



Comparison of Non-parametric Stability Statistics for Selecting Stable and Adapted Soybean Genotypes under Different Environments

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The objectives of this study were to investigate the comparison among non-parametric stability statistics and to evaluate seed yield stability of the sixteen soybean genotypes across four locations during the 2016, 2017 and 2018 growing seasons in Egypt. All trials were laid down in a randomized complete block design (RCBD) with three replications. The AMMI analysis showed a highly significant effect of genotype (G), environment (E) and G x E interaction (GEI). The major contributions to treatment sum of squares were GEI, followed by G and E. The AMMI analysis also partitioned the total GEI component into eleven PCAs and Residual. The first eight PCAs were highly significant and accounted for about 99.56% of the total GEI. Based on the static and dynamic concepts, the results of Spearman's rank correlation and PCA showed that stability measures could be classified into three groups. The non-parametric stability statistics i.e., YS_i , KR , TOP , RSM and δ_{gy} related to the dynamic concept and strongly correlated with mean seed soybean yield of stability. While, the other non-parametric stability statistics ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$, $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$, δ_r , MID , LOW) represented the concept of static stability, which were influenced simultaneously by both yield and stability. The non-parametric stability statistics in each the groups I, II, and III were positively and significantly correlated with each other, thus; any of these

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parameters could be considered as appropriate alternatives for each other. According to cluster analysis, soybean genotypes G6, G4, G8, G11, G9, G1, G7 and G2 were more stable varieties on the basis of mean seed yield and non-parametric stability statistics. In conclusion, both yield and stability should be considered simultaneously to exploit the useful effect of GEI and to make the selection of genotypes more precise and refined. Thus, the YS_i , KR , TOP , RSM and δgy were more useful statistics in soybean breeding programmes and could be useful alternatives to parametric stability statistics. According to most non-parametric stability statistics, the genotypes G6 and G11 were more stable coupled with high seed yield; therefore, these genotypes might be used for genetic improvement of soybean and they must be released in studied regions and other regions in Egypt.

Keywords: Comparison; non-parametric stability statistics; multi-environment; seed yield; soybean.

1. INTRODUCTION

Major goal of plant breeding programs is to increase stability and stabilize crop yield over a range of environments. The improved genotypes are evaluated in multi-environment trials to test their performance across different environments. Seed yield is a quantitative trait, whose expression is the result of genotype, environment and genotype x environment interaction [1]. Genotype x environment interaction (GEI) is of major importance to the plant breeder in developing improved varieties. When varieties are compared over a series of environments, the relative rankings usually differ [2]. GEI is a major problem when comparing the performance of genotypes across environments [3]. The study of the GEI may assist in the understanding of stability concept. Understanding the structure and nature of GEI is important in plant breeding programs because a high GEI value can seriously impair efforts in selecting superior genotypes relative to new crop introductions and cultivar development programs. It can help determine if they need to develop cultivars for all target environments or if they should develop specific cultivars for specific target environments. GEI occurs when the performance of the genotypes is not consistent from one environment to another. A high GEI value of quantitative trait such as grain yield can reduce the correlation between phenotype and genotype, and decrease progress in selection [4]. The basic cause of differences between genotypes in their yield stability is the wide range of GEI, i.e. the ranking of genotypes depends on the particular environmental conditions where they are grown. When discussing these unexpected variations in yield the term "phenotypic stability" is often used to refer to fluctuations in the phenotypic expression of yield while the genotypic composition of the varieties or populations remains stable.

The occurrence of GEI has led to the development of several stability parameters that can be used to estimate the stability of cultivar performance. Romagosa and Fox [5] and Huehn [6] indicated that there are two major approaches for studying GEI to determine the adaptation of genotypes. First, is the parametric (empirical and statistical) approach, which is more common and based on statistical assumptions about the distribution of genotype, environment and GEI effects. Second, is the nonparametric (analytical clustering) approach, which does not need any assumptions when relating to environment and phenotypic relative to biotic and abiotic environmental factors. Although several models for the statistical measurement of stability have been proposed, no single method adequately explains genotypic performance across environments. For practical applications, however, most breeding programs are now incorporating some elements of both parametric and non-parametric approaches [7].

Various methods use GEI to facilitate genotype characterization, and as a selection index together with the mean yield of the genotypes. Accordingly, genotypes (both high and low yielding) with minimal variance for yield across environments are considered stable. This may be regarded as a biological or static concept of stability [8]. This concept of stability is not acceptable to most of plant breeders and agronomists, who prefer genotypes with high mean yields and having the potential of response to agronomic inputs or better environmental conditions. The high yield performance of released cultivars is one of the most important targets of breeders; therefore, they prefer a dynamic (agronomical) concept of stability [7]. In dynamic stability, a genotype changes in a predictable manner across a wide range of environmental conditions [8].

Recently, there has been an increased interest in using nonparametric statistics in different agriculture-related disciplines as they provide a method to determine relative stability. Since Huehn [9] study on nonparametric statistics, numerous studies have used nonparametric statistics to analyze GE interactions in plant breeding trials (even for ratio scales including yield performance). Nonparametric statistics can be used for either ordinal or ratio scales. Nonparametric measures for stability based on ranks provide a viable alternative to existing parametric measures based on absolute data [10]. For many applications, including selection in breeding and testing programs, the rank orders of the genotypes are the most essential information. There is ample justification for the use of non-parametric measures in the assessment of yield stability of crop varieties. The main advantages include as follows; (i) Assumptions about the distribution of phenotypic observations are unnecessary, (ii) Sensitivity to measurement errors or to outliers is less than the parametric measures, (iii) Additions or deletions of one or a few genotypes do not cause distortions to nonparametric measures, (iv) Most of the time, the breeder, is concerned with crossover interaction; an estimate of stability based on rank information, therefore, seems more relevant and (v) These measures are particularly useful in situations where parametric measures fail due to large non-linear GEI [6,11,12]. Several non-parametric methods proposed by Huhn [9], Nassar and Huehn [10], Kang [13], Ketata et al. [14], Fox et al. [15] and Thennarasu [12] are based on the ranks of

genotypes in each environment and genotypes with similar ranking across environments are classified as stable. The objectives of this study include; 1) to analyze GEI 2) to identify promising high-yielding and stable genotypes across different environments and 3) to study the relationships, similarities and dissimilarities among the non-parametric stability statistics on grain yield of soybean in Egypt.

