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Original scientific article

MULTI-TRAIT SELECTION FOR MEAN PERFORMANCE AND STABILITY AMONG SOYBEAN GENOTYPES EVALUATED UNDER RAINFED CONDITIONS ACROSS DIVERSE ENVIRONMENTS IN INDIA

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Soybean [Glycine max (L.) Merr.] is the predominant rainfed Indian oilseed crop cultivated across diverse agro-climatic zones. Understanding the genotype × environment

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interaction (GEI) is crucial for development of stable and wider adaptable soybean varieties. In the current study, 10 elite breeding lines were evaluated across 19 diverse locations for days to flowering, days to maturity, plant height, hundred seed weight and grain yield during 2020. The stability index as measured through weighted average of absolute scores (WAASB) identified SL 1213 and DS 1320 to have stable grain yield. WAASBY superiority index, which is based on mean performance and stability, was also higher for SL 1213. Multitrait stability index (MTSI) was employed to select genotypes with higher grain yield, early flowering, early maturity, higher hundred seed weight and plant height, simultaneously and genotypes DS 1320 and SL 1213 were identified through MTSI. Based on the three indices, SL 1213 was found to be the candidate genotype for breeding for higher yield, wider adaptability and for ideotype breeding. Based on cluster analysis, SL 1213 × JS 22-07 and SL 1213 × NRC 149 were found to be the ideal cross combinations for developing high-yielding and wider adaptable genotypes. Through Principal Component Analysis (PCA), grain yield was found to be positively associated with Relative Humidity, Effect of temperature on radiation use efficiency, Deficit by precipitation, Total rainfall precipitation during the crop cycle, Global solar radiation based on latitude and Julian day and Dew-point temperature at 2 m above the surface of the earth.

Key words: Adaptability, grain yield, soybean, and stability

INTRODUCTION

Soybean (*Glycine max* L. Merril) is the prime leguminous crop across the globe, contributing one-fourth of edible oil for human consumption and two-third of protein share in livestock feed (JAISWAL *et al* 2019). Though India stands at fifth position in edible oil market in the world, about 60% of its edible oil demand is met through import (ICAR, 2021). Soybean is the foremost important Indian oilseed crop with a production of 12.99 million tons in an area of 12.51 million hectares (ICAR, 2021). However, its production is challenged with the rainfed cultivation and changing climate conditions. Development of high-yielding and wider adaptable soybean varieties is a thrust area to cope up with the increasing edible oil demand. Across diverse agro-climatic zones, manifestation of agronomic traits is attributed to the genotypic and environmental effects, and Genotype × Environment interactions (GEI) (YAN and TINKER 2006 and NATARAJ *et al* 2021). Soybean grain yield is a quantitative trait confounded with complex GEI that affect the heritability, which reduces the response to selection (LI *et al* 2008 and GERRANO *et al* 2020). In soybean Multi-environment trials (METs), majority of the total variation is attributed by E and GEI (GURMU *et al* 2009; BHARTIYA *et al.*, 2018, NATARAJ *et al* 2021 and YONAS *et al* 2022). Therefore, E and GEI are important factors to be considered for developing stable and wider-adaptable genotypes in soybean. Precise estimate of genotypic effects is necessary for effective selection of best performing genotypes. Additive main effect and multiplicative interaction **(**AMMI) and Best linear unbiased prediction (BLUP) are the two commonly used prediction models for grain yield in plant breeding (NATARAJ *et al* 2021). In several studies, BLUP model is reported to outperform AMMI in predicting the genotypic effects (PIPHO 1994, OLIVOTO 2019a, NATARAJ *et al* 2021). A recent BLUP based mixed model-WAASB is a graphic- based quantitative stability model that combines the features of BLUP and

AMMI models (OLIVOTO and LÚCIO 2019). A WAASB-derived superiority index, WAASBY has been developed by OLIVOTO *et al* 2019a to select superior genotypes based on their mean performance and stability. Simultaneous selection for multiple agronomic traits is essential in crop varietal developmental programs (NATARAJ *et al* 2021). A WAASBY-based multi trait stability index (MTSI) has been developed to select genotypes for multiple agronomic traits based on their mean performance and stability (OLIVOTO *et al* 2019 b). These three indices have been employed in identification of stable and superior genotypes in several crops for different economic traits such as grain yield (NATARAJ *et al* 2021), quality traits (ABDELGHANY *et al* 2021), disease resistance (TIZE *et al* 2021; RAJPUT *et al* 2022) and abiotic stress tolerance (ZUFFO *et al* 2020; SINGAMSETTI *et al* 2021;VINEETH *et al* 2022). With this background, current study was undertaken to identify genotypes based on grain yield stability and superiority, and based on multiple agronomic traits, using the WAASB-based models, and to study the association of grain yield with different climate parameters

Material and Methods

Ten genotypes (SL 1213, DS 1318, JS 22-01, NRC 149, DS 1326, SL 1234, Himso 1690, JS 22-07, DS 1320 and AUKS 218) evaluated in the current study are the elite, high-yielding breeding lines developed at different AICRP (All India Coordinated Research Project) centres (Table 1). During 2020, these genotypes were evaluated across nineteen locations in India. These locations are agro-ecologically diverse, including semi-arid Delhi (DLH), Ludhiana (LDH), Morena (MRN), Amravati (AMT), Kasbe Digraj (KDR), Parbhani (PAR), Pune (PUN), Adilabad (ADB) and Lok Bharti (LKB), sub-humid Bengaluru (BNG), Jabalpur (JBL), Raipur (RPR), Almora (ALM), Bhawanipatna (BPN), Pantnagar (PNT) and Ranchi (RNC), warm pre-humid Imphal (IMP) and Palampur (PLM) and humid Umiam (UMM) conditions. Field trials were conducted in RCBD (Randomized Complete Block Design) design with three replications of each genotype in a 4.05 m^2 size plot. Crop production and management practices were followed as per ICAR, 2009. Data on days to flowering and days to maturity has been recorded as per International Board for Plant Genetic Resources (IBPGR, 1984). Grain yield, hundred seed weight and plant height was recorded at R_8 growth stage (FEHR *et al* 1971). A random sample of hundred seeds was collected and weighed to record the hundred seed weight, and Plot yield was converted into Kg/ha.

