J. of Plant Production, Mansoura Univ., Vol. 13 (3):75-83, 2022

Journal of Plant Production

Journal homepage & Available online at: www.jpp.journals.ekb.eg

Estimation of AMMI and GGE Biplots for some Bread and Durum Wheat Genotypes

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ABSTRACT

Wheat breeders face environmental conditions and factors when developing and releasing a new cultivar from a breeding program, which considering a challenge especially with climate change. Genotype-by-environment interaction analysis is key for selection and cultivar release, and to identify suitable production and test environments. Therefore, the grain yield of 12 bread and 12 durum wheat genotypes were evaluated in six different locations from Nile valley to newly reclaimed land in the west desert of Egypt, in two successive 2018/19 and 2019/20 seasons. The mega-environment was tested with the winner genotypes, the stable genotypes, and the individual ideal genotypes by using additive main effect and multiplicative interaction (AMMI), and genotype main effect plus genotype × environment interaction (GGE) biplot methods. The results of AMMI and GGE biplot revealed four mega-environments, one of them had several environments with winner G_7 as well as a stable genotype. But the ideal genotype was G_2 for the bread wheat genotypes set. On the other hand, the durum wheat genotypes set is divided into two mega-environments with winners G_{16} and G_{17} (breeding lines) of grain yield. But the stable genotype and ideal genotype was G_{18} according to AMMI and GGE biplot analyses across tested environments.

Keywords: Stability, Grain yield, Genotypes × Environment, Mega-environments, Bread wheat, durum wheat

INTRODUCTION

Wheat (*Triticum spp.*) is an essential crop to human civilization because of its great role of enhancing global food security and the world feeding, which share approximately 20% of the total dietary calories and plant proteins globally. Currently, it is the most broadly cultivated cereal in the world with planted area annually of roughly 220 million hectares under various agro-climatic circumstances and wide ranges of regional geographic. Rely on climatic conditions, the annually production about 670 million tons. Subsequently, wheat is important and essential for worldwide food security (Shiferaw *et al*., 2013). Durum and bread wheat is a wide range cereal crop, grown in climatic regions fluctuating from warm, dry, cool, and wet environments *(Giraldo et al., 2016 and Zaïm et al*,. 2017). The climate resilience of wheat yield performance possesses a strong genetic basis, but the phenotypic outcome displays an interaction with the environment. The individual wheat genotype capacity is limited to maintain a high yield outcome under climatic variability conditions and extremes (Kahiluoto *et al*., 2019). Therefore, planting "a set of varieties with diverse responses to critical weather conditions is required to promote the climate resilience of a crop (Piepho, 2019 and Bocci *et al*. 2020). Egypt is located between 22º N – 32º N latitude and cultivated an irrigated area of about 1.4 million hectares (3.4 M feddan) spring bread and durum wheat (durum representing about 500000 feddans of total area) to produce 9 million tons with mean productivity of 6.3 tons ha^{-1}. The consumption, however, is about 22 million tons. Then the self-sufficient of wheat is about 41% (the Egyptian production covered less than half of consuming wheat). So, this boosts Egypt to import approximately 13 million tons. It makes Egypt the largest wheat importer globally, according to Food Agriculture Organization (FAO, 2019). The main environmental factors of Egypt are wheat production areas concentrating on the Nile valley and its delta (clay- clay loam) and the desert covered most of the region (Asseng *et al*., 2018). Egypt encounters a great challenge of limited water resources and a fixed Nile quota. In addition, its rainfall is scarce and distributed along the north coast (Alwang 2018; Asseng *et al*., 2018 and Elbeltagi *et al*., 2020). Hence, the government has established a national project to expand the reclamation areas in the west desert (sandy soil). In general, spring bread wheat produces in all of Egypt, but durum wheat concentrates in the south (Upper Egypt). These main problems are to improve and release stable and yielding cultivars. Plant breeding sciences and programs play a great role in feeding the world and increasing the productivity of agriculture. One aspect of plant breeding is to select and develop a stable genotype specifically to an aimed region (Yan, 2019). To recommend a stable genotype, repeating yield trials over years and locations is a common pattern used by breeders to conclude the recommendations. Moreover, breeders, farmers, and producers depend on variety trials. So, the breeders select elite advanced lines to release a new wheat cultivar. Hence, the farmer decides a suitable wheat variety to cultivate in their farms. And the producers select superior grains cultivars for process crop products and end use goods (Yan, 2014). Additionally, "Due to the presence of genotype by environment interaction (GE), no crop cultivar performed the best in all regions. Therefore, the growing regions of a crop must divide into sub-regions or mega-environments" (Gauch and Zobel, 1997 and Yan, 2019). Several methods used to identify target region into mega-environments. Meaningful delineation must be based on repeatable GE patterns (Yan, 2015 and 2016). The additive main effects and multiplicative interaction (AMMI) pattern is a widely used statistical method (Gauch, 1992). It is used to comprehend the structure of interactions between environments and genotypes. (Gauch, 2013) explained AMMI analyses by a simple protocol with four steps: (i) analysis of variance, (ii) model diagnosis, (iii) mega-environment delineation, and (iv) agricultural