2. MATERIALS AND METHODS

2.1 Genetic Material and Experimental Design

In order to evaluate seed yield stability of soybean and comparison among the non-parametric stability methods under four different locations sixteen genotypes were used as experimental material. The names, origin and genotypic codes of these genotypes are given in Table 1. The trials were conducted at Sakha, Etay El-Baroud, Sids and Mallawy locations, Egypt for three cropping seasons (2016, 2017 and 2018). All experiments were arranged in a randomized complete-block design with three replications. Each replication consisted of sixteen plots (genotypes). Each plot comprised of three rows with 3m long, 70 cm distances among rows and 20 cm distance among plants. All the recommended cultural practices of soybean production in the area were done as usually. During harvest seed yield was measured per plot for each genotype for each test experiment in kilograms/plot and converted to tonnes/feddan for the statistical analyses.

Table 1. List of sixteen genotypes of soybean used in this study

Genotype code	Name	Pedigree	Origin
G1	H1L3	H20L3 X Gassoy17	Field Corps Res. Institute (FCRI)
G2	H4L4	Dr101 X Lamar	FCRI
G3	H6L198	Toano X Nena	FCRI
G4	H18L270	Crowford X Dekabig	FCRI
G5	H18L34	Crowford X Dekabig	FCRI
G6	H18L48	Crowford X Dekabig	FCRI
G7	H18L54	Crowford X Dekabig	FCRI
G8	H18L69	Crowford X Dekabig	FCRI
G9	H10L288	N92-831 X Giza111	FCRI
G10	H11L384	Giza111 X Hc83-123-9	FCRI
G11	H15L270	Pershing X Giza111	FCRI
G12	H170L1	H113 X L105	FCRI
G13	H170L2	H113 X L105	FCRI
G14	H171	Giza21 X L154	FCRI
G15	Giza111	Crawford X Celest	FCRI
G16	Crawford	Williams X Columbus	United States American

2.2 Statistical Analysis and Procedures

Combined analysis of variance was done on grain yield in twelve different environments (in four locations and a period of three years). A combined ANOVA was conducted to determine the effects of genotype (G), environment (E) and GxE interactions (GEI). The Additive Main Effects and Multiplicative Interaction Model (AMMI) was used [16] to analyze the GEI and to adjust the main or additive genotype and environmental effects by analysis of variance, in addition to the adjustment of the multiplicative impacts for the GEI by principal component analysis. Statistical tests of significance for these factors were determined using F-tests. Sixteen non-parametric statistics were chosen to cover a wide range of philosophies of stability analysis. The non-parametric statistical methods adopted for the stability analysis of the genotypes were $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$ by Huehn [9], Nassar and Huehn [10], *RSM* by Kang [13], δr , δgy and *KR* by Ketata et al. [14], *TOP*, *MID* and *LOW* by Fox et al. [15], YS_i by Kang [13] and $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ by Thennarasu [12]. Spearman's rank correlation coefficients, principal component analysis (PCA) and cluster analysis were performed for a better understanding of the relationships among all possible pair-wise comparisons of grain yield and the parametric stability statistics. For statistical analysis the software's PAST version 2.17c, SPSS and PBSTAT-GE 2.7 were used.

3. RESULTS AND DISCUSSION

3.1 AMMI Anova

The analysis of variance according to the AMMI model of sixteen soybean genotypes tested in twelve environments (four locations and period of three years) showed highly significant differences ($P < 0.01$) among genotypes (G), environment (E) and GxE interaction (GEI) for seed yield/fed (Table 2). From the total sum of squares, the sum of square for GEI had the highest component (41.53%), followed by sum of squares for genotypes (38.14%) and environments (16.86%), indicating that there were substantial differences in genotypic response across environments. The high GEI value for seed yield suggests that some genotypes were not stable, whereas others were stable across environments. These results indicating the presence of variability among these components justify the use of stability statistics for the identification of stable genotypes

with superior seed yield of soybean under the various environments. Maia et al. [17], Yokomizo et al. [18] and Freiria et al. [19] analyzed the adaptability and stability of soybean genotypes and found that the mean squares of G, E and GEI were significant ($p \leq 0.01$). Therefore, the environments evaluated were distinct and the soybean genotypes presented a differentiated performance in response to environmental variations. The GEI component was partitioned into eleven PCs (Table 1). The first eight of interaction of principal component axes (PC1-PC8) were highly significant ($p < 0.01$) and obtained about 99.56% and 87.27% from the sum of square and the degree of freedom for GEI, respectively. A high significance ($p < 0.01$) was observed in the first two and four principal axes in soybean by Yokomizo et al. [18] and Freiria et al. [19], respectively. The values of the first two axes explained the range of 53 to 61 % of the variance in GEI [17,18,19]. The PC1 had higher value than other components, followed by PC2 and PC3 with 49.64%, 23.96% and 13.99, respectively, which cumulatively contributed to 87.59% of the total GEI, indicating the effective partition of the variability with AMMI model. Freiria et al. [19] observed that the first three principal axis accounted for 31.80%, 28.90% and 16.00 of the pattern associated with the GE interaction, respectively. Baker [20] and Crossa [21] elaborated that only qualitative or crossover interactions are relevant in agriculture, and appropriate statistical analysis is required to quantify them. To detect the relative stability of genotypes, the analysis of stability is necessary by applying either parametric or nonparametric methods or both. Thus, better understanding of the relative contribution of cultivars, environments and their interaction as a source of variation could potentially help breeders to develop cultivars with more stable performance [22].