Table 1. Details of the genotypes under study

Genotype	Code	Pedigree	Breeding centre
SL 1213	G1	SL 958 ×SL 955	Ludhiana
DS 1318	G2	P12 × DS 2711	Delhi
JS 22-01	G3	SL 738 × JS 95-60	Jabalpur
NRC 149	G4	NRC94 × SL958	Indore
DS 1326	G5	P12 × SL 688	Delhi
SL 1234	G6	SL 783 × SL 871	Ludhiana
HIMSO 1690	G7	Hara Soya × Pb 1	Palampur
JS 22-07	G8	SL 738 × JS 95-60	Jabalpur
DS 1320	G9	P9712 × DS 2961	Delhi
AUKS 218	G10	-	Kota

Statistical Analyses

ANOVA model followed was as per Patterson and Williams, 1976. ANOVA, stability analyses, correlation and cluster analyses were carried out using R package “metan” (OLIVOTO and LÚCIO, 2020). Correlation among the traits under study was done through pearson’s correlation coefficient. Genotypic diversity analysis among the genotypes was based on euclidean distance metric. Stability analysis was carried based on WAASB index (OLIVOTO *et al* 2019a). Lower the genotypic WAASB score, higher would be the stability, and vice-versa. Simultaneous selection for mean performance and stability was carried out through the superiority index WAASBY (OLIVOTO *et al* 2019a). Higher the WAASBY score, higher would be the magnitude of superiority, and vice-versa. Genotypic selection based on simultaneous consideration of multiple traits has been carried out using MTSI (OLIVOTO *et al* 2019b). MTSI score is calculated based on ideotype-genotype euclidean distance. Genotype with least MTSI is regarded to be closer to the ideotypes, and vice-versa. Relationship between grain yield and climatic variables such as relative humidity (RH), global solar radiation based on latitude and Julian day (RTA), The deficit of vapour pressure (VPD), growing degree-days (GDD), The slope of saturation vapour pressure curve (SPV), mean temperature (TEM), Actual duration of sunshine (SSH), Evapotranspiration (ETP), Daylight hours (DLH), Dew-point temperature at 2m above the surface of the earth (T2MDEW), Deficit by precipitation (PETP), Total rainfall precipitation during the crop cycle (PRECTOT), Effect of temperature on radiation use efficiency (FRUE), Wind speed at 2m height (WS) has been studied through principal component analysis (PCA). Data on different climatic variables has been obtained using R package “EnvRtype” (COSTA-NETO *et al*., 2021). PCA has been carried out using R package ‘factoextra’ (KASSAMBARA and MUNDT, 2017).

RESULTS

Mean performance of genotypes and environments and analysis of variance (ANOVA)

Mean performance of genotypes for different traits across different environments is given in Table 2. For days to flowering, grand mean was 45.17, with a range of 31.3 (AUKS 218 at Parbhani) to 68.3 (SL 1213 at Palampur). Environmental mean days to flowering was lowest (35.77) at Kasbedigraj and highest at Palampur (65.23). Mean value of days to flowering among genotypes was lowest in case of AUKS 218 (43.46) and highest in case of SL 1213 (46.95). In case of days to maturity, grand mean was 104.77, and it ranged from 86 (AUKS 218 at Bhawanipatna) to 125.66 (SL 1234 at Almora). Mean value of days to maturity among environments was lowest at Pune (89.50) and highest at Palampur (124.87). Mean value of days to maturity among genotypes was lowest for AUKS 218 (100.49) and highest for SL 1234 (107.86). Similarly, for 100-seed weight, the grand mean was 11.02 g, with a range of 6.41 g (SL 1234 at Pantnagar) to 17.83 g (HIMSO 1690 at Palampur). Mean value of 100-seed weight among environments was lowest at Delhi (8.19 g) and highest at Palamapur (16.77 g). Mean value of 100-seed weight among genotypes was lowest in case of AUKS 218 (9.70 g) and highest in JS 22-07 (13.04 g). For plant height the grand mean was 57.14 cm, and it ranged from 25.8 cm (SL 1213 at Umiam) to 135.06 cm (NRC 149 at Pantnagar). Mean plant height was lowest at Umiam (30.60 cm) and highest at Pantnagar (89.20 cm). Genotypes DS1318 (51.57 cm) and NRC 149 (76.75 cm) had the lowest and highest mean plant height, respectively.

Likewise, in case of grain yield, grand mean was 1697.15 Kg/ha, environmental mean grain yield was highest at Pune (2920.15 Kg/ha) and lowest at Jabalpur (475.71 Kg/ha). Mean value of grain yield among genotypes was highest in case of SL 1213 (1890.4 Kg/ha) and lowest in case of AUKS 218 (1512.66 Kg/ha). Overall, SL 1213 was found to be high-yielder and AUKS 218 was found to be early maturing among the genotypes under study. Genotypic performance for grain yield across environments is given in Figure S1. Pooled ANOVA revealed significant G×E interaction ($p<0.01$) for all the traits under study (Table 3). In case of grain yield, 58.90% of total variation was attributed to environmental effects, followed by GEI (29.63%) and genotypic effect (2.66%). Similarly, in case of remaining traits, predominant portion of the variation was explained by environmental effects, followed by GEI and genotypic effect.

