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GRAIN YIELD POTENTIAL AND STABILITY OF MUNGBEAN [*VIGNA RADIATA* (L.) WILCZEK] ADVANCED BREEDING LINES

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ABSTRACT

Mungbean yellow mosaic virus (MYMV) disease is one of the major biotic constraints in mungbean production. Development and deployment of MYMV disease resistant cultivars would contribute to sustainable mungbean production. However, for easy acceptance of such MYMV disease resistant cultivars by farmers, they should be in high yielding background. Under these premises, 19 F_6 MYMV disease resistant advanced breeding lines (ABLs) and their four MYMV disease resistant parents and one susceptible parent were field-evaluated in triplicated randomized complete block design to identify those that exhibit stable pod weight plant^{-1} and grain weight plant^{-1} across three seasons *viz*., 2020 summer, 2020 late rainy and 2021 summer seasons. Additive Main effects and Multiplicative Interaction (AMMI) model was used to detect and characterize ABL × season interaction (GSI). Genotype + Genotype × environment (GGE) bi-plot were used to visually interpret (subjective criterion) GSI patterns of ABLs and identify those that are stable across three seasons. AMMI Stability Value (ASV) and Stability index (SI) were used to assess stability of ABLs. One ABL namely Harsha × AVMU-1698-2018-3-55 was found stable across three seasons based on three criteria namely GE bi-plot, ASV and SI with high mean grain weight plant^{-1}.

Keywords: Mungbean [*Vigna radiata* (L.) Wilczek], AMMI, ASV, SI, GSI, GGE bi-plot

Introduction

Mungbean [*Vigna radiata* (L.) Wilczek] is commonly known as mung, moong, mungo, greengram, goldengram and chickasawpea. Mungbean is a diploid (2n=2x=22) annual legume species. India is the probable center of domestication (Fuller, 2007). Being an important short-duration *Kharif* grain legume, it is grown extensively in major tropical and subtropical countries of the world. Commercial production of mungbean hampered due to several production constraints, especially biotic constraints. Among the biotic constraints, diseases contribute to major production losses. Among all the diseases, the one caused by mungbean yellow mosaic virus (MYMV) is the most destructive one (Kang *et al*., 2005). It is caused by single-stranded circular DNA containing virus belonging to genus *Begomovirus*. The MYMV disease in mungbean is transmitted by whitefly, *Bemisia tabaci* Genn. Hemiptera: Aleyrodidae) (Nariani, 1960; Butler, 1977). Host plant resistance is not only effective, safe, reliable and long-lasting method of control, but also forms an important component of integrated disease management (IDM). Development and deployment of cultivars resistant to MYMV disease is expected to contribute to sustainable mung bean production.

Towards this effort, a few genotypes with high level of resistance to MYMV disease were selected in F_3 generation derived from crosses between agronomically superior but MYMV susceptible genotype and four diverse sources of MYMV disease resistance (Basanagouda *et al*., 2020). These were advanced to F_6 generation by single pod descent method without further selection to fix genes controlling MYMV disease resistance and to minimize the risk of losing genes controlling high grain yield. These F_6 generation genotypes are designated as advanced breeding lines (ABLs). We hypothesized that a few of these F_6 ABLs would serve as potential candidates for use as cultivars if they display grain productivity better than or at least as good as the check cultivar with good levels of resistance to MYMV disease. To test this hypothesis, the present study was undertaken with the following objectives. (1) To detect and characterize interaction of mungbean advanced breeding lines (ABLs) with temporal environments (2) To identify mung bean ABLs stable across temporal environments

Material and Methods

Basic genetic material

The basic genetic material consisted of four MYMV disease resistant genotypes namely, AVMU 1698, AVMU 1699, AVMU 16100, AVMU 16101 and one MYMV disease susceptible genotype, 'Harsha'. These five genotypes were procured from World Vegetable Centre, Taiwan. Extensive screening in field under natural infection at experimental plot and in laboratory dedicated for screening crop genotypes for responses to diseases caused by viruses at Main Agricultural Research Station (MARS), University of Agricultural Sciences (UAS), Bangalore confirmed MYMV disease resistance response of first four genotypes and susceptible response of Harsha (Nagaraj *et al*., 2019).

Development of experimental material

Using four MYMV disease resistant genotypes as male parents and 'Harsha' as female parent, four crosses namely (1) Harsha × AVMU 1698, (2) Harsha × AVMU 1699, (3) Harsha × AVMU 16100 and (4) Harsha × AVMU 16101 were affected during 2018 rainy season at the experimental plots of Department of Genetics and Plant breeding (GPB), College of Agriculture (CoA), UAS, Bangalore. A total of 19 MYMV disease resistant plants in F_3 population were selected during 2019 summer (Basanagouda *et al*., 2020). These F_3- selected plants were advanced to F_6 by selfing to fix the alleles controlling MYMV disease resistance and to minimize the risk of losing genes controlling higher grain yield potential. The 19 F_6 progenies derived from four crosses, hereafter referred to as advanced breeding lines (ABLs), constituted the experimental material (Table-1).

Field evaluation, sampling of plants and data collection of ABLs

The 19 ABLs along with their five parents were evaluated for their grain yield potential and stability at experimental plots of the department of GPB, CoA, UAS, Bangalore during 2020 summer, 2020 late rainy and 2021 summer seasons in three replicated Randomised complete block design. The seeds of each ABL were sown in 3m single rows spaced 0.3m apart. Ten days after sowing, seedlings were thinned to maintain a spacing of 0.10 m between plants.

Five plants were randomly selected from each ABL avoiding border ones. The data were recorded on these five plants for two quantitative traits such as pod weight plant^{-1} and grain weight plant^{-1}.

Statistical analysis

Analysis of variance

The replication-wise quantitative trait means of ABLs and their parents were used for all statistical analysis. Analysis of variance (ANOVA) (Panse and Sukhatme, 1984) was performed to detect significant differences, if any, among the ABLs. Pooled ANOVA (Sundara Raj *et al.* 1972) was performed to detect variation among the ABLs and their interaction with different seasons. Based on expected and observed mean squares attributable to ABLs and those due to their interaction with seasons, variances due to ABLs and those due to their interaction with seasons were estimated.

The *per se* performances of ABLs and their five parents were estimated based on two statistics namely, arithmetic mean and yield relative to the environmental maximum (YREM).

Estimation of YREM of genotypes

The yield relative to the environmental (seasons in the present study) maximum (YREM) (Yan, 1999) was calculated as $Y_{ij}= X_{ij} /MAX_{ij}$, where, Y_{ij} and X_{ij} are the YREM and quantitative trait value, respectively, of genotype 'i' in sowing season 'j'. MAX_j is the maximum yield (of any ABL/ parent) observed in sowing season 'j'. YREM is a simple and intuitive standardized measure of genotype performance. It is relatively independent of genotypes' attendance. The environment maximum is the attainable yield by the genotype in the tested environment. It is also indicative of crossover genotype by environment interaction. It is therefore more predictive of genotypes' performance over temporal environments than absolute performance for desired traits (Yan, 1999). YREM was estimated using MS Excel software.

