization of Ridge Gourd Genotypes [*Luffa acutangula* (L.) Robx.]

H.S. Shodhan Jain and S.N. Vasudevan
Department of Seed Science and Technology, College of Agriculture, UAS, GKVK, Bengaluru

The field experiment was conducted at Agriculture Research Station, Madenur, Hassan during *rabi* 2022 to know the influence of pre-harvest spraying of insecticides and botanicals on pulse beetle and storability of seeds in field bean (*Labalab purpureus* L.) var. HA-4. Freshly harvested seeds were collected and graded seeds were evaluated for their quality parameters in the laboratory. Among different pre-harvest sprays, spinosad 45 SC @ 0.04 ml/l recorded highest seed quality parameters such as 100 seed weight (19.30 g), seed germination (91.25 %), seedling vigour index-I (3728), seedling vigour index -II (6862), electrical conductivity (239.25 µScm^{-1}) and no seed infestation (zero number of eggs laid and zero number of egg hatch) were recorded and control recorded lowest seed quality parameters. Further, these seeds were stored in cloth bag under ambient condition up to six months and seed quality parameters were recorded at monthly intervals. The results revealed that among the different pre harvest sprays after six months of seed storability, spinosad 45 SC @ 0.04 ml/l had highest seed quality parameters such as 100 seed weight (19.02 g), seed germination (82.89 %), seedling vigour index-I (2520), seedling vigour index -II (4038) and lowest electrical conductivity (400.08 µScm^{-1}) and seed infestation (3.97 %). Emamectin benzoate and deltamethrin showed on par results with each other in all seed quality parameters and control recorded lowest seed quality parameters. This study concluded that, in field bean var. HA-4, preharvest spray of spinosad 45 SC @ 0.04 ml/l can control the bruchid infestation and maintain the seed quality parameters above IMSCS up to six months of storage period.

Morphological, Physiological and Biochemical Characterization of Bottle Gourd [*Lagenaria siceraria* (Mol.) Standl.] Genotypes

Kiran Nayak and S.N. Vasudevan
Department of Seed Science and Technology, College of Agriculture, UAS, GKVK, Bengaluru

Field experiment was conducted to evaluate twenty bottle gourd genotypes for growth and seed yield at Research and Development Station of Orbi Seeds International Private Limited, Sadahalli during *rabi*-summer, 2022-23 and the laboratory experiment on seed quality and storability was conducted at the Seed Technology Research Centre, AICRP on Seed (Crops) and Department of Seed Science and Technology, Gandhi Krishi Vignan Kendra, University of Agricultural Sciences, Bangalore. The results indicated that all the genotypes differed significantly for growth, seed yield and quality parameters. The genotype OSBG-005 was noted for earliness as it took minimum days to 50 per cent staminate and pistillate flowering (47.55 DAT and 49.95 DAT, respectively). The genotype OSBG-012 was found to be promising for higher vine length at 45 DAT and at maturity (252 cm and 716 cm, respectively), lower sex ratio (11.24), more number of fruits per vine (9.42), average fruit weight (1142.19 g), fruit yield per hectare (53.81 t ha^{-1}), seed yield per fruit (32.18 g) and seed yield per hectare (10.44 q ha^{-1}). All the genotypes showed variations in seed morphological characteristics (seed size, seed colour, seed shape and seed luster). Among the twenty genotypes, the genotype OSBG-001 recorded the significantly higher seed quality parameters *viz*., seed germination, mean seedling length, mean seedling dry weight, seedling vigour index-I, seedling vigour index-II and TDH activity (98.33 %, 39.01 cm, 75.22 mg, 3837, 7398 and 2.43 A_{480nm}, respectively) and lower electrical conductivity (72.35 µS/cm/g). In this study, eleven genotypes (OSBG-012, OSBG-014, OSBG-004, OSBG-006, OSBG-009, OSBG-005, OSBG-001, OSBG-002, OSBG-016, OSBG-011 and OSBG-008) were considered as good storer as these genotypes recorded germination percentage higher than the Minimum Seed Certification Standards for bottle gourd (60 %) after accelerated ageing.

Studies on Residual Effect of Pesticides on Biochemical and Physiological Parameters in Haemolymph of the Silkworm, *Bombyx mori* L.

N. Sandhya and N. Amarnatha
Department of Sericulture, College of Agriculture, UAS, GKVK, Bengaluru

A study on residual effect of recommended dose of pesticides *viz*., carbofuran, dimethoate, novaluron, azadirechtin, fenazaquin, dinotefuron and chlorfenapyr on biochemical and physiological parameters in haemolymph of silkworm was conducted at the department of sericulture, UAS, GKVK, Bengaluru. The results revealed a steady increase in heamolymph total protein and carbohydrate contents from first day to sixth day of fifth instar in water spray and absolute control. Whereas, in all pesticide treatments, protein content declined and carbohydrate content was elevated at a lower rate than in controls throughout the fifth instar. Amylase activity increased in controls upto fifth day of fifth instar and then declined. Whereas, in all pesticide treatments, the amylase activity was elevated upto third day and then declined. Acetylcholinesterase (AChE) activity in all pesticide treatments, exhibited a different trend and its inhibition was not prominent in carbofuran, dimethoate, novaluron and azadirechtin. However, novaluron showed an overall decline in AChE activity throughout the fifth instar. Peroxidase (POX) activity increased upto second day and there after decreased in all pesticide treatments. In controls, POX activity remained constant and decreased on sixth day of fifth instar. The bioassay of chemicals on silkworm revealed that, fifth instar larval, cocoon, shell and pupal weights and fecundity were highest in dimethoate (3.07g, 1.81g, 0.31g, 1.64g and 497.85, respectively) and least in chlorfenapyr (2.13g, 1.46g, 0.25g, 1.30g and 382.70, respectively). Larval mortality and deformed moths were least in carbofuran (5.42% and 2.00, respectively) and highest in chlorfenapyr (13.93% and 10.34, respectively). The pesticide chlorfenapyr had detrimental effect on larval and cocoon parameters even after waiting for safe period (10 days), though it is effective against foliar pests.