Table 2. Mean performance of 10 genotypes for different traits evaluated across 19 environments

Genotypes/Environment	Days to flowering (DTF)	Days to maturity (DTM)	100-seed weight (HSW) (g)	Plant height (PH) (g)	Grain Yield (GY) (Kg/ha)
SL 1213 (G1)	46.95	106.74	10.79	53.91	1890.40
DS 1318 (G2)	45.00	105.02	10.16	51.57	1813.72
JS 22-01 (G3)	44.30	102.16	11.89	53.98	1548.18
NRC 149 (G4)	45.14	106.35	11.94	76.75	1851.41
DS 1326 (G5)	46.04	106.79	10.50	53.02	53.02
SL 1234 (G6)	45.84	107.86	10.37	57.28	1610.13
HIMSO 1690 (G7)	45.72	107.37	10.89	54.92	1656.05
JS 22-07 (G8)	44.40	101.63	13.04	60.28	1659.08
DS 1320 (G9)	44.82	103.32	10.92	55.28	1630.9
AUKS 218 (G10)	43.46	100.49	9.70	54.45	1512.66
Adilabad (ADB)	39.50	101.43	14.22	54.06	2465.83
Almora (ALM)	62.17	117.87	9.19	60.73	1190.94
Amravati (AMT)	45.70	98.60	9.97	57.19	1614.81
Bengaluru (BNG)	38.17	97.47	16.51	44.36	1629.62
Bhawanipatna (BPN)	37.87	96.07	13.82	38.82	1977.77
Delhi (DLH)	49.53	113.10	8.19	50.67	1548.14
Imphal (IMP)	48.67	115.73	10.96	71.01	2552.25
Jabalpur (JBL)	44.23	103.87	9.44	56.34	475.71
Kasbe Digraj (KDR)	35.77	97.27	11.21	32.81	1241.14
Ludhiana (LDH)	54.20	115.00	8.40	56.43	1201.64
Lok Bharti (LKB)	48.30	103.97	9.17	79.19	1885.59
Morena (MRN)	38.87	90.73	8.78	36.73	744.85
Parbhani (PAR)	38.10	99.17	12.58	59.01	2172.01
Palampur (PLM)	65.23	124.87	16.77	82.89	1719.33
Pantnagar (PNT)	52.37	121.23	9.05	89.20	1506.16
Pune (PUN)	37.47	89.50	12.99	59.50	2920.15
Ranchi (RNC)	40.93	105.60	10.92	55.40	1964.60
Raipur (RPR)	40.30	106.20	8.55	70.80	1437.85
Umiam (UMM)	40.80	93.00	8.67	30.60	1997.52

Table 3. Pooled ANOVA for the traits under consideration.

Source of variation	DF	F value (%SS)				
		DTF	DTM	PH	H SW	GY
Genotype	9	57.81*** (1.25)	246.51*** (5.16)	147.88*** (12.47)	121.88*** (9.55)	14.61*** (2.66)
Environment	18	2148.83** (93.6)	2009.68** (84.17)	394.01*** (66.49)	478.60*** (75.02)	161.40*** (58.90)
Genotype x Environment	162	10.51*** (4.12)	25.63*** (9.66)	11.35*** (17.24)	8.610*** (12.14)	9.02*** (29.63)
Residual	342	- (0.17)	- (0.20)	- (0.57)	- (0.29)	- (6.9)
SE		0.36	0.47	0.82	11.00	169.00
SD		8.53	11.13	19.58	3.00	765.00
CV(%)		2.22	1.22	7.92	6.18	15.30
h^2 (BS)		16.00	29.00	35.00	36.00	2.00

DF- Degrees of freedom, DTF- Days to flowering, DTM- Days to maturity, PH-Plant height, HSE-Hundred seed weight and GY- Grain yield. ** - Significance at $p<0.01$ and *** - Significance at $p<0.001$. Figures in parenthesis are percent sum of squares (%SS)

For grain yield, the prediction accuracy of the BLUP model and predicted genotypic mean based on BLUP was highest for SL 1213 (1771 kg ha^{-1}), followed by NRC 149 (1756 kg ha^{-1}), DS 1318 (1742 kg ha^{-1}), DS 1326 (1736 kg ha^{-1}), and JS 22-07 1683 kg ha^{-1}) (Table S1). Four genotypes (SL 1213, NRC 149, DS 1318, DS 1326) had greater mean than the grand mean, and the remaining six genotypes (JS 22-07, HIMSO 1690, DS 1320, SL 1234, JS 22-01 and AUKS 218) had their mean below the grand mean (Figure S2).

WAASB-based stability analysis

Based on WAASB-based stability scores for the different genotypes under study, SL 1213 (4.94) was found to be highly stable, followed by DS 1320 (5.19), and SL 1234 (9.90), whereas NRC 149 (17.089) was found to be highly unstable, followed by AUKS 218 (16.827), JS 22-07 (14.47), and DS 1326 (14.45) (Table 4). Simultaneous interpretation of mean performance, stability, and environments is done using WAASB biplot, with four quadrants containing different classes of genotypes and environments (Figure 1). Unstable genotypes, having their mean lower than grand mean (AUKS 218, JS 22-07, JS 22-01, HIMSO 1690 and SL 1234) and highly discriminative environments (BNG, DLH, and JBL) are included in the first quadrant. In the second quadrant, unstable genotypes having their mean higher than grand mean and discriminating environments are included, genotypes NRC 149, DS 1326 and DS 1318 being most unstable and discriminating environments IMP, ADB, BPN, PUN, and UMM are included in this quadrant. The third quadrant includes stable, widely adapted genotypes having their mean lower than the grand mean, stable genotype included in this quadrant is DS 1320. Low productive and lesser discriminating environments MRN, PNT, ALM, KDR, RPR and AMT are included in the third quadrant. Similarly, in the fourth quadrant, widely adapted, high-yielding (genotypic means greater than grand mean) genotype SL 1213 with low WAASB score is included. Environments RNC, LKB, PAR and PLM which are less discriminative but more productive are included in fourth quadrant. Simultaneous selection for grain yield and stability has been done using WAASBY superiority index (Table 4). The genotype with the highest