Detection and characterization of genotype × season interaction

To detect (ABLs + parents) × season interaction (GSI) effects, data recorded from three seasons was subjected to Additive main effects and multiplicative interaction (AMMI) model (Gauch and Zobel,1988). The additive main effects of ABLs + parents and seasons were fitted by univariate ANOVA followed by fitting (ABLs + parents) × season interaction by interaction principal component (IPC) analysis based on AMMI model (Gauch and Zobel,1988). The sum of squares attributable to signal-rich component of GSI (GSI_{Signal}) were computed as GSI SS – GSI_{Noise}, where, GSI_{Noise}= GSI degrees of freedom × error mean squares from the AMMI ANOVA (Gauch 2013). The following model was used to estimate main effects of ABLs and seasons and (ABLs + parents) × season interaction effects.

$Y_{ij} = \mu + g_i + e_j + \sum_{k=1}^{n} \lambda_k \alpha_{ik} \gamma_{jk} + \varepsilon_{ij}$ where, Y_{ij} is the quantitative trait mean of i^{th} ABL in the j^{th} season, μ is the experimental quantitative trait mean, g_i and e_j are the i^{th} ABLs and j^{th} seasons mean deviation from experimental quantitative trait mean values, respectively. λ_k is the square root of eigen value of the k^{th} IPC axis, α_{ik} and γ_{jk} are the interaction principal components (IPC) scores for k^{th} IPC of the i^{th} ABL and j^{th} season, respectively and ε_{ij} is the residual. All the analyses were implemented using *Genstat* software v.18.

GGE bi-plot criteria to interpret ABL × season interaction

Genotype + Genotype × environment (GGE) bi-plot is a subjective/ qualitative means of characterizing (ABLs+ parents) × season interaction patterns and assessment of stability which utilises combination of GGE concepts and AMMI bi-plot (Yan *et. al.*, 2000). GGE bi-plot was used for visual interpretation of patterns of GEI. The GGE bi-plot is based on the following model.

$Y_{ij} - Y_i = \lambda_1 \alpha_{i1} \gamma_{i1} + \lambda_2 \alpha_{i2} \gamma_{j2} + \varepsilon_{ij}$ where, Y_{ij} is the trait mean of i^{th} ABL in the j^{th} season, Y_i is trait mean of all the ABLs in the j^{th} season, λ_1 and λ_2 are square root of eigen values of first and second IPC axes, 1 and 2, α_{i1} and α_{i2} are scores of the first and second IPC, respectively, for the i^{th} ABL and γ_{ij} and γ_{ij} are first and second IPCs respectively for j^{th} season.

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 (1) average-seasonal environment coordination (AEC) view of GGE bi-plot based on ABL-focused scaling for ranking of the test ABLs relative to ideal genotype; the ideal genotype is the one whose point is located in the centre of concentric circles in the GGE bi-plot (2) discriminating and representativeness of test seasonal environments view of GGE bi-plot, (3) polygon view of GGE biplot based on symmetrical scaling for determining "which-won-where" pattern of ABLs with test seasonal environment, and (4) AEC view of bi-plot based on seasonal environment-focused scaling for interpreting mean performance of the ABLs *vs.* their stability patterns.

AMMI model-based parameters to identify stable genotypes

The relative stability of genotypes can be estimated quantitatively based on the estimates of AMMI stability value (ASV) (Purchase *et al.* 2000) and Stability Index (SI) (Farshadfar, 2011).

AMMI stability value (ASV)

To facilitate an objective method of identifying genotypes with stable performance across different seasons of sowing, the ASV was estimated (Purchase *et al.,* 2000) as,

$$\mathbf{ASV}=\sqrt{\left[\frac{SSIPC1}{SSIPC2}(\mathbf{IPC1\ score})\right]^2+(\mathbf{IPC2\ score})^2}$$

where, SSIPC 1 and SSIPC 2 are sum of squares (SS) attributable to first two IPCs. 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 the IPC 1 score generally contributes proportionately more to GSI, it is weighted by the proportional difference between IPC 1 and IPC 2 scores in order to compensate for the relative contribution of IPC 1 and IPC 2 scores to total GSI sum of squares. Lower magnitude of estimates of ASV indicates greater stability, while higher magnitude of ASV indicates lower stability of genotypes (Purchase *et al.*, 2000).

Stability Index (SI)

As ASV considers only stability, regardless of grain yield potential of genotypes, SI was estimated to facilitate simultaneous selection of genotypes for desired performance for different quantitative traits and stability. SI was estimated as SI= RASV + RY where, RASV is rank of the ABLs based on ASV and RY is the rank of ABL based on quantitative trait mean (Farshadfar, 2011) across three different seasons of sowing. The ABLs with low SI were regarded as those with high trait expression and high stability.

Results and Discussion

ANOVA

Analysis of variance (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. Season-wise ANOVA revealed significant mean squares attributable to ABLs in all three seasons (Table-2). These results indicated substantial differences among the ABLs for traits investigated.

Pooled ANOVA

Pooled ANOVA partitions the total variation into sources attributable to ABLs, seasons, ABL × season interaction and pooled error. From plant breeding point of view, only variances due to ABLs and ABLs × season interactions (GSI) are exploitable. In the present study, while significant variances attributable to ABLs offer better scope for selection of ABLs with desired combination of traits, those due to significant ABLs × season interactions (Table-3) offer opportunities for maximizing the productivity of selected ABLs by identifying those that are specifically suited to a particular season.

AMMI model-based characterization of ABL × season interaction

Additive ANOVA detects genotype (g) × environment (e) interaction (GEI) only when the average of all (g-1) (e-1) contrasts is significant. Classical additive ANOVA indicate lack of GEI, even when there exists significant GEI for some of the contrasts. Hence, classical additive ANOVA is not a desirable method for detecting GEI. Researchers should declare absence of GEI only if GEI sum of squares of one degree of freedom (df) is not significant (Gauch, 1988). As an intermediate approach between 1 and (g-1) (e-1) df, AMMI model is widely used to unambiguously detect GEI (Gauch, 1988). AMMI model uses additive ANOVA for detection of main effect ABL and main effect season and multiplicative principal component analysis of ABL × season interaction effects. The rationale behind AMMI model is that observed performance of ABLs in a particular environment is not the best estimate of true performance of the ABLs in that environment. This is because, most often than not ABLs interact significantly with test environment(s). The ABL × seasonal environment in the present study 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 ABL × season interaction in to signal and noise components using several IPCs. While the first few IPCs capture most of the repeatable and predictable component, later IPCs capture non-repeatable and un-predictable component. In the present study, sum of squares (SS) attributable to ABL × season interaction was partitioned into those attributable to GSI_{Signal} and GSI_{Noise}. AMMI analysis is appropriate for data sets for which SS due to GSI_{Signal} are at least as large as those due to additive ABL main effects. This criterion is met in the present study and hence the use of AMMI analysis to detect and characterize ABL × season interaction and identify stable ABLs across seasons is justified.