3.2 Genotypic Mean Performance

In Egypt, selecting soybean genotypes for both high seed yield and popping expansion is very important as well as their integration with stability and adaptability in the different environments. The mean performances of seed yield (ton/fed) of sixteen soybean genotypes across twelve environments are given in Table 3. The average environmental seed yield at sixteen genotypes in twelve environments ranged from lowest at 1.19 ton/fed in Etay El-Baroud 2016 to the highest at 1.61 ton/fed in Mallawy 2016. During the three years, Mallawi location recorded highest seed yield, followed by Sakha, Sids and Etay El-

Baroud with 1.56, 1.48, 1.33 and 1.22 ton/fed., respectively. G6, G1, G8 and G14 gave the highest seed soybean yields averaging 1.87, 1.68, 1.99 and 1.83 ton/fed., in Sakha, Etay El-Baroud, Sids, Malloway locations, respectively. Most studied genotypes had higher grain yield than grand means under twelve environments. Values of environmental index varied between -0.21 at Etay El-Baroud 2016 to 0.21 at Malloway 2016 across twelve different environments. Consistent performances across different locations and/or years are referred to as yield stability [23]. This differential yield ranking of genotypes across the environments showed that the $G \times E$ interaction effect was of the crossover type [24].

3.3 Stability Parameters

Stability analyses were conducted using different non-parametric stability statistics. The mean grain yield and the non-parametric stability statistics are shown in Table 4. Based on the nonparametric stability statistics i.e. $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$, δr , δgy , KR and RSM , the genotypes with fewer changes (low values) in ranking were considered to be more stable than the others under different environments. On the other hand, the highest values of Y_i , YS_i and TOP , indicated that the genotype's performance was more stable across environments. Sixteen genotypes showed significant differences in seed soybean yield. The mean seed yield of sixteen genotypes across twelve environments ranged from the lowest at 1.05 ton/fed. to the highest at 1.64 and

the grand mean seed yield was 1.40 ton/fed. Nine genotypes had higher seed yield than grand mean seed yield. According to seed yield (Y_i) and Kang's yield and stability index (YS_i), the genotypes namely; G6, G11, G9 and G1 recorded the highest values and represented the most stable genotypes compared to the G13 and G16 genotypes.

According to Nassar and Huehn [10], the values of $Z_i^{(1)}$ and $Z_i^{(2)}$ were obtained on basis of the rank of the corrected data and summed over genotypes to obtain the two overall chi-square stabilities [$\text{Sum}(Z_i^{(1)})=36.97$ and $\text{Sum}(Z_i^{(2)})=45.10$]. The two overall chi-square stabilities were higher than the tabulated chi-square (χ^2 , $df=16$; $0.05=26.30$ and $0.01=32.00$), thus there was sufficient evidence for highly significant differences in stability among the sixteen genotypes across twelve environments. Based on the statistics $S_i^{(1)}$ and $S_i^{(2)}$ [10] and $NP_i^{(1)}$ [12], the genotypes G15, G11, G3 and G9 were considered stable in comparison to the other genotypes, because these genotypes had lower values than these parameters. The genotypes G14 and G13 on the other hand were unstable according to $S_i^{(1)}$, $S_i^{(2)}$ and $NP_i^{(1)}$ statistics. Genotypes G3, G2, G3 and G16 were the most stable genotypes based on both the two non-parametric stability statistics of Huehn [9] known as $S_i^{(3)}$ and $S_i^{(6)}$. However, the G6 and G8 for $S_i^{(3)}$ and $S_i^{(6)}$, the G9 for $S_i^{(3)}$ and the G1 for $S_i^{(6)}$ had the highest values and unstable.

Table 2. Combined ANOVA with AMMI analysis for grain yield of 16 genotypes tested under 12 different environments

Source of variation	df	Sum of squares (SS)	Mean squares	SS%
Environments (E)	11	10.59	0.96**	16.86
Replications (E)	24	0.17	0.01 ^{ns}	0.28
Genotypes (G)	15	23.96	1.60**	38.14
G x E	165	26.09	0.16**	41.53
PC1	25	12.95	0.52**	49.64
PC2	23	6.25	0.27**	23.96
PC3	21	3.65	0.17**	13.99
PC4	19	1.36	0.07**	5.22
PC5	17	0.97	0.06**	3.73
PC6	15	0.30	0.02**	1.16
PC7	13	0.27	0.02**	1.02
PC8	11	0.22	0.02**	0.84
PC9	9	0.07	0.01 ^{ns}	0.27
PC10	7	0.04	0.01 ^{ns}	0.17
PC11	5	0.00	0.00 ^{ns}	0.01
Residuals	360	2.01	0.01	3.20
Total	575	62.81		

C. V. % = 5.34%; ns, not significant, * and ** significant at the 0.05 and 0.01 probability level, respectively

Table 3. Mean grain yield and environmental index (E.I.) values of sixteen soybean genotypes tested in four locations and three seasons

