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THE PARAMETRIC AND NON-PARAMETRIC STABILITY ANALYSES FOR INTERPRETING GENOTYPE BY ENVIRONMENT INTERACTION OF SOME SOYBEAN GENOTYPES

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ABSTRACT

Seed yields of 15 soybean genotypes were evaluated in three locations i.e. Bursa, Samsun and Konya under main crop conditions through summer seasons from 2014 to 2016. The used design was a randomized complete block design with four replications. This research is aimed to estimate the stability parameters of seed yield of 15 soybean genotypes by used different stability analysis methods over nine environmental conditions and to study interrelationship among these stability methods. Genotypes, environments and genotype by environment interactions (GEI) played a significant role in terms of seed yield in this study. The genotypes KAMD 03, BATEM 306, BDUS 04, ARISOY and ATAEM 07 had higher seed yields and regression coefficient values above 1.0. These genotypes are sensitive to environmental variations and would be suggested for cultivation under favourable conditions, whereas KAMD 01, KASM 02 and KASM 03 with b_i<1 and lowest average yields were poorly adapted across unfavourable environment conditions. The genotype BDSA 05 having regression coefficient below 1.0 and higher seed yield than average yield were goodly adapted to unfavourable environment conditions. The results of most parametric and non-parametric stability analyses showed that genotypes BDUS 04, KASM 02, KASM 03, KAMD 03 and BDSA 05 were stable genotypes. These genotypes were demonstrated superior adaptability with high yield performances in many environments. Results of correlation analysis indicated that seed yield was significantly correlated with R_i^2 (P<0.05), $S_i(3)$ (P<0.05), D_i (P<0.01), $S_i(6)$ (P<0.01), TOP (P<0.01) and showed a negative and significant correlation with P_i and RS (P<0.01). The coefficient of regression (b_i) had positively significant associated with CV_i, α_i, $S_i(3)$ and $S_i(6)$ (P<0.01) and with the superiority parameter (TOP) (P<0.05).

Keywords: Adaptability, genotype by environment interaction, seed yield, soybean, stability

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill.) is a crop that is affected by environmental factors. Environmental factors such as precipitation, temperature, and relative humidity can not be controlled, although some of the environmental factors can be controlled, such as soil type, planting date, row spacing, plant population and cultural applications. Unfavourable environmental conditions have a negative effect on soybean growth, development and yield (Bakal et al., 2017). Therefore, information on the adaptability of a genotype has great importance. When genotypes are tested for yield performance in different environmental conditions, the effect of genotype by environment interaction is revealed in terms of seed yield, so that the stability status, general and specific adaptabilities of the genotypes are determined. Different yield response of cultivars from one environment to another is called genotype by environment (GEI) interaction (Allard, 1960;Vargas et al., 1998). The stability of seed yield in different crops has been statistically evaluated through analysis of GEI interaction in cultivar-adaptation trials conducted over several environments (Crossa, 1990; Piepho, 1998). Results of many previous researches revealed the importance of the genotype by environment interaction in the stability analysis of soybean (Radi et al., 1993; Ablett et al., 1994; Al-Assily et al., 2002; Meotti et al., 2012; Oliveira et al., 2012; Ikeogu and Nwofia, 2013; Silveira et al., 2016; Ilker et al., 2018a, Ilker et al., 2018b).

The change in yield performance of the genotype across different environmental conditions is very important for plant breeders. Therefore, in order to achieve success in plant breeding, the genotype by environment interaction must be studied. Understanding this interaction is essential for breeding programs in order to reduce the amplitude of the characteristics related to productivity due to the environmental variation (Duarte and Vencovsky, 1999). Indeed, the development of stable high yielding soybean cultivars is a vital goal of most breeding programs to enhance the soybean production (Morsy et al., 2015).

A number of methods are used to determine the stability performances of genotypes in various environments. When the genotype by environmental interaction is statistically significant, several parametric and non-parametric stability methods are used to reveal the stability performances of the genotypes. Since the current stability parameters give different results, these differences sometimes lead to incorrect decisions about the stability of genotypes. A single stability method can not be adequate to determine the stability performance of the genotypes across environments. Thus, the various stability parameters are compared and the availability of these methods becomes more useful by determining the statistical relationships between them (Yildirim et al., 1992).

The oldest and most reliable stability parameter known is the regression coefficient (b_i) introduced by Finlay and Wilkinson (1963) and Eberhart and Russell (1966). Some other parametric stability methods are environmental variance ($S^2{}_i$) and coefficient of variability (CV_i) (Francis and Kannenberg, 1978), desirability index (D_i^2) (Hernandez et al., 1993), superiority index (P_i) (Lin and Binns, 1988), mean variance component for a pair-wise genotype by environment interaction (P_{59}) (Plaisted and Peterson, 1959), ecovalence (W_i^2) (Wricke, 1962), stability variance (σ_i^2) (Shukla, 1972), environmental effects (α_i) and deviation from the linear response (λ_i) (Tai, 1971). Some non-parametric methods used in stability analysis are rank stability methods [($S_i(1)$, $S_i(2)$, $S_i(3)$ and $S_i(6)$] (Nassar and Huhn, 1987), superiority parameter (TOP) (Fox et al., 1990) and rank-sum (RS) method (Kang, 1988). When the above parametric methods are used for stability, estimations are made about the range of data and the uniformity of variance. As non-parametric methods are based on ranks and not on values, a genotype is considered stable if its ranking is relatively constant across environments (Flores et al., 1998).

