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

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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

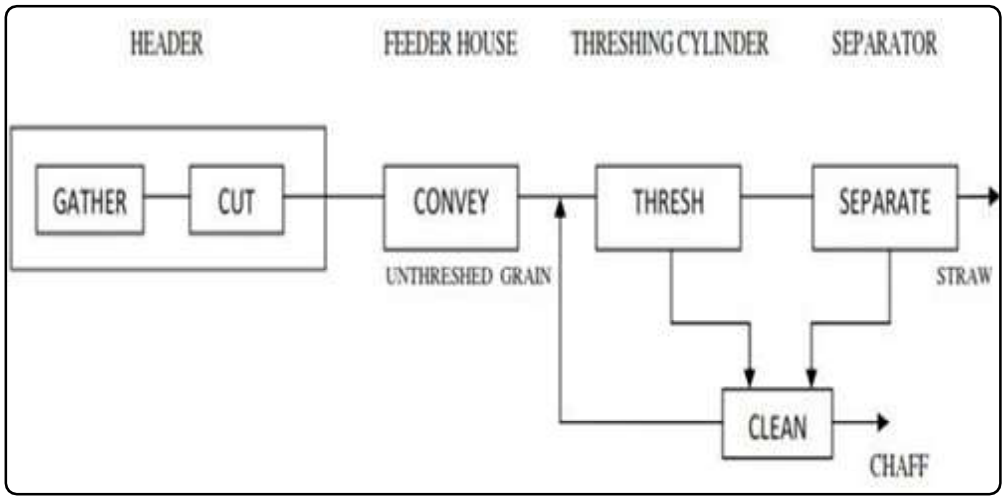

Fig. 1 : A process diagram of a combined harvester

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

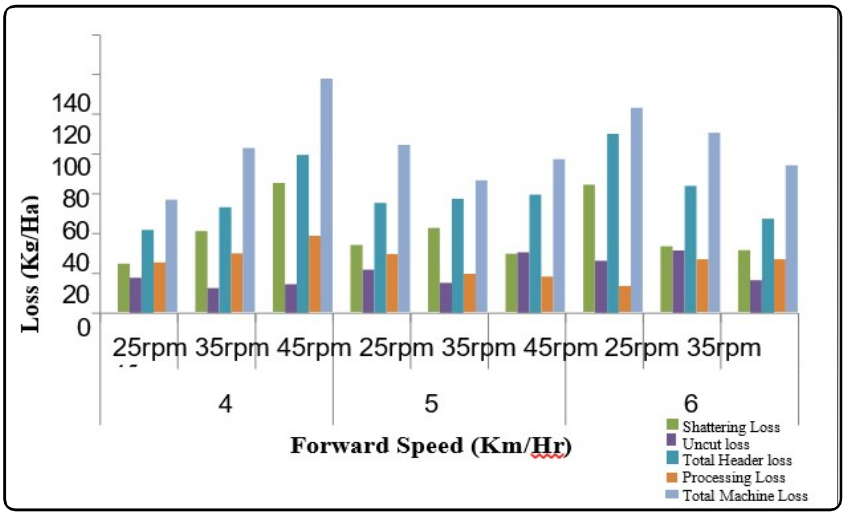

Fig. 2 : Effect of combine forward and reel speed on all losses

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

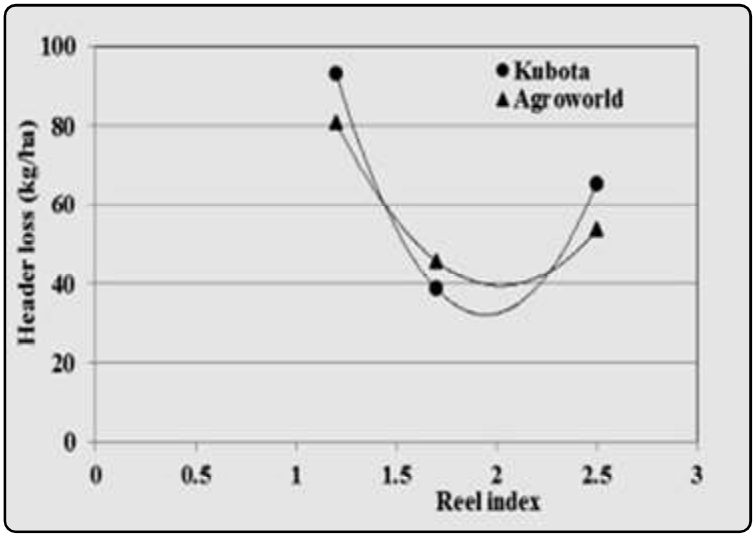

Fig. 3 : Header Losses at different reel index levels

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 %.

