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Stability Analysis of Mulberry (*Morus indica*) Varieties for Leaf Yield Based on AMMI Model and YREM Criterion

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Abstract

Leaves of mulberry, a perennial shrub is sole diet for monophagous silkworm which is the backbone of sericulture. The mulberry varieties with high stability across location/ year to which they are recommended are desirable for sustainable mulberry leaf production and hence silk. Under these premises, the present study was aimed at detecting and characterizing the variety × environment interaction (VEI) and identifying the varieties with high leaf yield potential and stability across five temporal environments. The nine mulberry varieties which were bred over last 40 years were evaluated in four-replicated randomized complete block design. Data were collected on leaf yield plant^{-1} from five harvests at 90 days intervals during three-year schedule. The weather conditions that prevailed during five harvests were considered as five different temporal environments to assess performance stability of varieties. Additive Main effects and Multiplicative Interaction (AMMI) model was used to detect and characterize VEI. Genotype + Genotype × environment (GGE) bi-plot was used as subjective criterion to interpret VEI patterns of varieties and identify those that are stable across five temporal environments. AMMI Stability Value (ASV) and Stability Index (SI) were used as objective criteria to assess relative stability of varieties. The varieties differed significantly and displayed significant VEI for leaf yield. Three of the nine varieties were highly stable with high mean leaf yield plant^{-1} across five temporal environments based on three criteria, namely GGE bi-plot, ASV and SI.

Keywords : VEI, AMMI, GGE biplot, AMMI stability value, Stability index, Mulberry variety

Silkworm rearing, popularly called as sericulture is an age-old Indian rural occupation. It is also one of the important agro-based rural cottage industries. It plays a major role in rural employment, poverty mitigation and earning foreign exchange. It is estimated that sericulture can create employment of 11-man days per kg of raw silk production (Anisha, 2014). About 92 per cent of the total Indian silk production comes from mulberry (*Morus* sps.). Mulberry can be grown in a wide range of agro-climatic conditions both in rainfed and irrigated areas. Its foliage is the sole diet for monophagous silkworm. Mulberry, a deep-rooted persistent crop continues to grow and generate leaves throughout the year in tropics. It is widely regarded as a perennial shrub. Therefore, identification of mulberry varieties which produce higher leaf yield and exhibits its stable performance throughout its growing period is critical for sustainable production of silk. The varieties with high stability across temporal environments such as years or seasons and/or their combination in locations to which they are recommended are desirable for sustainable mulberry leaf production and hence silk. Over the period of 40 years, high yielding varieties have been bred and released for commercial mulberry leaves production. During this long period, there has been significant shift in weather parameters such as rainfall distribution, relative humidity and air temperature driven by increased anthropogenic activities. This calls for assessment of pattern of stability of these varieties in the current climate scenario. Under these premises, the objectives of the present study were to (i) detect variety × environment interaction (VEI) (if any), (ii) characterize VEI and (iii) identify the varieties with high leaf yield potential and stability across temporal environments.

Material and Methods

The experimental material for the present study consisted of nine mulberry varieties namely V1 (CPH-1), V2 (CPH-2), V3 (OPH-3), V4 (OPH-4), V5 (OPH-5), V6 (a mutant reverted to wild type Mysore local), V7 (Mysore local), V8 [Kanva-2 (M5)] and V9 [Victory-1 (V1)] (Table 1).