The objectives of our study were to (i) evaluate seed yield of promising soybean genotypes under different environment conditions; (ii) examine the influence of genotype, environment and genotype by environment interactions in terms of seed yield, (iii) most accurately determined the adaptation and stability performances of promising soybean genotypes using parametric and non-parametric stability methods; (iiii) estimate correlative relationships between stability parameters and average seed yield across all environments.

MATERIALS AND METHODS

Eleven advanced generation lines (in third and fourth maturity groups) developed by Research Institutes of TAGEM and 4 standard varieties in third and fourth maturity groups (Table 1) were tested in the field experiments with replication performed during the three years (2014, 2015 and 2016) in 3 locations (Bursa, Samsun, and Konya) of main crop regions at the central, northern and western Anatolia in Turkey. In the research, years, environments (E), soil properties, amount of rainfall, among of the irrigation water and mean temperature during the growing period are also given Table 2. As seen from this table, the climate characteristics varied according to the environments. The experiments were conducted in a randomized complete block design with 4 replications. The sowings were done by using a plot drill in the plots of 5 m in length consisting of 4 rows in each plot, in a distance of 70 cm and contains 45 plants in the m^2. Sowings of the trials were generally completed from the second half of April until the beginning of May. The 180 kg ha^{-1} diamonium phophate was applied at the sowing time in the experiments. Prior to sowing, seeds were inoculated with *Rhizobium* bacteria culture where necessary. Weed control was done by hand or by herbicide. Disease and pest control was performed at required locations. In addition, sprinkler irrigation was done during the periods needed by plants in the experiments.

Statistical analyses

A combined ANOVA was first performed to estimate the genotype by environment interaction. The F-protected least significant difference (LSD) was calculated at the 0.05 probability level according to Steel and Torrie (1980). Then eleven parametric stability parameters were studied in accordance with Eberhart and Russel's (1966) regression coefficient (b_i), Pinthus's (1973) coefficients of determination (R_i^2), Wricke's (1962) ecovalance (W_i^2), Shukla's (1972) stability variance (σ_i^2), Francis and Kannenberg's (1978) coefficient of variability (CVi) and environmental variance (S_i^2), Tai's (1971) environmental effects (α_i) and deviation from the linear response (λ_i), Plaisted and Peterson's (1959) mean variance component for pair-wise GEI (P59), Hernandez et al. (1993)'s desirability index (D_{i2}), and Lin and Binn's (1988) superiority index (P_i).

In this study, several non-parametric statistics were also used to estimate the stability. These statistics consisted of three nonparametric stability statistics [$S_i(2)$, $S_i(3)$ and $S_i(6)$] (Huhn, 1979; Nassar and Huhn, 1987). In addition, the other two nonparametric statistics were used. One of them is a method described by Fox et al. (1990)'s who proposed a non-parametric superiority method for general adaptability using stratified ranking of cultivars. Kang's (1988) rank-sum (RS) is another non-parametric stability procedure where both yield and Shukla's (1972) stability variance were used as selection criteria. In addition, two-way relations between all stability parameters were determined by correlation analysis. All statistical analyses were performed using the SAS (Statistical Analyses Systems) program (SAS Institute, 1999).

Table 1. Code, pedigree, maturity group and breeding organization or variety owner of genotypes

Code	Pedigree	Maturity group	Breeding organization/ variety owner
		Lines	
KAMD 01	Macon x Defiance	3	KTAE
KAMD 03	Macon x Defiance	3	KTAE
KASM 02	Sprite 87 x Macon	3	KTAE
KASM 03	Sprite 87 x Macon	3	KTAE
KANA	NE 3297 x AP 2292	4	KTAE
KAND	NE 3399 x Defiance	3	KTAE
KAGMN	General x MN1301	4	KTAE
BATEM 306	Ataem 07 x Etae 08	4	BATEM
BDSA 05	Sprite 87 x Apollo	3	BDUTAE
BDUS 01	Umut 2002 x Sprite 87	3	BDUTAE
BDUS 04	Umut 2002 x Sprite 87	3	BDUTAE
		Standards	
ARISOY		3	Cukurova University
ATAEM 07		4	BATEM
BRAVO		3	PROGEN Seed Co.
NOVA		3	MAY Agro Co.

Table 2. Data on experiment, soil properties and climate for environments where the experiments were conducted

Code	Years	Environments	Soil properties	Mean temperatures at growing season (^{0}C)	Rainfall (mm)	Irrigation (mm)	Mean yield (t ha^{-1})
E1	2014	Bursa	pH= 7.2, clay-silt	18.3	537.4	65	4.22
E2	2015	Bursa	pH= 7.2, clay-silt	18.2	366.3	235	4.12
E3	2016	Bursa	pH= 7.2, clay-silt	19.2	180.7	420	2.65
E4	2014	Samsun	pH= 7.8, clay-loam	19.9	350.8	250	4.08
E5	2015	Samsun	pH=7.8, clay-loam	19.7	366.8	235	3.84
E6	2016	Samsun	pH=7.8, clay-loam	20.0	460.7	140	3.44
E7	2014	Konya	pH=7.7, clay-loam	18.3	205.2	500	3.85
E8	2015	Konya	pH=7.7, clay-loam	18.2	196.6	510	3.79
E9	2016	Konya	pH=7.7, clay-loam	19.2	86.2	620	2.33

RESULTS

Results of combined variance analysis for seed yield of 15 soybean genotypes examined in the nine environments are presented in Table 3. According to the results of the analysis of variance for seed yield, the genotypes and the environments as well as the genotype by environment interactions were found to be significant at P<0.01 (Table 3).

