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ASSESSMENT OF GENOTYPE BY ENVIRONMENT INTERACTION, YIELD STABILITY AND INTERRELATIONSHIPS AMONG DIFFERENT STABILITY MEASURES OF BREAD WHEAT GENOTYPES

Y.A. El-Gabry and Amal Z.A. Mohamed
Agron. Dept., Fac. of Agric., Ain Shams Univ., Shoubra El-Kheima, Egypt.

ABSTRACT

The objectives of this study were to compare nine parametric and 5 nonparametric stability measures and to identify high yielding and stable bread wheat genotypes in twelve variable environments during 2014-15 and 2015-16 growing seasons. The wheat genotypes comprised ten local cultivars and five exotic Syrian genotypes. They were grown in a split plot design arranged in a randomized complete blocks with 3 replications. Combined analysis of variance for grain yield (kg m^{-2}***) indicated that the genotypes, environments and their genotype x environment interaction effects were highly significant. The parametric stability statistics; deviation from regression (***S^2_d***) , ecovalence (***W_i***), stability variance (***σ_i^2***), coefficient of determination (***R^2***) and mean variance component for a pairwise G x E interaction (***P^{59}***) revealed that the local cultivar Sakha 93 was the most stable genotype, while cultivar's superiority index indicated that the local cv. Shakha 94 was considered the most stable genotype. The nonparametric stability statistics indicated that cv. Giza 168 exhibited the smallest changes in rank (***$S_i^{(2)}$***) and thus was the most stable genotype. According to the two nonparametric stability measures (TOP and RS), the two local cvs.; Sakha 94 and Sids 1 were the most stable genotypes for grain yield. As for comparing the fourteen stability measures, the*** S^2_d, W_i, σ_i^2, P^{59} ***and the nonparametric stability measures (***$S_i^{(2)}$, $S_i^{(3)}$ ***and*** $S_i^{(6)}$***) were nearly similar in assessing the relative stability of genotypes, whereas remaining stability measures deviated from others. The rank correlation analysis indicated that most nonparametric statistics were significantly correlated with parametric measures and therefore can be used as alternatives due to its simplicity.***

Key words**: *Bread wheat, Grain yield, Parametric and nonparametric stability measures, Correlation*.**

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is the most important cereal crop in Egypt and is being used as staple food for more than on third of the world. Increasing wheat productivity is a national target in Egypt to reduce the gap between wheat production and consumption. Hence, developing high yielding and stable varieties is always the main target for wheat breeding program. Analysis of genotype by environment interaction and estimation of phenotypic stability have been widely studied during the past decades. Subsequently, phenotypic stability was extensively discussed and several methods were proposed for its estimation (Lin *et al* 1986, Westcott 1986, Nassar and Huehn 1987 and Becker and Leon 1988). One of the reasons for growing genotypes in a wide range of environments is to estimate their phenotypic stability because of the increasing demands of growers for stable varieties especially in areas where climatic conditions are highly unpredictable. Huehn (1996) and Shrief (2003) indicated that there are two major approaches for studying G x E interaction and adaptation. The first one is parametric (empirical and statistical), which is more common and involves relating observed genotypic responses to a sample of environmental conditions. The second one is the nonparametric (analytical clustering) approach, which defines environments and phenotypes relative to biotic and abiotic factors. For practical applications, however, most breeding programs incorporate some elements of both approaches (Becker and Leon 1988 and Romagosa and Fox 1993). According to Lin *et al* (1986) and Huehn (1996), the classical parametric stability statistics include Eberhart and Russell's (1966) regression coefficient (b_i) and sum of squared deviations from regression ($S^2{}_d$), Wricke's (1962) ecovalence, Shukla's (1972) stability variance, Francis and Kannenberg's (1978) coefficient of variability for each genotype and mean of estimated variance components for the G x E interactions. Ranks of ecovalence and stability variance were proved to be identical (Kang *et al* 1987) and the latter was suggested for measuring stability, to save time and efforts. The parametric measures of phenotypic stability are mostly variance components or related statistics. These stability estimates have good properties under certain statistical assumptions, like normal distribution of errors and interaction effects, they may not perform well if these assumptions are violated, for example, in the presence of outliers (Huehn 1990 a). That means parametric tests for significance of variances and variance related measures could be very sensitive to the underlying assumptions. Thus, it is wise to search for alternative approaches that are more robust to departures from common assumptions, such as nonparametric measures. The nonparametric measures of phenotypic stability cluster genotypes according to their similarity of response to a range of environments (Lin *et al* 1986). The nonparametric approaches are based on ranks of genotypes and provide an important alternative to the parametric measures. Huehn (1990 a) proposed three nonparametric measures of phenotypic stability, mean of absolute rank differences $S_i^{(2)}$, variance of ranks $S_i^{(3)}$ and sum of the absolute deviations $S_i^{(6)}$, which are based on the ranks of genotypes in different environments. To compute these measures, however, the mean yield data have to be transformed into ranks for each genotype and environment, and the genotypes are considered stable if their ranks are similar across environments. According to Huehn (1990 a), the nonparametric method has the following advantages over the parametric stability statistics: reduction or avoidance of the bias caused by outliers, no assumptions are needed about the distribution of the phenotypic values, stability parameters based on ranks are easy to use and to interpret, additions or deletions of one or few genotypes or another group of material do not cause much variation of estimates. Unlike the parametric methods, and for many applications (e.g., selection in breeding and testing program). Huehn (1990 b) further indicated that knowledge of relations between different statistical measures of phenotypic stability (parametric and non-parametric), consistency of relationships among stability parameters, and repeatability of stability parameters are essential for an efficient use of stability estimation and in practical applications.