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DOI:10.21608/jpp.2022.131275.1103

recommendations. The genotypic main effect plus GE interaction (GGE biplot) analysis used by agricultural researchers, in particular, plant breeders had enhanced dramatically for analyzing multi-environment trial (MET) data (Yan *et al.* 2007). In the last step of a breeding program finishing by cultivar release, which had a large numbers of advanced breeding lines, it is possible to characterize each genotype in terms of its stability in countered with diverse environmental conditions (Cooper and DeLacy, 1994*;* Xu *et al.*, 2017; Zoric *et al.*, 2017 and Hassani *et al*., 2018). A review of the recent literatures represent that attempts have been made to separate the effects of GEI on wheat grain yield traits, and other crops using sophisticated multivariate statistical methods(Yan, 2016; Hassani *et al*., 2018; Yan and Frégeau-Reid, 2018). Some stability methods are considered as alternatives parameters and others as complementary measurements, and calculate more than one to investigate GE interaction could upsurge the efficiency and make adequate decision (Bornhofen *et al*., 2017 and Rezende *et al*., 2020a).

The investigation objectives were: (i) to evaluate the grain yield performance and stable genotype of 12 bread and 12 durum wheat genotypes across varied conditions in Egypt, and (ii) to delineation mega-environment and which-own-where genotypes (winner genotypes) of multi-environment trial.

MATERIALS AND METHODS

Plant materials and experimental procedures

Twenty-four bread and durum wheat genotypes a long with pedigree and selection history (Table 1) were evaluated separately (each twelve genotypes in an experiment) in six Research Stations of Agricultural Research Center ARC, Egypt. The survey of exotic materials, which came from CIMMYT (several yield trails, i.e., 30th ESWYT and 46th HTWYT) during growing seasons from 2016 to 2018, were done to select the elite bread wheat genotypes. The selected elite genotypes with three cultivars recently released Misr 3, Sids 14 and Sakha 95 (checks) were imbedded. On the other hand, durum wheat entries included ten breeding lines improved from the national breeding program with BaniSuef 5 and Sohag 4 check cultivars .

Table 1. Code, source and trail name, origin and pedigree of selected bread and durum wheat genotypes