Table 1

Mulberry varieties used in the present study

Variety	Pedigree/origin	Ploidy	Salient features
V1 Controlled pollinated Hybrid (CPH-1)	Colchicine treated Mysore local ♂ × colchine treated Kanva -2♀	Aneuploid	Bear spread shoots with closely spaced large leaves and faster growth
V2 Controlled Pollinated Hybrid (CPH-2)	Gamma Ray Irradiated Mysore local ♂ × Colchicine treated Kanva-2 ♀	Aneuploid	Bear erect shoots with closely arranged thick dark green unlobed leaves fast growing and early maturity
V3 Open Pollinated Hybrid (OPH-3)	Colchicine Treated Kanva-2 selected at Jnanabharathi Bangalore University	Aneuploid	Fast growing with big trunk and innumerable erect shoots with longest inter-nodal distance and bears large unlobed leaves borne on long petioles
V4 Open Pollinated Hybrid (OPH-4)	Colchicine Treated Kanva-2 Gamma Ray Irradiated, selected at Jnanabharathi Bangalore University	Aneuploid	Vertically growing sturdy shoots with shortest intermodal distance and bears dark green unlobed leaves
V5 Open Pollinated Hybrid (OPH-5)	Colchicine Treated Kanva-2 Ethyl Methane sulfonate treated selected at Jnanabharathi, Bangalore University	Aneuploid	Bear erect shoots with dark green and leathery unlobed leaves
V6 (Local)	7.5KR Gamma-ray irradiated clonal selection at Bangalore University, Jnanabharathi campus	Aneuploid	Display vigorous growth innumerable sturdy spreading shoots with reduced intermodal distance. Bears heart shaped unlobed closely arranged thick dark green shining leaves
V7 (Mysore Local)	Clonal selection from a local collection at CSRTI, Mysore	Diploid	Drought tolerant and recommended for rainfed ecosystem
V8 (Kanva-2)	Open pollination Hybrid selection made at Kanva Government silk Farm, Channapatna, Karnataka	Diploid	Bear erect spread sturdy shoots with reduced intermodal distance, shiny unlobed leaves with prolonged moisture retention capacity. Recommended for irrigated production ecosystem
V9 (Victory-1)	S-30 × Berc.776. at CSRTI, Mysore	Diploid	Fast growing sturdy shoots bearing boat shaped elongated dark green leaves

The planting material of the varieties *viz.,* V7, V8 and V9 were procured from Central Sericultural Research and Training Institute (CSRTI), Mysore where the varieties were bred. The rest of the six varieties were bred at the Department of Sericulture, Bangalore University, Jnanabharathi campus, Bengaluru. These varieties have been bred over last 40 years.

The varieties were evaluated in a randomized complete block design (RCBD) with four replications. The cuttings of each of the nine varieties were planted with a spacing of 2' × 2' consisting nine plants per replication during 2012 rainy season (September). The plants in experimental area were maintained for one year after planting without pruning. From second year onwards, plants of each variety in each replication were bottom pruned (plants were cut above 0.20m from the soil surface) after each leaf harvest by leaf picking method during 2013 rainy season. Plants were pruned using the same procedure for the second time (90 days after first pruning) during 2014 after leaf harvest. After second harvest and pruning, three more leaf harvests were made followed by bottom pruning 90 days after previous harvest. Thus, during three-year schedule, a total of five leaf harvests were made at 90 days intervals. The healthy crop was raised following recommended packages for production of mulberry leaves.

Sampling and Data Collection

The leaves were harvested manually from the nine varieties during 2013 July, 2014 January, 2014 September, 2015 July and 2016 April. Data was collected on leaf yield plant^{-1} from nine randomly selected plants/replicate/variety, after 90th day after each pruning (Tikader and Kamble, 2009). The data recorded from five harvests were considered as five different temporal environments for assessment of stability of varieties.

Statistical Analysis

The replication-wise quantitative mean leaf yield of the nine varieties were used for all statistical analysis as described in following sections.

ANOVA

ANOVA was performed to detect significant differences, if any, among the nine varieties for leaf yield.

Detection and Characterization of Variety × Environment Interaction (VEI)

For the purpose of detection of VEI, five crop harvests were considered as five different temporal environments. Replication-wise mean leaf yield data recorded from five crop environments was used to detect and characterize VEI based on additive main effects and multiplicative interaction (AMMI) model (Gauch and Zobel, 1988). The additive main effects of variety and environments were fitted by univariate ANOVA, followed by fitting multiplicative VEI by interaction principal component (IPC) analysis (Gauch and Zobel, 1988). The sum of squares attributable to signal-rich component of VEI (VEI_{Signal}) were computed as VEI SS – VEI_{Noise}, where, VEI_{Noise} = VEI degrees of freedom × error mean squares from the AMMI ANOVA (Gauch, 2013). The following model was used to estimate main effects of varieties and environments and VEI effects. $Y_{ij}=\mu+g_i+e_j+ \sum^{n}_{k=1} \lambda_k\alpha_{ik}\gamma_{jk}+\varepsilon_{ij}$, where, '$Y_{ij}$' is the mean leaf yield of ith variety in the jth environment, 'μ' is the experimental trait mean, 'g_i' and 'e_j' are the ith variety and jth environment mean deviation from 'μ', respectively. 'λ_k' is the square root of eigen value of the kth IPC axis, 'α_{ik}' and 'λ_{jk}' are the IPC scores for ith variety and jth environment, respectively and 'ε_{ij}' is the residual. All the analyses were implemented using R Studio software v.4.2.1.