Therefore, the main objectives of this research were to identify high yielding and stable genotypes and to study the associations among different parametric and nonparametric stability measures including mean yield *per se* in bread wheat.

MATERIALS AND METHODS

Four field experiments were conducted at two locations, i.e. Exp. and Res. Stat., Fac. of Agric., Ain Shams Univ., Shalakan, Kalubia Governorate and private farm in snoras, Fayoum Governorate, during 2014-15 and 2015-16 growing seasons. Fifteen bread wheat genotypes were used in this study. Ten of them are local cultivars namely, Shandaweel 1, Misr 1, Misr 2, Sids 13, Gemmeiza 7, Gemmeiza 9, Giza 168, Sakha 94, Sids 1 and Sakha 96. These cultivars were provided by the wheat Res. Dept., Field Crop Institute, Agric. Res. Center, Giza, Egypt. The remaining five wheat genotypes namely, line 606, Cham 6, Cham 8, IB 18 and Bohouth 6 are exotics and introduced from Syria. The experiments were laid out in a split plot design arranged in a randomized complete blocks with three replications, where the three nitrogen fertilization treatments, i.e. 50 , 50 + Biofertilizer and 75 kg N fed^{-1} were allocated in the whole plots, while the fifteen bread wheat genotypes were randomly distributed in the subplots. At each location in the two seasons, the planting took place in the third week of November. The experimental plot consisted of 2 rows. Each row was 3 m in length and 20 cm width. Seeds were spaced at 10 cm within row and one plant was left per hill. The nitrogen fertilizer was added in the form of ammonium nitrate (33%). The bacterial inoculums (Cerealin) was a mixture of *Azosperllum brasilense* and *Bacillus polymxa* spp. Seeds were treated with inoculums in the field directly before sowing as recommended, Other cultural practices needed for growing wheat were done during the two seasons. In consequence, the combinations between the two seasons, two locations and the three nitrogen fertilization treatments were considered as 12 variable environments.

Statistical analyses

Separate and combined analyses of variance for grain yield data (kg m^{-2}) were performed according to Gomez and Gomez (1984). The comparison among mean values was done using the least significant difference test (L.S.D) at the 5% probability level. Then, stability analyses were conducted using nine parametric and five nonparametric measures of phenotypic stability. The parametric stability measures were: the linear regression of genotype on environmental index (b_i) and deviation mean square from regression (S^2_d) according to Eberhart and Russell (1966), coefficient of determination (R^2) between average yield of each genotype and environmental index as outlined by Pinthus (1973), variance of genotype across environments (S_i^2), the coefficient of variability of each genotype (CV_i) according to Francis and Kannenberg (1978), the ecovalence stability index (W_i) as developed by Wricke (1962), the stability variance (σ_i^2) as outlined by Shukla (1972) and the superiority index (P_i) as outlined by Lin and Binns (1988), mean variance component for a pairwise G x E interaction (P^{59}) according to Plaisted and Peterson (1959). Three sets of nonparametric stability measures were estimated in this study. One of them was Nassar and Huehn (1987), who proposed three nonparametric stability statistics ($S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$) combining mean yield and stability. Another set of nonparametric stability measures was proposed by Kang (1988) as rank_sum (RS), where both yield and Shukla’s stability variance were used as a selection criterion that assign a weight of one, which allows identification of high yielding and stable genotypes. In this method, both highest yield and lowest stability variance of genotype are ranked one and after ranking all genotypes by yield and stability variance are added for each genotype. Then, a genotype with the lowest value is considered as the most desirable. Fox *et al* (1990) suggested a nonparametric superiority measure for general adaptability in which they used stratified ranking of the cultivars. Ranking was performed at each environment separately, and the number of environments at which the genotype occurred in the top, middle and low third of the ranks was computed. A genotype that occurred mostly in the top third was considered a widely adapted genotype. In addition, Spearman's rank correlations were computed between all pairs of stability measures, which obtained by different biometrical methods including mean yield.

