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Research Article

Estimation of Genotype × Environment interaction in soybean (*Glycine max* (L.) Merrill) crosses for grain yield and its component traits under different sowing dates

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Abstract
The study was conducted at AICRP on Soybean, Zonal Agricultural Research Station, UAS, GKVK, Bengaluru, to detect and quantify the stable performing genotypes by temporal environment interaction. Fifty-eight genetically stable soybean lines selected from F_5 population of four crosses were evaluated with two checks in α-lattice design with two replications, across three dates of sowing namely, 20thJanuary, 20th February and 20th March during, 2022. Pooled ANOVA revealed a significant difference for number of pods plant^{-1} and grain yield plant^{-1} attributable to genotypes × dates of sowing. The AMMI ANOVA indicated a significant difference attributable to GEI for number of pods plant^{-1}, and grain yield^{-1}. Based on the lower estimates of AMMI stability value and stability index for grain yield plant^{-1} lines 3, 23, 8, 5 and 14 in cross JS24-34 × RVS2001-18, 10, 3, 7 and 2 lines in cross JS20-34 × RVS2001-18, lines 9, 10, 6 and 8 in cross DSb-31 × MACS1460 and lines 12, 5, 1, 8 and 4 in cross DSb-21 × EC457254 were regarded as widely adaptable and stable genotypes.

Keywords: Stability, soybean crosses, AMMI analysis, G x E Interaction, GGE biplot.

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is a protein rich legume crop known as the 'golden' and 'wonder crop' belonging to the family *Leguminosae* originated in China and grown widely in Brazil, United States, Argentina, China, and India. It supplies 25% of the world's output of vegetable oil, nearly two third of the protein concentrate used for livestock feeding, and is a key component of formulated fish and poultry diets. India stands fifth in soybean production with an area of 11.4 mha, 13.26 mt of production and 1209.3 kgha^{-1} productivity (FAOSTAT, 2018). It is the world's driving oil seed crop and remains next just to groundnut and rapeseed mustard in India. It has flexibility towards an extensive variety of soil and environment (Boyer, 1982). Soybean grain yield is a perplexing trait and it is related to a few yield components and impacted by environment (Choi *et al.,* 2016; Obalum *et al,.* 2012). Soybean yield potential in different agro-biological conditions changes contingent upon the similarity with the agro-environment, biotic and abiotic stress extents (Penalba *et al.,* 2007; Zanon *et al.,* 2016). Natural factors, for example, soil type, developing season and agricultural practices frequently become a determinant for variation in soybean genotypes. It is likewise influenced by the interaction between genotype and environment (GEI), which cause trouble in choosing unrivalled lines (Kumar *et al.,* 2014). Genotypes performing well under a particular environment may not perform well over other environments due to genotype-environment interactions (GEI) (Kachapur *et al*., 2016).The assessment of stable genotypes to a wide range of environments is important for recommending cultivars in plant breeding programme (Manjubala *et al*., 2018).Such assorted conditions can be accomplished by the development of high-yielding and stable performing soybean varieties. The feasibility of selecting elite genotypes can be severely limited by substantial G×E for quantitative features like yield (Flores *et al.,* 1998). Therefore, stability is crucial to identify yield-contributing characteristics and understand the relationships between yield and G×E in order to develop new cultivars with better environmental adaption.

In a self-pollinated crop like soybean, the breeding procedure for the most part includes the hybridization of expected genotypes from the current germplasm. Quantitative traits such as grain yield, is highly influenced by G×E interaction, which necessitates evaluating and assessing performance stability of soybean genotypes. The effects of sowing date on grain yield vary with genotypes of the soybean crop. Therefore, assessment of the stability of genotypes is important for further validation and use as a variety or as a parent in the future breeding program. After considering the above advantages of selecting stable genotypes in soybean crop, current study was conducted for assessing the stability of selected plants from four crosses under three dates of sowing and thereby identify the best line with high yielding and stable performance for further use in breeding programs or exploitation as a variety.