Environments genotypes	Sakha				Etay El-Baroud				Sids				Mallawy			
	2016	2017	2018	Mean	2016	2017	2018	Mean	2016	2017	2018	Mean	2016	2017	2018	Mean
G1	1.59	1.50	1.76	1.62	1.53	1.86	1.64	1.68	1.59	1.58	1.58	1.58	1.57	1.44	1.51	1.51
G2	1.44	1.65	1.66	1.58	1.56	1.62	1.60	1.59	1.25	1.30	1.33	1.29	1.61	1.81	1.64	1.69
G3	1.60	1.51	1.59	1.57	1.34	1.07	1.25	1.22	1.50	1.48	1.42	1.47	1.44	1.41	1.64	1.50
G4	1.64	1.68	1.72	1.68	1.00	1.15	1.20	1.12	1.61	1.84	1.70	1.72	1.63	1.33	1.42	1.46
G5	1.31	1.33	1.40	1.35	0.90	0.84	0.88	0.87	1.30	1.00	1.20	1.17	1.71	1.37	1.64	1.57
G6	1.85	1.90	1.87	1.87	1.34	1.37	1.24	1.32	1.85	1.87	1.90	1.87	1.60	1.68	1.24	1.51
G7	1.75	1.68	1.70	1.71	1.55	1.46	1.49	1.50	1.38	1.32	1.30	1.33	1.58	1.53	1.82	1.64
G8	1.50	1.31	1.61	1.47	1.21	1.39	1.49	1.36	1.96	2.07	1.95	1.99	1.46	1.34	1.55	1.45
G9	1.71	1.63	1.74	1.69	1.44	1.41	1.67	1.51	1.59	1.46	1.77	1.61	1.68	1.32	1.79	1.60
G10	1.62	1.67	1.66	1.65	1.05	1.10	1.08	1.08	1.30	1.24	1.29	1.28	1.40	1.41	1.35	1.39
G11	1.83	1.75	1.71	1.76	1.63	1.58	1.51	1.57	1.51	1.54	1.47	1.51	1.61	1.77	1.67	1.68
G12	0.82	0.80	0.62	0.75	1.13	1.16	1.10	1.13	0.93	1.03	0.98	0.98	1.83	1.46	1.71	1.67
G13	1.20	1.25	1.48	1.31	0.56	0.98	0.80	0.78	0.63	0.59	0.60	0.61	1.67	1.34	1.45	1.49
G14	1.50	1.50	1.65	1.55	0.85	0.92	0.78	0.85	1.01	0.91	0.95	0.96	1.96	1.91	1.62	1.83
G15	1.24	1.27	1.26	1.26	1.00	1.12	1.05	1.06	0.99	1.01	1.02	1.01	1.42	1.59	1.38	1.46
G16	0.83	0.97	0.90	0.90	0.95	0.87	0.95	0.92	0.84	0.80	0.88	0.84	1.55	1.51	1.66	1.57
Grand mean	1.46	1.46	1.52	1.48	1.19	1.24	1.23	1.22	1.33	1.32	1.33	1.33	1.61	1.51	1.57	1.56
E.I	0.07	0.06	0.12	0.08	-0.21	-0.15	-0.17	-0.18	-0.07	-0.08	-0.06	-0.07	0.21	0.12	0.17	0.17
LSD 0.05	0.12	0.13	0.06		0.07	0.09	0.08		0.11	0.12	0.09		0.09	0.13	0.12	
LSD 0.01	0.16	0.17	0.08		0.09	0.12	0.11		0.14	0.16	0.12		0.12	0.17	0.16	
CV%	5.89	6.45	2.90		3.97	5.36	4.84		5.85	6.45	4.85		4.24	6.37	5.38	
P-value	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00	

Table 4. Mean grain yield (Y) and non-parametric stability statistics for sixteen soybean genotypes tested in twelve environments

Methods genotypes	Y_i	YS_i	$S_i^{(1)}$	$Z_i^{(1)}$	$S_i^{(2)}$	$Z_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	TOP	MID	BOT	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	δr	δgy	KR	RSM
G1	1.60	8.00+	5.71	0.25	24.57	0.30	23.84	6.34	58.33	25.00	16.67	4.08	0.86	0.81	0.97	3.59	0.12	5.83	13
G2	1.54	5.00+	5.74	0.29	23.72	0.17	19.70	5.29	33.33	50.00	16.67	3.92	0.54	0.73	0.90	3.37	0.17	6.33	15
G3	1.44	2.00+	3.91	3.07	10.97	2.89	8.41	3.02	0.00	66.67	33.33	2.83	0.39	0.36	0.45	2.61	0.16	8.67	12
G4	1.49	4.00+	5.89	0.53	25.54	0.50	27.52	6.09	50.00	25.00	25.00	4.42	0.80	0.68	0.83	4.21	0.27	7.08	18
G5	1.24	-6.00	4.61	0.78	15.06	1.05	12.82	2.77	8.33	16.67	75.00	3.17	0.26	0.33	0.41	3.64	0.29	11.17	18
G6	1.64	11.00+	6.68	2.92	33.54	4.13	46.15	8.71	58.33	33.33	8.33	5.25	1.75	1.13	1.36	4.54	0.27	4.92	13
G7	1.55	6.00+	4.30	1.59	13.24	1.75	14.85	4.84	50.00	50.00	0.00	3.00	0.55	0.62	0.77	2.75	0.17	5.58	10
G8	1.57	7.00+	6.73	3.12	35.52	5.56	31.51	6.04	25.00	50.00	25.00	4.67	0.55	0.75	0.89	4.66	0.28	7.58	20
G9	1.60	9.00+	4.05	2.50	13.72	1.55	32.01	5.71	75.00	16.67	8.33	2.42	0.57	0.69	0.79	3.86	0.16	5.17	10
G10	1.35	-3.00	4.44	1.19	15.66	0.85	11.28	2.56	8.33	58.33	33.33	2.92	0.29	0.38	0.44	3.22	0.22	10.00	15
G11	1.63	10.00+	3.91	3.07	10.70	3.04	11.00	4.69	75.00	25.00	0.00	2.67	0.67	0.77	0.96	2.02	0.12	4.08	4
G12	1.13	-8.00	6.59	2.55	32.75	3.61	24.10	4.38	16.67	33.33	50.00	4.75	0.45	0.52	0.63	4.80	0.37	10.50	30
G13	1.05	-10.00	6.94	4.13	36.82	6.62	7.78	1.85	8.33	0.00	91.67	5.17	0.37	0.43	0.51	3.09	0.40	13.50	29
G14	1.30	-5.00	7.03	4.60	38.73	8.35	26.39	4.32	16.67	33.33	50.00	5.83	0.53	0.57	0.67	5.00	0.44	10.42	25
G15	1.20	-7.00	3.38	5.83	8.75	4.27	6.03	1.57	8.33	8.33	83.33	2.25	0.18	0.23	0.28	2.57	0.20	12.08	14
G16	1.06	-9.00	5.91	0.55	25.33	0.46	9.98	2.28	8.33	8.33	83.33	4.17	0.28	0.37	0.46	3.42	0.31	12.92	26
Gran Mean		Sum($Z_i^{(1)}$)		Sum($Z_i^{(2)}$)		E($S_i^{(1)}$)		E($S_i^{(2)}$)		Var($S_i^{(1)}$)		Var($S_i^{(2)}$)		χ^2 table for $Z_i^{(1)}, Z_i^{(2)}$			χ^2 table for Sum ($Z_i^{(1)}, Z_i^{(2)}$)		
1.40		36.97		45.10		5.31		21.25		0.64		36.59		8.73				26.30	