RESULTS AND DISCUSSION

Analysis of variance and genotypic mean performance

A combined analysis of variance for grain yield of the fifteen bread wheat genotypes tested across twelve different environments is given in Table (1). The differences among genotypes (G), environments (E) and their interaction effects were highly significant. Similar results were found by many investigators, of them; Mohammed (2009), Ayalneh *et al* (2013), Abd El-Shafi *et al* (2014) and Yaghotipoor *et al* (2017). Of the total sum of squares of grain yield, the environmental effect accounted for 60.42%, while the genotypes and G x E interaction effects accounted for 8.68 and 27.71%, respectively. This result indicates that grain yield was significantly influenced by changes in environments, followed by G x E interaction and genotypic effects.

Table 1. Analysis of variance of 15 bread wheat genotypes tested across 12 environments.

SOV	df	SS	MS	% total sum of squares
Environments (E)	**11**	**15.72**	**1.4289****	**60.42**
Rep/E	**24**	**0.30**	**0.0126****	
Genotypes (G)	**14**	**2.26**	**0.1614****	**8.68**
G x E	**154**	**7.21**	**0.0468****	**27.71**
Pooled error	**336**	**0.53**	**0.0016**	

**** Significant at the 0.01 probability level.**

The highest magnitude of environmental variation is an indicative that complex external factors (biotic and abiotic) are one of the most important challenges in wheat improvement because most of the elements of environment are difficult to manage in the best interest of breeder during field experiment. The amount of variance contributed by G x E interaction was larger than that contributed by genotypes. This means that there was a marked G x E interaction effect present in multi-environment data, leading to the presence of substantial differences in genotypic responses across environments and revealing a large difference in genotypic performance and their rank orders across environments. These results are in accordance with those obtained by Abd El-Shafi *et al* (2014) and Yaghotipoor *et al* (2017). It is evident that selection and recommendation of new varieties would be difficult under such conditions, where G x E interaction effect is high owing to the masking effects of variable environments. In this connection, Pham and Kang (1988) reported that G x E interaction minimizes the utility of genotypes by confounding their yield performances. Thus, it is very important to study the yield levels, adaption patterns and stability of bread wheat genotypes in different environments. As illustrated in Table (2), the mean grain yield of wheat genotypes across environments varied from 0.60 kg m^{-2} for both Gemmeiza 9 and IB 18 to 0.84 kg m^{-2} for Sakha 94. The highest grain yield was obtained from environment No.8 (Shalakan location in second season (2015-16) with applying 50 kg N fed^{-1} + bio-fertilizer, while the lowest yield was recorded in the environment No. 4 (Fayoum location in first season 2014-15 using 50 kg N fed^{-1}). Moreover, the environments No.'s 2, 7, 9, 11 and 12 produced higher grain yields than the grand mean of the studied environments (Table 2). These environments could be considered as non-stress environments for such studied wheat genotypes. Mean grain yield of the 15 wheat genotypes across 12 variable environments also showed significant changes in ranks. These significant differences in yield ranks reflect the fluctuations of genotypes in their responses to the different environments of seasons, locations and N-fertilization treatments.

Table 2. Mean performance of 15 bread wheat genotypes tested in 12 environments.

Genotype	Environment												Average
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}	
Shandaweel 1	0.55	0.72	0.69	0.42	0.55	0.51	0.93	0.80	0.75	0.90	0.77	0.67	0.69
Misr 1	0.65	0.77	0.85	0.37	0.50	0.49	0.76	1.05	0.70	0.74	0.68	0.74	0.69
Misr 2	0.63	0.75	0.75	0.55	0.47	0.35	0.73	0.90	0.76	0.43	0.69	0.50	0.63
Sids 13	0.65	0.74	0.55	0.41	0.39	0.40	0.65	1.08	0.69	0.49	0.73	0.96	0.64
Gemmeiza 7	0.54	0.63	0.94	0.35	0.43	0.50	0.78	1.06	1.00	0.40	0.58	0.60	0.65
Gemmeiza 9	0.39	0.51	0.44	0.47	0.50	0.35	0.72	0.99	0.83	0.59	0.82	0.62	0.60
Giza 168	0.56	0.56	0.49	0.37	0.50	0.48	0.76	0.90	1.01	0.56	0.73	0.75	0.64
Sakha 94	0.61	0.96	0.73	0.44	0.50	0.39	1.02	1.45	1.01	1.01	1.02	0.90	0.84
Sids 1	0.90	0.74	0.73	0.57	0.60	0.54	0.84	1.08	1.03	0.60	0.93	0.93	0.79
Sakha 93	0.49	0.79	0.62	0.40	0.35	0.32	0.72	1.01	0.83	0.41	0.71	0.68	0.61
Line 606	0.75	0.76	0.65	0.32	0.60	0.61	0.91	0.89	1.03	0.60	0.59	0.42	0.68
Cham 6	0.54	0.45	0.52	0.38	0.50	0.59	0.76	1.05	0.90	0.69	0.95	0.77	0.68
Cham 8	0.50	0.77	0.72	0.49	0.61	0.40	0.96	0.94	0.74	0.89	0.90	0.79	0.73
IB 18	0.43	0.55	0.39	0.29	0.57	0.32	0.72	0.85	0.74	0.69	0.90	0.79	0.60
Bohouth 6	0.74	0.80	0.84	0.28	0.51	0.35	0.93	0.98	1.29	0.39	0.71	0.66	0.71
Average	0.59	0.70	0.66	0.41	0.50	0.44	0.81	1.00	0.89	0.62	0.78	0.72	0.68