WAASBY scores was SL 1213 (100.00), followed by DS 1318 (67.88), NRC 149 (58.29), and DS 1326 (56.862). SL 1213 was retained in the fourth quadrant, DS 1318, NRC 149 and DS 1326 were retained in the second quadrant. The genotype with lowest WAASBY score was AUKS 218 (0.753), followed by JS 22-01 (17.73), JS 22-07 (32.72), and SL 1234 (37.47). These genotypes were included in the first quadrant (Figure 1).

Table 4. Mean performance, WAASB, WAASBY of genotypes under study: rRESP – genotype ranking based on grain yield, rWAASB – genotype ranking based on WAASB, rWAASBY – genotype ranking based on WAASBY and rMTSI- genotype ranking based on MTSI

Genotype	GY	rRESP	WAASB	rWAASB	WAASBY	rWAASBY	MTSI	rMTSI
AUKS 218	1512.66	10	16.827	9	0.753	10	2.78	10
DS 1318	1813.72	3	11.510	5	67.88	2	1.69	5
DS 1320	1630.92	7	5.192	2	54.632	5	0.510	1
DS 1326	1798.99	4	14.454	7	56.862	4	1.51	4
HIMSO 1690	1656.04	6	10.993	4	42.237	6	1.09	3
JS 22-01	1548.18	9	13.058	6	17.728	9	2.11	7
JS 22-07	1659.08	5	14.479	8	32.716	8	2.22	8
NRC 149	1851.41	2	17.089	10	58.291	3	2.46	9
SL 1213	1890.40	1	4.943	1	100.00	1	1.01	2
SL 1234	1610.13	8	9.904	3	37.474	7	1.81	6

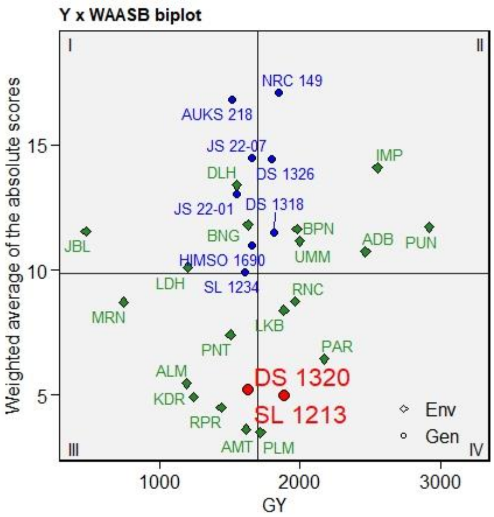

Figure 1. WAASB- based biplot for simultaneous interpretation of genotypes and environments.

GEN, genotype; ENV, environment; GY, grain yield; ADB, Adilabad; ALM, Almora; AMT, Amravati; BNG, Bengaluru; BPN, Bhawanipatna; DLH, Delhi; IMP, Imphal; JBL, Jabalpur; KDR, Kasbe Digraj; LDH, Ludhiana; LKB, Lok Bharti; MRN, Morena; PAR, Parbhani; PLM, Palampur; PNT, Pantnagar; PUN, Pune; RNC, Ranchi; RPR, Raipur; UMM, Umiam

Multi-trait stability (MTSI) analysis

Multi-trait stability analysis has been carried out targeting higher grain yield and early flowering, early maturity; higher hundred seed weight and plant height, simultaneously. Based on MTSI at 20% selection intensity, DS 1320 (MTSI = 0.510) and SL 1213 (MTSI = 1.01) were selected as ideotypes (Table 4; Figure 2). Selection differentials for the mean values of traits DTF, DTM, PH, HSW and GY were 0.77, 0.25, -2.55, -0.16 and 63.5, respectively. Percent selection differentials for the trait means for DTF, DTM, PH, HSW and GY were 1.71%, 0.24%, -4.46%, -1.47% and 3.74%, respectively. For the trait DTF, mean WAASBY index of the selected genotypes (1.12) was higher than the grand mean (0.77), in case of DTM, mean WAASBY index of the selected genotypes (0.84) was lower than the overall mean (1.27). Mean WAASBY index of selected genotypes (1.57), in case of PH is higher than that of mean value of the total genotypes under study. Mean WAASBY index of DS 1320 and SL 1213 (0.36), in case of HSW was lower than that of overall mean (0.56), similarly, in case of GY, Mean WAASBY index of selected two genotypes (5.07) was lower than that of the mean of the total genotypes under study. Selection differentials for the WAASBY index were 0.35, -0.42, 0.02, -0.20 and -6.94 respectively, for DTF, DTM, PH, HSW and GY. Percent selection differentials for the WAASBY indices for DTF, DTM, PH, HSW and GY were 45.8%, -33.2%, 1.48%, -35.4% and -57.8%, respectively (Table 5).

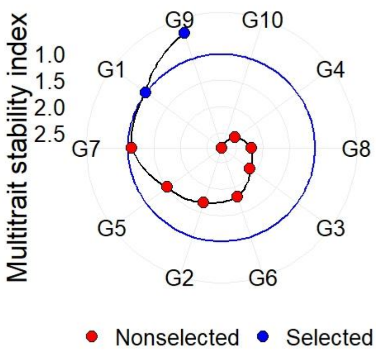

Figure 2. MTSI analysis of genotypes under study.