In our study, relatively low coefficient of variation demonstrated the existence of a good experimental precision. The estimated coefficient of determination (R^2) revealed that 80.2% of the general variation for seed yield was derived from the genotype by environment interaction model. In fact, the combined variance analysis showed that 61.0% of the total sum of squares was attributed to environmental effects whereas GEI and genotype effects were 14.3% and 3.31%, respectively (Table 3). The large environmental sum of squares indicated that there were large differences between the environments in terms of average grain yields.

Parametric stability components

Mean seed yield of environments over genotypes ranged from 2.33 t ha^{-1} for E_9 to 4.22 t ha^{-1} for E_1. Mean seed yield of genotypes over environments ranged from 3.33 t ha^{-1} for KAND to 3.92 t ha^{-1} for BDUS 04.

When considering the mean seed yields of the genotypes over the environments, it was determined that genotypes BDUS 04, BDSA 05, BATEM 306, KAMD 03, KANA, ARISOY and ATAEM 07 had the highest seed yields, whereas the lowest seed yields were obtained from KAND and NOVA genotypes. However, genotypes showed large differences across to the environments in terms of seed yield (Table 4).

Table 3. Results of combined variance analysis for seed yield of 15 soybean genotypes examined in the nine environmental conditions

Source	DF	SS	MS	F Ratio	Prob>F	% Total SS
Model	161	2822788	17532	9.5	<0.001	
Environment (E)	8	2149894	268737	144.9	<0.001	61.06
Replication (E)	27	50047	1853	1.0	0.4618	1.42
Genotype (G)	14	116577	8326	4.5	<0.001	3.31
E x G	112	503923	4499	2.4	<0.001	14.31
Pooled error	378	697826	1846	145.0		
Corrected total	539	3520614				
		CV(%): 11.9			R^2: 80.2	

DF: Degree of freedom, SS: Sum of squares, MS: Mean squares

The results of eleven parametric stability parameters and mean seed yields for 15 soybean genotypes at the 9 environments are presented in Table 5. Genotypes KAMD 03, BATEM 306, BDUS 04, ARISOY and ATAEM 07 had higher seed yields and regression coefficient values above 1.0 (Table 5). These genotypes are sensitive to environmental variations and would be suggested for cultivation under favourable conditions, whereas KAMD 01, KASM 02 and KASM 03 with $b_i<1$ and lowest average yields were poorly adapted across unfavourable environment conditions. On the contrary, the genotype BDSA 05 having regression coefficient below 1.0 and higher seed yield than average yield were goodly adapted to unfavourable environment conditions (Fig.1).

In the current study, Pinthus's coefficient of determination (R_i^2) values, which are the predictability of response estimates (R_i^2=1), ranged from 0.66 to 0.97. Coefficient of determination defines the amount of contribution proportionally of the stability model containing the genotype, environment and GEI effects on the general variation in terms of seed yield. Ecovalance (W_i^2) values were lowest for genotypes KASM 02, KASM 03, BDUS 04, KAMD 03, NOVA, BRAVO, BDSA 05, KAMD 01 and KANA, and highest for BDUS 01, BATEM 306, KAND and ARISOY (Table 5). As seen in Table 5, environmental variance (R_i^2) values were the lowest for the genotypes BDSA 05, KASM 02, KASM 03 and KAMD 01, and the highest for the genotypes BATEM 306, ARISOY, ATAEM 07, KAMD 03 and BDUS 04. According to coefficient of variation stability parameter (CV_i), genotypes BDSA 05, KASM 02, KASM 03 and KAMD 01 had the lowest coefficient of variation, whereas these values were the highest for genotypes ARISOY, BATEM 306, ATAEM 07 and KAMD 03.

The genotypes KASM 02, KASM 03, BDUS 04, KAMD 03, NOVA, BRAVO, KAMD 01 and BDSA 05 had the lowest stability variance (σ_i^2) while these values of the genotypes BATEM 306, ARISOY, BDUS 01, KAND and ATAEM 07 were the highest. Desirability index (D_i^2) ranged between 305.6 and 358.8 according to the current genotypes. However, the desirability index (D_i^2) for a stable genotype (standard genotype whose B=1) was estimated to be 327.7. The perfect stable genotype will not change its performance from one environment to another. This is equivalent to state α = -1 and λ = 1. According to these stability parameters, the genotypes BDSA 05 and KASM 03 could be considered as stable (Table 5) because these genotypes had values near to (αi = -1, λi = 1). On the other hand, the KAMD 03 was considered as a genotype having average stability since it was the values close to (α = 0 & λ = 1). Considering superiority index (P_i) value, a genotype with the lowest superiority index (P_i) value should be regarded as a superior genotype. Accordingly, the genotypes BDUS 04 and BDSA 05 having the lowest superiority index (P_i) value were found to be superior genotypes.

