

## Genotype by Environment Interaction and Yield Stability in Bread Wheat Cultivars under Rainfed Conditions

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### ABSTRACT

The concept of stability is important for the selection of the crop cultivars and in the breeding programs. The aim of this work was to evaluate the productivity of some bread wheat cultivars under rainfed conditions of different locations in the NWCZ of Egypt. Results of the current study showed that the studied cultivars performed differently in the different environment. AMMI analysis revealed that the environment was responsible for most of the cultivars yields variation also AMMI2 bi-plot revealed that East Barrani in the first season was the most favorable environment for all cultivars, and Sakha 94 was the superior cultivar in this environment. According to the Eberhart and Russel (1966), Sakha 94 was the most stable cultivar followed by Misr-1 Sakha-93 cultivar is considered as the most stable high yielding genotypes under both moderate and severe drought conditions.

**KEYWORDS:** Environment Interaction, Genotype, Rainfed Conditions, Wheat, Yield Stability.

### 1. INTRODUCTION

In Egypt, wheat is the most important staple crop in the country and an essential component of the Egyptian diet. According to the United States Department of Agriculture (Donley, 2020) total wheat production in Egypt is 9.5 million tons, and the total consumption is 20.4 million tonnes, compared 20.1 million tonnes the previous year. It attributes the uptick to an increase in food, seed and industrial (FSI) use consumption.

“The rise in FSI wheat consumption is attributable to population growth of about 2.4% per annum,” the USDA said. “Egypt, with a population of 99.4 million, is adding over 2 million people per year. It also is host to an estimated 5 million refugees from Iraq, Syria, Libya, Yemen and Sudan.” The wide gap between consumption and actual production forces the country to import 11 million tons to close this gap. Therefore, selecting the most adapted high yielding cultivars is one of the most important breeding programs in the country.

The cultivar performance, in an environment, is the production of the genotypic, environmental and the

interaction between the genotypes and the environmental effects (Donley, 2020). These effects give the cultivars their phenotypic values, used to select the high yielding and more stable cultivars in the different environments. Genotype by environment interaction is defined as the variation of the environmental conditions, such as drought, temperature, disease pressure, stress etc. which results in different genes expression in the same genotype but not necessarily, of different rank orders of genotypes through the tested environments (Purchase, 1997), crop improvement programs include examining many genotypes in a wide range of environments, including stress and non-stress environments. Genotypes, producing higher and stable yields under stress conditions, e.g., water scarcity, can be recommended for such environments. Dencis, *et al.*, (2000), Yan and Hunt 2001)

The concept of stability is important for the selection of the crop cultivars and in the breeding programs. In the multi-environment trials, the phenotypic performance of a genotype is not necessarily, the same under the diverse environments

(Ali, *et al.*, (2003). Some genotypes may produce a good yield under a certain environment and fail in several others. The stability could be a challenge, not only for changing the test environment but also, the growing season (Tarakanovas and Ruzgas 2006). High yield stability means that the genotype produces similar (high or low) yield under a wide range of environments (Tarakanovas and Ruzgas 2006) and all new improved cultivars should be adapted to a wide range of adverse environments.

There are several methods to estimate the genotype stability across different environments, some of these methods are univariate parametric methods, such as regression coefficient and deviation mean square (Eberhart and Russal, 1966), unbiased estimate of variance (Shukla, 1972) covariance of the sum of square (Wricke 1962; Lin *et al.*, 1986; Becker and Leon, 1988) joint regression (Finlay and Wilkinson 1963; Westcott 1986; Lin *et al.*, 1986; Becker and Leon 1988), the slope of the regression line (Lin *et al.*, 1986; Becker and Leon 1988) the coefficient of determination (Bilbro and Ray 1976) and coefficient of variation or variance of genotype means (Jalaluddin and Harrison 1993). With these univariate statistical methods, there are some of the multivariate methods to estimate stability such as the additive main effect and multiplicative interaction (AMMI model (Zobel *et al.*, 1988) and bi-additive models (Denis and Gower 1994)

The additive main effects and multiplicative interaction MMI (Zobel *et al.*, 1988) and the Eberhart and Russell regression (ERR, Eberhart and Russell

, 1966) methods have been used, extensively, among all stability statistics. The ERR regresses is the line yield within an environment on an index of environment productivity, which is generally calculated as the average yield of the environment (Eberhart and Russell, 1966). The ERR method has been shown to be a subclass of AMMI that tests a specific hypothesis (Gauch 1988). Both of these methods belong to the concept of dynamic stability (Mohamadi *et al.*, 2012) also the two of extract a pattern from GEI and use it to estimate stability.

