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Stability analysis in soybean (*Glycine max* L.) genotypes

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Abstract
The experiment was conducted in Randomized Block Design with three replications at Zonal Agriculture Research Station, Ganeshkhind, Pune during *Kharif* season (2023) for the evaluation of seed yield stability of 16 soybean genotypes over three sowing dates *viz.*, June, 15 (E1), July, 5 (E2) and July, 25 (E3). The study revealed that environmental variance was exhibited significant influence on most of the traits, indicating its strong role in character expression. The stability assessment highlighted that genotypes DS 228 (days to 50% flowering and days to maturity), JS 9305 (days to 50% flowering and plant height), DS 1510 (days to maturity and no. of primary branches), DS 1529 (pod length), JS 2425 (plant height), NRC 257 (plant height), KDS 344 (plant height), RSC 1172 (plant height), KDS 726 (plant height), Auks 212 (plant spread), AS 55 (pod length), JS 335 (pod length, no. of seed per pod and protein content), KDS 753 (100-seed weight) exhibited average stability, thus suitable for all three environments. The genotypes JS 2425 (Day to 50% flowering), KDS 344 (no. of pods per plant) and KDS 992 (protein content) exhibited below average stability indicated their suitability for favourable environment. The genotypes KDS 726 (number of primary branches and number seed per pod), DS 1529 (no. of seed per pod), DS 228 (no. of seed per pod), NRC 259 (no. of seed per pod), KDS 992 (no. of seed per pod) and KDS 753(no. of seed per pod) demonstrated above average stability indicated their suitability for stress environments.
The study concluded that sowing on June 15 (E1) was identified as the most favourable for achieving optimal seed yield and its contributing traits.

Keywords: Stability, genotypes, soybean, sowing dates

Introduction
Soybean (*Glycine max* (L.) Merrill), originated in China is a crucial oilseed crop cultivated throughout India during the *Kharif* season. Soybean belongs to genus Glycine, the sub-family-Papilionaceae and family-Leguminoceae. Soybean is crucial crop, widely valued for its nutritional benefits and economic significance. It is recognized globally for contributing to a healthy diet due to its high levels of isoflavonoids and folic acid. Soya products are beneficial for their potential health benefits, with their key components such as proteins, saponins, isoflavones, peptides and protease inhibitors. During the growing season 2022-23, soybean was cultivated on 120.50 million hectares globally, yielding a total of 391.17 million metric tons. The leading soybean producers were the United States (118.266 million tons), Brazil (152 million tons), Argentina (49.50 million tons), China (18.40 million tons) and India (12 million tons). India ranks the fourth-largest producer and cultivated across 12.7 million hectares. (International Soybean Research Association, 2023). Improving soybean yield, oil content and protein levels are major ongoing challenges for plant breeders. The primary goal is to develop genotypes that are both highly productive and adaptable to a wide range of environmental conditions. The process of identifying stable genotypes is complicated by genotype environment interaction (G × E). Although plant breeders have observed genetic variabilities related to adaptability, they have faced difficulties to fully exploit these variabilities in breeding stable genotypes. This is due to challenges in defining and measuring phenotypic stability. The development of new soybean varieties with stable performance or with good homeostasis, can lead to more consistent yields. To address genetic vulnerabilities that arise from narrowing of the genetic base of any crop, it is essential to study genotype-environment (GE) interactions (Kang, 1997) [6].

Therefore, this study aims to evaluate soybean genotypes for yield and related traits across various environments to identify those with reliable performance.

Materials and Methods

Experiment material used for present investigation includes 16 genotypes (14+2) were collected from Agriculture Research Station, Kasbe Digraj, Sangali. The experiment was conducted during the *Kharif*season of 2023 at Zonal Agriculture Research Station, Ganeshkhind, Pune with three different sowing dates asE1(15/06/2023), E2 (05/07/2023) and E3 (25/07/2023).The experiment was laid in RBD with three replications in each environment each line was sown in 2 rows of 4 meter length, with spacing of 45 x 5 cm. Observation were recorded on 13 characters *viz.*, Days to 50% flowering, Days to maturity, Plant height (cm), Plant spread (cm), Primary branches per plant (No.), Secondary branches per plant (No.), Number of pods per plant (No.), Pod length (cm), Number of seed per pod (No.), 100- seed weight (g), Protein content (%), Oil content (%), Seed yield per plant (g). Genotypes were analysed for stability parameters using Eberhart and Russell Model (1966) [3].