Studies on the Prevalence of Pebrine Disease in Magadi Taluk of Mysore Seed Area

B.R. Yashaswini and Fatima Sadatulla
Department of Sericulture, College of Agriculture, UAS, GKVK, Bengaluru

Preliminary survey on the current status of pebrine disease in Magadi taluk of Mysore seed area was conducted from November 2022 to April 2023. Further, characterization of pebrine spores isolated was done through SEM analysis. The results revealed that the disease incidence in pupae and mother moths samples collected from two Governament model grainages (Magadi and Kuduru) was found to be on par with 6.66 per cent. However, the DFLs collected from both the grainages had no incidence of pebrine. The overall per cent mean pebrine disease incidence in two government model grainages (Magadi and Kuduru) in Magadi taluk of Mysore seed area was 4.44. On microscopic examination of each of the thirty samples collected from Mathikere and Koramangala CRCs no pebrine spores were detected, indicating no pebrine incidence in Mattikere and Koramangala CRCs of Magadi taluk in Mysore seed area. The pebrine disease incidence in late age silkworms collected from farmers' field in Soluru, Kuduru and Kalya hoblies was 12.00, 8.00 and 8.00 per cent, respectively. The presence of pebrine in silkworm excreta collected from Soluru, Kuduru and Kalya hoblies from farmers' field was 8.00, 4.00 and 4.00 per cent, respectively. The overall average disease incidence covering the three different hoblies including 15 villages surveyed in Magadi taluk of Mysore seed area was 9.33 per cent in late age silkworms and 5.33 per cent in silkworm excreta. The pebrine spores isolated from Magadi taluk of Mysore seed area were ovo-cylindrical in shape with slight depression, the mean length × width was 4.33 ± 0.01 × 2.13 ± 0.01 µm. On comparing shape and size of this isolate with the previously reported microsporidian strains, it closely resembled with *Nosema* sp. Lbms strain which measures 4.36 × 2.14 µm and also has a slight depression.

Evaluation of Abamectin 1.9 % EC and Diafenthiuran 50 % WP for Safety Period on Mulberry Silkworm, *Bombyx mori* L

N.M. Kenchappa and K.S. Vinoda
Department of Sericulture, College of Agriculture, UAS, GKVK, Bengaluru

An experiment on 'Evaluation of abamectin 1.9 % EC and diafenthiuran 50 % WP for safety period on mulberry silkworm, *Bombyx mori* L' was carried out at the Department of Sericulture, CoA, GKVK, Bengaluru during 2022-2023. Among different molecules used, abamectin 1.9 % EC and diafenthiuron 50 %WP molecules were used for the study. Both the molecules did not exhibit any phytotoxicity symptoms on mulberry and also found safer to natural enemies in mulberry ecosystem. The leaf yield was significantly higher in abamectin 1.9 % EC (58,244.11 kg/ha/year) and diafenthiuron 50 %WP (56757.62 kg/ha/year) at 60 DAS. Both tested molecules were found safer to silkworm when the leaves were fed at 15 and 21 DAS, which is reflected through zero per cent mortality, cent per cent larval progression and better rearing (larval duration, larval weight and % ERR), productivity (cocooning percentage, cocoon weight and cocoon shell weight) and filament parameters (filament length, filament weight and non-breakable filament length) at 15 DAS. Further, both the molecules were effective against both thrips and broad mites exhibiting dual action as pesticide and acaricide, which saves additional investment on labour and input cost. Finally, abamectin 1.9 % EC (@ 0.75 ml/l) and diafenthiuron 50 % WP (@ 1 g/l) can be used a alternate molecules for effective management of both thrips and mites in mulberry with a safety period of 15 days.

Identifying Land Quality Monitoring Sites for Addressing Degradation Vulnerability of Tumkur District, Karnataka using Remote Sensing and GIS Techniques

I. Shafnas and K.S. Anil Kumar
Department of Soil Science and Agricultural Chemistry, College of Agriculture, UAS, GKVK, Bengaluru

The detailed soil characterization for identifying land quality monitoring sites for addressing degradation vulnerability of Tumkur district, Karnataka during 2021-2023 was carried out using remote sensing, GIS and field studies at Department of Soil Science and Agricultural Chemistry, UAS, Bangalore. Satellite imageries (Sentinel-2) of three-seasons were used along with soil map to delineate the degraded soils through visual image interpretation and land resource characterization. Thirteen soil pedons were selected from Tumkur district for the study. Findings related to various characteristics revealed that, the granite, gneissic and schistose landform and lateralized parent material gave rise to well drained, non-gravelly deep soils. Sand and clay content varied from 22.31 to 92.78 and 4.16 to 62.79 per cent, available WHC ranged from 31.37 to 90.13 mm m^{-1}. 61.5 per cent of pedons were found to be acidic, low to medium in Organic carbon, CEC: clay and base saturation ranged from 0.10 to 0.76 and 68.11 to 99.57 per cent, respectively. The soil organic carbon stock was markedly highest (10.00 kg m^{-3}) in Annehalli, Tumkur and the lowest (1.19 kg m^{-3}) in Kurubarahalli, Koratagere-1. The major taxa of the soils identified at great group level were *Ustipsamments, Haplustepts, Haplargids, Paleargids, Rhodustalfs, Paleustalfs, Kanhaplustalfs* and *Kandiustalfs* in the order of soil development. Based on weighted index model of degradation vulnerability assessment, low degradation class was noticed in pedons- 5, 9, 10, 11, 12, 13, medium in pedons- 2, 4 and 8, moderate in pedons- 1 and 3, high in pedon- 7 and very high in pedon- 6. Water erosion was the major degradation process followed by soil chemical and physical deterioration triggered by anthropogenic and climatic actions. Land quality monitoring sites characterized will help in identifying vulnerable soils for the purpose of making suitable combating plans, thereby ensuring sustainable management of land with enhanced productivity.