Code	Source and trail name	Origin	Pedigree and selection history
			Bread wheat genotypes
G1	17th HTWYT [a] 2017/2018	CIMMYT	FRET2/KUKUNA//FRET2/3/YANAC/4/FRET2/KIRITATI/5/2*TACUPETOF2001/BRAMBLING*2//KACHU CMSS11Y00877. T-099TOPM-099Y-099M-099NJ-099NJ-9WGY-0B-0SH
G2	23th HTWYT 2017/2018	CIMMYT	SAUAL/4/CROC_1/AE.SQUARROSA(205)//KAUZ/3/ATTILA/5/SAUAL/8/TACUPETO F2001 /6/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER /5/PASTOR /7/ROLF07/9/SAUAL/ YANAC//SAUAL CMSS11Y01008T-099TOPM-099Y-099M-0SY-16M-0WGY-0SH
G3	46th HTWYT 2017/2018	CIMMYT	NADI/COPIO//NADI CMSS11B00910T-099TOPY-099M-099NJ-099NJ-2WGY-0B-0SH
G4	9th WYCYT [b] 2017/2018	CIMMYT	TACUPETO F2001/BRAMBLING*2//KACHU/3/MUNAL #1 PTSS11B00016S-0SHB-099Y-099B-099Y-6Y-020Y-0B-0SH
G5	16th WYCYT 2017/2018	CIMMYT	8.111/RGB-U//WARD/3/FGO/4/RABI/5/AE.SQUARROSA(784)/7/2* CHWL86/6/FILIN/IRENA /5/ CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/ WEAVER. PT12SHB00007T-099Y-099B-099Y-28B-020Y-0B-0B-0SH
G6	17th WYCYT 2017/2018	CIMMYT	68.111/RGB-U//WARD/3/FGO/4/RABI/5/AE.SQUARROSA(784)/7/2*CHWL86/6/FILIN /IRENA /5/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER. PT12SHB00007T-099Y-099B-099Y-31B-020Y-0B-0B-0SH
G7	30th ESWYT [c] 2017/2018	CIMMYT	BORL14//KFA/2*KACHU CMSS11B00167S-099M-0SY-11M-0WGY-0SH
G8	44th HTWYT 2016/2017	CIMMYT	KACHU*2/CIRNO C 2008 CMSS10B01201T-099TOPY-099M-0SY-31M-0WGY-0SH-0SH
G9	Sakha breeding line	Egypt	Sakha Promising line (17-018) # 21
G10	Misr 3 Bread cultivar	Egypt	MISR 3
G11	Sids 14 Bread cultivar	Egypt	SIDS 14
G12	Sakha 95 Bread cultivar	Egypt	SAKHA 95
			Durum wheat genotypes
G13	Sids breeding line	Egypt	PLATA_6/GREEN_17/3/CHEN/AUK//BISU*2/5/PLATA_3//CREX/ALLA/3/SOMBRA_20/4/SILVER_14/MOEWE /6/ICAMOR-TA04-73/Ammar-8. SDD5301 -1SD -2SD-1SD-0SD
G14	Sids breeding line	Egypt	POD_20//SULA/ACO89/3/SORA/2*PLATA_12//SOMAT_3/4/PATKA_4/THKNEE_9//CABECA_1 /5/CF4-JS 21//RASCON_39/TILO_1. SDD5302 -1SD -1SD-1SD-0SD
G15	Sids breeding line	Egypt	POD_20//SULA/ACO89/3/SORA/2*PLATA_12//SOMAT_3/4/PATKA_4/THKNEE_9//CABECA_1 /6/ARMENT/4/2*SKEST//HUI/TUB/3/SILVER/5/TILO_1/LOTUS_4. SDD5303 -1SD -1SD-1SD-0SD
G16	Sids breeding line	Egypt	POD_20//SULA/ACO89/3/SORA/2*PLATA_12//SOMAT_3/4/PATKA_4/THKNEE_9//CABECA_1 /6/ARMENT/4/2*SKEST//HUI/TUB/3/ SILVER/5/TILO_1/LOTUS_4. SDD5303 -2SD -2SD-2SD-0SD
G17	Sids breeding line	Egypt	GUAYACANINIA/GUANAY/10/LD357E/2*TC60//JO69/3/FGO/4/GTA/5/SRN_1/6/TOTUS/7/ENTE/MEXI_2/HUI/4/YAV_1/3/LD357E/2*TC60//JO69/8/SOMBRA_20/9/JUPARE C 2001/ /11/ PLATA_10/6/MQUE/4/ USDA573//QFN/AA_7/3/ALBA-D/5/AVO/HUI/7/PLATA_13/8/ THKNEE_11/9/CHEN/ALTAR 84/3/HUI/POC//BUB/RUFO/4/FNFOOT . SDD5313 -1SD -1SD-1SD-0SD
G18	Sids breeding line	Egypt	BCRIS/BICUM//LLARETAINIA/3/DUKEM_12/2*RASCON_21/4/1A.1D 5+10-6/2*WB881 //1A.1D 5+10-6/3*MOJO/3/BISU_1/PATKA_3 /5/SOMAT_4/INTER_8. SDD5321 -6SD -1SD-1SD-0SD
G19	Sids breeding line	Egypt	BCRIS/BICUM//LLARETAINIA/3/DUKEM_12/2*RASCON_21/4/1A.1D 5+10-6/2*WB881//1A.1D 5+10-6/3*MOJO/3/BISU_1/PATKA_3 /8/GEDIZ/FGO//GTA/3/SRN_1/4/TOTUS/5/ENTE/MEXI_2//HUI/3/YAV_1/GEDIZ/6/SOMBRA_20/7/STOT//ALTAR 84/ALD. SDD5322 -9SD -1SD-1SD-0SD
G20	Sids breeding line	Egypt	BCRIS/BICUM//LLARETAINIA/3/DUKEM_12/2*RASCON_21/4/1A.1D 5+10-6/2*WB881//1A.1D 5+10-6/3*MOJO/3/BISU_1/PATKA_3 /8/GEDIZ/FGO//GTA/3/SRN_1/4/TOTUS/5/ENTE/MEXI_2//HUI/3/YAV_1/GEDIZ/6/SOMBRA_20/7/STOT//ALTAR 84/ALD. SDD5322 -9SD -1SD-2SD-0SD
G21	Sids breeding line	Egypt	POD_20//SULA/ACO89/3/SORA/2*PLATA_12//SOMAT_3/4/PATKA_4/THKNEE_9//CABECA_1 /6/ARMENT/4/2*SKEST//HUI/TUB/3/ SILVER/5/TILO_1/LOTUS_4. SDD5303 -2SD -2SD-1SD-0SD
G22	Sids breeding line	Egypt	ALTAR84/STINT//SILVER_45/3/GUANAY/4/GREEN_14//YAV_10/AUK/5/SOMAT_4/INTER_8 /6/VANRRIKSE_6.2//1A-1D 2+12-5/3*WB881. SDD5317 -5SD -1SD-1SD-0SD
G23	BaniSuef 5 Durum cultivar	Egypt	Bani Suef 5
G24	Sohag 4 Durum cultivar	Egypt	Sohag 4