Keys: Y_i : Mean response; YS_i : Kang's yield and stability index; $S_i^{(1)}, S_i^{(2)}, S_i^{(3)}, S_i^{(6)}$: Huehn [9], Nassar and Huehn's [10] nonparametric stability parameters; $Z_i^{(1)}, Z_i^{(2)}$: the Z-statistics are measures of stability for $S_i^{(1)}$ and $S_i^{(2)}$; TOP, MID and LOW: Fox et al. [15] number of sites at which the genotype occurred in the top, middle and bottom third of ranks; $NP_i^{(1)}, NP_i^{(2)}, NP_i^{(3)}, NP_i^{(4)}$: Thenarasu's [12] nonparametric stability parameters; $\delta r, \delta gy, KR$ Ketata et al. [14]; RSM: rank sum method, Kang's [13]

Table 5. Ranks of sixteen genotypes using non-parametric stability statistics in twelve different environments

Methods	Genotypes															
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16
Y_i	4	7	9	8	12	1	6	5	3	10	2	14	16	11	13	15
YS_i	4	7	9	8	12	1	6	5	3	10	2	14	16	11	13	15
$S_i^{(1)}$	7	8	2	9	6	12	4	13	3	5	2	11	14	15	1	10
$S_i^{(2)}$	9	8	3	11	6	13	4	14	5	7	2	12	15	16	1	10
$S_i^{(3)}$	10	9	3	13	7	16	8	14	15	6	5	11	2	12	1	4
$S_i^{(6)}$	15	11	6	14	5	16	10	13	12	4	9	8	2	7	1	3
TOP	3	7	16	5	11	3	5	8	1	11	1	9	11	9	11	11
MID	9	3	1	9	12	6	3	3	12	2	9	6	16	6	14	14
BOT	11	11	7	9	4	13	15	9	13	7	15	5	1	5	2	2
$NP_i^{(1)}$	9	8	4	11	7	15	6	12	2	5	3	13	14	16	1	10
$NP_i^{(2)}$	15	9	6	14	2	16	10	11	12	4	13	7	5	8	1	3
$NP_i^{(3)}$	15	12	3	10	2	16	9	13	11	5	14	7	6	8	1	4
$NP_i^{(4)}$	15	13	4	11	2	16	9	12	10	3	14	7	6	8	1	5
δr	9	7	3	12	10	13	4	14	11	6	1	15	5	16	2	8
δgy	1	3	2	6	8	6	3	7	2	5	1	10	11	12	4	9
KR	5	6	9	7	13	2	4	8	3	10	1	12	16	11	14	15
RSM	4	6	3	7	7	4	2	8	2	6	1	12	11	9	5	10
\bar{R}	8.53	7.94	5.29	9.65	7.41	9.94	6.35	9.94	7.06	6.24	5.59	10.18	9.82	10.59	5.06	8.71
SDR	4.61	2.77	3.79	2.69	3.74	6.02	3.39	3.58	4.97	2.63	5.43	3.09	5.56	3.55	5.44	4.52
RS	13.14	10.71	9.08	12.34	11.15	15.96	9.74	13.52	12.03	8.87	11.02	13.26	15.38	14.14	10.50	13.23

\bar{R} : Rank mean; SDR : Standard deviation of ranks; RS : Rank sum

Table 6. Spearman correlations among grain yield and non-parametric stability ranks for sixteen genotypes across twelve different environments

Parameters	Y_i	YS_i	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	TOP	MID	BOT	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	δr	δgy	KR
YS_i	1.00**															
$S_i^{(1)}$	0.23	0.23														
$S_i^{(2)}$	0.19	0.19	0.99**													
$S_i^{(3)}$	-0.58*	-0.58*	0.42	0.46												
$S_i^{(6)}$	-0.82**	-0.82**	0.18	0.22	0.84**											
TOP	0.82**	0.82**	0.03	0.01	-0.65**	-0.81**										
MID	0.35	0.35	0.04	0.03	-0.25	-0.32	-0.01									
BOT	-0.93**	-0.93**	-0.28	-0.27	0.52*	0.77	-0.84**	-0.43								
$NP_i^{(1)}$	0.18	0.18	0.97**	0.96**	0.43	0.24	0.00	-0.01	-0.23							
$NP_i^{(2)}$	-0.84**	-0.84**	0.15	0.20	0.72**	0.94**	-0.88**	-0.21	0.81**	0.23						
$NP_i^{(3)}$	-0.82**	-0.82**	0.25	0.27	0.68**	0.88**	-0.88**	-0.21	0.78**	0.28	0.94**					
$NP_i^{(4)}$	-0.79**	-0.79**	0.26	0.27	0.65**	0.88**	-0.86**	-0.18	0.76**	0.30	0.94**	0.99**				
δr	-0.04	-0.04	0.72**	0.75**	0.81**	0.46	-0.20	-0.08	-0.05	0.71**	0.30	0.29	0.27			
δgy	0.68**	0.68**	0.78**	0.74**	0.06	-0.36	0.47	0.23	-0.69**	0.73**	-0.41	-0.35	-0.35	0.55*		
KR	0.96**	0.96**	0.27	0.25	-0.55*	-0.80**	0.86**	0.38	-0.98**	0.21	-0.85**	-0.81**	-0.79**	0.01	0.70**	
RSM	0.75**	0.75**	0.75**	0.73**	-0.02	-0.34	0.51*	0.23	-0.76**	0.68**	-0.42	-0.34	-0.32	0.51*	0.90**	0.77**

Using the nonparametric superiority statistics, *TOP*, *MID* and *BOT* [15], the genotypes G11, G9, G6 and G1 were identified as the most stable genotypes because these genotypes were ranked and placed mostly in the top third. While, the genotypes G3, G10, G2, G7 and G8, and the genotypes G13, G15, G16 and G5 occurred in the middle and bottom thirds of the ranks, respectively; thus these genotypes were unstable. According to Thennarasu [12] non-parametric stability statistics, the genotypes G15, G5, G10 and G3 had the lowest values and were therefore considered highly stable according to $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$. On the other hand, the most unstable genotypes according to these statistics were G6 and G1. In respect to the non-parametric stability statistics by Ketata et al. [14], G11 had the minimum values according to δr , δgy and *KR*, followed by the genotypes G15, G3 and G7 using δr , then genotypes G1, G3 and G9 using δgy and the genotypes G6, G9, G7 and G1 using *KR*. Thus these genotypes were the most stable genotypes. According to the δr , δgy and *KR* statistics, the undesirable genotypes were the genotypes G14 and G12 using δr , δgy , and the genotypes G13, G16 and G15 by *KR*. As for rank sum method (*RSM*) by Kang [13], the genotypes G11, G9, G7 and G3 had the lowest values and were considered to be stable genotypes with high yields, unlike the genotypes G12, G13 and G16.