MATERIALS AND METHODS

The study was carried out by using F_4 population of four soybean crosses namely JS24-34 × RVS2001-18 (cross-1), JS20-34×RVS2001-18 (cross-2), DSb31 × MACS1460 (cross-3) and DSb-21 × EC457254 (cross-4) were obtained and experiment was conducted in All India Co-ordinated Research Project (AICRP) on Soybean, Zonal Agricultural Research Station (ZARS), University of Agricultural Sciences (UAS), Gandhi Krishi Vignana Kendra (GKVK), Bengaluru. Seeds of F_4 population of four crosses were sown in plots of eight rows each with row length of 5m. The progeny plants from F_4 population of the four crosses were selected based on grain yield and the selected plants were evaluated under three different dates of sowing. The experiment was conducted in α-lattice design with two replications. Number of single plants selected were 23, 10, 12 and 13 from the crosses JS24-34 × RVS2001-18, JS20-34×RVS2001-18, DSb31 × MACS1460, DSb-21 × EC457254 respectively with two checks JS335 and KBS23.Total 60 genotypes were sown in three different dates i.e. 20th January, 20th February and 20th March of the year 2022, each genotype was sown in a row length of 2 m. Recommended package of practices were followed to raise the healthy crop. Data were collected on six quantitative traits such as days to 50% flowering, plant height (cm), number of branches plant^{-1}, number of pods plant^{-1}, grain yield plant^{-1} (g) and 100 seed weight (g) from five plants selected at random from each genotype in two replications by avoiding border plants. Pooled ANOVA was performed to know the significance of GEI effects. Since GEI effect was found significant, data was subjected to Additive Main Effects and Multiplicative Interaction (AMMI) analysis. AMMI model (Gauch and Zobel, 1988) was used to detect and characterize the patterns of genotype and environment interaction. Visual and objective criteria were used to interpret GEI patterns of a genotype and their specific/wide adaptation. The visual criterion was based on Genotype **+** Genotype **×**Environment (GGE) bi-plot (Yan *et al.,* 2000). Objective criterion was based on the estimates of AMMI stability value (ASV) (Purchase *et al*., 2000) and Stability Index (SI) (Mahmodi *et al*., 2011).

RESULTS AND DISCUSSION

Analysis of variance by using AMMI Model: Pooled ANOVA revealed the significance of genotype, environment and GEI effects which indicates that the performance of soybean genotypes varies with dates of sowing (**Table 1**). To know the extent of interaction effect i.e., influence of dates of sowing on grain yield plant^{-1}of soybean genotypes, AMMI analysis was carried out.

Table 1. Pooled alpha lattice ANOVA

Source of variation	Degrees of freedom	Mean sum of squares					
		Days to 50% flowering	Plant height (cm)	Number of branches plant^{-1}	Number of pods plant^{-1}	Grain yield plant^{-1} (gm)	100 seed weight plant^{-1} (gm)
Genotypes	59	2.84*	44.14***	1.95	76.45*	31.81***	3.61***
Environment	2	1.76	646.46***	9.23*	79.68	181.1***	27.68***
Genotype × Environment	118	1.59	24.87	1.81	71.90**	5.51**	1.04
Replication	1	1.34	55.91	33.32***	86.45	28.46**	19.48***
Block	18	2.31	13.95	5.87	64.55	5.58	0.69
Error	41	2.17	21.17	2.61	48.30	3.65	1.26

*Significant at 5%; ** Significant at 1%; *** Significant at 0.1%

ANOVA based on AMMI model has also revealed that the sum of squares due to genotypes, environment and genotype × environment interaction was significant for grain yield plant^{-1} (**Table 2**) and the percent contribution of genotypic effects towards total variation was found to be more, followed by GEI and dates of sowing effects (**Table 2**). The grain yield plant^{-1} of soybean genotypes varies with dates of sowing as revealed by AMMI ANOVA table which showed nearly 15.35% of total variation is due to GEI effects.

GGE Bi-plot analysis: GGE biplots are the visual tools used to depict the pattern of GEI. Four different kinds of biplots have been plotted to identify the stable genotypes with good performance and to identify the ideal environment. The four different views of biplots are as follows, polygon view of GGE biplot, mean performance *vs.* stability patterns, discriminativeness *vs.* representativeness of GGE biplot and identification of ideal genotypes based on mean yield and stability.