LSD5% for Environments (E)= 0.02, Genotypes (G)= 0.02 and G x E interaction = 0.06.

E_1: Shalakan 2014/15 with 50 kg N fed.$^{-1}$; E_2: Shalakan 2014/15 with 50 kg N fed.$^{-1}$ + Bio; E_3: Shalakan 2014/15 with 75 kg N fed.$^{-1}$; E4: Fayoum 2014/15 with 50 kg N fed.$^{-1}$; E_5: Fayoum 2014/15 with 50 kg N fed.$^{-1}$ + Bio; E_6: Fayoum 2014/15 with 75 kg N fed.$^{-1}$; E_7: Shalakan 2015/16 with 50 kg N fed.$^{-1}$; E_8: Shalakan 2015/16 with 50 kg N fed.$^{-1}$ + Bio; E_9: Shalakan 2015/16 with 75 kg N fed.$^{-1}$; E_{10}: Fayoum 2015/16 with 50 kg N fed.$^{-1}$; E_{11}: Fayoum 2015/16 with 50 kg N fed.$^{-1}$ + Bio; E_{12}: Fayoum 2015/16 with 75 kg N fed.$^{-1}$.

The significant G x E interaction for grain yield suggests that some genotypes were stable, while others were unstable. Such interaction poses difficulties to wheat breeder in identifying genotypes that give consistent high grain yield under diverse environments unless stability analysis is undertaken. The G x E interaction significantly reduces a correlation between phenotypic and genotypic values. This indicates that G x E interaction of multi-environmental trials tends to confound varietal differences and make difficult varietal recommendations. In this respect, Pham and Kang (1988) indicated that G x E interaction minimizes the usefulness of genotypic means. These conditions imply the need for analyzing stability of genotypes across environments. Thus, it is imperative to undertake stability analysis in multi-environment trials. Furthermore, 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 genotypes, environments and their interactions as source of variation could potentially help the breeder to develop varieties with more stable performance.

Parametric stability statistics

The nine parametric stability statistics for the 15 bread wheat genotypes tested across twelve variable environments are given in Tables (3 and 4). Taking mean yield *per se* as a first parameter for evaluating the wheat genotypes. Sakha 94 followed by Sids 1, Cham 8 and Bohouth 6 gave the highest grain yield, while the genotypes; Gemmeiza 9, IB 18 and Sakha 93 had the lowest ones across environments. All genotypes showed regression coefficient (b_i) values, which were non-significantly different from unity, except Sakha 94. In contrast, all genotypes showed significant deviation mean squares from regression (S^2_d) greater than zero. Thus, based on the regression coefficient, all genotypes had an average response in all tested environments, except Sakha 94 with $b_i > 1$, which had higher mean yield than the grand mean and was responsive to improved environments. According to Becker and Leon (1988), genotypes with b_i values of unity showed an average response to changing environmental conditions. Meanwhile, most studied genotypes had deviations from regression significantly greater than zero and b_i values not significantly different from unity, suggesting that these genotypes are better adapted to high yielding environments. For the environmental variance (S_i^2), the cv. Shandweel 1 followed by Misr 1 and Misr 2 had the lowest variation across environments, while the cv. Sakha 94 and the Syrian genotype Bohouth 6 showed the largest variation. The ecovalence stability index (W_i) was lowest for the local cvs.; Sakha 93, Giza 168 and Sids 1 and highest for the genotypes; Bohouth 6 and Sakha 94. Francis and Kannenberg’s (1978) coefficient of variation (CV_i) is one of the parametric methods used to determine the stability of genotypes depending on the mean yield and CV_i values. Accordingly, the 15 wheat genotypes were classified into three groups. The first group consisted of the best genotypes, having yield above the grand mean and CV_i values below the mean, while the second group had high yield and large CV_i values.