GGE Bi-plot for Interpretation of VEI

Genotype + Genotype × environment (GGE) bi-plot is a subjective/qualitative graphical means of characterizing VEI patterns and assessment of relative stability of nine test varieties. GGE bi-plot utilises combination of GGE concepts and AMMI bi-plot (Yan *et al*., 2000). GGE bi-plot has been suggested for visual interpretation of patterns of VEI, representativeness and discriminating ability of the environments and relative stability of test varieties.

The GGE bi-plot is based on the following model. $Y_{ij}-Y_i=\lambda_1\alpha_{i1}\gamma_{j1}+\lambda_2\alpha_{i2}\gamma_{j2}+\varepsilon_{ij}$, where, '$Y_{ij}$' is the mean leaf yield of i^{th}variety in the j^{th} environment, 'Y_i' is trait mean of all the test varieties in the j^{th} environment, 'λ_1' and 'λ_2' are square roots of eigen values of first and second IPC axes, 1 and 2, '$á_{i1}$' and '$á_{i2}$' are scores of the first and second IPC, respectively, for the i^{th}variety and γ_{j1} and γ_{j2} are first and second IPC's, respectively for j^{th} environment.

AMMI Model-based Parameters to Identify Stable Varieties

The relative stability of nine varieties was assessed objectively based on the estimates of AMMI stability value (ASV) (Purchase *et al*., 2000) and Stability Index (SI) (Farshadfar, 2011). The procedure and formulae for estimating ASV and SI are described in the following sections.

AMMI Stability Value (ASV)

ASV was estimated as, **ASV**= $\sqrt{[\frac{SSIPC1}{SSIPC2}(\text{IPC1 score})]^2+(\text{IPC2 score})^2}$

Where, SSIPC 1 and SSIPC 2 are sum of squares (SS) attributable to first two IPC's. Conceptually, ASV is the distance from zero in a two-dimensional scatter diagram of IPC 1 *vs.* IPC 2 scores (Purchase *et al*., 2000). Since IPC 1 score generally contributes proportionately more to VEI, it was weighed by the proportional difference between IPC 1 and IPC 2 scores to compensate for the relative contribution of IPC 1 and IPC 2 scores to total VEI sum of squares. Lower the magnitude of estimates of ASV, greater is the stability of the test varieties. Higher the magnitude of estimates of ASV, lower in the stability of test varieties (Purchase *et al.,* 2000).

Stability Index (SI)

From farmers' point of view, mere high stability is not sufficient. The varieties which are stable should also produce at least acceptable leaf yield if not optimum yield. In this context, it is necessary to use a quantitative statistic which account for high leaf yield as well as stability. One such statistic is SI, which combines both stability and leaf yield of the varieties. SI facilitates selection of test varieties with high stability and high trait mean. SI was estimated as SI=RASV + RY where, RASV is rank of the test varieties based on ASV and RY is the rank of test varieties based on trait mean (Farshadfar, 2011) across five environments. The test varieties with low SI were regarded as those with high trait mean and high stability.

Estimation of Yield Relative to Environment Maximum (YREM)

VEI could be classified as non-crossover and crossover types. If the magnitude of performance changes but not the ranks of test varieties across environments, such an interaction is referred to as non-crossover VEI. If both magnitude and ranks of the test varieties change across environments, such an interaction is referred to as crossover VEI. It is the crossover VEI that challenges the breeder to select high yielding stable varieties. In the present study, a simple statistic, namely YREM (Yan, 1999) was used to detect crossover VEI and to quantify reduction in trait mean of test varieties due to crossover VEI. The YREM (Yan, 1999) was estimated as $Y_{ij}= X_{ij}/MAX_{ij}$, where, 'Y_{ij}'and 'X_{ij}' are the YREM and trait mean, respectively, of i^{th} variety in j^{th} environment. MAX_{ij} is the trait mean of highest performer in j^{th} environment. The analysis was implemented using statistical analysis option available in Microsoft Excel software.