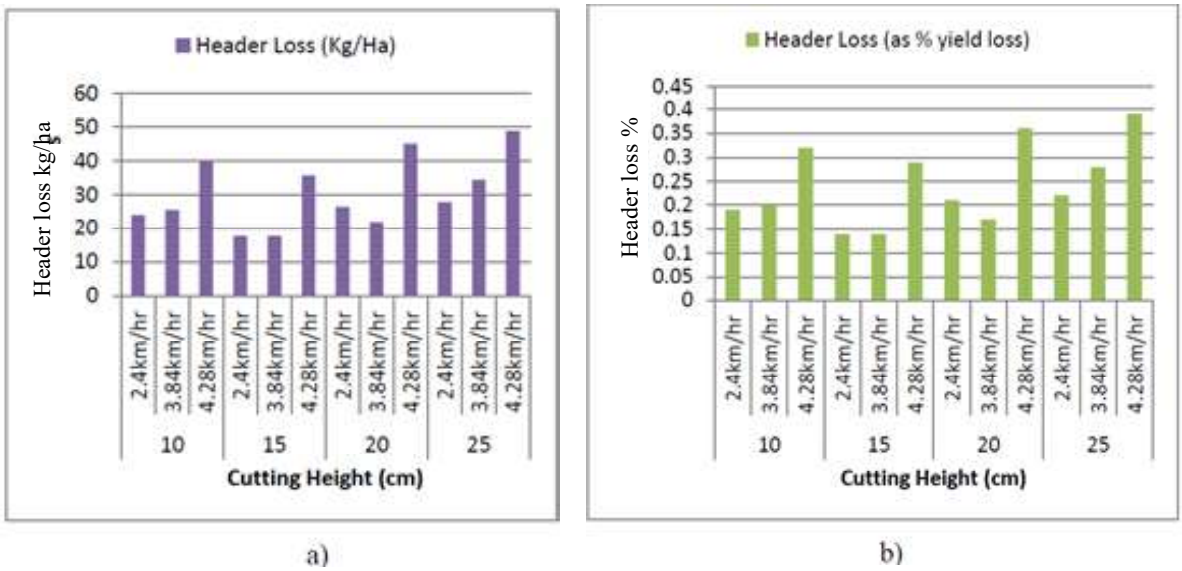

Fig. 4 : Header loss due to cutting height at different forward speeds

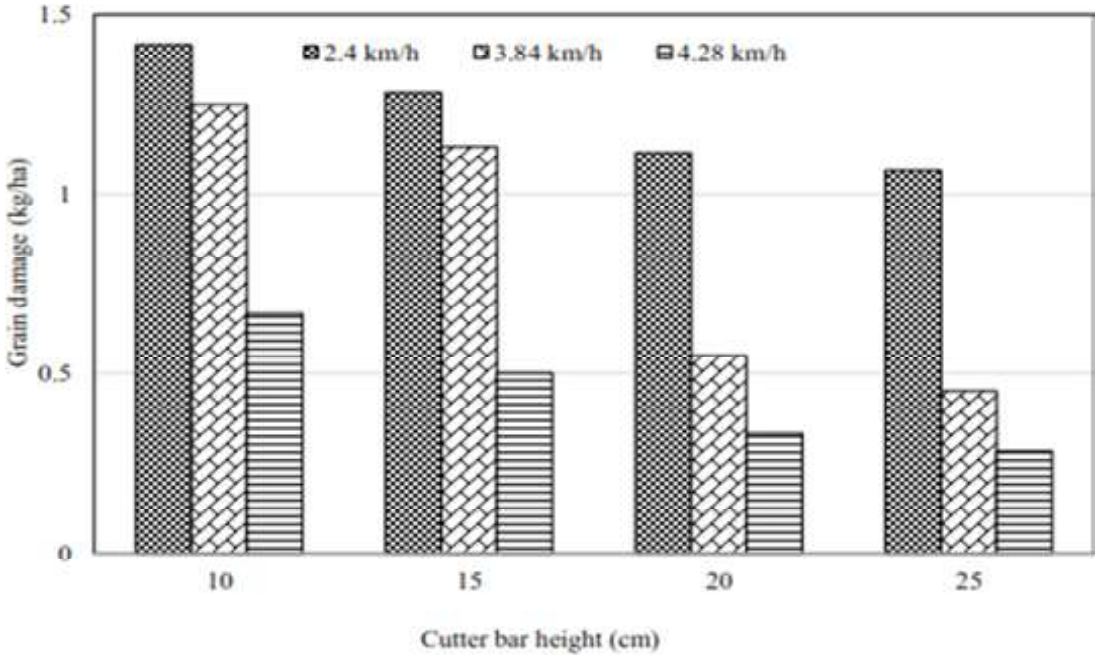

Fig. 5 : Effect of Cutter-bar height on grain damage

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.