The most stable genotypes based on most non-parametric statistics were G15, G16 and G13 although it had the lowest mean seed yield, unlike G6, G11, G9 and G1. The results showed that based on low values of statistics it is possible to select stable genotypes with low mean yield. This makes the statistics unsuitable for the identification of high yielding stable genotypes [25]. Generally, the genotypes G6, G11, G9 and G1 were most stable with higher seed yield values than other genotypes by three, nine, eight and four statistics out of sixteen non-parametric stability statistics used, respectively. The results of the statistics Y_i , YS_i , *TOP* and *KR*; the statistics $S_i^{(1)}$, $S_i^{(2)}$ and $NP_i^{(1)}$; the statistics $S_i^{(3)}$ and $S_i^{(6)}$; and the statistics $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ were very similar to each other for identification of stable genotypes, although some selected genotypes by most statistics had the lowest minimum mean yield performances. This result corroborates the results obtained by Di Mauro et al. [26] and Manjubala et al. [27] in soybean.

3.4 Ranking Method

According to ranks of sixteen genotypes using the non-parametric stability statistics (Table 5), the ranks of genotypes for Y_i and YS_i were identical. Also, often similar ranks for the genotypes were observed between *KR* with Y_i and YS_i ; $S_i^{(1)}$, $S_i^{(2)}$ and $NP_i^{(1)}$; and $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$, which suggested that these parameters were equal for selecting genotypes, therefore it was sufficient to use one of them. For this reason, it could be considered as appropriate alternatives for each other [28]. In Table 6, the estimates of non-parametric stability statistics displayed that the determination of stable genotypes based on a single statistic was contradictory but different in determining stable genotypes. For example, the genotype G6 was most stable by Y_i , YS_i and *KR*, while it was unstable by most other statistics compared to G13, G15 and G16. To determine the most desirable and stable genotypes according to the all studied statistics, the mean rank and standard deviation of ranks of all statistics were calculated. Based on rank method and the all statistics, the genotypes G7, G3 and G10 showed that the good rank mean that lowest standard deviation and the best rank sum of rank. Thus, these genotypes were identified as the most stable genotypes with good seed soybean yield. Furthermore, the genotype G6 was unstable under these statistics, although it gave highest seed soybean yield, because it is unstable by most studied statistical methods. Other genotypes were identified as semi-stable or semi-unstable. Ranking method has been used for selecting stable chickpea genotypes by Farshadfar et al. [29].

3.5 Relationship among Mean Yield and Non-parametric Stability Statistics

Spearman's rank correlation coefficients were calculated for each pair of seed yield and non-parametric stability statistics and are shown in Table 6. Perfect rank correlation coefficient was observed between mean seed soybean yield (Y_i) and YS_i ($r=1.00$). The Y_i showed highly significant rank correlation coefficients in positive direction with statistics *TOP*, δgy , *KR* and *RSM* ($P<0.01$). The strong association between Y_i and these non-parametric stability statistics were expected because the values of these parameters were the best for high yielding genotypes. These results indicated the close similarity and effectiveness of these statistics in ranking

genotypes for stability across environments. Therefore, any of these parameters could be used to select high yielding and stable genotypes in soybean. While, Y_i was not correlated with $S_i^{(1)}$, $S_i^{(2)}$, MID , $NP_i^{(1)}$ and δr , it showed a negative and significant correlation with $S_i^{(3)}$ ($P < 0.05$) and $S_i^{(6)}$, BOT , $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ ($P < 0.01$). The non-significant correlation among mean seed yield and stability parameters suggests that stability parameters provide information that cannot be gleaned from average yield alone [30]. Similar findings were mentioned by Mohammadi and Amri [31] in wheat, Noruzi and Ebadi [32] in sunflower and Dehghani et al. [33] in fescue. While in soybean, Manjubala et al. [27] stated that mean yield was statistically significant ($p < 0.01$) and positively correlated with RSM , $S_i^{(6)}$, $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$.

Highly significant or significant rank correlation coefficients in a positive direction were obtained between all possible pairs for YS_i , TOP , δgy , KR and RSM (except between TOP and δgy); for $S_i^{(1)}$, $S_i^{(2)}$, $NP_i^{(1)}$, δr , δgy and RSM ; and for $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$. Significant positive rank correlation coefficients were observed between the two statistics $S_i^{(3)}$ and δr ($P < 0.01$). The BOT statistic is significantly correlated in direction positive with $S_i^{(3)}$ ($P < 0.05$) and with $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ statistics ($P < 0.01$). The significant positive correlation between these stability statistics indicates their close relationship with each other and suggests that these parameters would play similar roles in stability ranking of genotypes, and vice versa. Thus these methods should not be treated as separate procedures (Lin et al. 1986). The statistics $S_i^{(1)}$ and $S_i^{(2)}$ by Yue et al. [34], Di Mauro et al. [26] and Manjubala et al. [27] and the statistics RSM , $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ by Manjubala et al. [27] were positively and significantly correlated ($P < 0.01$) indicating that they were similar for classifying soybean genotypes according to their stability under different environmental conditions [34].