Non-Parametric Stability Components

The results of five different non-parametric stability statistics are presented in Table 5. The genotypes KASM 02, KASM 03, BDUS 04 and KAMD 03 had the lowest $S_i(2)$ values and hence, these genotypes were accepted as stable genotypes. Whereas, the genotypes KAND, BDUS 01, BATEM 306, KAGMN and ARISOY having the highest $S_i(2)$ values were unstable. Accordingly, genotypes KASM 03, NOVA and KASM 02 had the lowest $S_i(3)$ and $S_i(6)$ values and therefore, these genotypes were regarded as the most stable genotypes. However, it was decided that the genotypes BATEM 306, ARISOY, BDUS 04 and ATAEM 07, which had both the highest average yields and the highest values of $S_i(3)$ and $S_i(6)$, were not stable genotypes (Table 5).

According to the results of the research, the highest TOP value was obtained from BDUS 04 genotype with 77.8, followed by ARISOY, ATAEM 07, KAGMN and KAMD 03 genotypes with 44.4. Genotypes KAND and KASM 03 had the lowest TOP values with 11.1. According to superiority parameter (TOP) method, genotypes BDUS 04, ARISOY, ATAEM 07, KAGMN and KAMD 03 having the highest TOP values, could be regarded as genotypes showing the highest general adaptability, whereas the general adaptation abilities of KAND and KASM 03 genotypes could be considered to be the lowest.

The last non-parametric stability statistic in the current study is rank-sum (RS) statistics. Accordingly, genotypes BDUS 04, KAMD 03, KASM 02 and BDSA 05 with the lowest rank-sum (RS) values were considered to be stable while genotypes KAND, BDUS 01 and KAGMN having the highest rank-sum (RS) values were unstable.

Table 4. Average seed yields of soybean genotypes tested in nine environmental conditions (t ha^{-1}

Genotypes	E1	E2	E3	E4	E5	E6	E7
BATEM 306	4.32 b-e	4.14 d-f	2.51 e	5.00 a	4.35 a	3.24 a-c	3.92 a-c
BDSA 05	4.53 a-c	3.96 e-g	3.45 a	4.17 a-d	3.95 a-c	3.57 a-c	3.86 b-d
BDUS 01	3.88 f-h	4.89 a	2.55 de	4.01 a-d	3.31 e	2.81 bc	3.77 b-d
BDUS 04	4.67 a	4.41 cd	2.43 ef	4.70 ab	4.07 a-c	3.90 a	4.40 a
KAGMN	4.48 a-c	3.81 g	2.92 bc	3.96 a-d	3.96 a-c	2.79 c	3.47 c-d
KAMD 01	4.13 d-f	3.70 g	3.05 b	3.50 cd	3.70 c-e	3.46 a-c	4.02 ab
KAMD 03	4.43 a-c	3.98 e-g	2.35 e-g	4.59 a-c	3.90 a-c	3.86 a	3.97 a-c
KANA	4.07 d-f	4.17 de	2.77 cd	3.50 cd	4.34 a	3.33 a-c	3.74 b-d
KAND	4.04 e-g	3.73 g	2.14 g	3.12 d	3.28 e	3.56 a-c	4.02 ab
KASM 02	4.26 c-e	3.88 fg	2.84 bc	3.94 a-d	3.66 c-e	3.63 ab	3.83 b-d
KASM 03	3.75 gh	3.81 g	2.89 bc	3.80 b-d	3.84 b-d	3.59 a-c	3.85 b-d
ARISOY	4.58 ab	4.78 ab	2.47 e	4.51 a-c	3.71 c-e	3.30 a-c	4.10 ab
ATAEM 07	4.36 b-d	4.53 bc	2.94 bc	4.18 a-d	3.94 a-c	3.64 ab	3.97 ab
BRAVO	4.23 c-e	3.86 fg	2.21 fg	4.20 a-d	4.22 ab	3.20 a-c	3.42 d
NOVA	3.59 h	4.21 de	2.22 fg	4.01 a-d	3.39 de	3.63 ab	3.43 d
Mean	4.22 A	4.12 A	2.65 D	4.08 A	3.84 B	3.44 C	3.85 B

E1: Bursa 2014; E2: Bursa 2015; E3: Bursa 2016; E4: Samsun 2014; E5: Samsun 2015; E6: Samsun 2016; E7: Konya 2014;
E8: Konya 2015; E9: Konya 2016.

Table 5. Mean seed yield values (t ha^{-1}) and 16 stability parameters of 15 soybean genotypes at the 9 environments in th