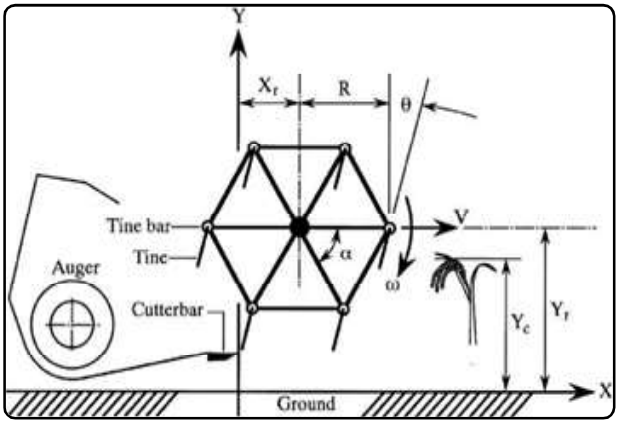

Fig. 7 : Tined combine harvester reel with a relevant parameter

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

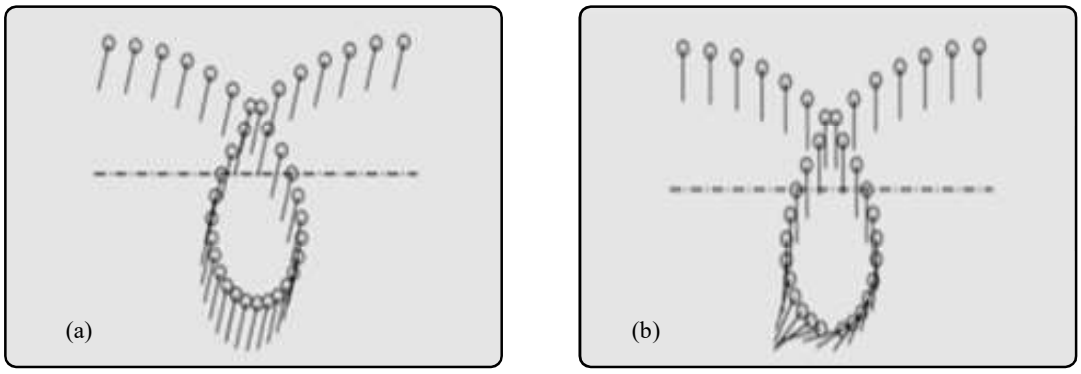

Fig. 8 : Tine kinematics; a) Conventional, b) Proposed (Moses *et al.,* 2012)