The principal component analysis (PCA) based on the rank correlation matrix was performed to better understand the relationship between seed yield and non-parametric stability statistics. The loadings of rank derived from seventeen non-parametric stability statistics for PCA1, PCA2 and PCA3 are shown in Table 7. The first three main PCAs extracted had Eigen values larger

than one (Eigen value > 1) with values 9.15, 5.40 and 1.12, respectively. While, the other PCAs had Eigen values less than one (Eigen value < 1). The PCA1, PCA2 and PCA3 explained 92.19% of the total variation in the original variables. According to Mohammadi and Amri [31] and Farshadfar et al. [29] the Eigen values had higher than one for the first two and first four PCAs, and which accounted for 79.60% and 87.71% of the variance of the original variables in wheat and chickpea, respectively. The analysis displayed that the PCA1 contributed to 53.85% of the variance of the original variables with statistics Y_i , YS_i , KR , TOP , RSM , δgy and MID . Therefore, the PCA1 could be considered as the high yield potential and most stable. As for the PCA2 accounted for 31.74% of the total variability with other studied statistics. Thus, the PCA2 could be regarded stable with high yield in some environments and low yield in other environments. On the other hand, the PCA3 accounted for 6.60% of the variances in the original variables, therefore it can be considered unstable with low yield in during twelve different environments. Selection of genotypes that had high PCA1 and PCA2 for non-parametric stability statistics were suitable under twelve different environments. Thus, the statistics Y_i , YS_i , KR , TOP , RSM and δgy and the statistics $S_i^{(1)}$, $S_i^{(2)}$, $NP_i^{(1)}$ and δr were superior statistics with their high PCA1 and PCA2 under the environments examined, respectively. Classification of genotypes examined based on these statistics was similar. This conformed with the earlier findings of Manjubala et al. [27] in soybean, Mohammadi and Amri [31] in wheat, Farshadfar et al. [29] in chickpea and Vaezi et al. [35] in barley.

The relationships (similarities and dissimilarities) among different non-parametric stability statistics are graphically displayed in a biplot of PCA1, PCA2 and PCA3 (Fig. 1). Based on agronomic (dynamic) and biological (static) concepts, the three PCAs mainly differentiated the statistics into three groups. The first group (G1) contained Y_i and the non-parametric stability statistics YS_i , KR , TOP , RSM and δgy . According to biplot analysis, these statistics were strongly correlated with Y_i ; this indicated that they were the same in ranking of genotypes, where Y_i has an important influence on the ranking across environments. The genotypes G6, G11, G9 and G1 were identified as the most stable genotypes with high seed yield by YS_i , KR and TOP statistics. According to these parameters, selection based

on soybean seed yield was favored and related to the dynamic concept of stability. According to Backer [8] and Becker and Leon [7], in this stability concept, it was not a requirement that the genotypic response to environmental conditions should be equal for all genotypes.

The two statistics δgy and RSM were located in both GI and GII, due to high correlation with the statistics in the two groups. The second group (GII) consists of the non-parametric stability statistics $S_i^{(1)}$, $S_i^{(2)}$, $NP_i^{(1)}$ and δr as well as δgy and RSM . These statistics were strongly correlated with each other. While, the statistics $S_i^{(1)}$, $S_i^{(2)}$ and $NP_i^{(1)}$ were not significantly correlated with mean seed yield. The genotypes G15, G11, G3 and G9 by $S_i^{(1)}$, $S_i^{(2)}$ and $NP_i^{(1)}$ were stable genotypes, but only genotype G15 had the lowest soybean seed yield. These provided a statistic of stability in the static sense; thus, both yield and stability of performance should be considered simultaneously to exploit the useful effect of GEI and to make selection of the genotypes more precise and refined. Therefore, these parameters allowed the identification of genotypes adapted to

environments with unfavorable growing conditions.

The third group (GIII) comprised of the non-parametric stability statistics $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ and BOT . These statistics were strongly associated with each other except ($S_i^{(6)}$ and BOT), while there were negatively correlated with the mean seed yield, indicating that they provided information that could not be gleaned from average yield alone. According to these statistics, the genotypes G15, G13 and G16 with low soybean seed yield were most stable and the genotype G6 with high seed yield was unstable. These statistics might not be appropriate as the responsive ones under favorable conditions and both breeders and farmers preferred to select high seed yield genotypes that performed consistently across environments. These statistics might not be as suitable as the other methods. Therefore, the use of these statistics are not recommended for cultivar selection. The MID statistic was not significantly correlated with mean yield and other studied statistics, thus it might not be as suitable as the other non-parametric stability statistics.

Table 7. Loadings of rank derived from seventeen non-parametric stability statistics for PCA1, PCA2 and PCA3

Statistic	Component		
	PCA1	PCA2	PCA3
Y_i	0.97	0.11	0.04
YS_i	0.97	0.11	0.04
$S_i^{(1)}$	0.13	0.97	0.01
$S_i^{(2)}$	0.10	0.97	0.00
$S_i^{(3)}$	-0.655-	0.60	-0.126-
$S_i^{(6)}$	-0.897-	0.34	-0.061-
TOP	0.85	-0.085-	-0.444-
MID	0.38	-0.017-	0.90
BOT	-0.951-	-0.175-	-0.088-
$NP_i^{(1)}$	0.08	0.95	-0.028-
$NP_i^{(2)}$	-0.920-	0.29	0.11
$NP_i^{(3)}$	-0.893-	0.34	0.14
$NP_i^{(4)}$	-0.875-	0.34	0.16
δr	-0.125-	0.86	-0.141-
δgy	0.63	0.73	0.04
KR	0.98	0.15	0.05
RSM	0.68	0.68	0.02
Eigen value	9.15	5.40	1.12
Explained variance	53.85	31.74	6.60
Cumulative variance	53.85	85.59	92.19

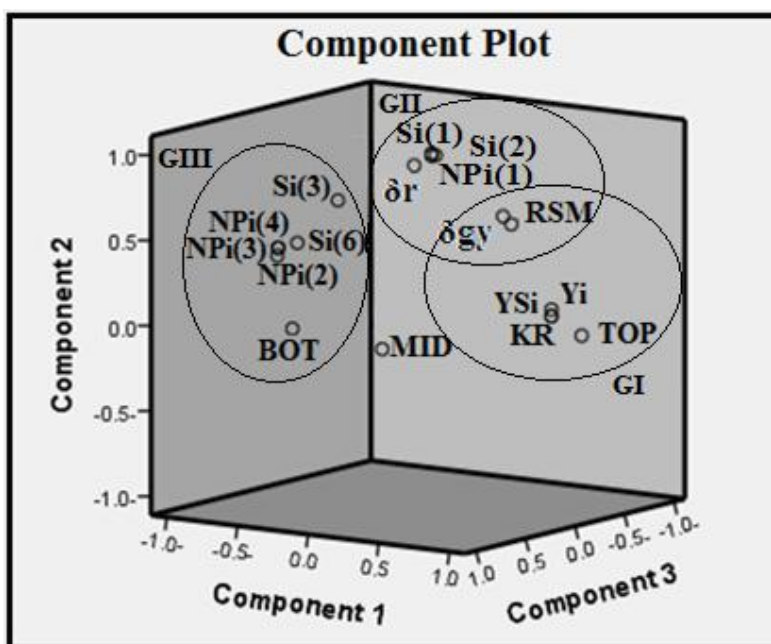


Fig. 1. Biplot diagram based on first three principal component axes for different non-parametric stability statistics