Studies on Potassium Dynamics under Central and Southern Dry Zones of Coconut Growing Areas of Hassan District of Karnataka

Gagan B. Shetty and S. Channakeshava
Department of Soil Science and Agricultural Chemistry, College of Agriculture, UAS, GKVK, Bengaluru

An investigation was undertaken to study the status and distribution of potassium in Central and Southern dry zone of coconut growing areas of Hassan district, Karnataka during 2022-23. The soil samples were collected from surface (0-30 cm) and sub-surface (30-60 cm) depth and analysed for different parameters. The results indicated that the soil pH ranged from neutral to slightly acidic, EC was normal and OC content varied from low to high in both the agro-climatic zones. Available nitrogen, phosphorus and sulphur status were moderate in surface soils but decreased with depth. Whereas, the available potassium status were higher in surface soils and reduced with depth. Among micronutrients, the available iron, manganese, and copper were sufficient, while zinc and boron were deficient. The average water soluble K, hot water soluble K, exchangeable K, non-exchangeable K, lattice K and total K in surface soils of coconut gardens of Central dry zone were 2.76, 9.25, 54.65, 555.35, 5896.00 and 6509.00 mg kg^{-1}, respectively, whereas that of sub-surface soil was 2.67, 7.70, 47.36, 699.66, 7282.00 and 8032.00 mg kg^{-1}, respectively. In the Southern dry zone, above mentioned potassium fractions in surface soil were 2.87, 8.85, 53.51, 546.61, 5603.00 and 6206.00 mg kg^{-1}, while that of sub-surface soils were 2.21, 7.20, 45.21, 709.20, 7431.00 and 8188.00 mg kg^{-1}, respectively. Water-soluble K and exchangeable K decreased with depth, while other potassium fractions increased. Subsurface soils exhibited higher potassium fixation compared to surface soils due to clay illuviation. Furthermore, cumulative K release, total step-K and constant rate potassium decreased with depth across the studied area. Knowledge of different forms of potassium in soil with their distribution has greater relevance in assessing the long-term K supplying power of soil to coconut palm and is important in formulating a sound fertilizer program for a given set of soil.

Spectral Studies of Soil Properties Using Ground and Satellite-Based Approaches in the Northern Transect of Bengaluru

H. Vimalashree and A. Sathish
Department of Soil Science and Agricultural Chemistry, College of Agriculture, UAS, GKVK, Bengaluru

A study to predict soil properties by using Vis –NIR lab Spectroscopy data and PRISMA satellite datawith pre-processing techniques and machine learning algorithm was made in 2022-23. A total of 280 surface soil samples were collected from different locations in the Northern transect of Bengaluru, these samples were analysed for various soil properties, including soil texture, available water content, pH, electrical conductivity (EC), organic carbon (OC), cation exchange capacity (CEC), total nitrogen (TN), total phosphorus (TP), total potassium (TK), calcium (Ca), magnesium (Mg) and sulphur (S), using standard analytical methods. The results revealed that soil texture was sandy clay loam with available water content (AWC) being 8.80 per cent. The prediction of soil properties using PRISMA satellite data random forest model performed best for sand, clay, EC, OC, TN, TK and Mg with R^2_{cal} values 0.80, 0.85, 0.73, 0.62, 0.54, 0.65 and 0.55 followed by PLSR for silt, AWC, pH, CEC, TP and Ca with R^2_{cal} values 0.73, 0.51, 0.62, 0.64, 0.61 and 0.42, respectively. Poor prediction was noticed in artificial neural network with R^2 values ranges between 0.18-0.51 for different soil properties. The prediction of soil properties using spectroscopy revealed that Random Forest model combined with SG Filter pre-processing technique predicted sand, silt, clay, EC, TN and TK with R^2_{cal} values of 0.88, 0.86, 0.92, 0.69, 0.72, 0.65 and 0.65, respectively. Multiplicative scatter correction pre-processing with PLSR model predicted TP with R^2_{cal} value of 0.63. The SVM model with SNV pre-processing yielded higher accuracy for AWC, Ca, Mg and S content with R^2_{cal} value of 0.68, 0.57, 0.65 and 0.63, respectively. SVM model with SG-filter pre-processing performed best for prediction of OC and CEC with R^2_{cal} value of 0.74 and 0.66.