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)

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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	35
Annealing	56	10 seconds	
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)

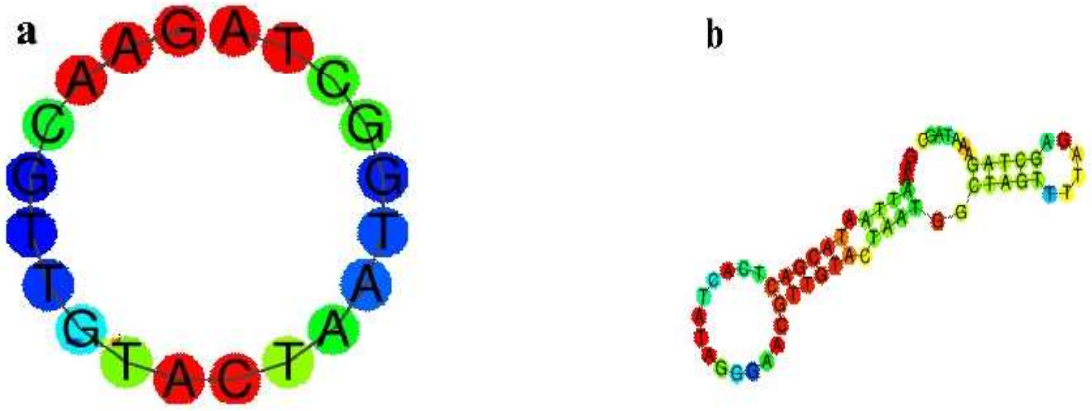

Fig. 1 : Structure of sgRNA for *SFSPR* gene (a) SFSPRsg (b) SFSPRSg casette

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

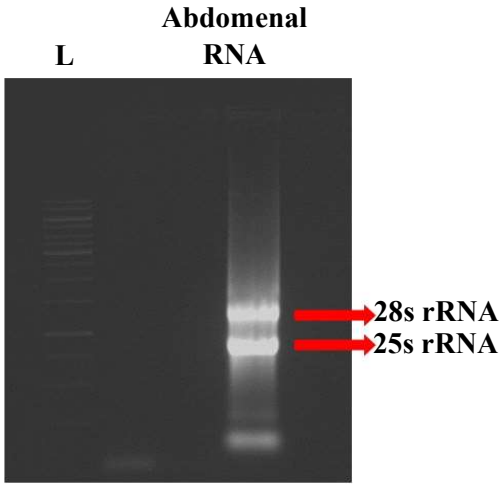

Fig. 2 : Total RNA isolation from abdomen of female *Spodoptera frugiperda*

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).