Table 2. AMMI ANOVA table for yield and its component traits

Source of variation	Degrees of freedom	Days to 50% flowering		Plant height (cm)		Number of branches plant^{-1}	
		MSS	Proportion	MSS	Proportion	MSS	Proportion
Genotypes	59	2.84*	17.84	44.13***	19.22	3.61	10.53
Environment	2	1.76	0.37	646.45***	9.54	27.68*	1.68
Genotype × Environment	118	1.59	20.02	24.87	21.66	1.04	19.60
PC1	60	1.66	53.20	33.34*	68.20	1.24	59.20
PC2	58	1.51	46.80	16.10	31.80	0.84	40.80
Residuals	123	1.90	24.98	21.39	19.43	1.19	31.59

Table 2. Contd……

Source of variation	Degrees of freedom	Number of pods plant^{-1}		Grain yield plant^{-1} (gm)		100 seed weight plant^{-1} (gm)	
		MSS	Proportion	MSS	Proportion	MSS	Proportion
Genotypes	59	76.45*	14.77	31.81***	44.25	3.61***	28.19
Environment	2	79.68	0.52	181.09***	8.53	27.68***	7.31
Genotype × Environment	118	71.90*	27.80	5.51**	15.35	1.04	16.35
PC1	60	94.97**	67.2	6.98***	64.40	1.24	60.40
PC2	58	48.04	32.8	4.00	35.60	0.84	39.60
Residuals	123	48.88	19.7	3.34	9.69	1.19	19.45

*Significant at 5%; ** Significant at 1%; *** Significant at 0.1%

Discriminativeness *vs.* representativeness of GGE biplot: An environment is considered as ideal when it is having good discriminating ability and it must be representative of all the testing environments. Based on discriminativeness *vs.* representativeness view of GGE biplot for grain yield plant^{-1}, environment 2 (February sowing) was more discriminative due to its long environmental vector and environment 1 (January sowing) was identified as a more representative one as it formed smaller angle with AEC, but environment 1 (January sowing) was showing shorter vector length hence, was less discriminative and environment 3 (March sowing) was forming a large angle with AEC, hence was considered to be less representative (**Fig. 1**).

Mean performance *vs.* stability patterns of genotypes: This view of biplot helps to identify the genotypes with high yielding potential and also depicts stability of the genotypes. Based on the mean performance *vs.* stability patterns, genotype C3-3 was found to be the highest grain yielder as it was located closer to the AEC arrow, followed by C2-6, C2-5, C2-2, C3-8, JS335, C4-12, C3-9, C2-7 and C3-7 (**Fig. 2**). Shorter the length of the genotype projections from AEC, the greater the stability of the genotypes. Hence, while looking for highly stable genotypes with high grain yield per plant, genotype C2-2 topped the list, followed by C3-3, C3-11, C2-6, C3-9 and C4-12.

Identification of ideal genotypes based on mean yield and stability: Ideal genotype is the one that is present closer to the small circle on the average environment axis (AEA). Genotype C4-3 was located very near to the centre of the concentric circles and this genotype was identified