Genotype	Stability parameters											
	X	b$_i$	R$_i^2$	W$_i^2$	S$_i^2$	CV$_i$	σ_i^2	P59	D$_i^2$	α_i	λ_i	P$_i$
ARISOY	3.67	1.47	0.97	12007.3	10475.8	27.9	1644.3	1373.2	320.0	0.50	0.87	1960.9
ATAEM 07	3.63	1.22	0.90	8709.6	7812.6	24.3	1168.6	1152.3	323.9	0.25	1.89	2003.4
BATEM 306	3.71	1.49	0.91	15598.8	10512.4	27.6	2162.2	1613.7	325.9	0.46	2.39	1943.4
BDSA 05	3.79	0.61	0.88	7425.7	2200.2	12.4	983.4	1066.4	358.8	-0.36	0.82	1318.0
BDUS 01	3.53	0.83	0.66	16406.5	5369.5	20.7	2278.8	1667.8	325.8	-0.13	4.64	2977.0
BDUS 04	3.92	1.26	0.95	5142.6	7446.1	22.0	654.2	913.5	352.6	0.26	0.80	874.7
BRAVO	3.48	1.01	0.85	6734.6	5510.2	21.3	883.8	1020.1	316.8	0.02	1.97	3062.6
KAGMN	3.51	0.83	0.79	8205.6	4192.9	18.4	1095.9	1118.6	325.1	-0.15	2.18	2868.5
KAMD 01	3.54	0.77	0.84	7253.6	3015.1	15.5	958.6	1054.8	331.0	-0.27	1.38	2906.6
KAMD 03	3.65	1.27	0.94	5947.1	7580.3	23.8	770.2	967.4	325.8	0.26	1.02	2016.6
KANA	3.61	0.94	0.86	7714.1	4446.2	18.5	1025.0	1085.7	333.2	-0.11	2.13	2542.9
KAND	3.32	0.85	0.71	11381.2	4427.5	19.9	1553.9	1331.2	306.7	-0.17	3.05	4974.1
KASM 02	3.59	0.69	0.95	4441.7	2482.9	13.9	553.1	866.5	336.6	-0.29	0.44	2267.5
KASM 03	3.51	0.81	0.95	4245.2	2943.4	15.4	524.7	853.4	326.9	-0.23	0.68	2766.0
NOVA	3.35	0.93	0.84	6268.6	4782.1	20.6	816.6	988.9	305.6	-0.05	1.81	3922.0
Mean	3.59	1.0										

X: mean seed yield (t ha^{-1}), b_i: regression coefficient, R_i^2: coefficients of determination, W_i^2: ecovalance, S_i^2: environmental variance, CV_i: coefficient of var
component for pair-wise GEI, D_i^2 : desirability index, α_i: environmental effects, λ_i: deviation from the linear response, P_i: superiority index, $S_i(2)$, $S_i(3)$, S$_i$(
parameter, RS: rank-sum

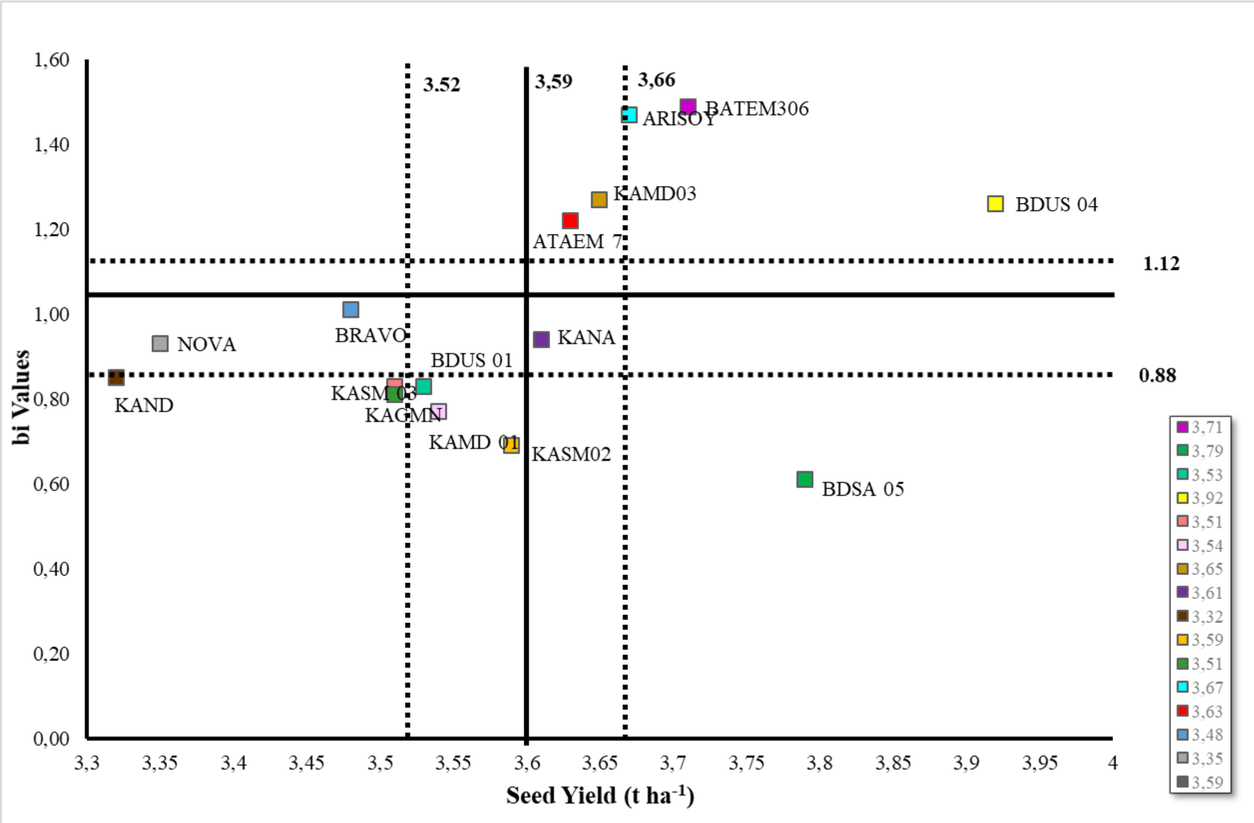

Figure 1. The mean seed yield of soybean genotypes and adaptation situations in terms of regression coefficient