G1, SL 1213; G2, DS 1318; G3, JS 22-01; G4, NRC 149; G5, DS 1326; G6, SL 1234; G7, HIMSO 1690; G8, JS 22-07; G9, DS 1320; G10, AUKS 218

Table 5. Selection differentials for the mean of the traits and their WAASBY scores. SD-selection differential, Xo-population mean and Xs-mean of selected genotypes

Trait	Mean				WAASBY			
	Xo	Xs	SD	%SD	Xo	Xs	SD	%SD
DTF	45.16	45.88	0.772	1.71	0.770	1.12	0.352	45.8
DTM	104.77	105.03	0.254	0.243	1.27	0.849	-0.422	-33.2
PH	57.14	54.60	-2.55	-4.46	1.55	1.57	0.0230	1.48
100SW	11.02	10.85	-0.162	-1.47	0.568	0.367	-0.201	-35.4
GY	1697.15	1760.66	63.5	3.74	12.0	5.07	-6.94	-57.8

Correlation and cluster analyses

Through correlation, it was found that the grain yield was positively correlated with hundred seed weight (r=0.35***) and plant height (r=0.15***), and negatively correlated with days to flowering (r=-0.15***) and days to maturity (r=-0.06^{ns}) (Figure 3). Based on Euclidean distance metric, 10 genotypes were grouped into two clusters. The first cluster comprised of six genotypes viz., DS 1320, SL 1234, JS 22-07, Himso 1690, JS 22-01 and AUKS 218 and second cluster comprised of four genotypes namely, NRC 149, SL 1213, DS 1326 and DS 1318 (Figure 4).

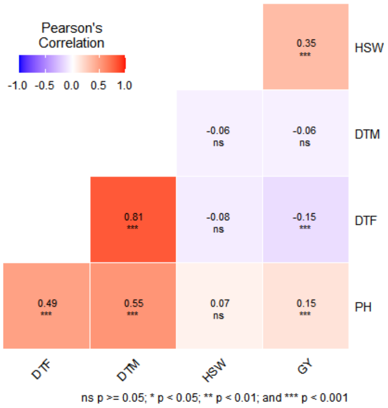

Figure 3. Correlation analysis of different traits under consideration

DTF, days to flowering; DTM, days to maturity; HSW, hundred seed weight; PH, plant height; GY, grain yield; ns- non significant

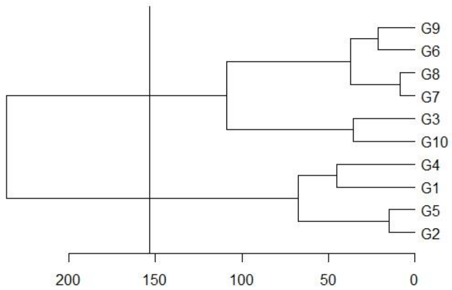

Figure 4. Cluster analysis of genotypes under study

G1, SL 1213; G2, DS 1318; G3, JS 22-01; G4, NRC 149; G5, DS 1326; G6, SL 1234; G7, HIMSO 1690; G8, JS 22-07; G9, DS 1320; G10, AUKS 218

Association of grain yield with different climate parameters

Relationship between grain yield and climatic variables has been studied through principal PCA. First two PCs (Principal components have explained 75.4% of the total variation

(Figure 5). Among different variables under study, RH has the highest contribution to the variation from the first two PCs, followed by RTA and VPD (Figure 6). Through PCA, it was found that the grain yield was positively associated with RH, followed by FRUE, PETP, PRECTOT, RTA and T2MDEW (Figure 5).

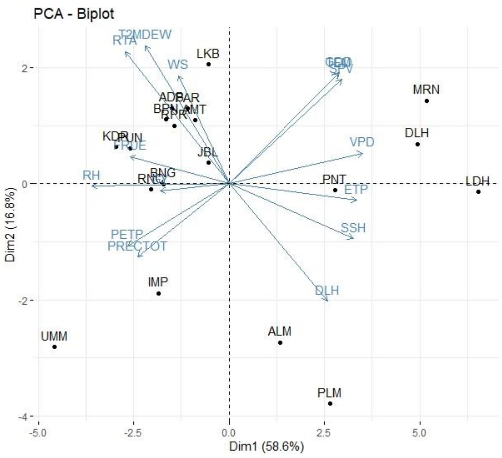

Figure 5. PCA of grain yield against different climatic variables

TEM- mean temperature at 2m height (°C d^{-1}), WS- wind speed at 2m height (m s^{-1}), RH- relative humidity (%), T2MDEW- dew-point temperature at 2 m above the surface of the earth (°C d^{-1}), GDD-growing degree-days (°C day^{-1}), FRUE-effect of temperature on radiation use efficiency, VPD-the deficit of vapour pressure (kPa), SPV-the slope of saturation vapour pressure curve (Kpa °C d^{-1}), ETP-evapotranspiration (mm d^{-1}), RTA-global solar radiation based on latitude and Julian day (MJ m^{-2} day^{-1}), SSH- Actual duration of sunshine (hours), DLH- Daylight hours (hours), PRECTOT- total rainfall precipitation during the crop cycle (mm), PETP- deficit by precipitation (mm d^{-1})