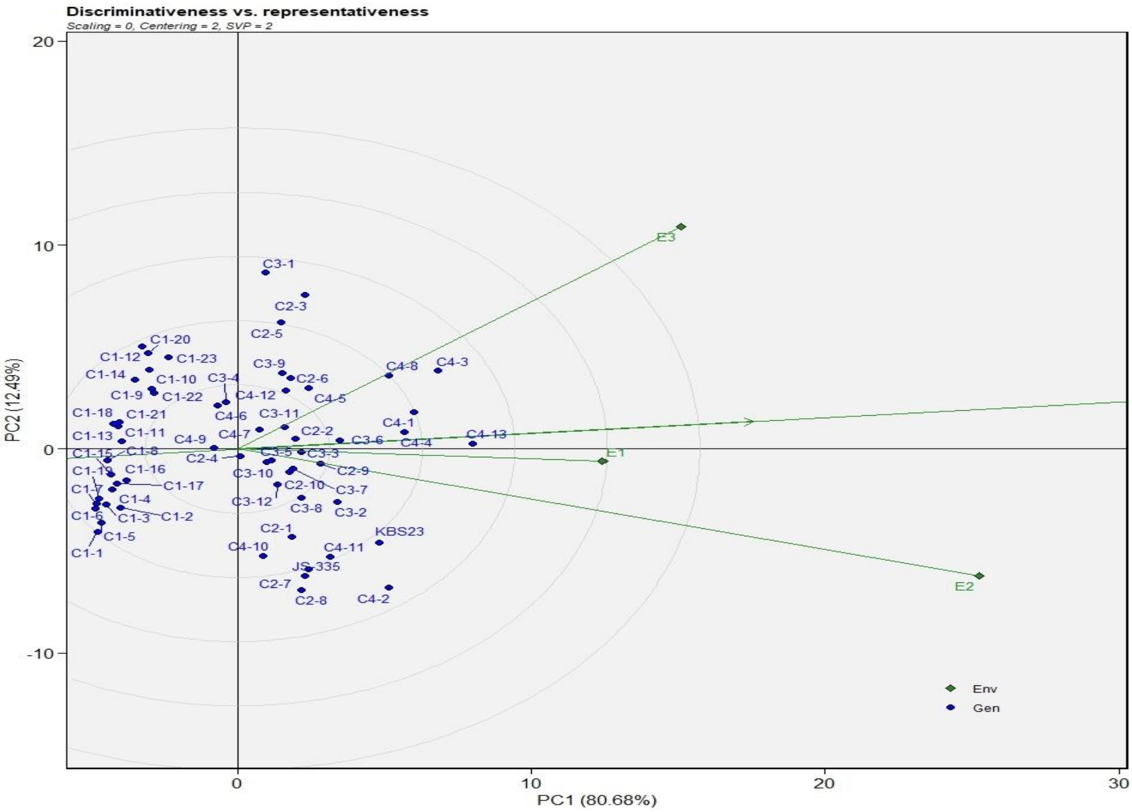

Fig. 1. Discriminative vs. representativeness view of GGE-Biplot for grain yield plant^{-1}

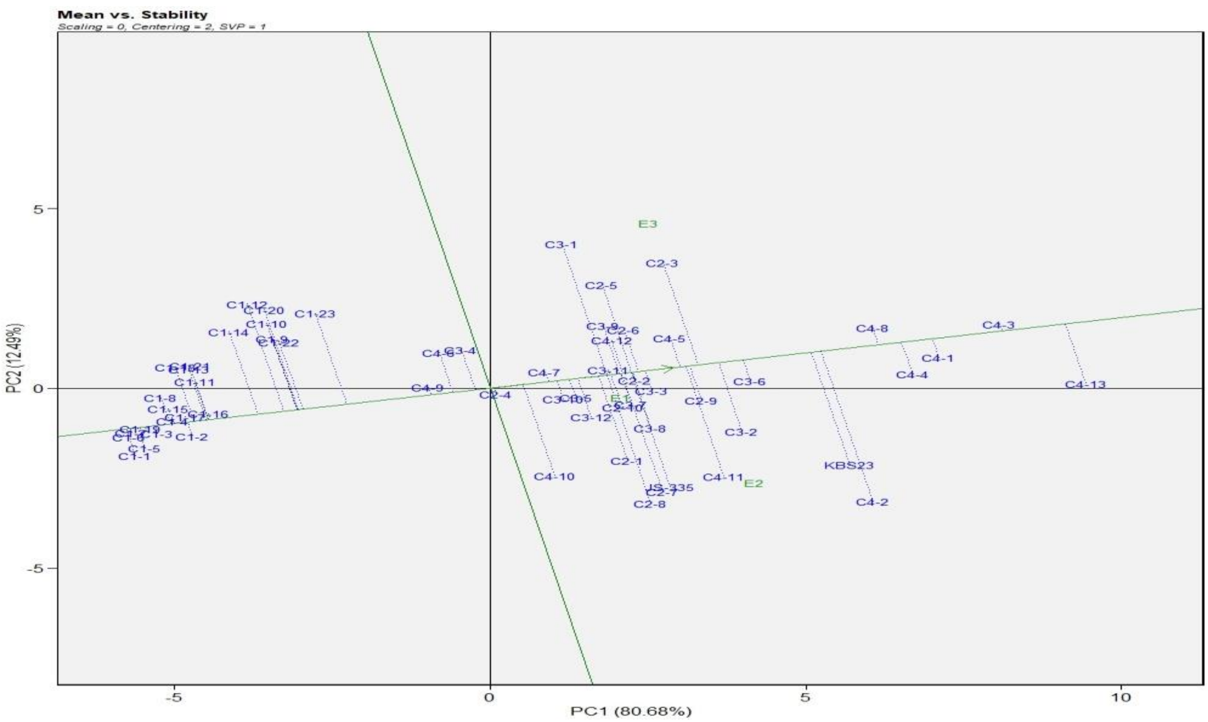

Fig. 2. Average environment coordination view of GGE-Biplot based on environment focused scaling for the mean performance vs. stability of grain yield plant^{-1}