YREM is a special type of standardized estimate of varieties' performance, with nullified environment main effect. It is also an intuitive and varieties' attendance-independent measure of test varieties' performance (Yan, 1999). It is a dynamic measure of varieties' performance, as it varies with the performance of best varieties in a given environment and the best variety also varies with the environment. The performance of best variety is its potential attainable in a given environment. Hence, YREM is an indicative of magnitude of cross-over VEI. It also quantifies the extent of reduction in leaf yield due to crossover VEI. Therefore, in the absence of crossover VEI, the average YREM of a variety tested across environment must be 1.0. Any departure of a variety's

YREM from 1.0 is interpreted as loss in its attainable trait mean attributable to crossover VEI (Yan, 1999). Thus, higher the value of YREM of a variety, lower is the magnitude of crossover VEI and lower is the extent of reduction in mean leaf yield of that variety even in the presence of crossover VEI. For example, if a variety has an across-environments' average YREM=0.80, then 20 per cent of its attainable leaf yield is lost due to crossover VEI.

Results and Discussion

ANOVA

ANOVA is the diagnostic step to detect different sources of variation relevant to the results of field experiments such as those being reported in the present study. Environment-wise ANOVA revealed significant mean squares attributable to test varieties in all five environments for leaf yield plant^{-1} (Table 2). These differences among varieties could be attributed to difference in the plant architecture driven by (i) differences in the chromosomal complement and (ii) history of genesis of the varieties. While varieties 1 to 6 are aneuploid, varieties 7, 8 & 9 are diploid, variety 1, 3, 4 & 5 are polyploids. While the varieties 1, 2 & 9 are hybrids developed by controlled pollination, varieties 3 & 8 are selections from open pollinated hybrids. While varieties 4 & 6 are gamma ray induced mutants, variety 5 is an *Ethyl methane sulfonate* (EMS) induced mutant.

Variety 7 is a selection from landrace from Mysore local, a traditional belt of sericulture. These results indicated substantial differences among the test varieties for leaf yield and thus provide justification for their use in the present study. Several previous researchers such as Pawan *et al.* (2018), Ahalya *et al.* (2020) and Serajur Rahman and Shahinul Islam (2020) reported significant variability among mulberry varieties for leaf yield. Similarly, Suresh *et al.* (2019) have also reported substantial differences among mulberry hybrids for leaf yield. Box-Whisker plots depicts the range of leaf yield plant^{-1} of nine test varieties across the five environments. Variety V9 was the highest leaf yielder followed by varieties, V3 and V1 (Fig. 1).

Detection and Characterization of VEI using AMMI Model

ANOVA which is a additive model detects VEI only when the average of all (v-1) (e-1) degrees of freedom (df) contrasts is significant. Classical additive ANOVA indicate a lack of VEI, even when there exists significant VEI for some of the contrasts. Hence, classical additive ANOVA is not a desirable method for detecting VEI. Researchers can declare absence of VEI if and only if VEI sum of squares of one degree of freedom is not significant (Gauch, 1988). As an intermediate approach between 1 and (v-1) (e-1) df, AMMI model is widely used to unambiguously detect VEI (Gauch, 1988). AMMI model uses additive ANOVA for detection of main effects of varieties and environments and multiplicative IPC analysis of VEI effects. The rationale behind the AMMI model is that the observed performance of test genotypes in a particular environment is not the best estimate of true

Table 2

ANOVA of mulberry varieties for leaf yield plant^{-1} (g) at five environments

Source of variation	DF	Environment 1	Environment 2	Environment 3	Environment 4	Environment 5
		MSS	MSS	MSS	MSS	MSS
Replication	03	205331 **	129910	70206 *	49060	292454 **
Varieties	08	302469 ***	117867 *	141785 ***	404701 **	631148 ***
Error	24	25573	69290	28521	87658	59590

df - degrees of freedom; MSS – mean sum of squares
*** Significant at P = 0.001; ** Significant at P = 0.01; * Significant at P = 0.05