Relationship among seed yield and stability parameters

The correlations between seed yield and stability parameters are presented in Table 6. Seed yield was significantly correlated with R_i^2 ($P<0.05$), $S_i(3)$ ($P<0.05$), D_i ($P<0.01$), $S_i(6)$ ($P<0.01$), TOP ($P<0.01$) and showed a negative and significant correlation with Pi and RS ($P<0.01$). The coefficient of regression (bi) had positively significant associated with CV_i, α_i, $S_i(3)$ and $S_i(6)$ ($P<0.01$) and with the superiority parameter (TOP) ($P<0.05$). Coefficient of determination (R_i^2) had negative and significant correlations with W_i^2, σ_i^2, P59 ($P<0.05$) and with λ_i, P_i, $S_i(2)$, RS ($P<0.01$). Ecovalance (W_i^2) was positively associated with CV_i ($P<0.05$), σ_i^2 ($P<0.01$), P59 ($P<0.01$), λ_i ($P<0.01$), $S_i(2)$ ($P<0.01$), $S_i(3)$ ($P<0.05$), and RS ($P<0.05$). Stability variance (σ_i^2) had positive and significant correlations with P59, λ_i, $S_i(2)$ ($P<0.01$), $S_i(3)$ and RS ($P<0.05$). P59 is significantly correlated with λ_i ($P<0.01$), $S_i(2)$ ($P<0.01$), $S_i(3)$ ($P<0.05$) and RS ($P<0.05$). Desirability index (D_i^2) had negative and significant correlations with P_i and RS ($P<0.01$). Desirability index (D_i^2) had negatively significant correlations with P_i and RS ($P<0.01$). Alpha (α_i) is significantly associated with $S_i(3)$ ($P<0.01$), $S_i(6)$ ($P<0.01$) and TOP ($P<0.05$). Lamda (λ_i) had positive and significant correlations with P_i ($P<0.05$), $S_i(2)$ and RS ($P<0.01$). The superiority index (P_i) was negatively correlated with $S_i(6)$ and TOP ($P<0.01$) and positively associated with RS ($P<0.01$). A non-parametric stability method, $S_i(2)$ was significantly correlated with RS ($P<0.01$), only. One other non-parametric method, $S_i(3)$ had positive and significant correlations with $S_i(6)$ ($P<0.01$) and TOP ($P<0.05$). $S_i(6)$ parameter were positively associated with TOP ($P<0.01$). Finally, TOP was negatively significant correlated with RS ($P<0.05$).

Table 6. Relationships between seed yields, parametric and non-parametric stability parameters for 15 soybean genotype

Measure	X	b_i	R_i^2	W_i^2	CV_i	σ_i^2	P59	D_i^2	α_i	λ_i	P_i
b_i	0.390										
R_i^2	0.574*	0.431									
W_i^2	-0.055	0.332	-0.511*								
CV_i	0.147	0.941**	0.141	0.523*							
σ_i^2	-0.055	0.332	-0.511*	1.000**	0.524*						
P59	-0.055	0.332	-0.511*	1.000**	0.524*	1.000**					
D_i	0.835**	-0.178	0.362	-0.267	-0.412	-0.267	-0.267				
α_i	0.397	0.994**	0.415	0.349	0.950**	0.349	0.349	-0.174			
λ_i	-0.426	-0.056	-0.885**	0.753**	0.231	0.753**	0.753**	-0.427	-0.044		
P_i	0.961**	-0.361	-0.668**	0.150	-0.115	0.150	0.149	-0.803**	-0.377	0.510*	
$S_i(2)$	-0.350	0.084	-0.716**	0.829**	0.323	0.829**	0.829**	-0.426	0.094	0.763**	0.463
$S_i(3)$	0.517*	0.710**	0.088	0.587*	0.704**	0.587*	0.587*	0.117	0.731**	0.202	-0.453
$S_i(6)$	0.805**	0.660**	0.336	0.309	0.543*	0.309	0.309	0.455	0.683**	-0.126	-0.724**
TOP	0.731**	0.532*	0.401	-0.134	0.388	-0.134	-0.134	0.453	0.557*	-0.315	-0.697**
RS	0.759**	-0.138	-0.808**	0.629*	0.172	0.629*	0.629*	-0.735**	-0.127	0.812**	0.794**

X: mean seed yield (t ha^{-1}), b_i: regression coefficient, R_i^2: coefficients of determination, W_i^2: ecovalance, S_i^2: environmental variance, CV_i: coefficient of var
component for pair-wise GEI, D_i^2 : desirability index, α_i: environmental effects, λ_i: deviation from the linear response, P_i: superiority index, $S_i(2)$, $S_i(3)$, $S_i($
parameter, RS: rank-sum

DISCUSSION

The coefficient of variation (CV) determined as 11.9% in the combined variance analysis for seed yield revealed the reliability of the model for the GEI. Carvalho et al. (2003) reported that a maximum variation coefficient of 16% can be proposed for seed yield under field conditions.