Effect of Drip Fertigation on Nutrient Uptake and Yield of Baby Corn (*Zea mays* L.) under Varied Moisture Regimes

SURESH AND M.A. ANANTHAKUMAR
Department of Soil Science and Agricultural Chemistry, College of Agriculture, V.C. Farm, Mandya

A field experiment was conducted during *rabi* 2022-23 at Water Technology Centre, ZARS, V.C. Farm, Mandya. The experiment was laid out in strip plot design with three replications comprised of irrigation levels at 90, 80, 70, and 60 per cent of field capacity (FC) in horizontal strips and fertigation levels at 100 and 75% RDF through drip fertigation and 100% RDF through soil-based application in vertical strips. The results revealed that irrigation at 90% FC recorded significantly higher plant height (192.81 cm), leaf area (5382 cm^2), husked cob yield (85.37 q ha^{-1}), dehusked cob yield (11.17 q ha^{-1}) and green stover yield (397.27 q ha^{-1}) with higher N, P and K uptake (105.38 kg ha^{-1}, 30.82 kg ha^{-1} and 81.51 kg ha^{-1}, respectively). Among fertigation levels, 100% RDF through drip fertigation resulted in significantly greater plant height (196.55 cm), leaf area (5457 cm^2), husked cob (87.53 q ha^{-1}), dehusked cob (11.78 q ha^{-1}) and green stover yield (412.98 q ha^{-1}) with higher N, P and K uptake (111.48 kg ha^{-1}, 31.45 kg ha^{-1} and 83.91 kg ha^{-1}, respectively). The irrigation with 60% FC recorded significantly higher water use efficiency for husked cob yield and green stover yield (27.83 and 131.12 kg ha-mm^{-1}). The correlation analysis indicated significant and positive correlation between total N, P, K uptake and yield. The study indicated that irrigation at 90% FC with fertigation of 100% RDF is beneficial in obtaining the highest net returns (Rs.106,331 ha^{-1}) and favorable benefit-cost ratio (2.46) in baby corn.

Effect of Zinc and Boron on Salt Stress in Rice Cultivated under Soils of Cauvery Command Area, Karnataka

B. RAJESHWARI AND R. SUMA
Department of Soil Science and Agricultural Chemistry, College of Agriculture, V.C. Farm, Mandya

A field experiment was conducted during *kharif* 2022-23 at College of Agriculture, V.C. Farm, Mandya using factorial RCBD comprising of two factors, *i.e.*, soil application (SA) of zinc sulfate at three levels (0, 20 and 40 kg ha^{-1} - Zn_0, Zn_{20} and Zn_{40}) and three times foliar spray (FS) of boric acid at four levels (0, 0.25, 0.5 and 0.75 % - B_0, $B_{0.25}$, $B_{0.5}$ and $B_{0.75}$), to study its effect on salt stress in rice. The salinity indices *i.e.*, relative water content, SPAD values, chlorophyll a and b were in higher amounts and proline, Na^+/K^+ and Na^+/Ca^{2+} in index leaves and roots were in lower amounts with Zn_{40}+$B_{0.5}$, after a week of second spray. However, after third FS of B, Zn_{40}+$B_{0.25}$ was found to be better in alleviating salt stress. The growth parameters *viz*., root length (18.00cm), root volume (54.37cc), plant height (89.51cm), number of tillers (10.07per $hill^{-1}$), leaf area (624.7 cm^2 $hill^{-1}$), dry matter production (20.31g hil^{-1}), yield parameters *viz*., number of panicles (276.7per m^2), panicle length (20.60cm) and panicle weight (3.13g) and filled grains per panicle (172) were highest with Zn_{40}+$B_{0.5}$ followed by Zn_{40}+$B_{0.25}$. Further, Zn_{40}+$B_{0.5}$ recorded higher concentration and uptake of macro and micronutrients in grains and straw. These significantly increased rice grain (49.90 q ha^{-1}) and straw yield (69.37 q ha^{-1}) with B:C of 1.99, indicating SA of Zn at 40 and three FS of B at 0.5 per cent is better for rice cultivation to overcome the salt stress in Cauvery Command Area.

Effect of Lipo-Chito Oligosaccharide Fortified Water Soluble Fertilizers and Biofertilizers on Soil Health and Productivity of Tomato (*Solanum lycopersicum* L.)

PALERU KUMARA MALLIKARJUNA AND G.G. KADALLI
Department of Soil Science and Agricultural Chemistry, College of Agriculture, UAS, GKVK, Bengaluru

A field experiment was conducted at GKVK, Bengaluru during *kharif* 2022 to study the 'Effect of lipo-chito oligosaccharide fortified water soluble fertilizers and biofertilizers on soil health and productivity of tomato (*Solanum lycopersicum* L.)'. The experiment was laid out in a randomized complete block design with seven treatments replicated four times. The treatments consist of different combinations of lipo-chito oligosaccharide fortified water-soluble fertilizers (LCO-WSF) and non-fortified water soluble fertilizers along with mycorrhizae and conventional fertilizers. Results revealed that application of LCO-WSF (19:19:19) @375 kg ha^{-1} + $Ca(NO_3)_2$ @ 62.5 kg ha^{-1} + KNO_3 @ 125 kg ha^{-1} at different splits along with 250 kg DAP recorded significantly higher growth andyield parameters compared to other treatments. Higher fruit yield (42.05 t ha^{-1}), plant nutrient uptake (130.97, 20.73 and 134.60 kg N, P and K ha^{-1}, respectively), gross and net returns (Rs.841099and Rs.564894 ha^{-1}, respectively) were also recorded in the same treatment. However, B:C was higher with application of conventional fertilizers. Significantly, higher nutrient use efficiencies (3.69, 2.26, 4.01q kg^{-1} N, P and K, respectively), microbial biomass carbon (383.0 µg g^{-1} soil), microbial biomass nitrogen (44.69µg g^{-1} soil) and soil enzymatic activities *viz.,* dehydrogenase (96.62 µg TPF g^{-1} soil h^{-1}) and acid phosphatase activity (30.22 µg TPF g^{-1} soil h^{-1}) were recorded with application of LCO-WSF (19:19:19) @ 280 kg ha^{-1} + $Ca(NO_3)_2$ @ 47 kg ha^{-1} + KNO_3 @ 94 kg ha^{-1} + Mycorrhiza @10 kg ha^{-1} compared to conventional fertilizer application.