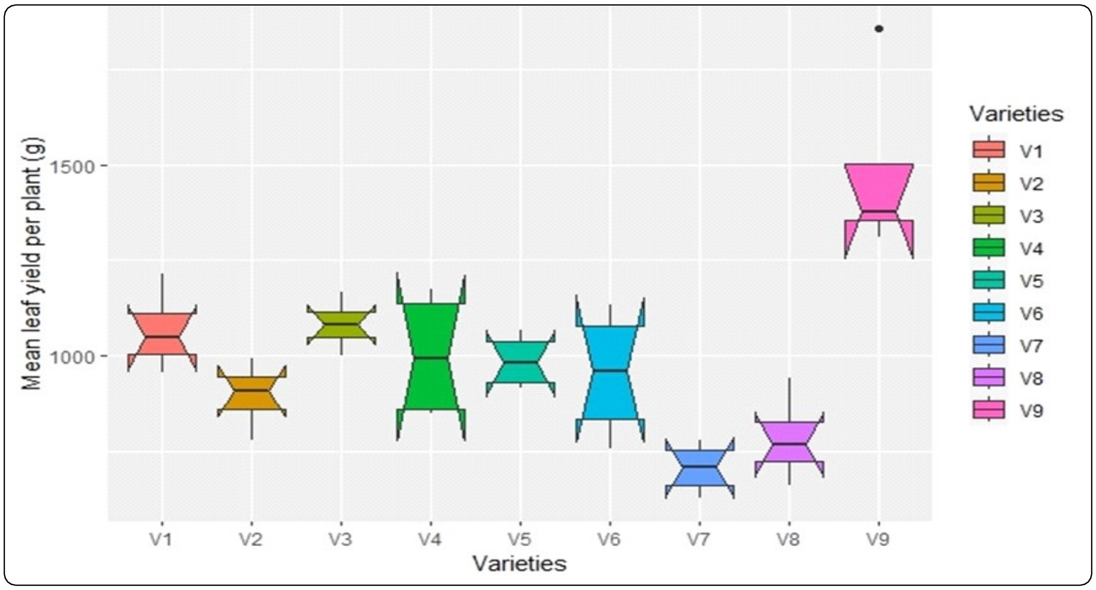

Fig. 1 : Box- Whisker plots showing mean variation for leaf yield plant^{-1} (g) among nine mulberry varieties

performance of those genotypes in that environment. This is because, more often test genotypes interact significantly with test environment (s) and hence VEI is a rule rather than an exception (Bernardo, 2020). The VEI effects consists of (1) signal / pattern attributable to repeatable and predictable component and (2) noise attributable to non-repeatable and un-predictable component.

AMMI model effectively dissects VEI in to 'signal' and 'noise' components using several IPC's. While the first few IPCs tend to capture most of the repeatable and predictable components, later IPC's capture non-repeatable and un-predictable component (Gauch, 2013). AMMI model estimates VEI for ith genotype and jth environment not only from data pertaining to ith genotype and jth environment, but also from data of all the genotypes' performance in all the test environments (Bernardo, 2020).

In the present study, sum of squares (SS) attributable to VEI was partitioned into those attributable to VEI Signal and VEI Noise. Differences among test genotypes and environments are necessary for existence of VEI effects. In this study, significant mean squares (Table 3) suggested presence of substantial variability among the test varieties for leaf yield plant^{-1}. Significant mean squares attributable to the VEI suggested differential performance of test varieties across the five environments. However, over 50 per cent of SS due to VEI signal contributes to SS attributable to VEI. Thus, a substantial portion of detected VEI effects is repeatable and hence predictable. However, mere detection of VEI does not provide information on the relative performance of varieties across different test environments. Stability analysis help the researcher to examine the performance of varieties relative to each other in different environments. Stability analysis requires AMMI model diagnosis, as AMMI constitutes a model family, not a single model. Consequently, model diagnosis is required to determine which member of this model family is best for a given data set and research purpose. The significance of mean squares attributable to IPC's is widely used as a criterion to diagnose the best AMMI model family member for given data set (Gauch, 2013). In the present study, the significance of mean squares attributable to first two IPC's indicate AMMI 2 is the best model family member that captures predictable component of VEI. Selection of the best AMMI model family member is the key for reliable estimates of varietal performance and selection of best variety with highly predictable performance in future years as well. Several previous researchers such as Piepho (1994) in faba bean,

TABLE 3

AMMI ANOVA of mulberry varieties for leaf yield plant^{-1} (g)

