Original Research Article

Comparison of non-parametric stability statistics for selecting stable and adapted soybean genotypes under different environments

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. ~~The all~~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), and 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 exhibited highly significant and were explained 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 can be classified into three groups. The non-parametric stability statistics i.e., *YSi*, *KR*, *TOP*, *RSM* and δgy 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* $NP_i^{(4)}$, *δr, MID, LOW*) represents the concept of static stability, which ~~were~~ was 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 parameter of them can 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 *YSi*, *KR*, *TOP*, *RSM* and δgy are more useful statistics in soybean breeding programmes and can 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 may be used for genetic improvement of soybean, and they must be released in studied regions and other regions in Egypt.

Key words: Comparison–Non-parametric stability statistics–Multi-environment–Seed yield–Soybean.

INTRODUCTION

Major goal of plant breeding programs is to increase stability and stabilize crop yield over ~~arrange~~ 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, which expression is the result of genotype, environment and genotype x environment interaction (Engqvist and Becker

1993). Genotype x environment interaction (GEI) is of ~~major~~ significant importance to the plant breeder in developing improved varieties. When varieties are compared over a series of environments, the relative rankings usually differ (Eberhart and Russell, 1966). GEI is a major problem when comparing the performance of genotypes across environments (Kang 1990). 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 significant GEI 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 significant GEI for a quantitative trait such as grain yield can reduce the correlation between phenotype and genotype, and decreases progress in selection (Comstock and Moll, 1963). The basic cause of differences between genotypes in their yield stability is the wide occurrence 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 & Fox (1993) and Huehn (1996) 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 genotype performance across environments. For practical applications, however, most breeding programs are now incorporating some elements of both parametric and non-parametric approaches (Becker and Leon 1988).

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 ~~considered~~ regarded as a biological or static concept of stability (Backer 1981). 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 (Becker and Leon 1988). In dynamic stability, a genotype changes in a predictable manner across a wide range of environmental conditions (Backer 1981).

Recently, there has been an increased interest in using nonparametric statistics in different ~~agriculture~~ agriculture-related disciplines as they provide a method to determine relative stability. Since Huehn (1979) article on nonparametric statistics, the number of articles which have used these statistics has increased sharply. 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 (Nassar and Huehn 1987). 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. Their chief advantages are (i) No assumptions about the distribution of phenotypic observations are needed, (ii) Sensitivity to measurement errors or to outliers are much less compared to 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 (Huehn 1996, Nassar et al., 1994 and Thennarasu, 1995). Several non-parametric methods proposed by Huhn (1979), Nassar and Huehn (1987), Kang (1988), Ketata et al. (1989), Fox et al. (1990) and Thennarasu (1995) 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 were 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.

MATERIALS AND METHODS

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 ~~four~~ 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 had contained 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. At harvest, seed yield was measured per plot for each genotype at 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	Untied States American

Statistical Analysis and Procedures:

Combined analysis of variance was done on grain yield during twelve ~~enviromnets~~ environments (four locations and 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 (Gauch, 1988) 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 ~~effects~~ 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 (1979), Nassar and Huehn (1987), *RSM* by Kang (1988), *δr*, *δgy* and *KR* by Ketata et al., (1989), *TOP*, *MID* and *LOW* by Fox et al., (1990), YS_i by Kang (1990) and $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ by Thennarasu (1995). Spearman's rank correlation coefficients, ~~principle~~ 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.

RESULTS and DISCUSSIONS

AMMI ANOVA

The analysis of variance according to the AMMI model of sixteen soybean genotypes tested in twelve environments (four locations and 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 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 and justifies the use of stability statistics for the identification of stable genotypes with superior seed yield of soybean under the various environments. Maia et al., (2006), Yokomizo et al., (2013) and Freiria et al., (2018) 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 principal component axis (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. Significance ($p < 0.01$) was observed in the first two and four principal axis in soybean by Yokomizo et al.,

(2013) and Freiria et al., (2018), respectively. The values of the first two axes explained the range of 53 to 61 % of the variance in GEI (Maia et al., 2006, Yokomizo et al., 2013 and Freiria et al., 2018). The PC1 had higher 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., (2018) mentioned 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 (1988) and Crossa (1990) 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 (Basford & Cooper, 1998).

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

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 during 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, Mallawy 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 Mallawy 2016 across twelve environments. Consistent performances across different locations and/or years are referred to as yield stability (Thillainathan & Fernandez 2002). This differential yield ranking of genotypes across the environments showed that the G × E interaction effect was of the crossover type (Yan and Hunt 2001).