The main objectives of this study were 1) to evaluate the productivity of some bread wheat cultivars under rainfed conditions of different locations in the NWCZ of Egypt.

2) to determine the most suitable cultivar for each location by evaluating the genotype by environment interaction using, the AMMI biplot model.

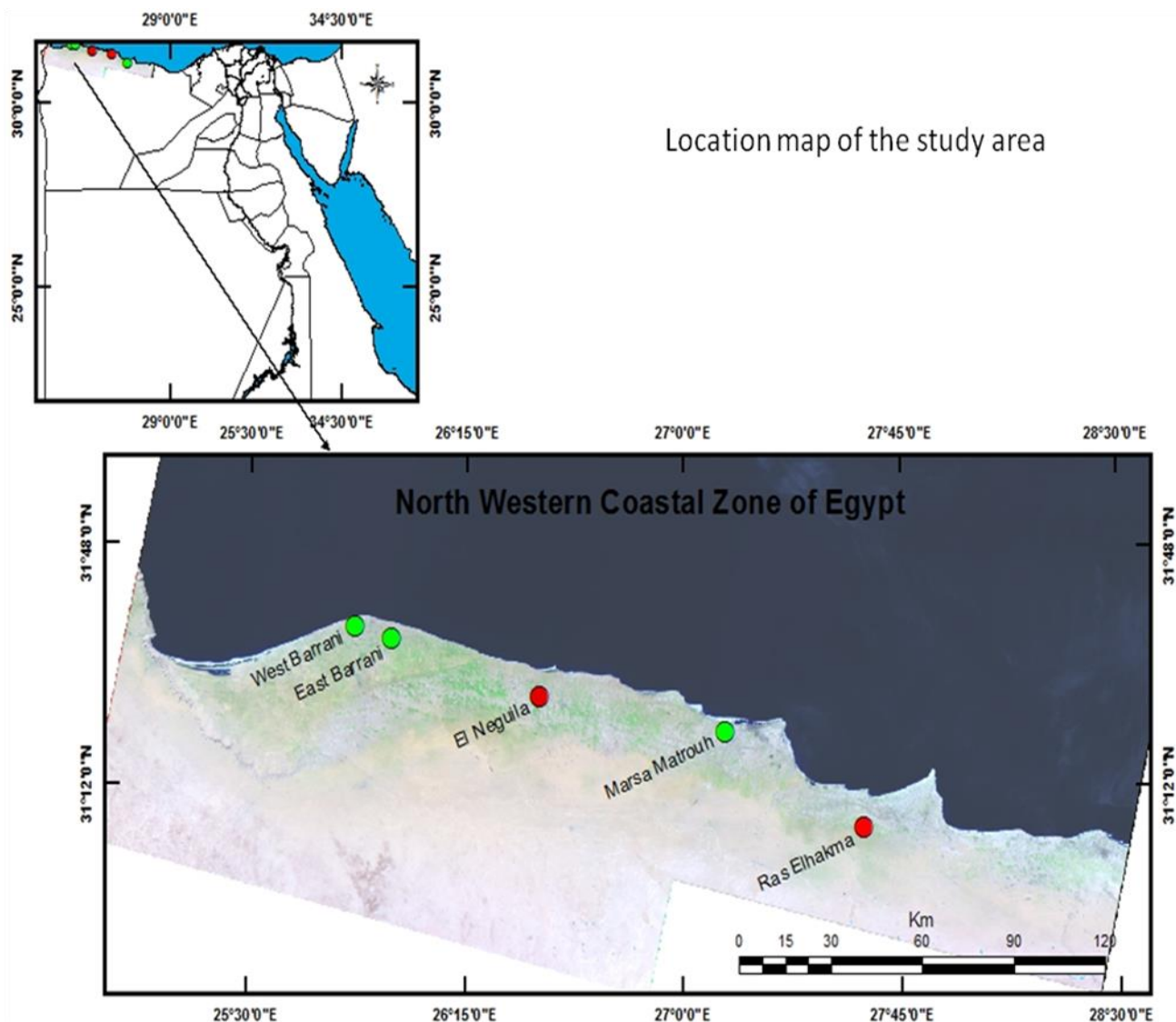
## 2. MATERIALS AND METHODS

### 2.1. Description of the study area

In order to identify the GEI, field experiments were conducted during the three growing seasons (2013/2014; 2014/2015 and 2015/2016 at nine different environments along the north western coast of Egypt. The environments were a combination of seasons and locations (Table 1). Six wheat cultivars were grown under the rainfed conditions at the studied locations. Locations coordinates, sowing dates and harvesting dates for the experimental sites are presented in Table (1).

**Table 1. Geographic coordinates, sowing and harvesting dates of the locations under study.**

	Location	Latitude	Longitude	Sowing date	Harvesting date
First season 2013/2014	Eest Barrani	31.60 °	25.86 °	Dec. 2013	May 2014
	Ras Elhakma	31 .10°	27. 62 °	16 Dec. 2013	12May 2014
Second season 2014/2015	Ras Elhakma	31 .10°	27. 62 °	26 Nov.2014	-
	Marsa Matrouh	31.34 °	27.14 °	4 Jan. 2015	-
	El Neguila	31. 43°	26 .50°	5 Jan. 2015	-
	West Barrani	31.60 °	25.86 °	23 Dec. 2014	28April2015
	East Barrani	31.57 °	25.99 °	11 Jan. 2015	-
Third season 2015/2016	Ras Elhakma	31 .10°	27. 62 °	9 Nov. 2015	24 April 2016
	El Neguila	31. 43°	26 .50°	1 Dec. 2015	12 April 2016
	East Barrani	31.60 °	25.86 °	10 Nov.2015	12 April 2016
	West Barrani	31.36°	25. 52°	7 Nov. 2015	23 April 2016



At each location, the experiment was laid out in a split plot design in randomize complete block design (RCBD) with three replications. The plot size was 10.5m<sup>2</sup>(3×3.5 m). Seeds were sown after the first