Source	Degrees of freedom	Sum of squares	Mean sum of squares	'F' Statistic	P(>F)	Proportion	Cumulative variance
Environment	04	20155051	5038763	33.73	2.46×10^{-7}	-	-
Replication (Env)	15	2240884	149392	2.76	1.10×10^{-3}	-	-
Varieties (V)	08	7728538	966067	17.85	2.49×10^{-17}	-	-
V × E interaction	32	5055226	157976	2.92	1.36×10^{-5}	-	-
PC1	11	2352318	213847	3.95	1.00×10^{-4}	46.50	46.50
PC2	09	1642182	182465	3.37	1.00×10^{-3}	32.50	79.00
PC3	07	871732	124533	2.30	3.10×10^{-2}	17.20	96.30
PC4	05	188994	37799	0.70	6.25×10^{-1}	3.70	100.00
Residual	120	6495214	54127	-	-	-	-
Total	211	46730139	221470	-	-	-	-
VEI signal	-	3323162					
VEI noise	-	1732064					

VEI signal SS (3323162) = VEI SS (5055226) - VEI noise SS (1732064), where, VEI noise SS (1732064) = VEI degrees of freedom (32) × AMMI Error MSS (54127)

Annicchiarico *et al.* (2006) in wheat, Ebdon and Gauch (2011) in turfgrass, Sadiyah and Hadi (2016) in rice, Spoorthi *et al.* (2021a) in dolichos bean and Kirankumar *et al.* (2023) in horse gram have also reported adequacy of most parsimonious AMMI model family namely AMMI 2 model to explain the observed variation attributable to VEI effects.

Significant VEI detected and characterized in the present study warrants exploiting patterns of stability of varieties. The performance consistency of test varieties was assessed based on GGE bi-plots and stability parameters. While, assessment of consistency based on GGE bi-plots is subjective, that based on stability parameters is objective.

Assessment of Stability Based on GGE Bi-Plot

A major purpose of yield-trial research is the selection of best variety for use as a cultivar in target environment. Stability of test varieties across temporal environments as is the case in the present study is particularly important as it reduces susceptibility to unpredictable component of VEI effects. The stability of test genotypes across five temporal environments can be qualitatively assessed using the graphical representation of test varieties based on their first two IPC's in GGE bi-plot (Yan *et al*., 2000). GGE bi-plot is a multivariate analytical tool that graphically displays the interaction between each variety and each environment. It is a two-dimensional graph and allows visualization of the inter-relationship among environments and test varieties. There are numerous ways to use and interpret GGE bi-plot. However, four views of the GGE bi-plot are most relevant (Segherloo *et al.,* 2010). These are (i) average environment coordination (AEC) view based on test variety-focused scaling for ranking of the test varieties relative to ideal variety; the ideal variety is the one whose point is located inthe centre of concentric circles in the GGE bi-plot (ii) discriminating and representativeness of test environments view (iii) polygon view based on symmetrical scaling for determining 'which-won-where' pattern of test varieties in test environments and (iv) AEC view based on environment-focused scaling for interpreting mean performance of the varieties vs. their stability patterns (Yan and Kang, 2003). The results of the four views of GGE bi-plot are discussed in the following heads.

Varieties Relative to Ideal Variety

An ideal variety is the one with high mean performance and high stability across the test environments. A single arrowed line passing through the origin in the biplot and centre of the circle is referred to as an average environment coordinate (AEC). The average environment is represented by the small circle at the end of the arrow (Yan andTinker, 2006). An ideal variety is present at the centre of concentric circles with AEC passing throughit in positive direction and has a vector length equal to the longest vector of the variety on the positive side of AEC. Using the ideal variety as centre, several concentric circles are drawn around to help in easy visualization of the distance between each test variety and ideal variety. Stable varieties are the ones which are located closer to the ideal variety. The test variety V1 was identified as near ideal ones on account of being closer to ideal variety which is located at origin (Fig. 2a).

Mean Performance *vs*. Stability Patterns

The mean performance and stability could be visualized based on the location of varieties in relation to AEC using AEC view of GGE bi-plot. The single-arrowed AEC points to higher mean performance of the variety across test environments (Yan, 1999). The variety with their points located towards AEC arrow are considered to exhibit high mean performance. On the contrary, the variety with their points located opposite to AEC arrow are considered to exhibit lower performance. Further, the relative lengths of projections of the variety from AEC are indicative of their relative stability. Shorter the length of the projections of genotypes from AEC, greater is the stability of the genotypes. Longer the projections of varieties, poorer in their stability (Yan and Kang, 2003). In the present study, test variety V3 with shortest vector from the AEC line was identified as a highly stable variety across test environments with higher mean leaf yield plant^{-1} (Fig. 2b).