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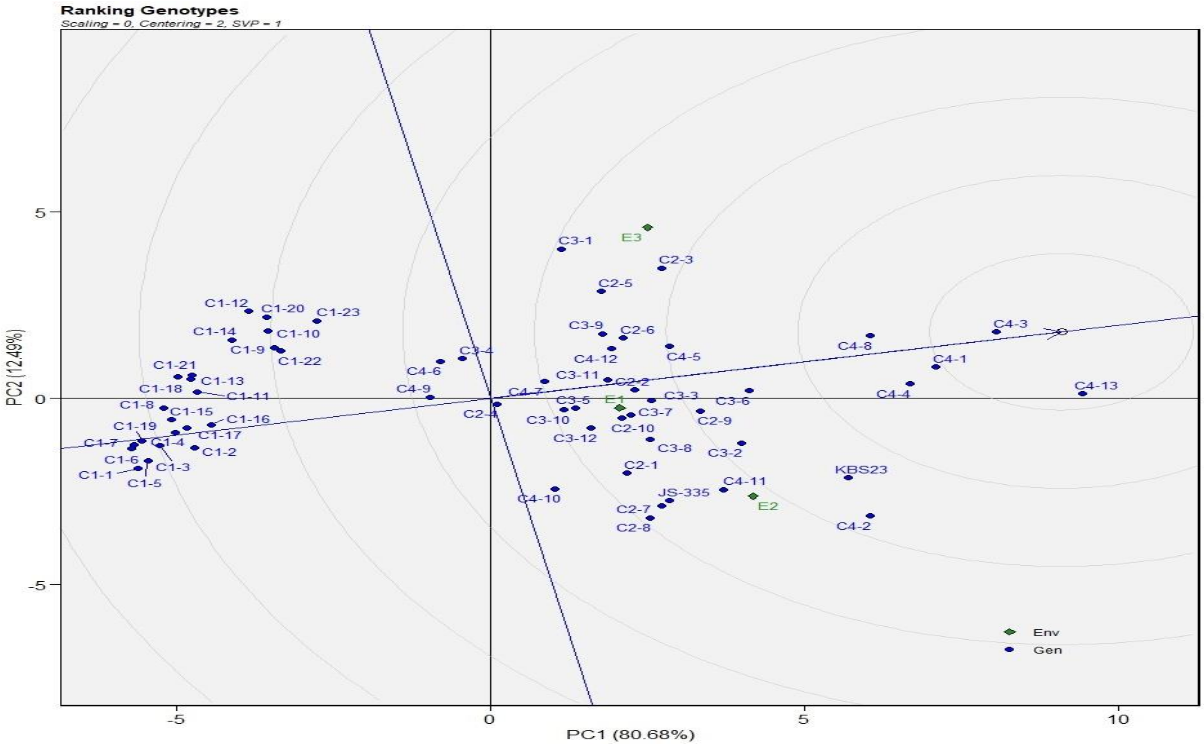

Fig. 3. Average environment coordination view of GGE-Biplot based on genotype-focused scaling for comparison of genotypes with the ideal genotype for grain yieldplant^{-1}