Differences among ABLs and/or seasonal environments are necessary for existence of ABL × season interaction. In the present study, AMMI ANOVA revealed significant mean squares attributable to ABLs and ABL × season interaction for both traits under study (Table-4). Mean squares attributable to seasonal environments were significant, indicating the ability of the temporal environments to discriminate ABLs under study. Significant mean squares attributable to ABLs suggested presence of substantial variability among the ABLs for both traits. Significant mean squares attributable to the ABL × season interaction suggested differential performance of ABLs across seasons. The proportion of total variation attributable to season main effect was higher than that attributable to the ABL main effect and ABL × season interaction effect for pod weight plant^{-1} and for grain weight plant^{-1} the proportion of total variance attributable to ABL × season interaction effect was higher than that attributable to ABL and season main effects. Thus, *per cent* contribution of variation attributable to ABLs, season and ABL × season interaction differed significantly for the traits studied (Table-4). Several researchers such as Nath (2012), Arunkumar and Konda (2014), Bhardwaj *et al.* (2014) and Ramkisanrao (2017) have also detected significant genotype × environment interaction for grain yield and component traits. The significant ABL × season interaction in the present study warrants identification of ABLs that are specifically suitable to each season to maximize mungbean production in each season.

Stability of ABLs across three temporal environments

GGE bi-plot

The stability and adaptability of ABLs over temporal environments can be qualitatively assessed using the graphical representation of GGE bi-plot that scatters ABLs based on their IPCs. Yan *et al.* (2000) proposed, a standard bi-plot of GGE, genotype (G) + Genotype × environment (GE) based on a SREG (sites regression) model referred to as GGE bi-plot. It is a multivariate analytical tool that graphically displays interaction between each ABL and each seasonal environment. It is a two-dimensional bi-plot and allows visualization of the inter-relationship among seasonal environments, and also the inter-relationship between ABLs and seasonal environments using (i) average seasonal environment coordination (AEC) view of GGE-biplot based on genotype-focused scaling for identification of genotypes relative to ideal genotypes, (ii) discriminativeness and representativeness view of GGE bi-plot (iii) polygon view of GGE bi-plot based on the symmetrical scaling for "which won-where" pattern of genotypes and seasonal environments and (iv) average seasonal environment coordination (AEC) view of GGE bi-plot based on environment-focused scaling for the mean performance vs. adaptability pattern (Yan, 2003). The discussion of the results on GGE biplot is focused on two important productive traits such as pod weight plant^{-1} and grain weight plant^{-1}.

Genotype(s) relative to ideal genotype

An ideal ABL is the one with high mean performance and high stability over the environments. A single arrowed line passing through origin in the biplot and centre of the circle is average seasonal environment coordinate (AEC). The average seasonal environment is represented by the small circle at the end of the arrow. An ideal genotype is present at the centre of concentric circles with AEC passing through it in positive direction and has a vector length equal to the longest vector of the ABL on the positive side of AEC. Using the ideal genotype as centre several concentric circles were drawn around to help in easy visualization of distance between each ABL and ideal genotype. Stable ABLs are the ones which are located closer to the ideal genotype.

For pod weight plant^{-1}(g), two ABLs namely, Harsha × AVMU-16101-2018-3-20 (G-16) and Harsha × AVMU-1699-2018-3-10 (G-6) and one parent AVMU 1699 are identified as near ideal ones (Figure-1a). On the contrary, the ABLs viz., Harsha × AVMU-1698-2018-3-42 (G-3) and Harsha × AVMU-16100-2018-3-69 (G-14) were near-ideal genotypes for grain weight plant^{-1} (g) (Figure-1b).

Discriminative and representative ability of environments

Dotted line connecting the test seasonal environment pointing to the origin is called seasonal vector. The length of seasonal vectors and angle between the respective seasonal vector with AEC helps in identifying discriminating and representative ability of the temporal environments. A discriminative seasonal environment is able to discriminate between ABLs while a representative seasonal environment should represent average of the three test seasonal environments. Shorter and longer seasonal environment vectors indicate lower and higher discriminative ability of the seasonal environments, respectively. Small and large angle between seasonal environment vectors and AEC indicate most and least representative ability of seasonal environments, respectively. Acute and obtuse angle between the seasonal environment vectors indicate similarity and dissimilarity between the test seasonal environments, respectively.

In the present study, 2020 late rainy season is both discriminative and representative for pod weight plant^{-1}, as its seasonal environment vector is longer than the other seasonal environment vectors and acute angle with AEC (Figure-2a). On the contrary, for grain weight plant$^{-1,}$ all seasonal environments are equally discriminative as seasonal environment vectors of all seasons are of comparable length, but 2020 late rainy season is representative as it has very small angle with AEC. Hence, 2020 late rainy season is considered as best one to evaluate for grain weight as it is equally discriminative with other seasons (Figure-2b).

Which won where?

Polygon view of GGE biplot helps in identifying which won where pattern of genotypes. A polygon is formed by joining all the ABLs farther from the biplot origin in such a way that all the other ABLs fall 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 genotype in each sector is the winning ABL at environments whose markers (point) fall into the respective sector (Yan *et al*., 2000). Thus, seasonal environments whose markers fall in the sector will have the same winning genotype, while seasonal environments of different sectors have different winning genotypes. Thus, polygon view of GGE biplot indicates the presence or absence of crossover ABL × seasonal interaction.

In the present study, ABL Harsha × AVMU-1698-2018-3-55 (G-4) was the winner in 2020 late rainy season and ABL Harsha × AVMU-1698-2018-3-12 (G-1) was the winner in 2021 summer season for pod weight plant^{-1} (Figure-3a). For grain weight plant^{-1}, AVMU 16100 (G-22), Harsha × AVMU-16101-2018-3-59 (G-19) and Harsha × AVMU-16100-2018-3-46 (G-13) occupied vertices of the polygon. While the ABL AVMU 16100 (G-22) was winner in the 2020 summer season, ABL Harsha × AVMU-16101-2018-3-59 (G-19) in late 2020 rainy season and Harsha × AVMU-16100-2018-3-46 (G-13) was the winner in 2021 summer season (Figure-3b).

Mean performance *vs*. stability patterns

The mean performance and stability could be visualized based on the location of genotypes in relation to AEC using AEC view of GGE bi-plot. The single arrowed AEC points to higher mean performance of the genotypes across locations (Yan, 1999). The genotypes with their points located towards arrow of AEC are considered to exhibit high mean performance. On the contrary, the genotypes with their points located opposite to AEC arrow are considered to exhibit lower performance. Further, the relative lengths of projections of the genotypes from AEC are indicative of their relative stability, shorter the length of the projections of genotypes from AEC, greater (wide) is the adaptability of the genotypes. The greater the absolute length of the projections of genotypes, greater would be their poor adaptability (Yan and Kang, 2003).

In the present study, the ABL Harsha × AVMU-16101-2018-3-08 (G-15) was identified as highly stable over test seasonal environments for pod weight plant^{-1} with shortest vector (Figure-4a). As far as grain yield plant^{-1} was concerned, ABL, Harsha × AVMU-1698-2018-3-12 (G-1) was found to be highly stable with shortest vectors from AEC and ABLs, Harsha × AVMU-1698-2018-3-55 (G-5) and Harsha × AVMU-16100-2018-3-46 (G-13) were found located towards AEC arrow indicating their higher mean performance (Figure-4b).