Table 3. Mean grain yield (kg m-2), 9 parametric and 6 nonparametric stability statistics for 15 bread wheat genotypes tested over 12 variable environments

Genotype	Mean	Parametric									Nonparametric				
		b_i	S^2_d	S^2_i	W_i	CV_i	σ^2_i	R^2	P^{59}	P_i	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	TOP	RS
Shandaweel 1	0.688	0.657	0.011	0.020	1006	22.53	0.016	0.7524	0.016	0.048	18.93	19.99	4.71	33.33	15
Misr 1	0.692	0.847	0.010	0.030	706	25.52	0.010	0.8419	0.013	0.041	15.30	20.40	4.93	33.33	10
Misr 2	0.626	0.733	0.011	0.030	855	25.97	0.013	0.7965	0.015	0.065	17.72	16.57	3.98	16.67	18
Sids 13	0.645	1.002	0.016	0.050	1081	33.38	0.017	0.8230	0.016	0.057	21.30	26.60	4.87	25.00	21
Gemmeiza 7	0.651	1.105	0.020	0.060	1377	36.54	0.021	0.8190	0.018	0.055	21.79	24.24	5.05	25.00	21
Gemmeiza 9	0.603	0.987	0.009	0.040	616	32.42	0.009	0.8825	0.012	0.069	18.33	12.78	3.42	8.33	19
Giza 168	0.639	0.970	0.007	0.040	457	29.48	0.006	0.9070	0.011	0.055	11.17	6.95	2.44	8.33	13
Sakha 94	0.837	1.624	0.013	0.100	1738	36.60	0.027	0.9348	0.021	0.012	29.55	29.25	8.08	66.67	15
Sids 1	0.791	0.927	0.008	0.040	554	23.60	0.008	0.8838	0.012	0.021	14.08	18.33	6.67	66.67	5
Sakha 93	0.611	1.141	0.006	0.050	451	35.07	0.006	0.9360	0.011	0.063	16.79	13.12	3.23	8.33	14
Line 606	0.678	0.805	0.022	0.040	1539	29.77	0.024	0.7061	0.020	0.053	30.09	38.75	6.97	41.67	20
Cham 6	0.675	1.004	0.014	0.050	949	31.26	0.015	0.8398	0.015	0.047	16.81	21.11	4.74	16.67	16
Cham 8	0.726	0.851	0.013	0.040	942	26.00	0.014	0.8032	0.015	0.038	19.46	27.68	6.55	58.33	10
IB 18	0.603	0.953	0.016	0.040	1096	34.31	0.016	0.8062	0.016	0.073	24.42	21.31	4.55	25.00	24
Bohouth 6	0.707	1.395	0.026	0.080	2032	40.73	0.032	0.8462	0.023	0.043	26.93	37.90	7.12	41.67	19

b_i: regression coefficient; S^2_d: deviation from regression; S_i^2: environmental variance; W_i: Wricke's ecovalence; CV_i: coefficient of variation; σi2: Shukla's stability variance; R^2: coefficient of determination; P^{59}: Plaisted and Peterson's stability parameter; P_i: Lin and Binn's superiority index; $S_i^{(2)}$: between ranks variance over environments; $S_i^{(3)}$: the sum of the absolute deviations of the squares of ranks for each genotype; $S_i^{(6)}$: the sum of squares of ranks for each genotype relative to the mean of ranks; TOP: the parameter of Fox et al (1990); RS :Kang's rank sum.

Table 4. Ranking of bread wheat genotypes according to parametric and nonparametric stability statistics

Genotype	Mean	Parametric									Nonparametric				
		b_i	S^2_d	S^2_i	W_i	CV_i	σ^2_i	R^2	P^{59}	P_i	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	TOP	RS
Shandaweel 1	6	13	7	1	9	1	9	14	10	7	8	6	6	7	7
Misr 1	5	10	5	3	5	3	5	7	5	4	3	7	9	6	2
Misr 2	12	12	6	2	6	4	6	13	8	13	6	4	4	11	9
Sids 13	10	2	11	12	10	10	11	9	9	11	10	11	8	10	14
Gemmeiza 7	9	7	13	13	12	13	12	10	12	10	11	10	10	9	13
Gemmeiza 9	15	3	4	7	4	9	4	5	4	14	7	2	3	14	10
Giza 168	11	4	2	5	2	6	2	3	2	9	1	1	1	13	4
Sakha 94	1	15	8	15	14	14	14	2	14	1	14	13	15	1	6
Sids 1	2	6	3	4	3	2	3	4	3	2	2	5	12	2	1
Sakha 93	13	8	1	11	1	12	1	1	1	12	4	3	2	15	5
Line 606	7	11	14	8	13	7	13	15	13	8	15	15	13	5	12
Cham 6	8	1	10	10	8	8	8	8	6	6	5	8	7	12	8
Cham 8	3	9	9	6	7	5	7	12	7	3	9	12	11	3	3
IB 18	14	5	12	9	11	11	10	11	11	15	12	9	5	8	15
Bohouth 6	4	14	15	14	15	15	15	6	15	5	13	14	14	4	11