Studies on Carbon Fractions in different Land Use Systems in Chintamani Taluk of Eastern Dry Zone of Karnataka

TAMONASH ROY AND J. SARALAKUMARI
Department of Soil Science and Agricultural Chemistry, College of Agriculture, UAS, GKVK, Bengaluru

To study the effect of different land use systems (LUS) on carbon fractions and soil physico-chemical properties,180 soil samples were collected from nine different LUS (forest, pasture land, mango, cashew, mulberry, irrigated maize, irrigated tomato, rainfed ragi and fallow land) at two depths (0-15 and15-30 cm) in Chintamani taluk of Karnataka. Results revealed that the physical properties like soil texture, BD and MWHC varied from sandy loam to sandy clay loam, 1.21 to 1.46 Mg m^{-3} and 12.34 to 47.12 per cent, respectively. The soil pH varied from moderately acidic to neutral pH among the different LUS. Soil organic carbon (11.45, 9.38 g kg^{-1}), Exch. Ca [4.76, 4.54 cmol (p+) kg^{-1}], Exch. Mg [2.69, 2.45 cmol (p+) kg^{-1}], available sulphur (15.78, 12.25 mg kg^{-1}), DTPA-Fe, Mn, Zn, Cu (26.40, 20.48; 35.67, 28.58; 2.10, 1.78; 2.11, 1.89 mg kg^{-1}) were found higher in forest land than other LUS in both surface and subsurface soils respectively and highest mean N (287.56, 232.84 kg ha^{-1}), P_2O_5 (43.34, 34.65 kg ha^{-1}), K_2O (294.67, 276.11 kg ha^{-1}) were found in tomato LUS in both depths. Similarly, higher total carbon (16.46 13.67 g kg^{-1}), microbial biomass carbon (402.50, 334.08 g kg^{-1}), very labile C (4.34, 3.82 g kg^{-1}), labile C (4.04, 3.01 g kg^{-1}), less labile C (3.56, 2.89 g kg^{-1}), non-Labile C (4.16, 3.53 g kg^{-1}) and passive carbon pool (52.02, 51.56 %) was recorded in forest LUS butactive carbon pool (73.13, 71.53 %) was recorded higher in tomato LUS among all the LUS.

Effect of Long Term Fertilization and Manuring on Nutritional Quality of Finger Millet

B.O. RACHANA AND G.G. KADALLI
Department of Soil Science and Agricultural Chemistry, College of Agriculture, UAS, GKVK, Bengaluru

A field experiment was carried out in the year 2022 (*kharif*) in LTFE plot which has been in progress since 1986 at ZARS, UAS, GKVK, Bengaluru with finger millet-maize cropping sequence. Eleven treatments with three replications laid in randomized block design. Significantly higher SQI (0.98) was recorded in 100% NPK + FYM + Lime (T_{10}) and lowest was observed in control (0.70) followed by 100% N. Highest growth and yield parameters of finger millet were recorded in 150% NPK with grain yield of 3040.51 kg ha^{-1} which was at on par with T_{10}. Comparison among different treatments with respect to grain quality of finger millet revealed that lowest true and bulk density of grain was recorded in T_{10} and colour of grain under 100% NP was significantly darker. Integration of FYM, lime and fertilizers (T_{10}) produced superior quality grains with highest value of crude fat, crude fibre, ash, thiamine, riboflavin and minerals *viz*., K, Ca, Mg, S, Na, Mn, Zn and B and lower moisture content and carbohydrates was recorded highest in control.Minerals like P, Fe and Cu were recorded highest in150% NPK. Phytonutrients (total phenols, tannins and oxalates) of grains were noticed highest in control. Treatment T_{10}recorded with significantly higher water and oil absorption capacity of flour, sensory score of ragi *dumplings* and better quality of finger millet straw. To maintain both soil quality and nutritional quality of finger millet conjunctive use of organic manures, lime and fertilizers in balanced form in *Alfisols* is very much essential.

Effect of Humic Granules on Soil Fertility and Productivity of Soybean [*Glycine max* (L.) Merr.]

LEELAPRASAD CHILUKURI AND G.G. KADALLI
Department of Soil Science and Agricultural Chemistry, College of Agriculture, UAS, GKVK, Bengaluru

A field study on effect of humic granules on soil fertility and productivity of soybean (*Glycine max* (L.) Merr.) was conducted at GKVK, Bengaluru during *kharif* 2022-23. The experiment was laid out in RCBD with fifteen treatments replicated thrice. Treatments include varied levels of Humic Granules (HG) (5 and 10%) in combination with inorganic fertilizers along with FYM. Besides a laboratory incubation experiment was conducted for selected six treatments of field study for 60 days to know the nutrient release pattern. Results of the field study revealed that application of HG 10% @ 40 kg ha^{-1} along with 100 % NPK and FYM @ 6 t ha^{-1} (T_{12}) recorded significantly higher growth, yield and quality parameters (crude protein). Further, T_{12} showed significant increase in plant nutrient uptake (221.20, 20.93 and 58.26 kg N, P and K ha^{-1}, respectively) and demonstrated improved soil properties *viz.,* organic carbon (0.49%), cation exchange capacity (16.87 c mol (p+) kg^{-1}), soil available nutrients (nitrogen, phosphorus, potassium and sulphur) and biological properties (DHA, urease, APA, MBC and MBN). However, treatment T_{11} (100 % NPK + FYM @ 6 t ha^{-1}+ HG 10% @ 30 kg ha^{-1}) found on par with T_{12} which recorded higher B:C ratio. Results of the incubation study indicated that treatment (100 % NPK + FYM @ 6 t ha^{-1}+ HG 10% @ 40 kg ha^{-1}) prominently enhanced the release of nitrogen, phosphorus and micronutrients over treatments without HG during the course of incubation.