effective rain during the rainy season. The rainfall average and distribution during the grown seasons at the different locations are presented in Table (2).

**Table 2. Monthly total precipitation over the studied locations at the three growing seasons.**

Month	East Barrani 2013/2014	Ras elhekma 2013/2014	West Barrani 2014/2015	East Barrani 2015/2016	West Barrani 2015/2016	Ras Elhekma 2015/2016
Oct.	1.260	1.10	0.00	15.42	13.26	2.790
Nov.	1.060	13.74	1.17	40.16	49.31	23.49
Dec.	25.11	53.03	9.48	84.78	139.76	94.11
Jan.	85.27	27.54	49.03	9.54	36.18	58.46
Feb.	18.83	19.02	7.80	9.19	0.00	18.89
Mar.	0.00	2.908	7.14	1.96	0.915	13.90
Apr.	2.974	1.362	0.00	0.90	0.00	7.79
Total	134.5	118.70	74.61	161.94	239.43	219.4

Data from individual locations were subjected to statistical analysis using analysis of variance (ANOVA) to determine the significance of the main effects and their interaction. Least Significant Difference (LSD) was used to obtain the significant difference between individual means according to Gomez and Gomez (1984) using Crop Stat 7.2 statistical software package developed by IRRRI (IRRI, 2009). Eberhart and Russell's joint regression analysis ( $S^2di$ ), (Eberhart and Russell, 1966) was used in the domain of crop Stat 7.2 statistical software package. The analysis was performed using the model as:

$$Y_{IJ} = MI + BI_{IJ} + \Delta IJ$$

where  $Y_{IJ}$  is the adjusted mean phenotypic value for the  $I$ TH line at the  $J$ TH environment,  $MI$  is the overall mean of  $I$ TH line,  $BI$  is the regression coefficient from the ERR (estimated as  $B$ , the ERR stability index),  $IJ$  is the environmental index, and  $\Delta IJ$  is the residual error. This statistical method has two indices to measure the genotypes stability across different environments:

1-Regression coefficient

$$b_i = 1 + \frac{(\sum_i(x_{ij} - \bar{x}_i - \bar{x}_j + \bar{x}_{..}))(x_{.j} - \bar{x}_{..})}{(\sum_j(x_{.j} - \bar{x}_{..})^2)}$$

2- Variance of the regression deviations

$$s_{di}^2 = \frac{1}{E-2} \left[ \sum_i(x_{ij} - \bar{x}_i - \bar{x}_j + \bar{x}_{..}) - (b_i - 1)^2 \sum_i(x_{.j} - \bar{x}_{..})^2 \right]$$

where  $X_{ij}$  is the value of genotype  $i$  at the environment  $j$ ,  $\bar{x}_i$  is the mean of genotype  $i$ ,  $\bar{x}_j$  is the mean of environment  $j$ ,  $\bar{x}_{..}$  is the grand mean, and  $E$  is the number of environments.

The Additive Main effect and Multiplication Interaction AMMI model suggested by Zobel *et al.*, 1988 was used as follows:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \sum_{n=1}^N \lambda_n \gamma_{in} \delta_{jn} + \theta_{ij} + \varepsilon_{ij}$$

where  $\mu$  is the overall mean,  $\alpha_i$  is the effect of  $i$ th genotype,  $\beta_j$  is the effect of  $j$ th environment,  $\sum_{n=1}^N \lambda_n \gamma_{in} \delta_{jn} + \theta_{ij}$  is the GEI and  $\lambda_n$  is the eigenvalue of  $n$ th interaction principal component (IPC),  $\gamma_{in}$  and  $\delta_{jn}$  are the  $i$ th genotype and  $j$ th environment eigenvectors for the  $n$ th IPC, and  $\theta_{ij}$  is the GEI residuals.

The degrees of freedom (DF) for the IPCA axis were calculated based on the following method (Zobel *et al.*, 1988).  $DF = G + E - 1 - 2n$ ;

Where:  $G$  = the number of genotypes,  $E$  = the number of environments and  $n$  = the  $n^{th}$  axis of IPCA.

The biplot display of principal component analysis was used to identify stress-tolerant and high-yielding cultivars and to study the interrelationship between the stress-tolerant attributes. The principal component analysis and principal component plot were done using crop Stat 7.2 statistical software package.

### 3. RESULTS

#### 3.1. Eberhart and Russell model

According to Eberhart and Russell statistical method (Eberhart and Russell 1966) for studying the stability of different genotypes grown in a number of environments, a genotype could be considered as stable when it has a coefficient of regression ( $b_i$ )=1 and deviation from regression = 0. Based on the data presented in Table 3, the coefficient of regression for the studied cultivars ranged from 0.293 to 1.498. Based on grain yield, Sakha 94 has a  $b_i$  value of 1.107 followed by Misr 1(0.879) which are considered the most stable cultivars (closer to 1) as compared to the other cultivars, while Gemmiza 11 has a  $b_i$  value of 0.293 followed by Giza 168 1.498 and these cultivars are considered as unstable cultivars.

According to the deviation from regression values which ranged from 0.00 to 0.08, Gemmiza 11 has the lowest value of deviation from regression 0 followed by Giza 168 (0.01) and Sides 12 (0.01) which considered as the most stable cultivars while Sakha 93 has the highest values of deviation from regression (0.08) followed by Sakha 94 (0.05) which can be classified as less stable cultivars as compared to the others. The coefficient of determination varied from 2% recorded by Sakha 94 to 96% which produced by Gemmiza 11.

It can be concluded that Sakha 94 produced the closest to 1 value for the  $b_i$  (1.107) and Gemmiza 11 produced the lowest deviation from regression of 0. Different ranking of genotypes according to their stability based on these two coefficients are stated by Gebru, and Abay, 2013, Rasul *et al.*, 2006 and Sayar *et al.*, 2013. However, some studies found the regression coefficient to be better indicator for genotypic response under varying environments based on Finly and Wilkinson (1963), where stability is expressed as a linear relationship between the yield of genotypes over many environments i.e., the regression coefficient ( $b_i$ ), and a genotype with  $b_i = 1$  can be considered stable.