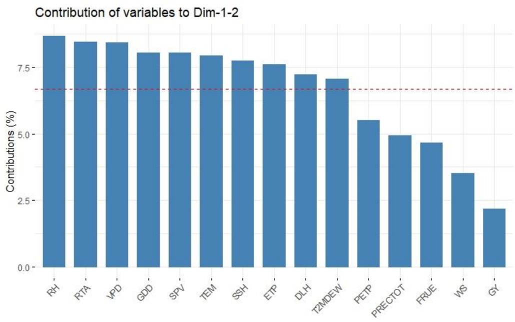

Figure 6. Contribution of variables to the first two principal components

RH- relative humidity (%), RTA-global solar radiation based on latitude and Julian day (MJ m^{-2} day^{-1}), VPD-the deficit of vapour pressure (kPa), GDD-growing degree-days (°C day^{-1}), SPV-the slope of saturation vapour pressure curve (Kpa °C d^{-1}), TEM- mean temperature at 2m height (°C d^{-1}), SSH- Actual duration of sunshine (hours), ETP-evapotranspiration (mm d^{-1}), DLH- Daylight hours (hours), T2MDEW- dew-point temperature at 2 m above the surface of the earth (°C d^{-1}), PETP- deficit by precipitation (mm d^{-1}), PRECTOT- total rainfall precipitation during the crop cycle (mm), FRUE-effect of temperature on radiation use efficiency, WS- wind speed at 2m height (m s^{-1}), GY- grain yield.

DISCUSSION

Owing to the diverse agro-climatic conditions and rainfed model of cultivation, accounting of environmental effects and GEI is vital in breeding for stable and wider adaptable soybean varieties in India. Current investigation aimed at identification of stable soybean genotypes using a recent BLUP-based mixed model, WAASB and its derived superiority index, WAASBY and multi-trait stability index (MTSI). Predominant portion of the total variation in case of grain yield was explained through environmental effects followed by GEI, and least portion was attributed by genotypic effects. This results in lower heritability and proves the importance of understanding and accounting of genotypic effects and GEI in breeding for wider adaptability in soybean in India. Similar results have been reported in previous studies demonstrating the complexity of grain yield trait in soybean (BHARTIYA *et al* 2018; NATARAJ *et al* 2021). Through WAASB biplot, SL 1213 and DS 1320 were identified to be stable and high yielding genotypes. Through WAASBY index, SL 1213 and DS 1318 were identified to be superior with respect to grain yield. Ideotype breeding aiming at multiple desirable agronomic traits results in development of mega-varieties in any crop (NATARAJ *et al* 2021). MTSI is a powerful tool in selecting genotypes based on multiple traits across the environments (OLIVOTO *et al* 2019b). Genotype with least MTSI is considered to be the ideal genotype. In the current study, lesser days to flowering and maturity, higher plant height, hundred seed weight and grain yield was considered for multi-trait based genotypic selection. Genotypes DS 1320 and SL 1213 had least MTSI. Genotype SL 1213 was identified to be the superior genotype with respect to all the three indices. Further, it was bred at Ludhiana, a hot-spot for yellow mosaic virus and is resistant to this disease. Therefore, it can be the potential parent for breeding for higher yield and wider adaptability, YMV resistance and also for ideotypes breeding based on multiple agronomic traits. Hence Positive correlation with hundred seed weight and plant height as reported previously (YADAV *et al* 2009; BHARTIYA and ADITYA 2016; WANG *et al* 2012; SHIVAKUMAR *et al* 2019; LI *et al* 2020) indicates direct selection for seed weight and plant height improves grain yield. Negative correlation was found between grain yield and days to maturity, which is in accordance with previous reports (WANG *et al* 2012; BHARTIYA and ADITYA 2016; NATARAJ *et al* 2021; MARANNA *et al* 2022). Hundred seed weight is the most important trait contributing to the grain yield in soybean (KUMAWAT *et al* 2019). Stable genotype SL 1213 having lower HSW and JS 22-07 with higher HSW were found to be diverse through cluster analysis. These two genotypes can be employed as parents to develop high-yielding and stable genotypes. Likewise, plant height is another important trait that contributes to the grain yield and eases harvesting. In the current study, stable genotype DS 1320, having lower plant height and NRC 149 with highest plant height fell under two different clusters. Hybridization among them can result in development of stable and high yielding genotypes with higher plant height. Positive association of RH, FRUE, PETP, PRECTOT, RTA and T2MDEW with grain yield was found through PCA. High yielding environment, Pune was found to have higher FRUE, similarly, Imphal and Umiam were having higher PETP and PRECTOT and Adilabad and Parbhani were having higher RTA and T2MDEW. These results are in conformity with MOHANTY *et al*. (2015), DAKHORE and KADAM (2018) and NEGI *et al*. (2020). Further, future studies will be aimed at employing envirotyping techniques to identify mega-environments in India based on multi-year data of long-term co-ordinated trials, as done in case of maize hybrids in China (YUE *et al* 2022).

CONCLUSION

In the current study, for all the traits under consideration, genetic variation was predominantly contributed by environmental effects, followed by GEI and genotypic effect. Based on WAASB, WAASBY and MTSI indices, SL 1213 was found to be candidate genotypes for breeding for higher yield, wider adaptability and for ideotypes breeding. Jabalpur, Delhi and Bengaluru were found to be less productive and more discriminative, while Palampur, Lokbharti, Ranchi and Parbhani were found to be more productive and less discriminative. Through PCA, positive association of RH, FRUE, PETP, PRECTOT, RTA and T2MDEW with grain yield was identified.

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REFERENCES

ABDELGHANY AM, S. ZHANG, M. AZAM, AS SHAIBU, Y. FENG, J. QI, J. LI, Y. LI, Y. TIAN, H. HONG, *et al* (2021): Exploring the Phenotypic Stability of Soybean Seed Compositions Using Multi-Trait Stability Index Approach. Agronomy, *11*:2200. https://doi.org/ 10.3390/agronomy11112200

BHARTIYA A. and JP ADITYA (2016): Genetic variability, character association and path analysis for yield and component traits in black seeded soybean lines under rainfed condition of Uttarakhand hills of India. Legume Research, *39*, 31–34.