Time Series Analysis of Desertification Status Mapping in Bellary District

S.A Bhoomika and S. Dharumarajan
Department of Soil Science and Agricultural Chemistry, College of Agriculture, UAS, GKVK, Bengaluru

Desertification is one of the most serious environmental problems that adversely affect land productivity, ecosystem, biodiversit and human livelihoods in arid, semi-arid and dry sub-humid regions. Periodical assessment of desertification status is important for a suitable comprehensive plan. In the present study, desertification status maps of Bellary district of Karnataka have been prepared using LANDSAT imageries for two time frames (2000-01 and 2020-21) and change detection analysis has been carried out. It was found that 34.85 per cent of the total geographical area in Bellary district affected by desertification processes in 2020-21. Among the desertification processes, vegetation degradation contributes 15.32 per cent of TGA, followed by water erosion (8.58 %), chemical degradation (4.34 %) and mining (3.72 %). Change detection shows that desertification in Bellary have increased by 3.79 per cent from 2000-01 to 2020-21. To compare properties of degraded and non-degraded soil, 107 soil samples of both degraded and non-degraded area were collected and analyzed for bulk density, texture, available water capacity, pH, EC, organic carbon, cation exchange capacity and exchangeable sodium percentage. It was found that degraded soil shows less favorable condition for crop productivity by having high alkalinity, low organic matter content, lower cation exchange capacity, high Exchangeable sodium percentage, low available water content and higher bulk density compared to non-degraded soils. Hence, suitable strategies have to be arrived for combating desertification processes to get rid of further aggravation.

Comparative Study on Emission of CH_4 and N_2O in Natural Farming, Organic and Conventional Farming

R.V. Lohith and M. Mahadeva Murthy
Department of Forestry and Environmental Sciences, College of Agriculture, UAS, GKVK, Bengaluru

The field experiment was conducted on 'Comparative study on emission of CH_4 and N_2O in natural farming, organic and conventional farming' during 2019-21 at experimental sites of the Research Institute of Organic Farming and National Seed Project, UAS, GKVK, Bengaluru for two crop sequence direct seeded rice-soybean and finger millet-field bean was grown in two different plots consisting of five treatments each of different farming practices laid out in RCBD and replicated five times. The results of the experiment for CH_4 emission, among farming practices organic farming showed higher emission followed by medium emission in UAS-B POP and farmers practice and less emission were found in natural farming. N_2O emission among farming practices was shown higher emission in UAS-B POP and farmers practice followed by medium emission in organic farming and less emission was found in natural farming for all four crops. The results of growth and yield parameters among farming practices for the above two crop sequence showed that UAS-B POP was significantly higher compared to famers practice, organic farming and natural farming. The economics was calculated among the farming practices for the above two crop sequence and results showed higher gross returns, net returns and B:C ratio in UAS-B POP followed by farmers practices, organic farming and natural farming. The energy budgeting was calculated among the farming practices for two crop sequences, the total energy input and the total energy output were found higher in organic farming practice followed by natural farming, UAS-B POP and farmers practice.

Studies on Seed Source and Nursery Management Regime in Indian Sandalwood (*Santalum album* L.)

V.R. SHWETHA AND M. MAHADEVAMURTHY
Department of Forestry and Environmental Sciences, College of Agriculture, UAS, GKVK, Bengaluru

A study was conducted to identify the potential seed sources from different regions of Karnataka and to develop nursery management regime for sandalwood. Seeds were collected from seven different locations of Karnataka (S1-Bevinahally; S2-Doranalu; S3-Gottipura; S4-Gungaraghatti; S5-Muddenahally; S6-Narasapura; S7-Tavarekere) and to compare S8-Marayoor seeds were procured from Kerala Forest Research Institute. Seed source S8 (68.66%) displayed the highest germination. Among the Karnataka seed sources S3-Gottipura (51.67%) recorded the highest germination and growth parameters. To improve the germination of Gottipura seed source, three distinct priming methods were employed, *viz.,* biopriming with *Pseudomonas fluorescens* and *Trichoderma viride,* nutripriming with varying concentrations of KNO_3 and $MnSO_4$ and hydropriming with double distilled water. Nutriprimimg with $MnSO_4$ at 0.4M concentration for three days, yielded optimal germination (84.00%) and hydroprimimg yielded lowest germination of all priming methods. Next step in nursery management regime is selecting suitable container and optimizing potting media for quality stocking production. Different types and sizes of container and potting media were evaluated. Out of 20 combinations studied 30 cm x 20 cm poly bag, in combination with a potting media soil, rice husk and farmyard manure in 2:1:1 ratio, consistently recorded superior seedling growth. The assessed growth attributes were significantly enhanced with this specific combination. Later growth attributes of the species was evaluated with six different host species (*Crotalaria juncia, Mimosa pudica, Casuarina equisetifolia, Cajanus cajan, Crotalaria retusa* and *Alternanthera sessilis*). Host species *Crotalaria retusa* recorded the highest growth attributes. Economic viability of the the treatments was also assessed. These series of experiments collectively offer a holistic framework for Indian sandalwood nursery management regime.