**Table 3. Stability parameters of wheat cultivars for the grain yield.**

Cultivar	Mean yield (t/ha)	$b_i$	SE	MS-TXL	MS-REG	$S^2_{di}$	$R^2(\%)$
Sakha 93	0.60	1.40	0.459	0.07	0.06	0.08	16.00
Sakha 94	0.55	1.107	0.428	0.04	0.00	0.05	2.00
Misr1	0.44	0.879	0.272	0.02	0.01	0.03	5.00
Giza168	0.66	1.498	0.236	0.03	0.06	0.01	69.00
Gemmiza 11	0.42	0.293*	0.106	0.04	0.12	0.00	96.00
Sids 12	0.34	0.703	0.144	0.01	0.02	0.01	59.00

Whereas;  $b_i$  is the regression coefficient, MS-TXL is contribution of each cultivar to interaction MS .MS-REG is the contribution of each cultivar to the regression component of the cultivar by location interaction,  $S^2_{di}$  is the regression deviation mean square,  $R^2$  is the coefficient of determination.

This method was modified from regression analysis which originally proposed by Yates and Cochran (1938).

The main problem with stability statistics is that they don't provide an accurate picture of the complete response pattern (Holhas, 1995). The reason is that a genotype's response to varying environments is multivariate (Lin *et al.*, 1986) whereas the stability indices are usually univariate.

Through multivariate analysis, genotypes with similar responses can be clustered, and thus the data can be summarized and analyzed more easily (Gauch, 1982; Crossa, 1990). Characterization of the response patterns of genotypes to environmental change enables extrapolation to a much wider range of environments than those tested (Holhas, 1995). One of the multivariate techniques is the AMMI model, AMMI model, (additive main effects and multiplicative interaction method). It combines the analysis of variance of genotypes and the environment main effects with principal component analysis of the GEI into a unified approach (Gauch, 1988; Zobel *et al.*, 1988; Gauch and Zobel, 1990).

### 3.2. AMMI analysis

In this study 6 environments were cultivated by 4 wheat cultivars in the first and the second seasons, while in the third season two more cultivars were added. Grain yield for the missing cultivars in the first and second seasons were estimated by the software i.e., Cropstat and the genotype by Environment interaction were tested using the AMMI model.

The AMMI analysis for the grain yield (Kg/ha) of the tested genotypes and locations showed that (59.38%) of the total sum squares was due to the environmental effects while the genotypes showed 11.7 % of the total sum of squares and the genotype by environment interaction attributed with 29.34 % of the sum of squares (Table 4). A large percent of the sum squares for the environment indicated that environments were diverse which cause the most of the variation in grain yield. In the analysis of variance, the sum squares of GxE were 2.5 times higher than that of genotypes.

**Table 4. The analysis of variance of the AMMI model.**

S.O.V.	df	S.S	M.S	Variation %
Cultivars	5	350759	70151.8	11.70
Environments	5	1767680	353537	59.38
Cultivars X Environments	19	873451	45971.1	29.34
AMMI COMPONENT 1	9	665686	73965.2	76.21
AMMI COMPONENT 2	7	147500	21071.4	16.88
AMMI COMPONENT 3	5	40593.3	8118.66	4.64
AMMI COMPONENT 4	3	19623.6	6541.22	2.24
Total	29	2976780		

The principal components (IPCs) were represented as IPC1, IPC2, IPC3 and IPC4. Two IPCs out of four were highly significant according to the AMMI analysis of variance, were IPC1 captured (76.21%) of the genotype by environment interaction, while IPC2 represented 16.88 % of the GXE interaction. The first two principal components collectively contributed to 93.09% of the total GEI.