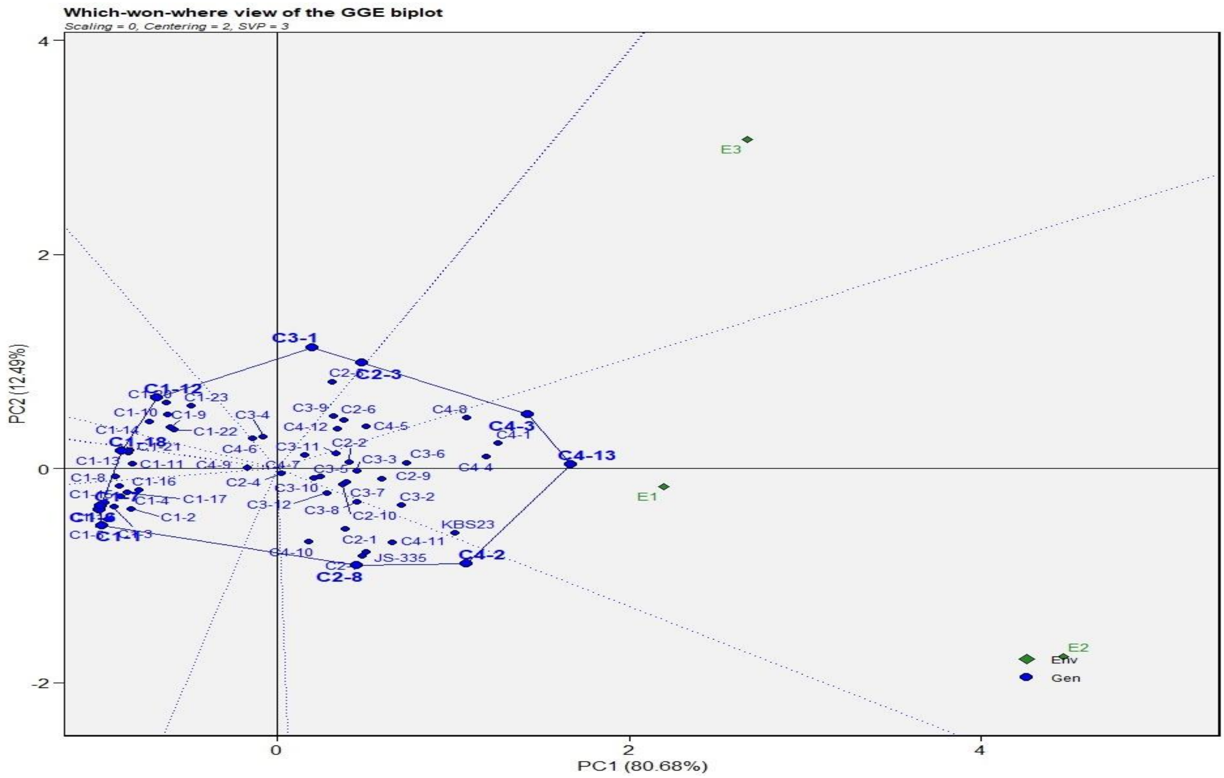

Fig. 4. Polygon view of GGE-Biplot based on symmetrical scaling for 'which-won where' pattern of genotypes and environments for grain yield plant^{-1} across the environment

as the near-ideal genotype for grain yield plant^{-1}. On the contrary, genotypes C4-13, C4-1, C4-4 and C4-8 (**Fig. 3**) were located farther from the centre of the concentric circles.

Polygon view of GGE biplot: This view of biplot is useful for delineating mega environments. This view of biplot is also helpful to exploit specific adaptability of the genotypes. The genotypes which were found at the vertex of the polygon were considered as the winning genotype. The winning genotypes for grain yield plant^{-1} as per polygon view of GGE biplot wereC4-13 and C4-3 in both environment 1 (January sowing) and environment 2 (February sowing). Genotype C2-3 was the winner for grain yield plant^{-1} (**Fig. 4**) in environment 3 (March sowing).

Objective criteria for identifying stable genotypes: Based on the estimates of AMMI stability value, the ranks to the

Table 3. Estimates of ASV and SI to assess the stability of soybean genotypes in JS24-34 × RVS2001-18

JS24-34 × RVS2001-18	Grain yield plant^{-1} (gm)				
	Mean	ASV	Rank	SI	Rank
1	14.35	7.94	22	42	17
2	15.71	6.15	18	22	8
3	14.97	0.26	1	9	1
4	15.54	8.63	23	29	12
5	14.89	2.08	4	15	4
6	15.41	4.93	16	23	9
7	14.69	2.59	6	21	7
8	14.91	1.97	3	12	3
9	14.83	3.73	11	23	9
10	14.75	2.68	7	20	6
11	14.30	3.48	10	31	13
12	14.74	4.52	14	28	11
13	15.76	7.05	19	22	8
14	14.91	2.49	5	15	4
15	15.66	5.54	17	22	8
16	16.13	7.32	20	21	7
17	14.48	4.45	13	31	13
18	14.65	3.32	9	26	10
19	14.48	7.54	21	40	16
20	14.20	4.31	12	35	14
21	14.29	4.66	15	37	15
22	14.66	1.59	2	18	5
23	15.86	2.94	8	10	2