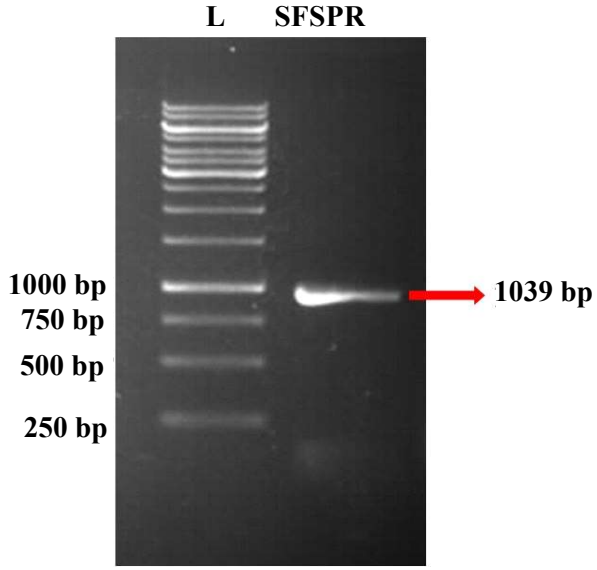

Fig. 3 : PCR amplification of *Spodoptera frugiperda SPR* gene

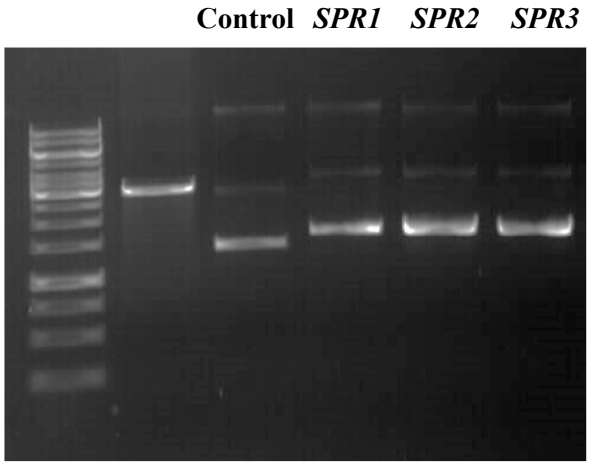

Fig. 4 : Control plasmid compared with *Spodoptera frugiperda SFSPR* gene clones

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

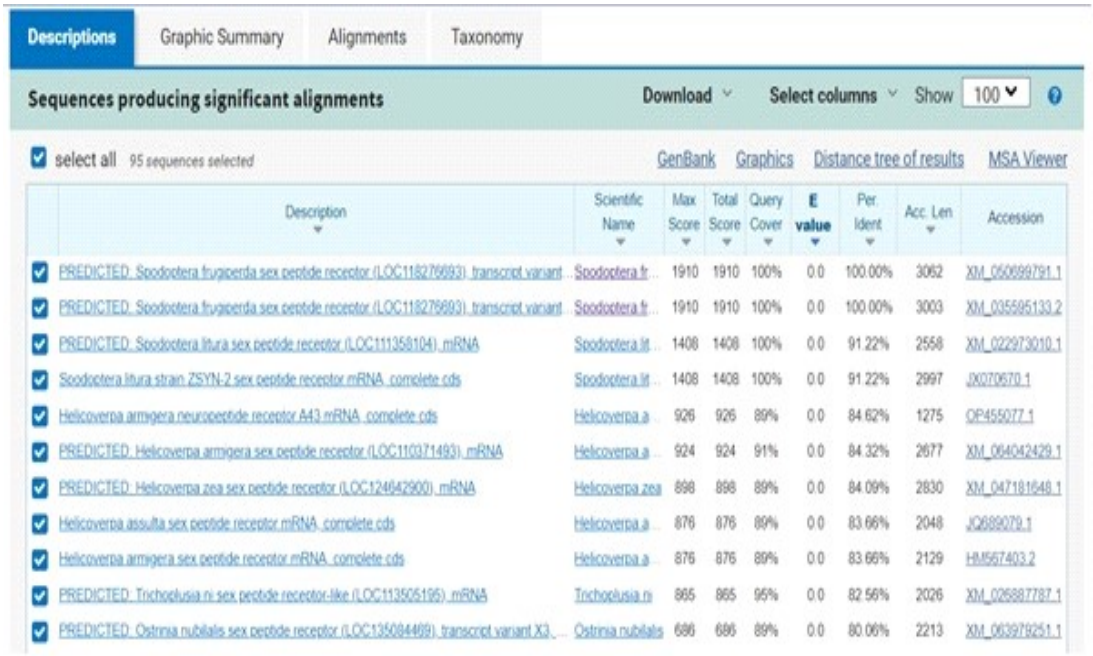

Fig. 5 : Sequence similarity of the *SPR* gene among related lepidoptera

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.