AMMI model-based stability parameters

AMMI Stability value (ASV)

ASV provides objective assessment of stability and hence help to identify ABLs stable over the three seasonal environments. ASV is the distance from zero in a two-dimensional scatter-gram of IPCA 1 (Interaction Principal Component Analysis Axis 1) scores against IPCA 2 (Interaction Principal Component Analysis Axis 2) scores. In the present study, ASV were estimated using both IPCA1 and IPCA2, as they significantly contributed towards total ABL × season interaction variance for grain yield plant^{-1}, whereas the ASVs of pod weight plant^{-1}(g) were estimated using only IPCA1 as it alone significantly explained most of the ABL × season interaction variance.

In the present study, the estimates of ASV were lower in magnitude with respect to the ABLs, Harsha × AVMU-2018-16101-3-20 and AVMU 1699 for pod weight plant^{-1} (g), and Harsha × AVMU-2018-16100-3-69 and Harsha × AVMU-1698-2018-3-28 for grain weight plant^{-1} (g) (Table-5). Hence, these ABLs are considered stable across three seasonal environments for respective traits.

Stability index (SI)

Stability index (SI) which incorporates both quantitative traits mean and stability in a single criterion helps in simultaneous selection of ABLs with desired performance for different quantitative traits coupled with stability. The ABLs with low SI are regarded as those with high trait expression and high stability. In the present study, the estimates of SI were lower in magnitude for the ABLs viz., Harsha × AVMU-2018-1699-3-19 and Harsha × AVMU-16100-2018-3-05 for pod weight plant^{-1} (g), and Harsha × AVMU-1698-2018-3-55 and Harsha × AVMU-1698-2018-3-28 for grain weight plant^{-1} (g) (Table-5). These ABLs are regarded as the best ones with high trait mean and stability. Several researchers such as Patel *et al.* (2009), Arunkumar and Konda (2014) and Bharadwaj *et al.* (2014) have also identified genotypes stable across temporal environments based on stability index.

YREM, as indicator of cross over ABL × season interaction

YREM is an indicative of crossover genotype by environment interaction. Therefore, in the absence of crossover ABL × season interaction, the average YREM of a ABL tested across seasons must be 1.0. Any departure of YREM of a genotype from 1.0 is attributable to loss in its attainable grain yield due to crossover ABL × season interaction. The ABLs Harsha × AVMU-1699-2018-3-19, Harsha × AVMU-1698-2018-3-55 and Harsha × AVMU-16101-2018-3-08 with relatively high YREM of 0.87, 0.84 and 0.84 respectively, suggest that 17, 16 and 16 *per cent* of pod yield will be lost due to crossover ABL × season interaction. Further, two ABLs Harsha × AVMU-1698-2018-3-55 and Harsha × AVMU-16101-2018-3-59 with comparatively higher YREM of 0.88 and 0.84, respectively, suggest that 12 and 16 *per cent* of attainable grain yield will be lost due to crossover ABL × season interaction (Table-6). These ABLs were better than their parents with relatively higher estimates of YREM, further suggesting that their grain yield losses due to crossover ABL × season interaction is lower than their parents.

Table 1: Pedigree of mungbean ABLs derived from F$_3$-selected MYMV disease resistant plants and their parents

Cross	Pedigree of MYMV resistant plants selected in F$_3$ generations
Harsha × AVMU 1698	1. Harsha × AVMU-1698-2018-3-12 2. Harsha × AVMU-1698-2018-3-28 3. Harsha × AVMU-1698-2018-3-42 4. Harsha × AVMU-1698-2018-3-55 5. Harsha × AVMU-1698-2018-3-62
Harsha × AVMU 1699	6. Harsha × AVMU-1699-2018-3-10 7. Harsha × AVMU-1699-2018-3-19 8. Harsha × AVMU-1699-2018-3-49 9. Harsha × AVMU-1699-2018-3-60
Harsha × AVMU 16100	10. Harsha × AVMU-16100-2018-3-05 11. Harsha × AVMU-16100-2018-3-26 12. Harsha × AVMU-16100-2018-3-38 13. Harsha × AVMU-16100-2018-3-46 14. Harsha × AVMU-16100-2018-3-69
Harsha × AVMU 16101	15. Harsha × AVMU-16101-2018-3-08 16. Harsha × AVMU-16101-2018-3-20 17. Harsha × AVMU-16101-2018-3-38 18. Harsha × AVMU-16101-2018-3-49 19. Harsha × AVMU-16101-2018-3-59
Parents	1. AVMU 1698 2. AVMU 1699 3. AVMU 16100 4. AVMU 16101 } Resistant to MYMV disease 5. Harsha-Susceptible to MYMV disease

Table 2: ANOVA of mungbean ABLs evaluated across three seasonal (temporal) environments pod weight plant^{-1} and grain weight plant^{-1}

Source of Variation	Degrees of freedom	Pod weight plant^{-1} (g)			Grain weight plant^{-1} (g)		
		Summer season- 2020	Late rainy season- 2020	Summer season- 2021	Summer season- 2020	Late rainy season- 2020	Summer season- 2021
ABLs and their five parents	23	2.83**	6.34**	1.89**	0.18**	2.18**	0.12**
Replication	02	0.88	0.67	1.75	0.03	0.14	0.05
Error	46	0.29	0.72	0.59	0.01	0.12	0.03

* Significant at P = 0.05; ** Significant at P = 0.01

Table 3: Pooled ANOVA of mungbean ABLs evaluated across three seasonal (temporal) environments pod weight plant^{-1} and grain weight plant^{-1}

Source of variation	Degrees of freedom	Pod weight plant^{-1} (g)	Grain weight plant^{-1} (g)
Replication	02	1.16	1.77
ABLs and their five parents	23	4.05**	8.76**
Seasons	02	71.59**	2278.13**
(ABLs + parents) × season	46	1.99**	7.35**
Pooled error	142	0.72	1.00

* Significant at P = 0.05; ** Significant at P = 0.01

Table 4: AMMI ANOVA of mungbean ABLs evaluated across three seasonal (temporal) environments pod weight plant^{-1} and grain weight plant^{-1}

Source of variation	Degree of freedom	Pod weight plant^{-1} (g)		Grain weight plant^{-1} (g)	
		Mean sum of squares	% Variation	Mean sum of squares	% Variation
Total	143	2.66		0.33	
(19 ABLs and their five parents) × 3 season	71	4.62**	86.12	0.60**	89.84
19 ABLs and their five parents	23	4.05**	28.41	0.62**	33.61
Seasons	2	71.59**	43.70	0.91**	4.31
(ABLs + parents) × season	46	1.99**	27.92	0.57**	62.08
IPCA 1	24	2.75**	72.13	0.98**	89.97
IPCA 2	22	1.16	27.87	0.12*	9.99
Error	69	0.72	12.96	0.06	9.42
GSI_{signal}		58.38 (63.80 % of GSI)		23.28 (88.74% of GSI)	
GSI_{noise}		33.12 (36.20% of GSI)		2.95 (11.26% of GSI)	