Enhancement of Bio-Energy Value Chain from Simarouba Seeds

THORAT ADITYA KALIDAS AND H.B. RAGHU
Department of Forestry and Environmental Sciences, College of Agriculture, UAS, GKVK, Bengaluru

THE study was conducted at the University of Agricultural Sciences, GKVK, Bengaluru during 2022-23 to explore how pyrolysis temperature influence the quality and recovery of Simarouba seed coat biochar. To study impact of the biochars produced at different temperatures (300°C [BC_1], 400°C [BC_2] and 500°C [BC_3]) on maize growth and yield parameters,a polyhouse pot experiment was conducted comprising 13 treatments with three replications under CRD. Results showed that, biochar yield reduced significantly from 78.15 to 39.23 per cent with rise in temperature from 300 to 500°C. BC_3 showed significantly lower bulk density and higher pH (8.67), electrical conductivity, water holding capacity, total carbon, fixed carbon, potassium and calcium content. T_5 (75% RDF + BC_1 + 25% Simarouba cake on N basis + SSP), exhibited significantly higher plant height, number of leaves and leaf area per plant at 60 and 90 DAS, ultimately improving cob length (16.93 cm), cob girth (12.78 cm), number of seeds per cob (474.90), test weight of kernels (24.03 g), grain yield per plant (114.09 g) and total dry matter production per plant (207.21 g). Grain and stover yield per hectare were calculated to be significantly higher in T_5. When 25% RDF, 75% Simarouba cake on N basis and SSP was applied with BC_1 (T_{11}) showed significantly higher organic carbon, nitrogen, phosphorous, calcium, magnesium and sulphur content in post-harvest soil. Conversely, 25% RDF, 75% Simarouba cake on N basis and SSP with BC_3 (T_{13}) significantly improved bulk density, water holding capacity and potassium content. T_5 was found most efficacious, reducing chemical fertilizer usage by 25 per cent and boosting maize yield by approximately 30 per cent per hectare.

Studies on the Relationship of Bird Diversity with Respect to Habitat and Water Quality in the Selected Lakes of Bengaluru

S. Swetha and M. Mahadeva Murthy
Department of Forestry and Environmental Sciences, College of Agriculture, UAS, GKVK, Bengaluru

Urban landscape is characterized by a blend of man-made and natural ecosystems, including parks, avenues, buildings and lakes. Among these, lake ecosystems play a crucial role as habitats for diverse avian species. Nonetheless, the deterioration of lake ecosystems is jeopardizing both the diversity and composition of the bird populations. The present study is conducted to unravel the intricate relationship of lake habitat features and water quality, fostering a deeper understanding of their combined influence on avian diversity. A total of 61 bird species belonging to 10 orders and 20 families was recorded across eight selected lakes of North Bengaluru. Among the bird species studied, *Anhinga melanogaster, Mycteria leucocephala, Pelecanus philippensis* and *Threskiornis melanocephalus* belonged to the near threatened category and *Sterna aurantia* is considered as vulnerable species. The highest Shannon-Weiner diversity (3.65) and Pielou's Evenness (0.96) was recorded in Puttenahalli lake (Yelahanka) whereas least Shannon-Weiner diversity (2.57) and Pielou's Evenness (0.76) was found in Allalasandra lake. The vegetation survey recorded a total of 34 tree species as planted on the islands across eight selected lakes. Among the studied lakes, Yelahanka lake had the highest tree diversity with 194 individuals representing 26 species. Allalasandra lake and Rachenahalli lake resulted in low species diversity, limited habitat factors and poor water quality, indicating a high level of pollution. Jakkur lake and Yelahanka lake exhibited a high bird population, better habitat factors and moderate water quality, indicating lower pollution. These insights are crucial for proper conservation efforts and sustainable urban development strategies that will safeguard the avian heritage of the city.

Influence of Temporal Crop Canopy Changes on Runoff and Soil Moisture Content in *Alfisols* of Eastern Dryzone of Karnataka

Soumya P. Jakati and Murukannappa
Department of Soil and Water Engineering, College of Agricultural Engineering, UAS, GKVK, Bengaluru

A field experiment entitled 'Influence of temporal crop canopy changes on runoff and soil moisture content in *Alfisols* of eastern dry zone of Karnataka' was conducted during the *kharif* season of 2022 at All India Coordinated Research Project for Dryland Agriculture (AICRPDA), located at University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bengaluru. The purpose of this experiment was to establish the relationship between rainfall and runoff under various crop canopy coverage conditions in the Eastern Dry Zone of Karnataka. The experiment was laid out with five treatments. Among different treatments, the treatment with higher canopy cover T_1 (Pomelo) resulted in less per cent of runoff (5.33) and substantially higher average moisture content at 0-15 cm and 15-30 cm depth (12.31 and 14.05 per cent) and exhibited lower particle density, bulk density and higher porosity, water holding capacity, rapid infiltration rate and better crop growth attributes resulted in higher fruit yield (9918 kg ha^{-1}), superior rainwater use efficiency (7.83 kg ha-mm^{-1}) and higher B:C ratio (7.41) as compared to other treatments which have lesser canopy cover (T_2 Castor, T_3 Pigeon pea, T_4 Chick pea and T_5 Control). Overall adoption of higher canopy coverage is realized as the best practice to retain greater amount of soil moisture content and it created a positive impact on organic matter, water holding capacity, overall soil health, crop growth and yield.