Table 4. Estimates of ASV and SI to assess the stability of soybean genotypes in JS20-34 × RVS2001-18

JS20-34 × RVS2001-18	Grain yield plant^{-1} (gm)				
	Mean	ASV	Rank	SI	Rank
1	18.31	4.05	6	15	8
2	18.56	0.95	3	10	4
3	18.80	0.74	2	6	2
4	19.10	7.49	10	12	6
5	17.39	0.72	1	11	5
6	18.62	6.49	8	13	7
7	19.01	3.77	5	8	3
8	18.62	6.16	7	13	7
9	18.32	6.76	9	17	9
10	19.23	1.00	4	5	1

Table 5. Estimates of ASV and SI to assess the stability of soybean genotypes in DSb-31 × MACS1460

DSb-31 × MACS1460	Grain yield plant^{-1} (gm)				
	Mean	ASV	Rank	SI	Rank
1	18.84	2.88	12	18	7
2	18.16	0.69	3	14	5
3	18.57	0.89	6	15	6
4	18.67	0.84	5	13	4
5	19.43	2.61	11	13	4
6	19.36	0.97	8	11	2
7	17.72	1.59	10	22	8
8	18.53	0.54	2	12	3
9	19.95	0.72	4	5	1
10	18.99	0.53	1	5	1
11	18.92	1.20	9	14	5
12	18.81	0.95	7	14	5

Table 6. Estimates of ASV and SI to assess the stability of soybean genotypes in DSb-21 × EC457254

DSb-21 × EC457254	Grain yield plant^{-1} (gm)				
	Mean	ASV	Rank	SI	Rank
1	21.39	1.47	7	10	3
2	17.95	0.98	3	14	6
3	19.41	1.22	4	12	5
4	18.73	0.87	2	11	4
5	22.72	1.53	8	9	2
6	20.43	2.55	13	19	9
7	22.01	1.57	9	11	4
8	21.12	1.44	6	10	3
9	19.60	2.01	10	17	8
10	17.43	2.16	11	23	10
11	18.25	1.43	5	15	7
12	21.11	0.58	1	6	1
13	17.32	2.26	12	25	11

genotypes could be assigned. The genotypes with lower ASV values were assigned lower ranks. The estimates of ASV for grain yield plant^{-1}of progenies of JS24-34 × RVS2001-18 cross (cross 1) was lower in magnitude for the following lines 3, 22, 8 and 5 (T**able 3**). In JS20-34 × RVS2001-18 (cross 2) the lines 5, 3, 2 and 10 (**Table 4**), in DSb-31 × MACS1460 (cross 3) lines 10, 8, 2, 9, 4 and 3 (**Table 5**), while in DSb-21 × EC457254 (cross 4) lines 12, 4, 2 and 3 (**Table 6**) had a lower magnitude of ASV. Hence, based on the ASV values above-mentioned lines of the respective crosses were found to be stable in all three environments under study.

The lines 3, 23, 8, 5 and 14 (**Table 3**) in JS24-34 × RVS2001-18 (cross 1), lines 10, 3, 7 and 2(**Table 4**) in JS20-34 × RVS2001-18 (cross 2), lines 9, 10, 6 and 8(**Table 5**)of DSb-31 × MACS1460 (cross 3), lines 12, 5, 8 and 7 (**Table 6**) in DSb-21 × EC457254 (cross 4) were found to have lower estimates of SI for the trait grain yield plant^{-1} and hence were considered as stable and better-performing genotypes in the respective crosses.

In conclusion, the mean of six quantitative traits of each genotype subjected to ANOVA following AMMI model indicated significant difference attributable to GEI for grain yield^{-1}. The visual criterion based on GGE bi-plot and objective criterion based on the estimates of ASV and SI indicated that genetically stabilised F_5 lines 3, 23, 8, 5 and 14 of the cross JS24-34 × RVS2001-18, lines 10, 3, 7 and 2 of the cross -, JS20-34 × RVS2001-18 lines 9, 10, 6 and 8 of the cross DSb-31 x MACS1460- and lines 12, 5, 1, 8 and 4 of the cross DSb-21 x FC457254 -F_5- were identified as stable and better performing . These could be subjected for large scale yield evaluation and use in the breeding programmes for development of stable and high yielding elite cultivars.

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