The third group consisted of poorly performing genotypes with yield less than grand mean and CV_i values above the mean. Hence, the five genotypes; Shandweel 1, Misr 1, Misr 2, Sids 1 and Cham 8 were classified in group I. Likewise, the four genotypes; Sakha 94, Line 606, Cham 6 and Bohouth 6 were classified in group II, while the six genotypes; Sids 13, Gemmeiza 7, Gemmeiza 9, Giza 168, Sakha 93 and IB 18 were classified in group III and thus were judged as unstable. According to Shukla's stability variance (σ_i^2), entries with minimum variance are considered more stable. Hence, the three local cvs.; Giza 168, Sakha 93 and Gemmeiza 9 were the most stable genotypes, while the two genotypes; Bohouth 6 and Sakha 94 were considered as the least stable ones. Coefficients of determination (R^2) between average yield of each genotype and environmental index were in the range of 0.7061 to 0.9360, in which a variation of mean grain yield was explained by genotype response across environments. Accordingly, the two local cvs.; Sakha 93 and Sakha 94, which had the highest r_i^2 values, were the most stable genotypes. When the stability statistic of Plaisted and Peterson (1959) was used, it indicated that the two local cvs.; Giza 168 and Sakha 93 had lower P^{59} values and could be considered as stable genotypes. According to Lin and Binns (1988), the superiority measure (P_i) of genotype is estimated by the squares of differences between an entry mean and maximum entry mean, summed and divided by twice the number of environments. Genotypes with the lowest P_i values are considered the most stable. Accordingly, the superiority measure of the tested genotypes indicated that the two local cvs.; Sakha 94 and Sids 1 were the most stable genotypes, while the two genotypes; IB 18 and Gemmeiza 9 were the least stable ones.

Nonparametric stability statistics

The results of nonparametric stability measures are presented in Tables (3 and 4). The $S_i^{(2)}$ statistic is based on ranks of genotypes across environments and they give equal weight to each environment. Genotypes with fewer changes in ranking are considered to be more stable (Becker and Leon 1988). Accordingly, the two local cvs.; Giza 168 and Sakha 93 had the smallest changes in rank and thus, are regarded as the most stable genotypes.

The other nonparametric stability statistics ($S_i^{(3)}$ and $S_i^{(6)}$) combining yield and stability based on yield ranks of genotypes in each environment were proposed by Nassar and Huehn (1987). These statistics measure stability in units of the mean rank of each genotype. As for $S_i^{(2)}$, the two local cvs.; Giza 168 and Sakha 93 were the most stable genotypes according to $S_i^{(3)}$ and $S_i^{(6)}$ statistics. The nonparametric superiority measure of Fox *et al* (1990) consisted of scoring the percentage of environments in which each genotype ranked in the top, middle and low third of trial entries. According to this measure, a genotype that appears in the top third of entries across localities can be considered as relatively well adapted and stable. On the basis of this measure, the two local cvs.; Sakha 94 and Sids 1 were considered as adapted genotypes, because they ranked in the top third of genotypes in a high percentage of environments (high top value of 66.67%) and was followed by the Syrian genotype Cham 8 (58.33%). The undesirable genotypes identified by this method were the three local cvs.; Gemmeiza 9, Giza 168 and Sakha 93. According to the rank_sum (RS) statistic, the three genotypes; Misr 1, Sids 1 and Cham 8 had the lowest RS values and therefore were considered to be stable genotypes with high yields. These results are in agreement with most of the previous data of parametric stability measurements. According to Becker and Leon (1988), these nonparametric stability measures are distributed freely and there is no assumption on the distribution of values. Therefore, they are more robust and less sensitive to errors of measurements than the parametric stability statistics.

Associations among parametric and nonparametric stability measures

The interrelationships of the different stability statistics determined from Spearman's rank correlation analysis are presented in Table (5). The results showed that mean yield across environments was significantly and positively correlated with each of P_i and TOP statistics.