Results and Discussion

Estimates of environmental indices (Ej) are presented in Table 1 which revealed that E1 was favourable for the characters *viz.*, days to 50 per cent flowering (0.292), days to maturity (1.493), plant height (19.40), plant spread (13.071), no. of primary branches (0.099), no. of pods per plant (3.073), pod length (0.046), no. of seed per pod (0.026), 100-seed test weight (0.198), protein content (0.133), oil content (0.021) and seed yield per plant (1.942). Environment E2 was favourable for characters *viz.*, days to 50 per cent flowering (0.000), plant spread (2.025), no. of primary branches (0.082), no. of secondary branches (0.153), no. of pods per plant (1.017), 100-seed test weight (0.315), protein content (0.114) and seed yield per plant (1.050). Environment E3 was not favourable for all the characters. In general, E1 was the most favorable for yield and yield promoting characters.

Pooled analysis of variance indicated in Table 2 which showed that genotypes differed significantly for all characters except plant height, plant spread and number of pod per plant when tested against pooled deviation and G x E. Environment variance was found significant for characters *viz.*, days to 50 per cent flowering, days to maturity, plant height, plant spread, number of primary branches, number of secondary branches, pod length, 100-seed weight and seed yield per plant when tested against pooled deviation and G x E indicates presence of variation among environments. Variance due to Environment + (Genotype x Environment) significant for the characters days to 50 per cent flowering, plant height, plant spread, number of secondary branches and pod length when tested against pooled deviation. The analysis of variance showed that the mean sum of squares due to environment (linear) was highly significant for all the traits except number of seeds per pod and oil content when tested against G X E, pooled deviation and pooled error indicated that a major part of variation could be attributed to linear response. Both linear and non-linear component of G x E was found significant for pod length. Linear component of G x E was also significant for pod length when test against pooled deviation suggested the predictability of performances of genotypes for those characters. The similar findings were reported by Tiwari *et al.* (2016) [10], Koraddi *et al.* (2017) [8], Jakhar *et al.* (2018) [4], Pallavi *et al.* (2019) [9].

The mean values, regression coefficient (bi) and deviation from regression (S^2di) for 16 genotypes over 3 environments are presented in Table 3. The range of variation for the mean performance, linear regression coefficients (bi) and deviation from regression (S^2di) for the characters studied and described in detail. Regression coefficient (bi) is considered as parameter of response, while S^2di is considered a parameter of stability. For a given value of the independent variable, the value of dependent variable may be estimated using regression equation, provided S^2di is not significantly different from zero. Assuming $S^2di = 0$, a high value of bi >1 and significant indicates that the variety is more responsive and therefore, should be recommended only for highly favourable environments. A relatively minimum value of bi, around 1 and non-significant, suggests that the variety is less responsive to environmental changes and thus more adaptive. Conversely, if bi <1 and significant, the variety may be suitable only for poor environments. If S^2di is significant, it invalidates the linear prediction. However, if S^2di is non-significant, the performance of genotype for a given environment may be predicted. Accordingly, a variety whose performance can be predicted (*i.e.* $S^2di = 0$) is said to be stable.

The average stability was observed in the following genotypes, DS 228 and JS 9305 (days to 50 per cent flowering), DS 228 and DS 1510 (days to maturity), JS 2425, JS 9305, NRC 257, KDS 344, RSC 1172 and KDS 726 (plant height), Auks 212 (plant spread), DS 1510 the (number of primary branches), AS 55, DS 1529 and JS 335 (pod length), JS 335 (number of seed per pod), KDS 753 (100-seed weight) and JS 335 (protein content). These genotypes indicated their suitability across all environments for their respective traits. The genotypes KDS 726 (number of primary branches), DS 1529, DS 228, NRC 259, KDS 992, KDS 753 and KDS 726 (number of seeds per pod) demonstrated above average stability, indicating their suitability for poor or stress environments for the respective characters. The genotypes JS 2425 (days to 50% flowering), KDS 344 (number of pods per plant) and KDS 992 (protein content) showed below average stability indicating their suitability for rich or favourable environments for the respective characters.