BHARTIYA A., JP ADITYA, V. KUMARI, N. KISHORE, JP PURWAR, A. AGRAWAL, L. KANT, A. PATTANAYAK (2018): Stability analysis of soybean [*Glycine max* (L.) Merrill] genotypes under multi-environments rainfed condition of North Western Himalayan hills. Indian Journal of Genetics and Plant Breeding, *78*(3), 342–347.

COSTA-NETO G, GALLI G, CARVALHO HF, CROSSA J AND FRITSCHE-NETO R (2021) EnvRtype: a software to interplay enviromics and quantitative genomics in agriculture. Genes Genomes Genetics 11, 1–20.

DAKHORE, KK and YE KADAM (2018): Effect of Weather Parameters on Crop Growth, Development and Yield of Kharif Cotton Varieties under Extended Sowing Times. Int. J. Curr. Microbiol. App. Sci, *7*(12), pp.3411-3418.

FEHR WR, CE CAVINESS, DT BURMOOD, JS PENNINGTON (1971): Stage of development descriptions for soybeans, Glycine max (L.) Merr. Crop Science, *11*, 929–931.

GERRANO AS, WS JANSEN VAN RENSBURG, I. MATHEW, AIT SHAYANOWAKO, MW BAIRU, SL VENTER, W. SWART, A. MOFOKENG, J. MELLEM, M. LABUSCHAGNE (2020): Genotype and genotype × environment interaction effects on the grain yield performance of cowpea genotypes in dryland farming system in South Africa. Euphytica, 216, 80.

GURMU, F., MOHAMMED, H., & ALEMAW, G. (2009). Genotype × environment interactions and stability of soybean for grain yield and nutrition quality. African Crop Science Journal, 17, 87–99.

ICAR-Indian Institute of Soybean Research. (2021) Annual Report, 2021. https://iisrindore.icar.gov.in/pdfdoc/AR2021.pdf

JAISWAL S., PV JADHAV, RS JASROTIA, *et al* (2019): Transcriptomic signature reveals mechanism of flower bud distortion in witches'-broom disease of soybean (Glycine max). BMC Plant Biol *19*, 26. https://doi.org/10.1186/s12870-018-1601-1

KASSAMBARA A. and F. MUNDT (2017): Factoextra: extract and visualize the results of multivariate data analyses. *R package version 1.0.7.* Available at https://CRAN.R-project.org/package=factoextra (Accessed 25 November 2022)

KUMAWAT G., A. YADAV, S. MARANNA, RM PATEL, S. GUPTA, GK SATPUTE, S. CHAND, SM HUSAIN (2019): Validation of QTLs for seed weight in backcross population derived from an interspecific cross in soybean (*Glycine max* (L.) Merr.). J. Oilseeds Res., *36*(4): 210-216.

LI YC, DY YU, R. XU, JY GAI (2008): Effects of natural selection of several quantitative traits of soybean RIL populations derived from the combinations of Peking ×7605 and RN-9×7605 under two ecological sites. Scientia Agricultura Sinica, *41*, 1917–1926.

LI M. *et al* (2020) Identification of traits contributing to high and stable yields in different soybean varieties across three Chinese latitudes.Front. Plant Sci. *10*, 1642.

MARANNA S., V. NATARAJ, G. KUMAWAT, S. CHANDRA, V. RAJESH, R. RAMTEKE, RM PATEL, MB RATNAPARKHE, SM HUSAIN, S. GUPTA, N. KHANDEKAR (2021): Breeding for higher yield, early maturity, wider adaptability and waterlogging tolerance in soybean (*Glycine max* L.): A case study. Scientific Reports. https://www.nature.com/articles/s41598-021-02064-x.

MOHANTY M., NK SINHA, S. LENKA, KM HATI, J. SOMASUNDARAM, R. SAHA, RK SINGH, RS CHAUDHARY, A. SUBBA RAO (2015): Climate change impacts on rainfed soybean yield of central India: management strategies through simulation modelling. In Climate change modelling, planning and policy for agriculture (pp. 39-44). Springer, New Delhi.

NATARAJ V., A. BHARTIYA, CP SINGH, HN DEVI, MP DESHMUKH, P. VERGHESE, K. SINGH, SP MEHTRE, V. KUMARI, S. MARANNA, G. KUMAWAT, MB RATNAPARKHE, GK SATPUTE, V. RAJESH, S. CHANDRA, R. RAMTEKE, N. KHANDEKAR, S. GUPTA (2021): WAASB-based stability analysis and simultaneous selection for grain yield and early maturity in soybean. Agronomy Journal *113*, 3089–3099.

NEGI A., R. RANJAN, A. KUMAR (2020) Effect of weather parameters on productivity of soybean crop. Journal of Pharmacognosy and Phytochemistry, *9*(6S), pp.227-230.

OLIVOTO T. and ADC LUCIO (2020): Metan: an R package for multi-environment trial analysis. Methods in Ecology and Evolution *11*, 783–789.

OLIVOTO T., ADC LUCIO, JAG DA SILVA, VS MARCHIORO, VQ DE SOUZA, E. JOST (2019a): Mean performance and stability in multi-environment trials I: combining features of AMMI and BLUP techniques. Agronomy Journal *111*, 2949–2960.

OLIVOTO T., ADC LÚCIO, JAG SILVA, BG SARI, MI DIEL (2019b): Mean performance and stability in multi-environment trials II: Selection based on multiple traits. Agronomy Journal, *111*, 2961– 2969.