Grain yield is a complex character which is an outcome of interactions between many plants traits, which are in turn influenced by their genetic makeup and the growing environments. Our results showed a change in the rankings of the cultivar under varying environments in regard to their grain yield, and the analysis of variance showed a significant difference between cultivars, environments and their interaction. The large sum square and highly significant mean square of environment indicated that the environments were diverse, the large differences among environmental means caused most of the variation in the grain yield. These findings are in agreement with those obtained by Mohammadi, *et al.*, 2007, Farshadfar 2008, Nachit *et al.*, 1992, Brancourt-Hulmel and. Lecomte .2016, Mohammadi and Amri 2013.

### 3.3. AMMI 1 model

Genotypes and environments that had IPCA1 values close to zero were characterized with a low

interaction effect (Figure 2), being considered stable (wide adaptation) (De Vita *et al* 2010). Environments responded differently in regard to grain Yield. Ras Elhekma in 2015/2016 season had a high negative IPCA1 value, with environmental mean being > the grand mean. Also, East Barrani in 2013/2014 had a high positive IPCA1 value, with environmental mean <the grand mean. West Barrani in 2014/2015 and West Baranni in 2015/2016 had also a high positive IPCA1 value with environmental mean being close to the grand mean. On the other hand, Ras Elhekama in 2013/2014 had IPCA1 score of just under zero and an environmental mean close to zero, also east Barrani in 2015/2016 had IPCA1 value of just above zero and an environmental mean close to zero which indicate that they had a low interaction effect. From the above mention results two out of six locations i.e., Ras Elhekma in 2015/2016 season and East Barrani in 2013/2014 had high IPCA1 scores, indicating high G×E interactions.

Cultivars can be characterized also based on their interactions with the environments. Sids 12 cultivar had IPCA1 score close to the zero line, which indicate that it had a stable performance across the testing environments (Carbonell *et al.* 2008). On the other hand, Sakha 93 show large deviations from zero on the ordinate indicating specific adaptation to the environments with the same IPCA1 sign.

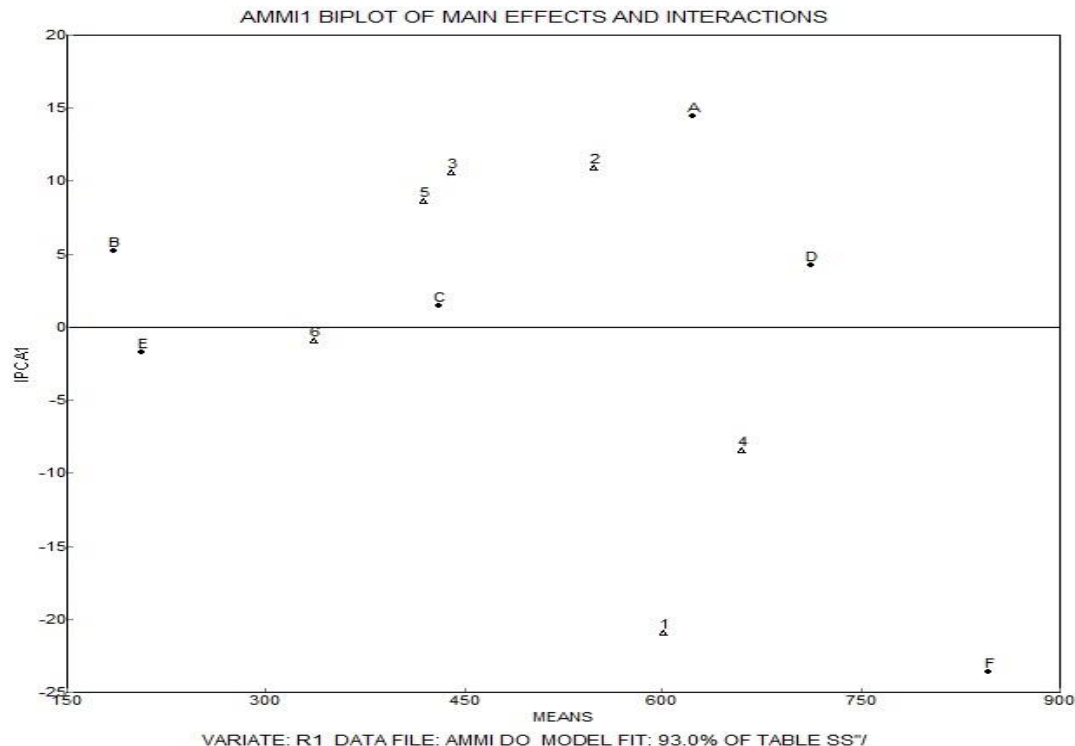


Fig 2. AMMI 1 Biplot of the main effects and interaction.