* Significant at P = 0.05; ** Significant at P = 0.01

Table 5: Estimates of IPC scores and AMMI model-based parameters to assess stability of mungbean ABLs across three seasonal (temporal) environments

ABLs	Pod weight plant^{-1}(g)							Grain weight plant^{-1}(g)						
	MEAN	RY	IPCA1	IPCA2	ASV	RASV	SI	MEAN	RY	IPCA1	IPCA2	ASV	RASV	SI
01	6.32	23	-0.34	0.16	6	35	6.32	3.82	17	0.28	0.02	2.51	17	34
02	7.02	17	-0.77	0.14	5	39	7.02	3.99	11	0.02	-0.20	0.26	3	14
03	6.77	20	-0.57	0.47	15	39	6.77	4.06	10	0.05	-0.04	0.46	4	14
04	8.57	4	0.81	1.06	23	27	8.57	4.28	4	-0.06	-0.64	0.83	7	11
05	7.21	13	-0.41	0.13	4	23	7.21	3.63	22	0.50	0.09	4.54	21	43
06	7.96	8	0.16	1.03	22	11	7.96	3.82	16	0.16	-0.07	1.47	10	26
07	9.01	1	-0.23	0.33	9	7	9.01	4.50	3	-0.74	0.02	6.68	22	25
08	7.44	12	-0.52	0.07	2	27	7.44	3.56	23	0.29	-0.12	2.61	19	42
09	8.62	3	0.68	0.35	11	23	8.62	4.11	7	-0.17	-0.26	1.56	12	19
10	7.94	9	0.32	0.24	7	20	7.94	4.09	8	-0.20	0.08	1.79	13	21
11	6.04	24	-0.21	0.65	18	28	6.04	3.67	19	0.27	0.06	2.40	16	35
12	8.16	6	0.56	0.27	8	23	8.16	4.19	5	-0.12	0.06	1.10	9	14
13	6.59	21	-0.55	0.40	12	37	6.59	3.38	24	0.46	-0.21	4.15	20	44
14	6.48	22	0.07	0.33	10	27	6.48	3.81	18	-0.01	0.09	0.15	1	19
15	8.73	2	0.88	1.12	24	26	8.73	4.11	6	-0.28	0.15	2.56	18	24
16	7.66	10	0.00	0.45	14	11	7.66	4.07	9	-0.26	0.10	2.31	15	24
17	7.14	15	0.15	0.85	20	22	7.14	3.66	20	0.11	-0.19	1.03	8	28
18	6.93	18	0.14	0.88	21	26	6.93	3.63	21	0.07	-0.09	0.66	6	27
19	7.57	11	0.76	0.02	1	32	7.57	4.65	1	-1.10	0.03	9.91	24	25
Parents														
AVMU 1698	7.17	14	-0.44	0.83	19	27	7.17	3.94	14	0.16	0.46	1.54	11	25
AVMU 1699	8.14	7	0.04	0.60	17	9	8.14	3.99	12	0.00	0.17	0.18	2	14
AVMU 16100	8.21	5	-0.39	0.50	16	14	8.21	3.96	13	0.77	0.08	6.97	23	36
AVMU 16101	7.03	16	-0.61	0.44	13	34	7.03	4.60	2	0.05	0.46	0.66	5	7
Harsha	6.78	19	0.45	0.13	3	33	6.78	3.87	15	-0.26	-0.03	2.31	14	29
SEm± 0.71 : CD @ p= 5%=1.98								SEm± 0.60: CD @ p = 5%=1.68						

Table 6: Estimates of YREM of mungbean ABLs for pod weight plant^{-1} and grain weight plant^{-1}

ABLs	Pod weight plant^{-1}(g)				Grain weight plant^{-1}(g)			
	Summer season-2020	**Late rainy season-2020**	**Summer season-2021**	**Mean**	**Summer season-2020**	**Late rainy season-2020**	**Summer season-2021**	**Mean**
Harsha × AVMU-1698-2018-3-12	0.62	0.44	0.79	0.62	0.81	0.48	0.84	0.71
Harsha × AVMU-1698-2018-3-28	0.78	0.46	0.84	0.69	0.76	0.58	0.87	0.74
Harsha × AVMU-1698-2018-3-42	0.84	0.53	0.63	0.67	0.81	0.61	0.87	0.76
Harsha × AVMU-1698-2018-3-55	0.73	0.92	0.87	0.84	0.84	0.80	0.99	0.88
Harsha × AVMU-1698-2018-3-62	0.81	0.56	0.75	0.71	0.82	0.42	0.82	0.69
Harsha × AVMU-1699-2018-3-10	0.78	0.62	0.82	0.74	0.77	0.57	0.84	0.73
Harsha × AVMU-1699-2018-3-19	0.94	0.73	0.94	0.87	0.77	0.84	0.84	0.82
Harsha × AVMU-1699-2018-3-49	0.82	0.55	0.82	0.73	0.73	0.51	0.81	0.69
Harsha × AVMU-1699-2018-3-60	0.73	0.81	0.93	0.82	0.74	0.66	0.88	0.76
Harsha × AVMU-16100-2018-3-05	0.81	0.79	0.73	0.78	0.79	0.66	0.82	0.76
Harsha × AVMU-16100-2018-3-26	0.65	0.46	0.64	0.58	0.78	0.53	0.80	0.70
Harsha × AVMU-16100-2018-3-38	0.74	0.84	0.83	0.80	0.82	0.69	0.85	0.79
Harsha × AVMU-16100-2018-3-46	0.75	0.48	0.71	0.65	0.71	0.39	0.81	0.64
Harsha × AVMU-16100-2018-3-69	0.58	0.54	0.78	0.63	0.76	0.59	0.79	0.71
Harsha × AVMU-16101-2018-3-08	0.72	0.88	0.91	0.84	0.79	0.69	0.80	0.76
Harsha × AVMU-16101-2018-3-20	0.76	0.65	0.82	0.74	0.78	0.70	0.81	0.76
Harsha × AVMU-16101-2018-3-38	0.64	0.60	0.84	0.69	0.71	0.56	0.82	0.70
Harsha × AVMU-16101-2018-3-49	0.73	0.62	0.64	0.66	0.71	0.54	0.79	0.68
Harsha × AVMU-16101-2018-3-59	0.61	0.79	0.82	0.74	0.73	0.97	0.82	0.84
Parents								
AVMU 1698	0.77	0.51	0.80	0.70	0.87	0.61	0.78	0.75
AVMU 1699	0.83	0.71	0.83	0.79	0.81	0.61	0.81	0.74
AVMU 16100	0.87	0.61	0.90	0.79	0.93	0.44	0.92	0.77
AVMU 16101	0.84	0.53	0.70	0.69	0.82	0.77	0.80	0.80
Harsha	0.59	0.64	0.74	0.66	0.71	0.66	0.79	0.72
SEm±	0.31	0.48	0.43	0.71	0.05	0.20	0.10	0.60
CD @ p= 5%	0.72	1.16	1.03	1.98	0.12	0.43	0.23	1.68