Process Technology for Development of Sprouted Green Gram Flakes and their Storage Stability

MALLELA PREM KUMAR AND P.N. KRISHNAMMA
Department of Processing and Food Engineering, College of Agricultural Engineering, UAS, GKVK, Bengaluru

As a result of growing modernization, people perceptions of eating habits have been changed and they want dishes that are quickly prepared and nutritious. Pulses, as dietary staples offer nutrients and crucial protein; green gram, a pulse variant and its sprouted form provide concentrated proteins, aiding energy, blood sugar regulation and overall health, diversifying dietary options. The study focused on optimizing the production of sprouted green gram flakes by examining soaking time (6 h); sprouting time (6, 12 and 18 h); cooking methods (open, microwave and steam cooking methods) at different drying time (30, 60 and 90 min), drying temperature at 60°C and packaging with MPE and PP pouches. The best conditions optimized for the process of green gram flakes production are: 6 h of soaking, 12 h of sprouting, cooking time of 4.5 minin microwave cooking at 85-100°C and drying of flakes at 60°C for 60 min. The optimized product results in high flake yield and best quality with 19.54% protein, 2.48 % fat, 3.65 % ash, 3.69 % fibre, 11.95 % moisture content and 57.86 % carbohydrates. Salt treatments significantly reduced cooking time without compromising nutritional content. Microwave cooking exhibited superior qualityand nutrient retention compared to other methods. Sensory evaluations also favoured microwave-cooked flakes for appearance, colour, texture, taste and overall acceptability, although the control samples exhibited more favour. In terms of packaging, the study favoured Metalized Polyester Film (MPE) over Poly Propylene (PP) for three months due to its superior preservation of quality and lower moisture content increase over time.

Design and Development of Feeding Mechanism to the Hypobaric Processor for Millets Popping

SHWETA KRISHNA PATTAR AND M. MANJUNATHA
Department of Processing and Food Engineering, College of Agricultural Engineering, UAS, GKVK, Bengaluru

VERY recent studies on popping of millets under reduced pressure (hypobaric) demonstrated with improved popping yield, popping quality and less energy at lower temperature than conventional popping. However, providing feeding and stirring mechanism reported to improve the functioning of the existing hypobaric popping machine. Therefore, in the current investigation a feeding mechanism was designed and developed to the hypobaric processor for studying its popping performance. The feeding mechanism was comprised of a feed hopper, two control valves and a grain holder. Sorghum and finger millet were selected for popping at different feeding rates (15, 20 and 25 g). Among the two millets, sorghum was found to be responded well for popping based on popping characteristics at 20 g feed rate. The performance of the feeding mechanism was evaluated at process conditions of 25-45 kPa and 80-100°C using response surface methodology. The optimal process conditions were found to be a vacuum pressure of 45 kPa and a popping temperature of 91°C which resulting in higher popping yield (82.20 %), popping effectiveness (62.24 %), volumetric expansion ratio (7.83), color value (79.23) with highest acceptability score (8.34) and reduced unpopped kernel percentage (11.35 %), bulk density (108.72 kg/m^3), product hardness (61.35 N) and fracturability value (42.68 N). Sorghum popped under hypobaric conditions (91°C and vacuum pressure of -45 kPa) using the hypobaric processor having feeding mechanism improved popping yield by 4-5 per cent, reduced un-popped kernel by 2-3 per cent and reduced charring of the grains by 3-4 per cent. The hypobaric processor with feeding mechanism eliminates the need for frequent resetting of temperatures and vacuum; improves popping yield and popping characteristics; reduces charring of millets.

Development and Validation of Stocheometric Model in Groundnut

V. Arpitha and M.H. Manjunatha
Department of Agricultural Meteorology, College of Agricultural Engineering, UAS, GKVK, Bengaluru

Groundnut is an important oilseed crop grown in tropical and subtropical regions around the world. The research was conducted to study the influence of weather parameters on total dry matter production, pod yield and to develop the stocheometric model in groundnut. Regression equations were generated using the weather and pod yield data from 2001 to 2018. The stocheometric model was developed using dataof derived weather parameters like GDD, SR, AET of fourteen years (2000, 2002-2014). The model was validated for two dates of sowing over four years (2015-2018).The influence of combined weather parameters was higher with coefficient of determination (0.2419 and 0.1370) at 50 per cent flowering and harvest stages during first and second date of sowing, respectively than the influence of single weather parameteron total dry matter production. Combination of highly influencing weather parameters resulted in higher predictions on pod yield over single weather parameters.The developed stocheometric crop weather model showed good agreement between observed and predicted valueswith higher coefficient of determination (0.77) at pod filling stage and it was lower (0.08) at 30 days after sowing stage. The validation of the model showed good fit in all the years (2015-2018) for first date of sowing except 2018 (good fit to the second date of sowing).This model helps in the prediction of total dry matter production at the end of each stage and pod yield well before the harvest of the groundnut crop with accuracy level ranging from 8-77 per cent.

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DESHPANDE, S. S. AND BARGALE, P. C., 2004, Impact of nutrition education on utilization of soybean in selected rural areas of Bhopal district. Proc. Nutrition Society of India. XXXVI Annual meet, 5-6 November, Mysore.

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Thesis

MAMATHALAKSHMI, N., 2013, An analysis of livelihood security among agricultural labourers in Karnataka. *Ph.D. Thesis* (Unpub.), Univ. Agric. Sci., Bangalore

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UNITED STATES DEPARTMENT OF EDUCATION (2009, October 22). U.S. Secretary of Education Arne Duncan says colleges of education must improve for reforms to succeed. http://www.ed.gov/news/pressreleases/2009/10/10222009a.html

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THE MYSORE JOURNAL OF AGRICULTURAL SCIENCES

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1.	Name of the Publication	—	The Mysore Journal of Agricultural Sciences
2.	ISSN	—	0047 - 8539
3.	Place of Publication	—	Bengaluru
4.	Periodicity of the Publication	—	Quarterly
5.	Publisher's Name	—	Dr. K.H. Nagaraj, Editor University of Agricultural Sciences GKVK, Bengaluru - 560 065
6.	Editor's Name	—	Dr. K.H. Nagaraj
	Nationality	—	Indian
	Address	—	Editor Communication Centre University of Agricultural Sciences GKVK, Bengaluru - 560 065
7.	Names and addresses of individuals who own the newspaper and partners or shareholders holding more than one per cent of the total capital	—	University of Agricultural Sciences GKVK, Bengaluru - 560 065

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