PATTERSON, H.D. AND E.R. WILLIAMS (1976): A new class of resolvable incomplete block designs. Biometrika *63*(1):83-92.

PIEPHO H.P (1994): Best Linear Unbiased Prediction (BLUP) for regional yield trials: A comparison to additive main effects and multiplicative interaction (AMMI) analysis. Theoretical and Applied Genetics *89*, 647–654. RAJPUT LS, V. NATARAJ, S. KUMAR *et al* (2022): WAASB index revealed stable resistance sources for soybean anthracnose in India. The Journal of Agricultural Science 1–11.

SHIVAKUMAR M., G. KUMAWAT, V. NATARAJ, C. GIREESH, S. GUPTA, GK SATPUTE, MB RATNAPARKHE, DP YADAV (2019): NAM population – a novel genetic resource for soybean improvement: development and characterization for yield and attributing traits. Plant Genetic Resources: Characterization and Utilization 1–9.

SINGAMSETTI A., JP SHAHI, PH ZAIDI, K. SEETHHARAM, MT VINAYAN, M. KUMAR, S. SINGLA, K. SHIKHA, K. MADANKAR (2021): Genotype × environment interaction and selection of maize (*Zea mays* L.) hybrids across moisture regimes. Field Crops Research *270*. 108224

TIZE I., AK FOTSO, EN NUKENINE, C. MASSO, FA NGOME, C. SUH, VW LENDZEMO, I. NCHOUTNJI, G. MANGA, E. PARKES, P. KULAKOW, C. KOUEBOU, KKM FIABOE, R. HANNA (2021): New cassava germplasm for food and nutritional security in Central Africa. Scientific Reports *11*, 7394.

VINEETH TV, I.PRASAD, AR CHINCHMALATPURE, BM LOKESHKUMAR, S. KUMAR, KT RAVIKIRAN, PC SHARMA (2022): Weighted Average Absolute Scores of BLUPs (WAASB) based selection of stable Asiatic cotton genotypes for the salt affected Vertisols of India. Indian J. Genet. Plant Breed *82*(1): 104-108

WANG B., L. ZHANG, H. DAI, C. WANG, L, WEI, XU R. (2012): Genetic variation, correlation and principal component analysis on agronomic traits of summer sowing soybean (*Glycine max* Merr.) in Huanghuai region. Soybean Science *31*, 208–212.

YADAV NS, K.SINGH, BV SINGH, K. PANDEY, MK GUPTA (2009): Correlation and path coefficient study in elite breeding lines of soybean [Glycine max (L.) Merrill.]. Pantnagar Journal of Research *7*, 155–160

YAN W. and na tinker (2006): Biplot analysis of multi environment trial data: Principles and applications. *Canadian* Journal of Plant Science *86*, 623-645.

YONAS, W., A.TESFAYE, S. ALAMERE (2022): Evaluation of yield performance of early maturing soybean (Glycine max L. Merill) genotypes in Ethiopia by GGE Biplot model. Int. J. Agril. Res. Innov. Tech. *12*(2): 101-110.

YUE H., T. OLIVOTO, J. BU, J. LI, J. WEI, J. XIE, S.CHEN, H.PENG, M.NARDINO, X. JIANG (2022): Multi-trait selection for mean performance and stability of maize hybrids in mega environments delineated using envirotyping techniques. Front. Plant Sci. *13*:1030521.

ZUFFO AM, F. STEINER, JG AGUILERA, PE TEODORO, LPR TEODORO, A. BUSCH (2020): Multi-trait stability index: A tool for simultaneous selection of soya bean genotypes in drought and saline stress. Journal of Agronomy and Crop Science *206*, 815–822.

SELEKCIJA VIŠE OSOBINA ZA SREDNJE PERFORMANSE I STABILNOST MEĐU GENOTIPIMA SOJE, PROCENA U KIŠNIM USLOVIMA U RAZLIČITIM OKRUŽENJIMA U INDIJI

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Izvod

Soja je dominantna indijska uljarica koja se gaji u različitim agro-klimatskim zonama. Razumevanje interakcije genotip × sredina (GEI) je ključno za razvoj stabilnih i šire adaptiranih sorti soje. U ovoj studiji, 10 elitnih linija je gajeno na 19 različitih lokacija i praćeni su: dani do cvetanja, dani do zrelosti, visina biljke, težina stotinu semena i prinos zrna tokom 2020 godine. Indeks stabilnosti meren preko ponderisanog proseka apsolutnih rezultata (VAASB) identifikovao je da SL 1213 i DS 1320 imaju stabilan prinos zrna. VAASBI indeks superiornosti, koji se zasniva na srednjim performansama i stabilnosti, takođe je bio viši za SL 1213. Indeks stabilnosti više osobina (MTSI) je korišćen za izbor genotipova sa većim prinosom zrna, ranim cvetanjem, ranom zrelošću, većom masom stotinu semena i visinom biljke, istovremeno i genotipovi DS 1320 i SL 1213 su identifikovani preko MTSI. Na osnovu tri indeksa, utvrđeno da je genotip SL 1213 kandidat za oplemenjivanje za veći prinos, širu prilagodljivost i za ideotipsko oplemenjivanje. Na osnovu klaster analize, utvrđeno je da su SL 1213 × JS 22-07 i SL 1213 × NRC 149 idealne kombinacije za razvoj visokoprinosnih i šire adaptiranih genotipova. Analizom glavnih komponenti (PCA), utvrđeno je da je prinos zrna pozitivno povezan sa relativnom vlažnošću, uticajem temperature na efikasnost korišćenja radijacije, deficitom prema padavinama, ukupnim padavinama, globalnim sunčevim zračenjem na osnovu geografske širine i julijanskog dana i temperature tačke rose na 2 m iznad površine zemlje.

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