Code	**ABL**
1	Harsha × AVMU-1698-2018-3-12
2	Harsha × AVMU-1698-2018-3-28
3	Harsha × AVMU-1698-2018-3-42
4	Harsha × AVMU-1698-2018-3-55
5	Harsha × AVMU-1698-2018-3-62
6	Harsha × AVMU-1699-2018-3-10
7	Harsha × AVMU-1699-2018-3-19
8	Harsha × AVMU-1699-2018-3-49
9	Harsha × AVMU-1699-2018-3-60
10	Harsha × AVMU-16100-2018-3-05
11	Harsha × AVMU-16100-2018-3-26
12	Harsha × AVMU-16100-2018-3-38
13	Harsha × AVMU-16100-2018-3-46
14	Harsha × AVMU-16100-2018-3-69
15	Harsha × AVMU-16101-2018-3-08
16	Harsha × AVMU-16101-2018-3-20
17	Harsha × AVMU-16101-2018-3-38
18	Harsha × AVMU-16101-2018-3-49
19	Harsha × AVMU-16101-2018-3-59

Parents	
20	AVMU 1698 (R)
21	AVMU 1699 (R)
22	AVMU 16100 (R)
23	AVMU 16101 (R)
24	Harsha (S)
Seasons (Temporal environments)	
1	Summer 2020
2	Late rainy 2020
3	Summer 2021

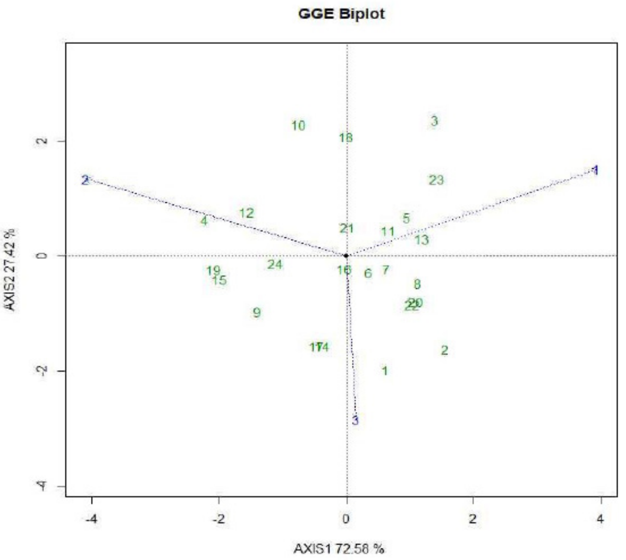

Fig. 1a: Average seasonal environment coordination (AEC) view of GGE-biplot for identification of ABLs relative to ideal genotypes for pod weight plant^{-1}(g)

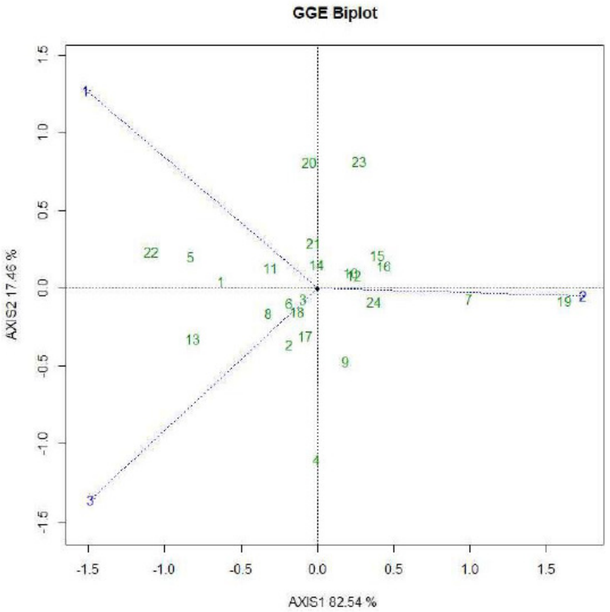

Fig.1b: Average seasonal environment coordination (AEC) view of GGE-biplot for identification of ABLs relative to ideal genotypes for grain weight plant^{-1}(g)

Code	ABL
1	Harsha × AVMU-1698-2018-3-12
2	Harsha × AVMU-1698-2018-3-28
3	Harsha × AVMU-1698-2018-3-42
4	Harsha × AVMU-1698-2018-3-55
5	Harsha × AVMU-1698-2018-3-62
6	Harsha × AVMU-1699-2018-3-10
7	Harsha × AVMU-1699-2018-3-19
8	Harsha × AVMU-1699-2018-3-49
9	Harsha × AVMU-1699-2018-3-60
10	Harsha × AVMU-16100-2018-3-05
11	Harsha × AVMU-16100-2018-3-26
12	Harsha × AVMU-16100-2018-3-38
13	Harsha × AVMU-16100-2018-3-46
14	Harsha × AVMU-16100-2018-3-69
15	Harsha × AVMU-16101-2018-3-08
16	Harsha × AVMU-16101-2018-3-20
17	Harsha × AVMU-16101-2018-3-38
18	Harsha × AVMU-16101-2018-3-49
19	Harsha × AVMU-16101-2018-3-59

Parents	
20	AVMU 1698 (R)
21	AVMU 1699 (R)
22	AVMU 16100 (R)
23	AVMU 16101 (R)
24	Harsha (S)
Seasons (Temporal environments)	
1	Summer 2020
2	Late rainy 2020
3	Summer 2021

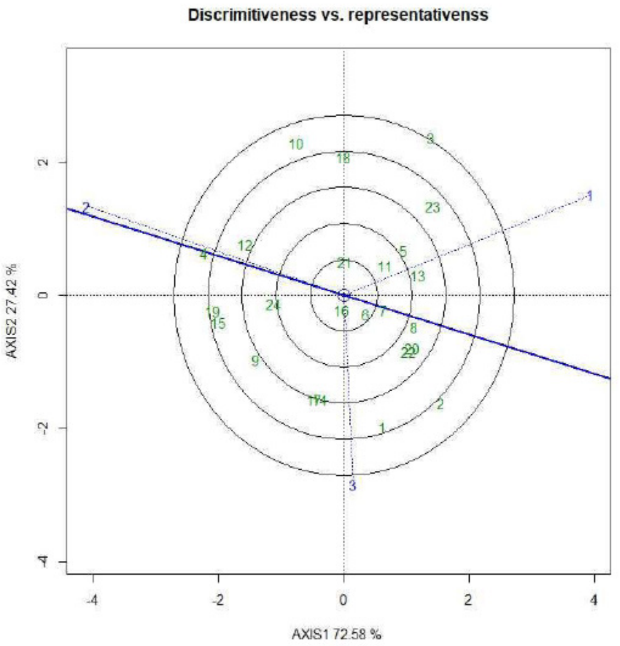

Fig. 2a: Discriminative *vs.* representativeness view of GGE bi-plot for pod weight plant^{-1}(g)