Table 5. Spearman's correlation coefficients among ranks of grain yield, parametric and nonparametric stability statistics for 15 bread wheat genotypes tested across 12 different environments

Statistic	Parametric										Nonparametric			
	Mean	b_i	S^2_d	S^2_i	W_i	CV_i	σ_i^2	R^2	P^{59}	P_i	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	TOP
Parametic														
b_i	-0.525*													
S^2_d	-0.186	0.168												
S^2_i	-0.057	-0.025	0.500											
W_i	-0.343	0.421	0.907**	0.564*										
CV_i	0.154	0.021	0.439	0.946**	0.507									
σ_i^2	-0.399	0.316	0.874**	0.635*	0.960**	0.535*								
R^2	0.032	0.161	0.554*	-0.354	0.393	-0.364	0.276							
P^{59}	-0.329	0.539*	0.864**	0.468	0.982**	0.446	0.907**	0.446						
P_i	0.968**	-0.407	-0.029	-0.029	-0.179	0.186	-0.263	0.186	-0.143					
Nonparametric														
$S_i^{(2)}$	-0.171	0.411	0.829**	0.579*	0.914**	0.564*	0.877**	0.400	0.914**	0.004				
$S_i^{(3)}$	-0.539*	0.389	0.857**	0.546*	0.875**	0.404	0.887**	0.364	0.829**	-0.400	0.839**			
$S_i^{(6)}$	-.836**	0.493	0.579*	0.389	0.686**	0.204	0.715**	0.111	0.657**	-.729**	0.586*	0.839**		
TOP	0.879**	-.582*	-0.371	-0.068	-0.521*	0.079	-0.528*	-.157	-0.539*	0.768**	-0.436	-.671**	-886**	
RS	0.482	-0.157	0.714**	0.464	0.621*	0.539*	0.558*	0.425	0.604*	0.625*	0.675**	0.382	-0.007	0.218

*** and ** denote significant at 0.05 and 0.01 levels of probability, respectively.**

Such significant associations suggested that simple use of mean value of grain yield could be made in order to judge the stability of these wheat genotypes. Therefore, it seems that breeding for high grain yield would also enable a genotype to attain greater stability.

The regression coefficient (b_i) was positively and significantly correlated with P^{59} statistic. Furthermore, it is worthy to note that correlation between b_i and S^2_d statistics was found to be insignificant, indicating independence of these two stability measures. The S^2_d statistic showed significant and positive correlations with W_i, σ_i^2, R^2, P^{59}, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$ and RS statistics. The good correlation between S^2_d and W_i indicated that these two measures led to similar result. These findings agreed with Letta (2007), Shah *et al* (2009) and Ayalneh *et al* (2013). Also, these correlations indicated that most parametric stability measures were inter-correlated with nonparametric measures and therefore, can be used as alternatives. In this respect, Nguyen *et al* (1980) found that the most desirable stability statistic among R^2, S^2_d and W_i would be the coefficient of determination because it is a standardized form and the results are comparable between experiments directly regardless of the measurement scale used. Also, Langer *et al* (1979) obtained high correlations among R^2, S^2_d and W_i for three groups of oats cultivars. They concluded that any of these would be a satisfactory parameter for measuring stability. In addition, the environmental variance (S_i^2) exhibited significant and positive associations with W_i, CV_i, σ_i^2, $S_i^{(2)}$

and $S_i^{(3)}$. Also, the coefficient of variation (CV_i) gave significant and positive correlations with σ_i^2, $S_i^{(2)}$ and RS. Moreover, both of W_i and σ_i^2 statistics had positive and significant associated with Huehn's nonparametric measures ($S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$) as well as RS statistics. In this connection, Piepho and Lotito (1992) found correlations between parametric and nonparametric stability measures. In addition, P^{59} exhibited significant positive correlations with $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$ and RS. The superiority index (P_i) had significant positive associations with TOP and RS. The nonparametric method of $S_i^{(2)}$ exerted positive and significant correlations with $S_i^{(3)}$, $S_i^{(6)}$ and RS. $S_i^{(3)}$ had positive and significant association with $S_i^{(6)}$. Similar results were found by Kilic *et al* (2010) and Bishnoi and Hooda (2018).

It could be concluded that evaluation based on several seasons and locations provide useful information to determine adaptation and stability of genotypes and provide satisfactory knowledge about the magnitude and cause of the environmental effects in wheat breeding programs. Based on the different stability statistics, the three local cvs.; Sakha 93, Sids 1 and Giza 168 were the most stable in grain yield across the tested environments showing broader adaptability. These data, also, suggest that the P^{59} or other stability statistics could be used in addition to mean yield by the wheat breeder in the selection process when G x E interaction is present. Additionally, similar emphasis should be placed on sampling locations in wheat regional tests.