3.4. The AMMI2 model

The vector length in the AMMI model can be used to determine the discriminative Yield. Ras Elhekma in 2015/2016 season had a high negative IPCA1 value, with environmental mean being > the grand mean. Also, East Barrani in 2013/2014 had a high positive IPCA1 value, with environmental mean < the grand mean. West Barrani in 2014/2015 and West Baranni in 2015/2016 had also a high positive IPCA1 value with environmental mean being close to the grand mean. On the other hand, Ras Elhekama in 2013/2014 had IPCA1 score of just under zero and an environmental mean close to zero, also east Barrani in 2015/2016 had IPCA1 value of just above zero and an

environmental mean close to zero which indicate that they had a low interaction effect. From the above mention results two out of six locations i.e., Ras Elhekma in 2015/2016 season and East Barrani vectors of RE 13, EB15 and WB 14 and another acute angle between WB15 and EB13 environments indicated that each two of these environments were similar for yield determination. Yet, environments with obtuse angle RE 15 and WB15, EB13 and WB14, WB14 and RE15, RE13 and RE15 were different for yield determination. Sakha 94, GM and SD were the superior cultivar in Barrani 2013/2014, Barrani 2014/2015 and East Barrani 2015/2016 respectively.

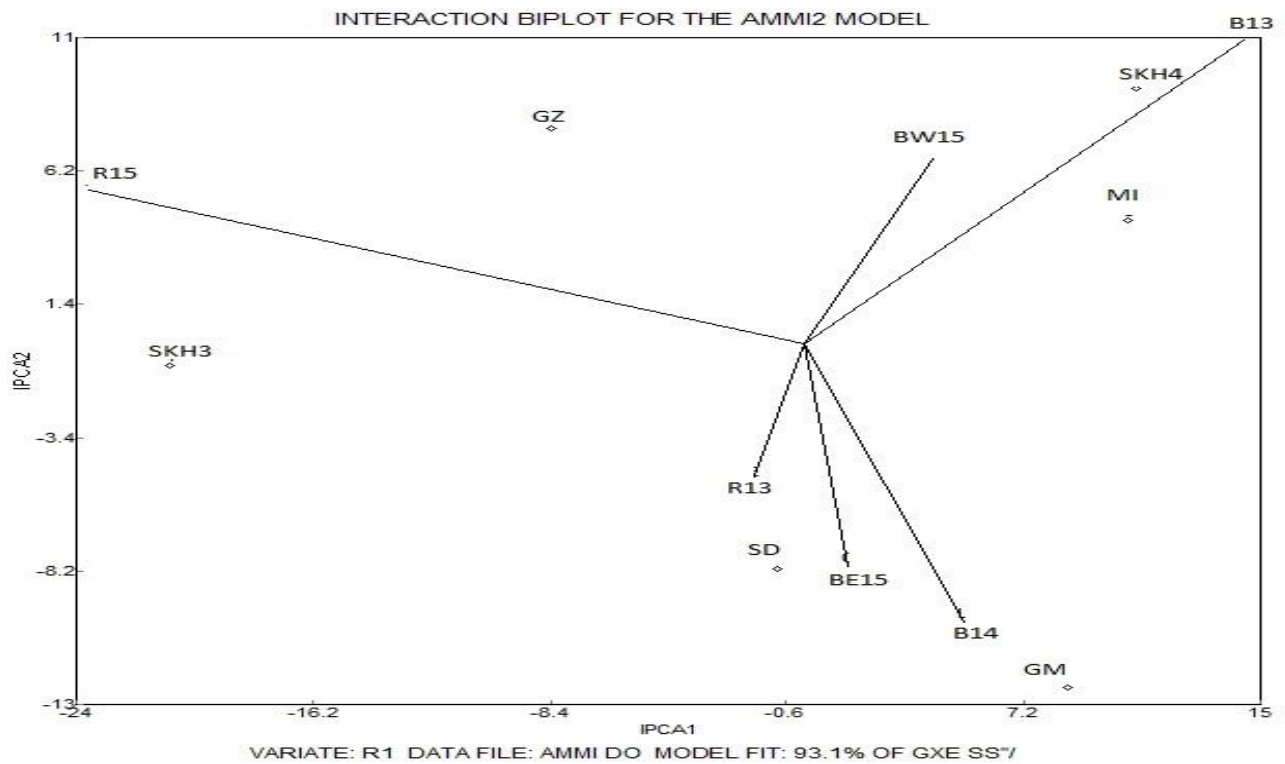


Fig 3. Interaction biplot for the AMMI2 model

The analysis of AMMI and principal component showed that there were a huge different among the studied environments which led to different yield performance among the tested cultivars. The mean square of the IPC1 and IPC2 were collectively accounted for 93.09% of the GxE interaction. Thus, the AMMI with only the two interaction principal component axes was found to be the best predictive model. Similar results that found the first two principal components to predict validation observation (Huang *et al.*, 2016., Kaya 2002).

In the AMMI-2 biplot the interaction between genotypes and environments can be clearly seen. The greater the IPC scores (positive or negative), the more adaptive genotype to certain environments. However, a genotype with IPCA scores close to zero show the high stability of such genotype to the all environments. our results show that Barrani 2013/2014 was the most favorable environment for all cultivars and Sakha 94 was the superior cultivar in this environment.