The GEI sum of squares is about 4.5 times larger than the genotype sum of squares. This suggested that the genotypes had differently response across environments in terms of grain yield. The significance of the GEI effect suggests that there are significant differences in responses of genotypes to environments, and hence sensitivity and instability (Akcura et al., 2009). In addition, Radi et al. (1993) found large magnitude of GEI and concluded that the soybean genotypes fluctuated in the rank performance for seed yield across the tested environments. As partly different from our findings, Morsy et al. (2015) found that 61.8% of the total sum of squares was attributed to GEI whereas the environment and genotype sources of variation were 12.0% and 11.5%, respectively. They reported that there were substantial differences in genotypic response across environments which advocated the adequacy of running stability analysis.

Parametric stability components

The genotypes examined within the scope of the research showed significant differences in terms of seed yield. The genotypes BDUS 04, BDSA 05, BATEM 306, KAMD 03, KANA, ARISOY and ATAEM 07 had the highest seed yields when considering the mean seed yields of the genotypes over the environments, whereas the lowest seed yields were obtained from KAND and NOVA genotypes (Table 4). Our findings were consistent with the results reported by Chandrakar et al. (1998), Rao et al. (2002), Ramana and Satyanarayana (2005), Gurmu et al. (2009) and Chaudhary and Wu (2012).

According to Eberhart and Russell (1966), regression coefficients (b_i) approximating 1.0 coupled with deviation from regression (S^2_{di}) of zero indicate average stability. For Eberhart and Russell (1966) the ideal genotype is one that has high average yield, regression coefficient equal to the unit (b=1), and deviation regression the lowest possible. If the regression coefficient (b value) is not significantly different from unity, the genotype is considered adapted to all environments. Also, the genotype that has significant b value greater than one is more responsive to high yielding environments, whereas any genotype with significant b value less than one is adapted to low yielding environments (Morsy et al., 2015). In addition, it is generally accepted that genotypes with high average yield are good adapted to the tested environments whereas genotypes with low average yield are poorly adapted to the environments.

The genotypes KANA, BDUS 01, KAGMN, KAND, BRAVO and NOVA had regression coefficients near to 1.0 for seed yield. Therefore, these genotypes were considered as stable in response to all environments. However, it was revealed that the genotypes BDUS 01, KANA and KAGMN having seed yields near to average yield were moderately adapted to all environments, whereas the genotypes KAND, BRAVO and NOVA having lower seed yields than average were poorly adapted to all environments (Fig. 1). Our findings correspond to that of Tadesse et al. (1997), Hossain et al. (2003), Oliveira et al. (2012), El-Refaey et al. (2013), Morsy et al. (2015) and Ilker et al. (2018), who reported that some cultivars had high yields under favourable environments, while others adapted to poor environments. In addition, the current results are supported the conclusion of Yothasiri and Somwang (2000), Primomo et al. (2002) and Olievira et al. (2012) who reported that genotypes with higher stability or good adaptability in a wide range of environment were found for seed yield.

All of the values of coefficient of determination estimated were not significantly different from 1.0. Pinthus (1973) used the coefficient of determination as a stability parameter and assumed that the genotypes having the coefficient of determination near to 1 were stable. In fact, it is necessary to evaluate the stability states of genotypes with a coefficient of determination near to 1, according to whether the b values are equal to or less/highest than 1. Thus, in our study, stability states of the genotypes determined according to Eberhart and Russell's (1966) regression coefficients (b_i) were verified by Pinthus's (1973) coefficient of determination (R_i^2) too. It was found that the coefficients of determination were lower than 70%, in which this percentage is a reference for the regression to satisfactorily explain the behavior of the genotype according to the environment (Cruz et al., 2006). In a previous study, it was reported that the some genotypes were adapted to favourable environments since values of coefficient of regression were greater than the unit (b > 1), and the coefficient of determination higher than 70% (Oleivera et al., 2012). On the other hand, Silveira et al. (2016) reported that the coefficient of determination values obtained for the cultivars, except for SYN 9070, were considerably lower, thus justifying the use of adaptability analysis methods and more refined stability for decomposition of the GEI.

Wricke (1962) suggested the use of ecovalance (W_i^2) as a stability parameter. The genotypes with the smallest ecovalance (W_i^2) values are considered as stable (Wricke, 1962). Genotypes KASM 02, KASM 03, BDUS 04, KAMD 03, NOVA, BRAVO, BDSA 05, KAMD 01 and KANA were regarded as stable genotypes according to Wricke's (1962) ecovalance (W_i^2) parameter. According to Francis and Kannenberg (1978), genotypes exhibiting low environmental variance (S_i^2) and coefficient of variation (CV_i) are considered as stable (Lin et al., 1986). Accordingly, the BDSA 05, KASM 02, KASM 03 and KAMD 01 genotypes having both lower environmental variance and lower coefficient of variation values could be considered as stable.

The stability method of Shukla (1972) was used as a stability parameter in the current study. An unbiased estimate using stability variance (σ_i^2) of genotypes was determined according to Shukla (1972). It was considered that the genotypes KASM 02, KASM 03, BDUS 04, KAMD 03, NOVA, BRAVO, KAMD 01 and BDSA 05 were stable while the genotypes BATEM 306, ARISOY, BDUS 01, KAND and ATAEM 07 were unstable. In fact, no one of the genotypes had statistically significant stability variance (σ_i^2). Contrary to our findings, Morsy et al. (2015) noted that concerning stability-variance method of Shukla (1972), that no one of the tested genotypes were to be stable because they had highly significant σ^2 values. The same researchers explained that although the 12 genotypes had highly significant values of σ^2 (unstable based on Shukla model), they were stable considering YS statistic due to their high yields.