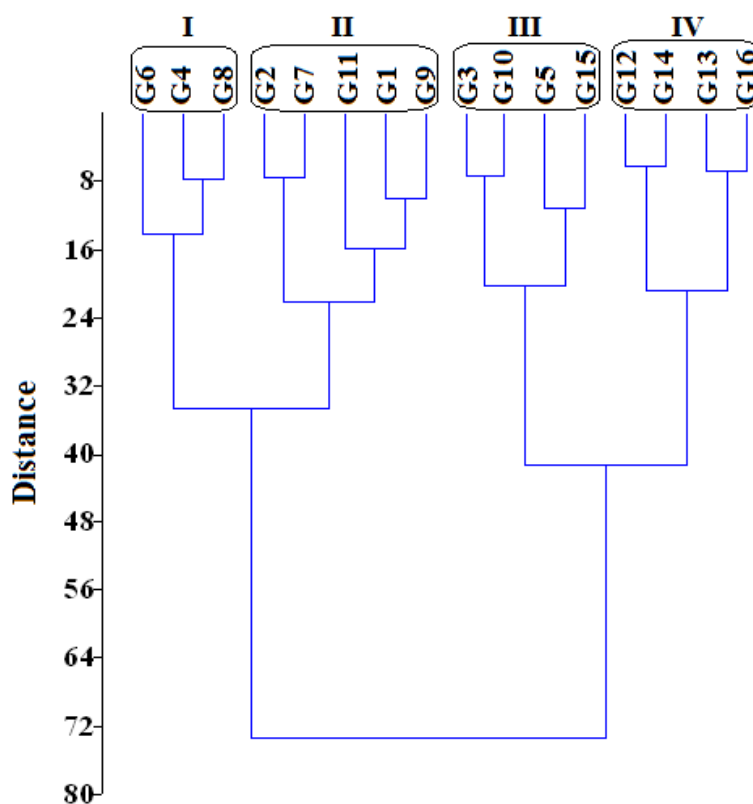


Fig. 2. Dendrogram showing hierarchical classification of sixteen soybean genotypes based on the non-parametric stability statistics using Ward method

Generally, the non-parametric stability statistics YS_i , KR , TOP , RSM and $\bar{\delta}gy$ are related with dynamic stability, and other remaining statistics are associated with static stability. The non-parametric stability statistics in the two groups I and II as measures of genotypic performance, are attempting to integrate both yield and adaptability. Thus, these statistics can be used to recommend genotypes adapted to favorable conditions in Egypt. The measure of dynamic stability depends on the specific set of tested genotypes, unlike the measure of static stability [36]. Static stability may be more useful than dynamic stability in a wide range of situations, especially in developing countries [37]. Similar findings were reported in other crops including wheat by Mohammadi and Amri [31], lentil by Sabaghnia et al. [38], chickpea by Farshadfar et al. [29] and barley by Vaezi et al. [35].

3.6 Cluster Analysis

Cluster analysis with Ward method was performed on the basis of mean seed yield and non-parametric stability statistics to classify the sixteen genotypes of soybean into four clusters (Fig. 2). Each cluster contained genotypes that were highly similar. Therefore, there was considerable variation among the studied genotypes under twelve different environments. Hybridization/crossing between any distantly related populations is expected to yield more heterosis and vigorous plants. The first cluster (I) consists of G6, G4 and G8 genotypes. The G6 genotype had the highest seed yield and most stable by Y_i , YS_i , TOP and KR statistics. The G4 and G8 genotypes had moderate yields. The second cluster (II) included the high yielding the genotypes G11, G9, G1, G7 and G2. The G11 and G9 genotypes by all non-parametric stability statistics except $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ and the G1, G2 and G7 genotypes by Y_i , YS_i , TOP , $\bar{\delta}r$, $\bar{\delta}gy$, KR and RSM statistics were identified as stable genotypes. The genotypes G3, G10, G5 and G15 were classified as the third cluster (III). These genotypes had moderate values of seed soybean yields except the G15 had low yield. These genotypes were identified as stable genotypes by $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$, and only the G15 genotype by $NP_i^{(1)}$. Finally, the genotypes G12, G14, G13, G16 had low yields and clustered in the fourth cluster (IV). The G13 and G16 genotypes were identified stable genotypes by $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$, while the G12 and G14 had low

stability. In summary, the non-parametric stability statistics identified the genotypes in clusters I and II as the most stable genotypes, and the genotypes in cluster IV as unstable ones. The remaining genotypes were intermediate between these two groups. With regards to most of the parametric stability statistics, the genotype G6 and G11 had found to be the most stable with high grain yield and are recommended for use under unfavorable and favorable conditions in Egypt. Therefore, the cluster analysis is proved useful for the identification of high yielding genotypes for breeding purposes as well as for commercial exploitation [25].

4. CONCLUSIONS

Both yield and stability of performance should be considered simultaneously to exploit the useful effect of GEI and to make the selection of the genotypes more precise and refined. The non-parametric stability statistics provided a lot of flexibility for plant breeders for simultaneous selection for yield and stability. Based on Spearman's rank correlation coefficients and PCA, the YS_i , KR , TOP , RSM and $\bar{\delta}gy$ are useful statistics in breeding programmes where high seed yield, popping expansion and stability are essential traits for selecting genotypes, thus these statistics can be recommended for evaluating the stability of soybean genotypes across the various environments in Egypt. According to cluster analysis, soybean genotypes G6, G4, G8, G11, G9, G1, G7 and G2 were more stable varieties on the basis of mean seed yield and non-parametric stability statistics. Based on most non-parametric stability statistics, the genotypes G6 and G11 can be recommended as the most stable genotypes with regard to both stability and seed yield across the different environments, therefore, these genotypes must be released in regions under study and other regions in Egypt.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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