Table 3. Mean grain yield and environmental index (E.I.) values of sixteen soybean genotypes tested under 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	

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 are 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*, indicates that a 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 at1.05 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 G6, G11, G9 and G1 were recorded the highest values and represented the most stable genotypes, unlike, the genotypes G13 and G16 under twelve environments.

According to Nassar and Huehn (1987), 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 chisquare stabilities [Sum($Z_i^{(1)}$)=36.97 and Sum($Z_i^{(2)}$)= 45.10]. The two overall chi-square stabilities were higher than the tabulated chi-square (x^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 $S_i^{(2)}$ (Nassar and Huehn 1987) and $NP_i^{(1)}$ (Thennarasu's 1995), the genotypes G15, G11, G3 and G9 were considered stable in comparison to the other genotypes~~,~~ because these genotypes had lower values by these parameters. Whilst, the genotypes G14 and G13 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 ~~the~~ both the two non-parametric stability statistics of Huehn (1979) which are 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 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($S_i^{(2)}$)	x^2 table for $Z_i^{(1)}$, $Z_i^{(2)}$	x^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

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 (1979) Nassar and Huehn's (1987) 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., (1990) number of sites at which the genotype occurred in the top, middle and bottom third of ranks; $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$: Thennarasu's (1995) nonparametric stability parameters; δr, δgy, *KR* Ketata et al., (1989); *RSM*: rank sum method, Kang 's (1988)

Using the ~~he~~ nonparametric superiority statistics, *TOP*, *MID* and *BOT* (Fox et al., 1990), the genotypes G11, G9, G6 and G1 were identified as the most stable genotypes, because these genotypes are 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 ~~are~~ occurred in the middle and bottom thirds of the ranks, respectively~~,~~; thus these genotypes are unstable. Concerning ~~to~~ the other Thennarasu's (1995) 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., (1989), G11 had the minimum values by *δr*, *δgy* and *KR*, followed by the genotypes G15, G3 and G7 using *δr*, the 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 (1988), 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 but to have low mean yield. This makes the statistics as not so useful for the identification of high yielding stable genotypes (Segherloo et al., 2008). Generally, the genotypes G6, G11, G9 and G1 were most stable and 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 *Yi*, *YSi*, *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., (2000) and Manjubala et al., (2018) in soybean.

Ranking method

~~The ranks of sixteen genotypes according to non-parametric stability statistics are presented in Table 5. The ranks of genotypes for *Yi* and *YSi* were identical. Also, often similar ranks for the genotypes were observed between *KR* with *Yi* and *YSi*; between $S_i^{(1)}$, $S_i^{(2)}$ and $NP_i^{(1)}$; and between $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$, which suggest that these parameters are equal for selecting genotypes~~. According to ranks of sixteen genotypes using the non-parametric stability statistics, the ranks of genotypes for *Yi* and *YSi* were identical. Also, often similar ranks for the genotypes were observed between *KR* with *Yi* and *YSi*; between $S_i^{(1)}$, $S_i^{(2)}$ and $NP_i^{(1)}$; and between $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$, which suggest that these parameters are equal for selecting genotypes, therefore it is sufficient to use one of them. For this reason, it is could be considered as appropriate alternatives for each other (El-Hashash and Agwa, 2018). In Table 6, the estimates of non-parametric stability statistics displayed that the determination of stable genotypes based on a single statistic was contradictory, also these statistics were different in determining stable genotypes. For example, the genotype G6 had most stable by *Yi*, *YSi* and *KR*, while it was unstable by most other statistics, unlike the 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 means, 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. Further, 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., (2012).

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Table 5: Ranks of sixteen genotypes using non-parametric stability statistics in twelve 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

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 (*Yi*) and *YSi* (r=1.00). The *Yi* showed highly significant rank correlation coefficients in positive direction with statistics *TOP*, δgy, *KR* and *RSM* ($P<0.01$). The strong association between *Yi* 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 parameter of them can be used to select high yielding and stable genotypes in soybean. While~~,~~ *Yi* was not correlated with $S_i^{(1)}$, $S_i^{(2)}$, *MID*, $NP_i^{(1)}$and δr, and it showed a negative and significant correlation with Si(3) ($P<0.05$) and with $S_i^{(6)}$, *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 suggest that stability parameters provide information that cannot be gleaned from average yield alone (Mekbib 2002). Similar findings were mentioned by Mohammadi and Amri (2008) in wheat, Noruzi and Ebadi (2015) in sunflower and Dehghani et al., (2016) in fescue. While in soybean, Manjubala et al., (2018) 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 *YSi*, *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 $NP_i^{(4)}$. The significant positive rank correlation coefficients ~~was~~ 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., (1997), Di Mauro et al., (2000) and Manjubala et al., (2018) and the statistics *RSM*, $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ by Manjubala et al., (2018) 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 (Yue et al., 1997).