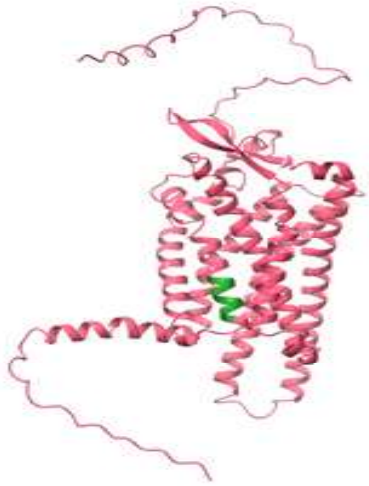

Fig. 6 : Three dimensional protein structure of *S. frugiperda* SPR. The lime color in the protein structure represents the SFSPRsg sequence

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.

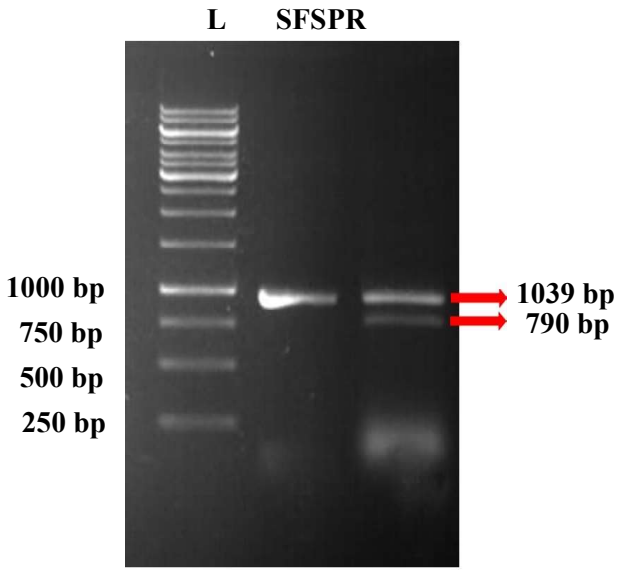

Fig. 7 : *In vitro* restriction assay of SFSPRsg

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

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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).

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

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).

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

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

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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

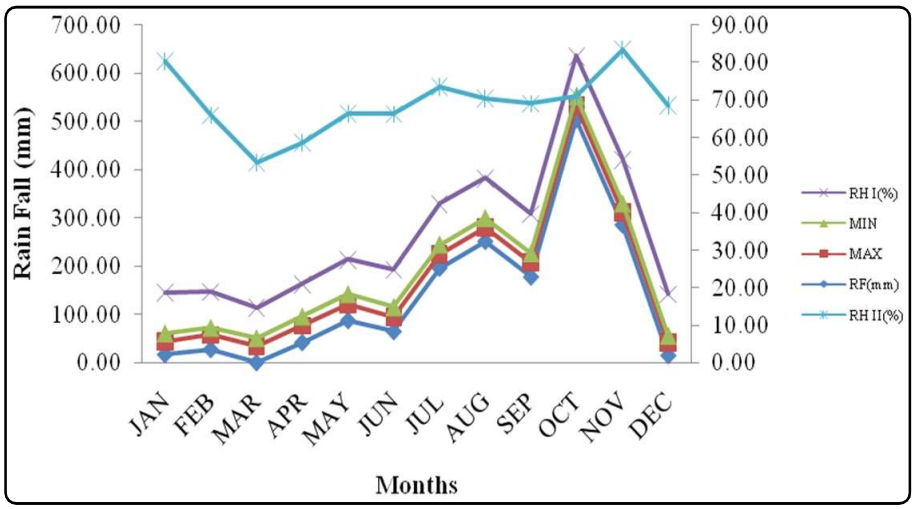

Fig. 2 : Weather data of Chintamani taluk during 2021-22

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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