Which-Won-Where View

Polygon view of GGE biplot helps in identifying which-won-where pattern of varieties. A polygon is formed by joining all the test varieties farther from the biplot origin in such a way that all of them fell within the polygon. Perpendicular lines called equality lines, originating from biplot origin are drawn to each side of the polygon. The equality lines divide the bi-plot into sectors. The vertex variety in each sector is the winning variety at environments whose markers (point) fall into the respective sector (Yan *et al*., 2000). Thus, environments whose markers fall in the sector will have the same winning variety, while environments of different sectors have different winning varieties. Thus, polygon view of GGE biplot indicates the presence or absence of crossover VEI. In the present study, test variety V4 was the winner in E1 environment and V9 was the winner in E2, E3, E4 and E5 environments for leaf yield plant^{-1} (Fig. 2c).

Discriminative Ability and Representativeness of Test Environments

Dotted line connecting the test environment pointing to the origin is called environment vector. The length of environment vectors and angle between the respective environment vector with AEC helps in identifying discriminating ability and representativeness of the test environments. A discriminative environment is the one which has the ability to discriminate between test varieties while a representative environment should represent average of the four test environments. Shorter and longer environment vectors indicate lower and higher discriminative ability of the environments, respectively. Small and large angle between environment vectors and AEC indicate most and least representativeness of environments, respectively. A cute and obtuse angle between the test environment vectors indicate similarity and dissimilarity between the test environments, respectively. In the present study, E5 is discriminative environment and E2 is representative environment for leaf yield plant^{-1} (Fig. 2d).