Table 1: Estimation of environmental index for all thirteen characters

Sr. No.	Character	Environmental index (Ij)		
		E1	E2	E3
1	Daysto50per cent flowering	0.292	0.000	-0.292
2	Days to maturity	1.493	-0.069	-1.424
3	Plant height(cm)	19.40	-1.742	-17.662
4	Plant spread(cm)	13.071	2.025	-15.096
5	No. of Primary branches	0.099	0.082	-0.181
6	No. of Secondary branches	-0.056	0.153	-0.097
7	No. of pods per plant	3.073	-1.017	-4.090
8	Pod length(cm)	0.046	-0.032	-0.013
9	No. of seeds per pod	0.026	-0.011	-0.015
10	100-seed weight(g)	0.198	0.315	-0.514
11	Protein content (%)	0.133	0.114	-0.247
12	Oil content (%)	0.021	-0.011	-0.010
13	Seed yield per plant(g)	1.942	1.050	-2.993

Table 2: Analysis of variance for stability as per Eberhart and Russell Model (1966) for all thirteen characters in soybean

S. N.	Sources	Genotypes	Environment	GX E	E + (G X E)	E (L)	G XE (L)	Pooled deviation	Pooled error
	Degrees of freedom	15	2	30	32	1	15	16	90
1	Days to 50%flowering	20.108 **++##	1.360 **++##	0.053	0.134 *++	2.720 **++##	0.055	0.047	0.087
2	Days to maturity	127.94 **++##	34.078 **++##	3.518 ##	5.428 ##	68.156 **++##	3.087 ##	3.703 **##	0.374
3	Plant height(cm)	35.471 ##	5532.156 **++##	28.232 ##	372.228 **++##	11064.310 **++##	19.301 ##	34.841**##	7.096
4	Plant spread(cm)	25.896 ##	3222.652 **++##	29.935 #	229.480 **++##	6445.304 **++##	32.622 ##	25.546**##	2.972
5	No. of primary branches	0.142 **++##	0.392 **++##	0.031	0.053 ##	0.785 **++##	0.027	0.033	0.025 *
6	No. of secondary branches	2.400 **++##	0.287 **++##	0.047	0.062 *	0.574 **++##	0.066 *	0.025	0.058
7	No. of pods per plant	121.900 ##	217.631 ##	98.538 #	105.98 ##	435.263 *+##	127.749 ##	64.994 **##	17.180
8	Pod length(cm)	1.107 **++##	0.027 **++##	0.004 **	0.005 **	0.053**++##	0.006 **	0.001	0.005 **
9	No. of seeds per pod	0.126 **++##	0.008	0.006	0.006	0.017	0.006 ##	0.005	0.005
10	100-seed weight(g)	14.400 **++##	3.221 **++##	0.258 #	0.443 ##	6.443 **++##	0.217	0.280 ##	0.162
11	Protein content (%)	0.954 **++##	0.738 #	0.325 #	0.350 ##	1.476 *+##	0.385 #	0.248	0.184
12	Oil content (%)	0.763 **++##	0.005	0.200	0.188	0.010	0.169	0.217	0.220
13	Seed yield per plant(g)	38.367 *+##	110.667 **++##	17.924 ##	23.721 ##	221.334 **++##	23.602 ##	11.481 **##	4.524

+,++indicatessignificantat5and 1 per cent level of significance, respectively when tested against G×E
*,**indicatessignificantat5 and 1per cent level of significance, respectively when tested against the pooled deviation (PD)
#,##indicates significant at5 and 1per cent level of significance, respectively when tested against pooled error(PE)

Table 3: Stability parameters (mean, bi, S^2di) for all thirteen characters in soybean