For analyzing the  $G \times E$  interaction, it was unavailable to grow all the cultivars in all the environments, thus producing unbalanced data which is common in plant breeding programs (Kang and Magari 1996). The unbalancedness of the data can be classified as planned and unplanned (Searle 1987), and it has been studied by many researchers using different approaches (Gauch and Zobel, 1990; Rameau and Denis, 1992). In our case, we used the approach of Restricted Maximum Likelihood (REML) which is already CROPSTAT software built in and the missing mean yield of cultivars is calculated using the Best Linear Unbiased Predictors (BLUPs; Henderson, 1975).

#### 4. CONCLUSION

Results showed that the studied cultivars performed differently in the different environment and. AMMI analysis revealed that the environment was responsible for most of the cultivars yields variation also AMMI2 bi-plot revealed that East Barrani in the first season was the most favorable environment for all cultivars, and Sakha 94 was the superior cultivar in this environment. According to the Eberhart and Russell Sakha 94 was the most stable cultivar followed by Misr-1 Sakha-93 cultivar is considered as the most stable high yielding genotypes under both moderate and severe drought conditions.

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## الملخص العربي

### التركيب الوراثي عن طريق التفاعل البيئي والثبات المحصول في أصناف قمح الخبز تحت ظروف الزراعة المطرية

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يعد مفهوم الاستقرار مهماً لاختيار أصناف المحاصيل وفي برامج التربية. كان الهدف من هذا العمل هو تقييم إنتاجية بعض أصناف قمح الخبز في ظل ظروف الزراعة المطرية في مواقع مختلفة في شمال غرب مصر. أظهرت نتائج الدراسة الحالية أن إنتاجية الأصناف المدروسة يختلف باختلاف البيئة. حيث أظهر تحليل التفاعل البيئي الوراثي **AMMI** أن البيئة كانت مسؤولة عن معظم التباينات في إنتاجية الأصناف قيد الدراسة، كما أظهر تحليل **AMMI2 bi-plot** أن منطقة شرق براني في الموسم الأول كانت البيئة الأكثر ملاءمة لجميع الأصناف، وكان صنف القمح سخا ٩٤ هو الصنف الأفضل في هذه البيئة. وفقاً لإبيرهارت ورسل، كان الصنف سخا ٩٤ هو الصنف الأكثر استقراراً، يليه صنف القمح مصر ١. بينما اشارت النتائج ان الصنف سخا ٩٣ يعتبر الصنف الأكثر استقراراً وإنتاجية في ظل ظروف المعتدلة والشديدة الجفاف.

**الكلمات المفتاحية:** التفاعل البيئي - التركيب الوراثي - الظروف المطرية - القمح - الثبات المحصولي