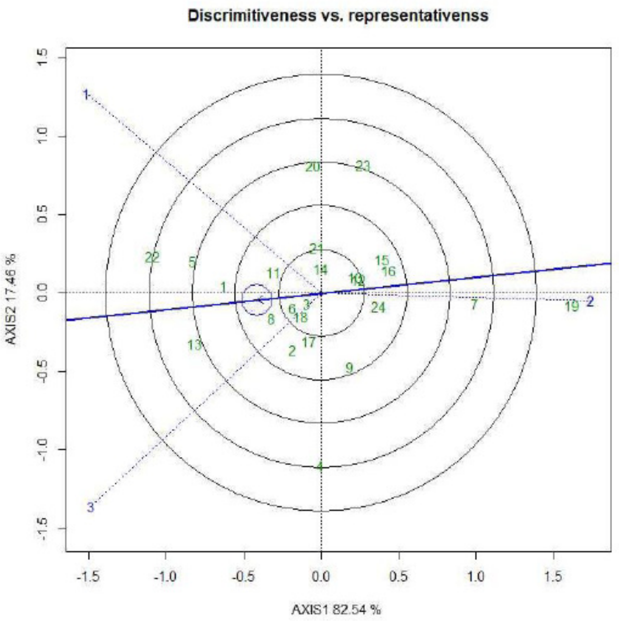

Fig. 2b: Discriminative *vs.* representativeness view of GGE bi-plot for grain weight plant^{-1}(g)

1	Harsha × AVMU-1698-2018-3-12
2	Harsha × AVMU-1698-2018-3-28
3	Harsha × AVMU-1698-2018-3-42
4	Harsha × AVMU-1698-2018-3-55
5	Harsha × AVMU-1698-2018-3-62
6	Harsha × AVMU-1699-2018-3-10
7	Harsha × AVMU-1699-2018-3-19
8	Harsha × AVMU-1699-2018-3-49
9	Harsha × AVMU-1699-2018-3-60
10	Harsha × AVMU-16100-2018-3-05
11	Harsha × AVMU-16100-2018-3-26
12	Harsha × AVMU-16100-2018-3-38
13	Harsha × AVMU-16100-2018-3-46
14	Harsha × AVMU-16100-2018-3-69
15	Harsha × AVMU-16101-2018-3-08
16	Harsha × AVMU-16101-2018-3-20
17	Harsha × AVMU-16101-2018-3-38
18	Harsha × AVMU-16101-2018-3-49
19	Harsha × AVMU-16101-2018-3-59

Parents	
20	AVMU 1698 (R)
21	AVMU 1699 (R)
22	AVMU 16100 (R)
23	AVMU 16101 (R)
24	Harsha (S)
Seasons (Temporal environments)	
1	Summer 2020
2	Late rainy 2020
3	Summer 2021

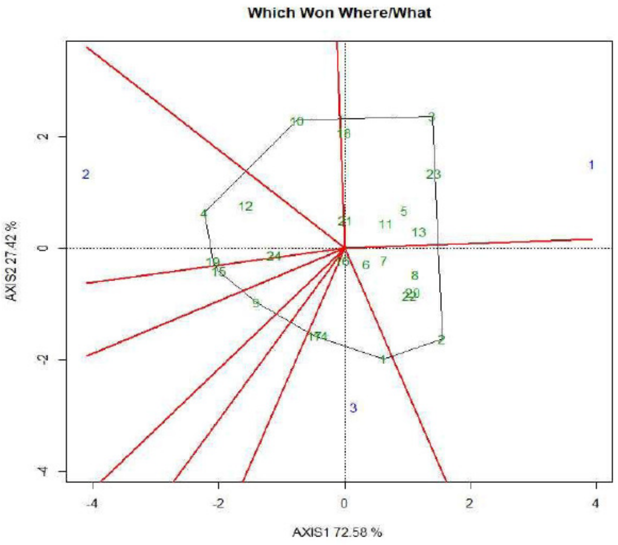

Fig. 3a: Polygon view of GGE bi-plot based on the symmetrical scaling for "which won-where" pattern of ABLs and seasonal environments for pod weight plant^{-1}(g)

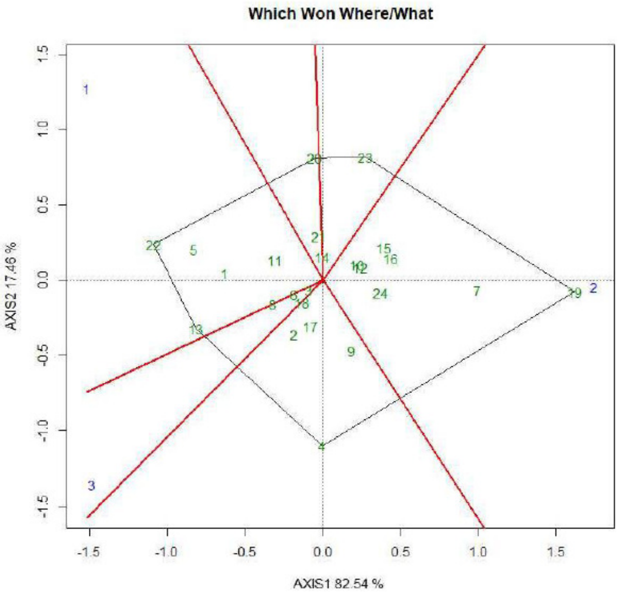

Fig. 3b: Polygon view of GGE bi-plot based on the symmetrical scaling for "which won-where" pattern of ABLs and seasonal environments for grain weight plant^{-1}(g)

Code	ABL
1	Harsha × AVMU-1698-2018-3-12
2	Harsha × AVMU-1698-2018-3-28
3	Harsha × AVMU-1698-2018-3-42
4	Harsha × AVMU-1698-2018-3-55
5	Harsha × AVMU-1698-2018-3-62
6	Harsha × AVMU-1699-2018-3-10
7	Harsha × AVMU-1699-2018-3-19
8	Harsha × AVMU-1699-2018-3-49
9	Harsha × AVMU-1699-2018-3-60
10	Harsha × AVMU-16100-2018-3-05
11	Harsha × AVMU-16100-2018-3-26
12	Harsha × AVMU-16100-2018-3-38
13	Harsha × AVMU-16100-2018-3-46
14	Harsha × AVMU-16100-2018-3-69
15	Harsha × AVMU-16101-2018-3-08
16	Harsha × AVMU-16101-2018-3-20
17	Harsha × AVMU-16101-2018-3-38
18	Harsha × AVMU-16101-2018-3-49
19	Harsha × AVMU-16101-2018-3-59

Parents	
20	AVMU 1698 (R)
21	AVMU 1699 (R)
22	AVMU 16100 (R)
23	AVMU 16101 (R)
24	Harsha (S)
Seasons (Temporal environments)	
1	Summer 2020
2	Late rainy 2020
3	Summer 2021