Sr. No.	Genotypes	Days to 50 percent flowering			Days to maturity			Plant height (cm)			Plant spread (cm)			No. of primary branches			No. of secondary branches			No. of pods per plant		
		Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
1	AS55	42.33	1.713	0.08	92.00	1.401	1.92*	75.16	0.772	47.99 *	49.82	0.637	-2.28	3.00	0.736	-0.03	4.36	1.213	-0.05	58.17	0.844	18.86
2	Abs85	40.56	0.571	-0.07	86.78	1.363	-0.23	77.39	0.679	142.92 ***	53.73	0.854	0.30	3.20	1.807	0.00	5.27	0.619	-0.01	68.14	2.131	11.34
3	Auks212	41.00	1.142	-0.09	99.67	3.129	12.12***	71.48	0.823	56.40 *	57.58	1.099	-2.97	3.16	1.607	-0.02	5.76	-0.413	0.05	65.53	-3.747	23.12
4	DS1529	43.78	1.713	-0.07	105.56	1.513	1.50*	75.49	0.932	25.48	48.31	0.926	-2.59	3.11	1.339	-0.02	5.82	2.684	0.02	54.48	1.171	58.56 *
5	DS228	37.78	1.142	0.21	96.89	1.024	-0.33	77.71	0.980	50.21 *	55.11	0.928	25.73 **	3.07	1.875	-0.01	6.22	-0.181	-0.05	63.38	-2.214	47.10
6	DS1510	42.56	0.571	-0.07	98.67	1.035	-0.27	65.82	1.175	-8.24	52.49	1.257	14.27 *	3.29	0.893	-0.01	5.58	1.729	-0.02	64.51	0.725	-15.93
7	JS335	36.11	0.571	-0.07	97.67	0.733	5.33***	72.82	1.138	11.85	50.80	0.994	24.58 **	3.20	1.473	-0.02	5.73	1.316	-0.06	66.11	-1.643	192.71 ***
8	JS2425	37.67	2.285*	-0.09	95.00	1.100	12.47***	75.91	0.989	-10.01	51.51	0.840	21.23 **	3.11	2.143	0.02	6.33	-0.465	-0.06	60.16	0.128	56.68 *
9	JS9305	37.00	1.142	-0.09	100.0	1.353	0.49	76.51	1.144	-10.04	52.18	0.699	23.11 **	3.13	1.093	-0.02	5.84	3.123	-0.05	57.62	1.743	176.76 **
10	NRC257	38.78	0.571	-0.07	94.33	0.953	13.75***	76.98	1.167	3.21	57.40	1.367	17.08 *	3.02	0.066	0.03	6.93	-1.548	0.00	61.07	4.068	21.92
11	NRC259	38.11	0.571	-0.07	92.11	0.377	2.64**	74.62	0.881	-5.61	51.09	0.696	-2.39	3.04	0.693	0.08*	6.44	-0.207	-0.05	78.67	1.647	54.39 *
12	KDS992	43.67	1.142	-0.09	97.89	1.708	-0.30	76.53	1.221	110.08 ***	52.27	1.784	130.05 ***	3.09	0.536	0.01	6.36	2.064	-0.06	67.24	1.827	-17.70
13	KDS344	42.67	1.142	-0.09	109.67	0.228*	-0.38	77.60	1.038	-7.81	47.24	1.002	0.02	3.04	-0.604	0.19**	6.29	1.987	-0.05	67.15	2.230*	-17.69
14	RSC1172	41.00	0.571	0.08	105.89	0.869	4.70**	78.49	0.950	1.29	48.96	0.876	48.19 ***	3.93	0.380	-0.02	7.78	-0.129	-0.02	76.80	3.154	29.47
15	KDS753	42.33	-0.001 *	-0.09	106.56	-0.101	0.10	74.80	1.222*	-10.16	52.29	0.998	46.65 ***	3.20	1.473	-0.02	7.67	1.858	-0.04	65.44	4.128	129.39 **
16	KDS726	43.33	1.142	-0.09	108.11	-0.690*	-0.34	81.22	0.888	-4.28	53.96	1.043	19.78 **	3.22	0.491*	-0.03	7.38	2.348	-0.06	61.93	-0.193	-15.60
	Mean	40.54	1		99.17	1		75.53	1		52.17	1		3.18	1		6.24	1		64.78	1	