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

The ~~principle~~ principal component analysis (PCA) based on the rank correlation matrix was performed to better understand the relationship ~~among~~ 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 eigenvalues larger than one (Eigen value >1) with values 9.15, 5.40 and 1.12, respectively. While, the other PCAs had eigenvalues 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 (2008) and Farshadfar et al., (2012) the eigenvalues had higher than one for the first two and first four PCAs, and which account~~ing~~ 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 ~~in~~ to 53.85% of the variance of the original variables with statistics *Yi*, *YSi*, *KR*, *TOP*, *RSM*, *δgy* and *MID* . Therefore, the PCA1 can be named as the high yield potential and most stability. As for the PCA2 explained 31.74% of the total variability with other studied statistics. Thus, the PCA2 can be named stable with high yield in some environments and low yield in other environments. On the other hand, the PCA3 explained 6.60% of the variances in the original variables~~,~~; therefore it can be named unstable with low yield in during twelve environments. Selection of genotypes that have high PCA1 and PCA2 for non-parametric stability statistics are suitable under twelve environments. Thus, the statistics *Yi*, *YSi*, *KR*, *TOP*, *RSM* and *δgy* and the statistics $S_i^{(1)}$, $S_i^{(2)}$, $NP_i^{(1)}$ and δr ~~are~~ is superior statistics with their high PCA1 and PCA2 under these studied environments, respectively. Classification of studied genotypes based on these statistics was similar. This agrees with the earlier findings of Manjubala et al., (2018) in soybean, Mohammadi and Amri (2008) in wheat, Farshadfar et al., (2012) in chickpea and Vaezi et al., (2019) in barley.

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
$S_i^{(3)}$	-.655-	0.60	-.126-
$S_i^{(6)}$	-.897-	0.34	-.061-
TOP	0.85	-.085-	-.444-
MID	0.38	-.017-	0.90
BOT	-.951-	-.175-	-.088-
$NP_i^{(1)}$	0.08	0.95	-.028-
$NP_i^{(2)}$	-.920-	0.29	0.11
$NP_i^{(3)}$	-.893-	0.34	0.14
$NP_i^{(4)}$	-.875-	0.34	0.16
δr	-.125-	0.86	-.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

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 distinguish the statistics into three groups. The first group (GI) contained *Yi* and the non-parametric stability statistics *YSi*, *KR*, *TOP*, *RSM* and *δgy*. According to biplot analysis, these statistics are strongly correlated with Yi~~,~~; this indicates that they are the same in ranking of genotypes, where Yi 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 *YSi*, *KR* and *TOP* statistics. According to these parameters, selection based on seed soybean yield is favored, and is related to the dynamic concept of stability. According to Backer (1981) and Becker and Leon (1988), 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 ~~the~~ 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 ~~to~~ 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 seed soybean yield. These provide a statistic of stability in the static sense~~,~~ ; thus, ~~the~~ 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 allow 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 are negatively correlated with the mean seed yield, indicating that they provide information that cannot be gleaned from average yield alone. According to these statistics, the genotypes G15, G13 and G16 with low seed soybean yield were most stable and the genotype G6 with high seed yield was unstable. These statistics may not be appropriate as the responsive ones under favorable conditions and ~~the~~ both breeders and farmers prefer to select high seed yield genotypes that perform consistently across environments. These statistics may not be as suitable as the other methods. Therefore, we do not recommend the use of these statistics for cultivar selection. The MID statistic was not significantly correlated with mean yield and other studied statistics, thus it is may not be as suitable as the other non-parametric stability statistics.