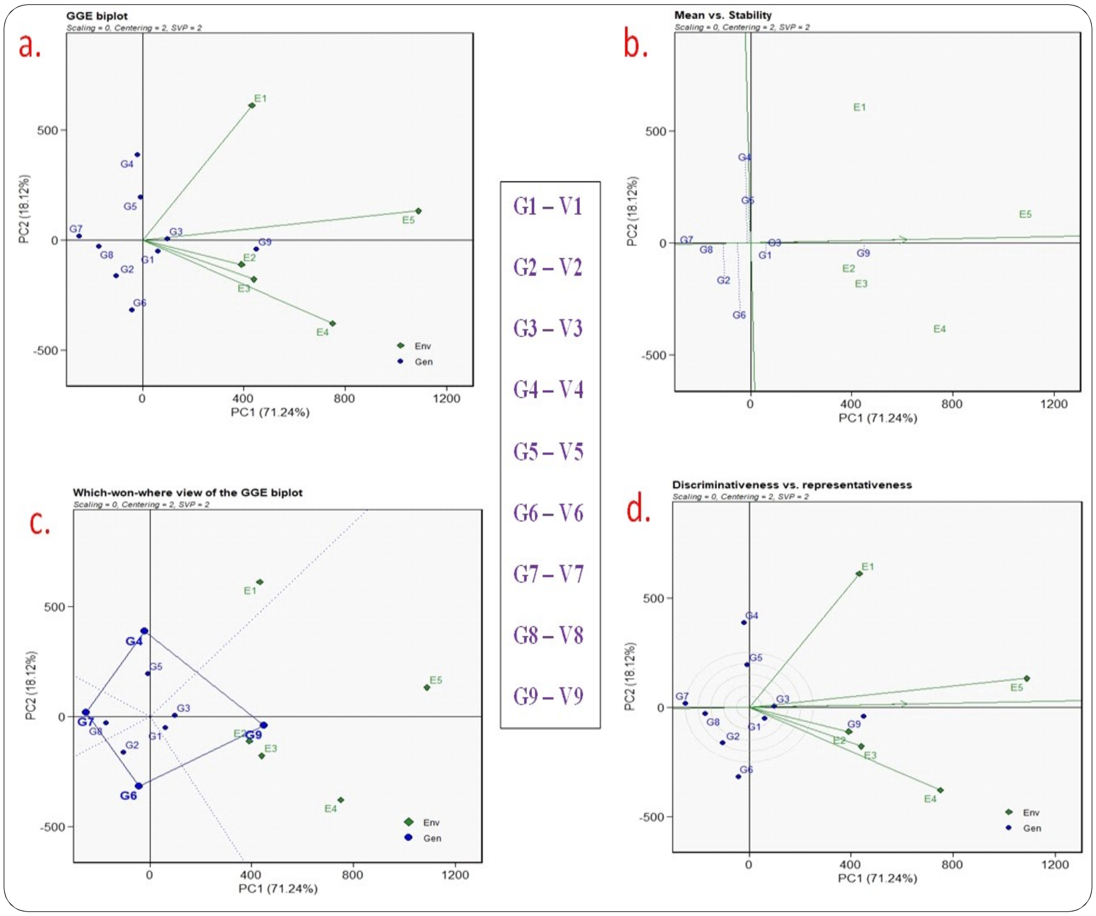

Fig. 2 : Average environment coordination view for (a) identification of test genotypes relative to ideal genotypes (b) mean vs stability of test genotypes (c) polygon view for which won-where pattern of genotypes and (d) discriminative vs representativeness of GGE-biplot for leaf yield plant^{-1} (g)

AMMI Model-Based Stability Parameters

AMMI Stability Value (ASV)

ASV provides an objective criterion of assessment of stability and hence help to identify test varieties stable across the five environments. ASV is the distance from zero in a two-dimensional scatter-plot of IPC 1 scores against IPC 2 scores. In the present study, the estimates of ASVs were obtained using both IPC 1 and IPC 2, as they significantly contributed towards total VEI variance (Table 3). V1 and V8 with lower magnitude of the estimates of ASV for leaf yield plant^{-1} (Table 4) were adjudged as stable varieties across the five test environments.

Stability Index (SI)

SI which considers both mean leaf yield and stability in a single criterion helps in simultaneous selection

TABLE 4

Estimates of AMMI model-based parameters to assess stability of nine mulberry varieties for leaf yield plant^{-1}

Varieties	ASV	RASV	Mean	RY	SI	Average YREM
V1	4.47	2	1053.44	3	5	0.76
V2	13.37	5	918.68	7	12	0.66
V3	6.70	3	1077.72	2	5	0.77
V4	27.89	9	1000.59	4	13	0.72
V5	13.47	6	987.15	5	11	0.71
V6	22.03	8	954.71	6	14	0.68
V7	7.82	4	755.29	9	13	0.54
V8	2.04	1	817.42	8	9	0.59
V9	21.47	7	1394.74	1	8	1.00

ASV: AMMI Stability Value, RASV: Rank of the test variety based on ASV, RY: Rank of the test variety based on mean value, SI: Stability Index, YREM: Yield relative to environment maximum of varieties with desired performance for mean leaf yield coupled with stability. The varieties with low SI are regarded as those with high leaf yield and stability. In the present study, V1 and V3 with lower magnitude of SI (Table 4), were regarded as the best varieties with high leaf yield and stability across five test environments. Several researchers such as Patel *et al*. (2009), Arunkumar & Konda (2014), Bharadwaj *et al*. (2014), Vaijayanthi *et al*. (2016), Vaijayanthi *et al*. (2017), Kavya & Rangaiah (2019) and Kirankumar *et al*. (2023) have also identified genotypes stable across temporal environments based on SI. Of these two genotypes, V1 was found highly stable across five test environments based on three criteria, namely GGE bi-plot, ASV and SI.

Yield Relative to Environment Maximum (YREM)

A simple statistic, namely YREM was used to detect crossover VEI and to quantify reduction in leaf yield potential of test varieties due to crossover VEI. Higher the value of YREM of a variety, lower is the magnitude of crossover VEI and the lower is the extent of reduction in leaf yield potential of that variety even in the presence of crossover VEI. Considering that YREM is a simple statistic which is independent of varieties' attendance, it could be used as a predictor of varieties' performance in future years (Yan, 1999). In the present study, unit YREM of variety V9 (Table 4) indicates that their interaction with the five test environments is of non-crossover type. Unit YREM of all these varieties also indicates that they remained highest yielders in all the five test environments and their leaf yield potential as assessed in this study is attainable in all the test temporal environments without any loss, even if there exists cross-over VEI. Ashwini *et al*. (2021) and Kirankumar *et al*. (2023) in horse gram and Spoorthi *et al.* (2021b) in dolichos bean have also used YREM to detect crossover VEI and to identify stable genotypes.

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