According to Plaisted and Peterson (1959) when a genotype have the small values in terms of mean variance component for a pair-wise genotype-environment interaction (P59), it can be considered to be stable genotype. Thus, the stability parameter, P59 of Plaisted and Peterson (1959) revealed that the genotypes KASM 02, KASM 03, BDUS 04, KAMD 03 and NOVA had lower P59 values and could be considered as stable genotypes. However, the genotypes BDUS 01, BATEM 306, ARISOY, KAND and ATAEM 07 with the highest P59 values were determined to be unstable.

According to the significance tests, there were not significant D_i^2 values of the genotypes. Considering the desirability index of Hernandez (1993), it can be assumed that all genotypes are stable. The two components were defined as genotypic stability parameters by Tai (1971). The first statistic in them is α that measure the linear response of environmental effects while the second one is λ that reflects the deviation from linear response in terms of magnitude of the error variance. In our study, none of the genotypes showed above average stability. In a similar study, Morsy et al. (2015) reported that 17 soybean genotypes out of 26 were spotted in the average stability area (P = 0.99) while only one genotype (H4L24) had degree of low average stability. Similar results were obtained by Al-Assily et al. (1996) and Morsy et al. (2012). Our results were compatible with those of previous studies given above.

Non-Parametric Stability Components

Nassar and Huhn's (1987) rank stability method, $S_i(2)$ are based on ranks of genotypes across environments and they give equal weight to each environment. Genotypes with fewer changes in ranking are considered to be more stable (Becker and Leon, 1988). Nassar and Huhn's (1987) two other non-parametric stability statistics [$S_i(3)$ and $S_i(6)$] combine yield and stability based on yield ranks of genotypes in each environment. Fox et al. (1990) proposed a superiority parameter (TOP) method which is a non-parametric stability method obtained with the rate of first three ranks in each environment according to performance order of genotypes tested in different environments to reveal their genotypic stability. Genotypes with a TOP value close to 100 are the most stable genotypes, and the high TOP value also indicates the general adaptability of a genotype (Fox et al., 1990). Kang (1988) noted that genotype with a low rank-sum are regarded as the most desirable genotype. Similar findings were obtained by Kılıç and Yagbasanlar (2010), who conducted their studies on durum wheat. Piepho and Lotito (1992) reported that the non-parametric models of stability would be used only when the necessary assumptions for the parametric stability models are violated.

Relationship among seed yield and stability parameters

When the results of correlation analysis were evaluated, it was seen that between seed yield and many stability parameters were also significant relations as well as to be between each of these parameters. Especially, the strong linear correlations between regression coefficient (b_i) and CV_i, α_i, $S_i(3)$ and $S_i(6)$ and (TOP) parameters shows that these parameters give parallel results to each other. According to Oliveira et al. (2003), the correlation between the estimates of parameters of adaptability and/or stability contributes to better predict the behavior of the evaluated genotypes. Oleivera et al. (2012) reported that comparing the four methods used in their study, there was an agreement the classification of the strain LG 4 for greater adaptability and stability in a favourable environment. Morsy et al. (2012) found high positive correlation coefficient (0.97**) between mean seed yield and YS indicating that using YS as a stability parameter may not provide more information than the mean seed yield itself.

CONCLUSION

This study has provided evaluation of the environmental and agronomic performance of certain soybean genotypes. For this, adaptation - stability cases of genotypes were examined comparatively using different 11 parametric and 5 non-parametric stability analysis methods.

Genotypes, environments and genotype by environment interactions (GEI) played a significant role in terms of seed yield in this study. When considering the mean seed yields of the genotypes over the environments, it was determined that genotypes BDUS 04, BDSA 05, BATEM 306, KAMD 03, KANA, ARISOY and ATAEM 07 had the highest seed yields, whereas the lowest seed yields were obtained from KAND and NOVA genotypes. According to most of parametric and non parametric stability methods, BDUS 04, KASM 02, KASM 03, KAMD 03 and BDSA 05 genotypes were determined to be stable genotypes. These genotypes were demonstrated superior adaptability with high yield performances in many environments. According to Eberhart and Russell (1978), genotypes KAMD 03, BATEM 306, BDUS 04, ARISOY and ATAEM 07 had higher seed yields and regression coefficient values above 1.0. These genotypes are sensitive to environmental variations and would be suggested for cultivation under favourable conditions, whereas KAMD 01, KASM 02 and KASM 03 with $b_i<1$ and lowest average yields were poorly adapted across unfavourable environment conditions. The genotype

BDSA 05 having regression coefficient below 1.0 and higher seed yield than average yield were goodly adapted to unfavourable environment conditions.

Results of correlation analysis indicated that seed yield was significantly correlated with R_i^2 ($P<0.05$), $S_i(3)$ ($P<0.05$), D_i ($P<0.01$), $S_i(6)$ ($P<0.01$), TOP ($P<0.01$) and showed a negative and significant correlation with P_i and RS ($P<0.01$). In addition, the coefficient of regression (b_i) had positively significant associated with CV_i, α_i, $S_i(3)$ and $S_i(6)$ ($P<0.01$) and with the superiority parameter (TOP) ($P<0.05$).

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