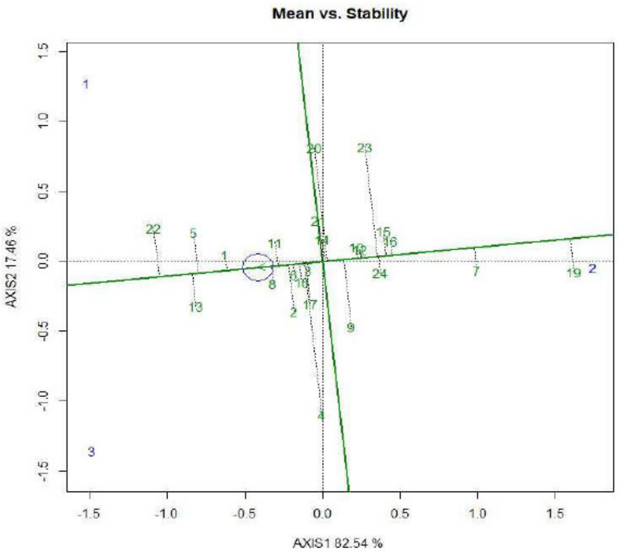

Fig. 4a: Average seasonal environment coordination (AEC) view of GGE bi-plot based on seasonal environment-focused scaling for the mean performance *vs.* stability for pod weight plant^{-1}(g)

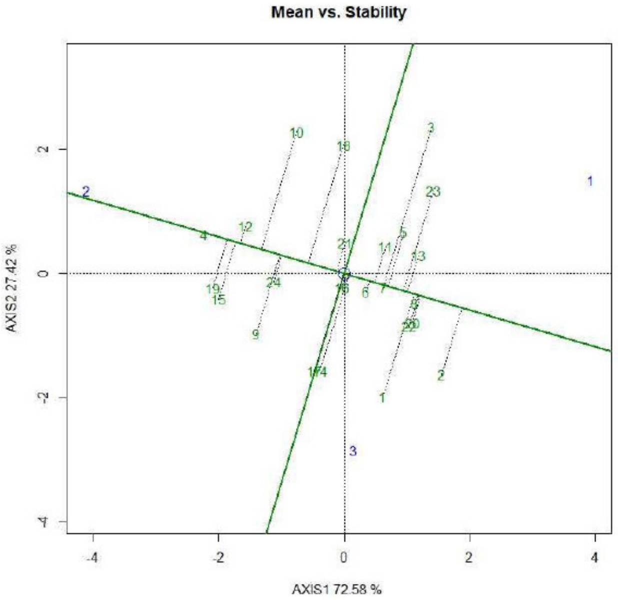

Fig. 4b: Average seasonal environment coordination (AEC) view of GGE bi-plot based on seasonal environment-focused scaling for the mean performance *vs.* stability for grain weight plant^{-1}(g)

Declaration

The authors do not have any conflict of interest.

References

Arunkumar, B. and Konda, C.R. (2014) Genotype and environment interaction and stability analysis for seed yield in yellow mung bean (*Vigna radiata* L.). *J. Appl. Nat. Sci.*, **6**(2), 782-785.

Basanagouda, G. (2020) Inheritance of mung bean yellow mosaic virus (MYMV) disease resistance in mung bean (Vigna radiata L.). *Plant Genet.,* **18**(3), 196 – 199

Bhardwaj, R., Shekhawat, A.S., Mundiyara, R. and Sharma, N.C. (2014) Study of Stability Parameters for Seed Yield and its Components in Mung Bean (*Vigna radiata* L. Wilczek). *J. Plant Sci. Res.*, **30**(2), 205-212.

Butler, N.S. (1977) Whitefly as carrier of plant virus. Everyday science. 22,27-29

Farshadfar, E. (2011) Chromosomal localization of the genes controlling adaptation in *Agropyron elongatum* using a new AMMI–based simultaneous selection index of yield and yield stability. *Int. J. Plant Breed.*, **5**(2), 80-83.

Fuller, D.Q. (2007) Contrasting patterns in crop domestication and domestication rates, recent archaeobotanical insights from the Old World. *Ann. Bot.* **100**(5), 903–924.

Gauch, H.G. and Zobel, R.W. (1988) Predictive and postdictive success of statistical analyses of yield trials. *Theor. Appl. Genet.*, **76**(1), 1-10.

Gauch, H.G. (2013) A simple protocol for AMMI analysis of yield trials. *Crop Sci.*, **53**(5),1860-1869.

Kang, B.C., Yeam, I. and Jahn, M.M. (2005) Genetics of plant virus resistance. *Annu. Rev. Phytopath*, **43**,581-621.

Nagaraj., Basavaraj, S., Padmaja, A.S., Nagaraju, N. and Ramesh, S. (2019). Identification of stable sources of resistance to Mungbean yellow mosaic virus (MYMV) disease in mungbean [*Vigna radiata* (L.) Wilczek]. *Plant Genet.*, **17**(4), 362-370

Nariani, T.K. (1960) Yellow mosaic of mung (*Phaseolus aureus* L.). *Indian Phytopathol.*, **13**, 24-29.

Nath, A. (2012) Stability analysis in mungbean *(Vigna radiata* L. Wilczek*). Doctoral dissertation.,* Mahatma Phule Krishi Vidyapeeth, Rahuri.

Panse, V.G. and Sukhatme, P.V. (1984) Statistical methods for agricultural workers, ICAR Publication, New Delhi, 145.

Patel, J.D., Naik, M.R., Chaudhari, S.B., Vaghela, K.O. and Kodappully, V.C. (2009) Stability analysis for seed yield in green gram (*Vigna radiata* (L.) Wilczek). *Agric. Sci. Digest*, **29**(1), 36-38.

Purchase, J.L., Hatting, H. and Van Deventer, C.S. (2000) Genotype × environment interaction of winter wheat (*Triticum aestivum L.*) in South Africa, II. Stability analysis of yield performance. *South African J. Plant Soil*, **17**(3), 101-107.

Ramkisanrao, B.G. (2017) Stability analysis for grain yield and it's components of advanced breeding lines in mungbean. Doctoral dissertation., Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

Segherloo, A.E., Sayyed, H.S., Dehghani, H. and Kamran, M. (2010) Screening of superior chickpea genotypes for various environments of Iran using genotype plus genotype × environment (GGE) bi-plot analysis. *Crop Sci.* **2**(9), 286-292.

Sundara Raj, N., Nagaraju, V. S., Venkataramu, M. N. and Jagamath, M. K. (1972) Design and Analysis of Field Experiments, *Univ. Agric. Sci., Bangalore*, p.424.

Yan, W. (1999) Methodology of cultivar evaluation based on yield trial data-with special reference to winter wheat in Ontario. Doctoral dissertation, University of Guelph, Ontario, Canada.

Yan, W. and Kang, M.S. (2003) GGE biplot analysis, A graphical tool for breeders, geneticists, and agronomists. *CRC Press, Boca Raton, First edition, FL.*

Yan, W., Hunt, L.A., Sheng, Q. and Szlavnics, Z. (2000) Cultivar evaluation and mega-environment investigation based on the GGE biplot. *Crop Sci.*, **40**(3), 597-605.