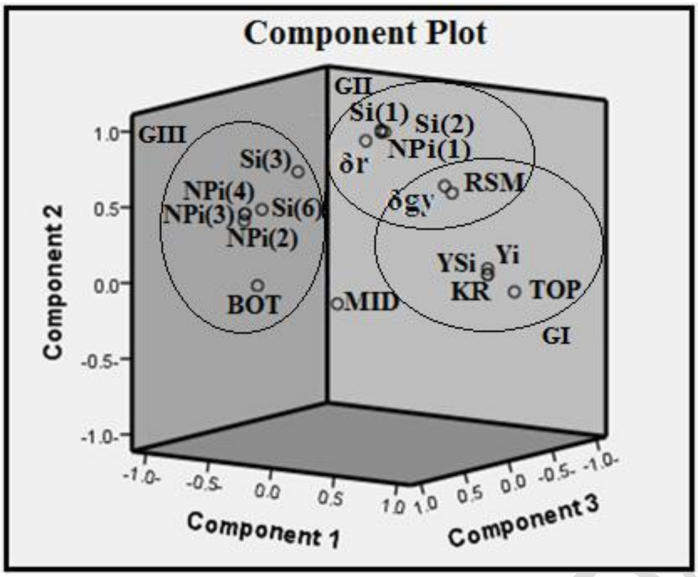

Figure 1. Biplot diagram based on first three principal component axes for different non-parametric stability statistics.

Generally, the non-parametric stability statistics *YSi*, *KR*, *TOP*, *RSM* and *δgy* were 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 (Lin et al., 1986). Static stability may be more useful than dynamic stability in a wide range of situations, especially in developing countries (Simmonds 1991). Similar findings were reported in other crops including wheat by Mohammadi and Amri (2008), lentil by Sabaghnia et al., (2006), chickpea by Farshadfar et al., (2012) and barley by Vaezi et al., (2019).

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 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 *Yi*, *YSi*, *TOP* and *KR* statistics. While, the G4 and G8 genotypes had moderate yields. The second cluster (II) include 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 *Yi*, *YSi*, *TOP*, *δr*, *δgy*, *KR* and *RSM* statistics were identified a stable genotype~~s~~. 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 which had ~~was~~ 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 we 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 (Segherloo et al., 2008).

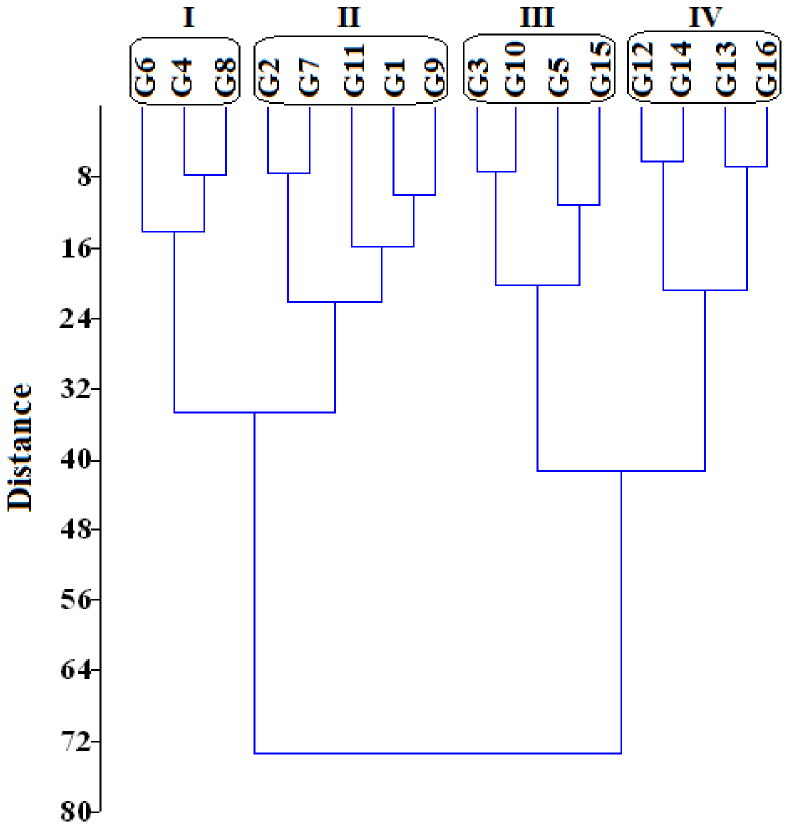

Figure 2. Dendrogram showing hierarchical classification of sixteen soybean genotypes based on the non-parametric stability statistics using Ward method.

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 *YSi*, *KR*, *TOP*, *RSM* and *δgy* 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 studied regions and other regions in Egypt.

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