In summary, the most stability measures identified Sakha 93 and Sids 1 as the most stable genotypes and the two Syrian genotypes; IB 18 and Bohouth 6 as unstable ones. The remaining genotypes were intermediate between these two groups. As the result of these analyses, the local cv.; Sids 1 was demonstrated stable and good yield performance. In short, the current study indicated the possibility of improving progress from selections under diverse environmental conditions by applying different analytical parameters of stability.

CONCLUSION

Bread wheat genotypes showed differences in stability and performance across environments and the importance of genotype by environment interactions were clearly observed. Therefore, exploiting genotype x environment interaction in crop improvement activities is the main target of plant breeder to identify superior genotype.

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تقدير التفاعل بين التركيب الوراثي و البيئة و الثبات المحصولي و التلازمات بين مقاييس الثبات المختلفة لتراكيب وراثية من قمح الخبز

ياسر عبد الجواد الجابرى و أمل زكريا امين محمد

قسم المحاصيل – كلية الزراعة – جامعة عين شمس – شبرا الخيمة – مصر.

يهدف هذا البحث إلى مقارنة معايير الثبات المختلفة لبعض الأصناف المحلية والمستوردة وذلك لاختيار أفضلها من حيث الكفاءة وسهولة القبول لاستخدامها في برامج تربية القمح ولهذا الغرض استخدمت تسع مقاييس معيارية وخمسة أخرى غير معيارية للثبات لصفة محصول الحبوب (جم/م٢) لعشرة أصناف محلية من قمح الخبز هي شندويل ١، مصر ١، مصر ٢، سدس ١٢، جميزة ٧، جميزة ٩، جيزة ١٦٨، سخا ٩٤، سدس ١، سخا ٩٣ وخمسة تراكيب وراثية سورية هي سلالة 06، شام ٦، شام ٨، IB 18، بحوث ٦ قيمت تحت ١٢ بيئة مختلفة تمثل التوافقات بين موسمين زراعيين (٢٠١٤ –

١٥ ، ٢٠١٥ ، ١٦) وموقعين (شلقان بمحافظة القليوبية وسنورس بمحافظة الفيوم) وثلاثة معاملات من التسميد النيتروجيني (٥٠ ، ٥٠ + تسميد حيوي ، ٧٥ كجم ن/فدان). وكان التصميم التجريبي المستخدم هو القطع المنشقة مرة واحدة في ثلاثة مكررات حيث وزعت معاملات التسميد في القطع الرئيسية والتراكيب الوراثية بالقطع الفرعية. وقد أظهرت نتائج التحليل التجميعي معنوية كل من البيئات والتراكيب الوراثية والتفاعل بينهما مما يدل على اختلاف استجابة التراكيب الوراثية من القمح مع البيئات المختلفة والحاجة إلى إجراء تحليل الثبات. واستخدمت المقاييس المعيارية للثبات وهي متوسط مجموع مربعات الانحرافات عن خط الانحدار (S^2_d)، والمكافئ البيئي (W_i)، تباين الثبات (σ_i^2)، معامل التحديد (R^2)، متوسط مكون التباين للتفاعل بين التركيب الوراثي والبيئة (P^{59}) أن الصنف المحلي سخا ٩٣ على أكثر التراكيب الوراثية ثباتا ، بينما دلل مقياس دليل التفوق (P_i) أن سخا ٩٤ هو أكثر التراكيب الوراثية ثباتا. كما أوضحت نتائج مقاييس الثبات غير المعيارية ($S_i^{(2)}$ ، $S_i^{(3)}$ ، $S_i^{(6)}$) أن الصنف المحلي جيزة ١٦٨ على أقل التراكيب الوراثية تغيرا في الترتيب ولهذا يعتبر أكثر التراكيب الوراثية ثباتا. وتبعا للمقياسين غير المعياريين للثبات (مقياس التفوق TOP الذي اقترحه Fox وآخرون ومقياس مجموع الرتبة RS لـ Kang) يعتبر الصنف المحلي سخا ٩٤ وسدس ١ هما أكثر التراكيب الوراثية ثباتا لمحصول الحبوب. وبمقارنة مقاييس الثبات المختلفة اتضح أن متوسط مجموع مربعات الانحرافات عن خط الانحدار والمكافئ البيئي وتباين الثبات ومكون التباين للتفاعل بين التركيب الوراثي والبيئة و٣ مقاييس غير معيارية ($S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$) كانت متطابقة تقريبا في تعيين الثبات النسبي للتراكيب الوراثية للقمح الخبز ومع ذلك كانت معايير الثبات مختلفة في تحديد ثبات التراكيب الوراثية. وتشير نتائج التلازم بين مقاييس الثبات المختلفة أن معظم مقاييس الثبات غير المعيارية ترتبط ارتباطا معنويا وموجبا مع مقاييس الثبات المعيارية ولهذا يمكن أن تستخدم بدلا منها لها أهمية في القياس.