Sr. No.	Genotypes	Pod length (cm)			No. of seed per pod			100-seed weight (g)			Protein content (%)			Oil content (%)			Seed yield per plant (gm)		
		Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
1	AS55	4.39	0.943	0.00	2.64	8.350	0.00	20.45	0.537	0.17	38.91	3.576	-0.03	18.81	-13.391	0.19	26.22	1.228	-4.58
2	Abs85	4.35	0.827	0.00	2.69	-0.441	0.02 *	19.62	1.484	-0.12	38.91	3.087	-0.14	18.68	-19.082	0.40	29.39	2.051	0.01
3	Auks212	4.13	-1.601	0.00	2.98	0.701	0.00	14.50	1.546	-0.12	39.77	-0.155	-0.05	19.45	-8.780	0.24	22.52	-1.482	1.56
4	DS1529	4.01	1.129	-0.01	3.00	-0.002*	0.00	18.60	-0.605	0.90 *	39.11	1.805	-0.15	19.83	-2.531	-0.11	25.31	0.963	9.56
5	DS228	3.52	-0.393	-0.01	3.00	-0.002*	0.00	17.92	1.713	0.24	39.10	-0.238	-0.18	18.90	-1.204	-0.22	28.23	-0.795	11.49
6	DS1510	3.01	0.079	0.00	2.93	2.108	0.02 *	12.59	1.188	-0.16	38.81	0.590	-0.13	19.82	-15.505	0.12	19.24	0.652	0.30
7	JS335	4.02	1.115	0.00	2.98	0.965	0.00	18.02	1.322	-0.10	39.16	0.910	0.13	19.07	-7.021	-0.10	29.37	-0.581	26.64 *
8	JS2425	3.49	1.733	-0.01	2.62	4.042	0.00	17.91	0.353	-0.05	38.36	3.713	-0.09	19.91	9.815	-0.20	22.99	0.303	11.99
9	JS9305	4.80	3.425	0.00	3.42	-0.969	0.00	18.85	-0.302	0.41	38.94	1.868	-0.16	19.13	23.290	-0.16	30.63	1.024	37.79 **
10	NRC257	3.96	0.684	0.00	3.07	-2.112	0.02 *	14.68	1.694	-0.16	38.57	0.369	0.97 *	18.80	-28.142	-0.17	21.80	2.713	-0.32
11	NRC259	2.99	0.002	0.00	3.00	-0.002*	0.00	15.01	0.944	0.03	39.01	3.358	0.23	18.72	5.101	-0.21	29.53	1.362	-0.10
12	KDS992	4.01	3.019	0.00	3.00	-0.002*	0.00	18.16	1.710	0.12	39.54	3.088 *	-0.20	18.96	12.277	-0.21	31.27	1.837	-1.04
13	KDS344	3.97	1.326	-0.01	3.02	1.668	0.00	15.40	1.016	0.08	37.91	-0.425	-0.20	19.50	-3.920	0.06	24.83	1.181	-4.16
14	RSC1172	3.17	-0.635	0.00	2.62	1.668	0.00	15.20	1.872	0.52 *	38.93	-0.202	-0.18	19.60	14.033	-0.22	24.99	2.542	-4.03
15	KDS753	4.90	2.077	0.00	3.00	-0.002*	0.00	17.29	1.024	-0.02	37.59	-2.162*	-0.20	19.95	27.313	0.64	29.27	3.124	29.05 **
16	KDS726	4.79	2.286	0.00	3.00	-0.002*	0.00	18.52	0.498	0.12	38.19	-3.047	1.13 *	20.18	23.166	-0.20	28.99	-0.122	-3.82
	Mean	3.97	1		2.94	1		17.05	1		38.80	1		19.33	1		26.54	1	

*, **, ***: Significant at 10, 5 and 1 per cent level of significance, respectively.

Conclusion

The study identified several soybean genotypes with stable performance across different environments. Genotypes like DS 228, JS 9305, and KDS 753 demonstrated favorable adaptability and stability for key traits, making them potential candidates for consistent yields under variable conditions. These findings will aid in breeding programs focused on improving soybean productivity and stability.

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