To examine these plant materials (both wheat groups) in different agro-climate conditions established a multi-environment trial. The locations were Nubaria, Sakha, Sids, Shandaweel, West El Mynia, and East Owainat (Table 2), these sites represent most latitudes of Egypt (22º N – 32º N) during two cropping seasons commencing from 2018. Table 2 shows the several soil types from clay soil to sandy soil and calcareous sandy loam, and the elevation from 270 m in the South of Egypt to six and half meters above sea level in the North, as well as the site differences of temperature. The experimental design was a randomized complete block design (RCBD) with three replicates in each environment, and the experimental unit was a 4.8 m² plot (6 rows, 4-m-long, and 20 cm rows spacing). The agronomic practices of wheat were applied in each environment following the procedures of ARC, Ministry of Agriculture and Land Reclamation of Egypt.The recommended package of wheat production is most of the wheat area irrigated around the Nile River and its Delta, except the negligible area in the North Coast with rain lower than 150 mm/year (Abdelmageed *et al*. 2019). And the feddan (4200 m^2) is fertilized by 75 kg nitrogen. However, locations West El Mynia and East Owainat (new reclamation area) are irrigated by dripping and sprinkling systems, respectively.

Table 2. Describing location and their agro-climatic conditions

Environment	Location	Growing season	Latitude	Longitude	Soil type	Elevation m	Temperature (ºC)		
							Min.	Max.	Ave.
E1 E2	Sakha	2018-2019 2019-2020	31° 5′ N	30° 56′ E	Clay	6.5	17.84 17.45	23.42 23.19	20.6 20.7
E6 E7	Nubaria	2018-2019 2019-2020	30° 38' N	30° 4' E	Calcareous sandy loam	11	13.45 13.09	23.68 22.98	18.56 17.36
E5 E9	Sids	2018-2019 2019-2020	28° 54′ N	30° 56′ E	Clay	31	10.65 10.72	25.14 25.11	17.36 17.34
E3 E4	Shandaweel	2018-2019 2019-2020	26° 33′ N	31° 42 ′ E	Clay	61	11.40 11.52	25.75 26.00	18.53 18.76
E8	West El Mynia	2019-2020	28° 8' N	30° 32' E	Sandy	101	10.87 10.27	24.49 24.36	16.89 16.78
E10 E11	East Owainat	2018-2019 2019-2020	22° 34' N	28° 44' E	Sandy	270	12.09 12.43	27.68 27.91	19.47 19.69

Statistical analyses

Preliminary test of homogeneity of variance was performed to identify whether individual experiment (RCBD) included or not to determine (GE) interaction using combined analysis. Grain yield (Kg ha^{-1}) data used to conduct statistical analyses from repeated experiments over the environments (E) combination. The genotype by environment interaction GEI analyzed through additive mean multiplicative and interaction AMMI (Gauch and Zobel 1988 and Gauch, 1988), which univariate ANOVA and multivariate principal component analysis PCA to partitioning the GE component, computing by AMMISOFT program according to (Gauch, 2013). In addition, F-test suggested by (Gollob, 1968), and AMMI Stability Value (ASV) suggested by (Purchase 2000), was calculated to detected which genotypes are stable across the environments. All data subjected to analysis by GenStat Statistical Software 19th Edition. Graphical analyses for GGE biplot (genotype G + GEI) described by (Yan *et al*. 2000, 2001), were conducted by GenStat 19th to identify, i.e., mega-environment, which-won-where pattern, genotype ranking rely on mean performance and stability and ideal genotypes over environments.

RESULTS AND DISCUSSION

Results

AMMI analysis of variance

Results demonstrated AMMI analysis of variance with interaction principal component (IPCAs), source of variation including genotypes (G), environment (E), and their interaction (GE) along with three IPCAs. All these items recorded a highly significant difference ($P < 0.01$) for grain yield (GY) for both sets of wheat (Table 3). The total sum of square was divided to its component; environment sum of square recorded 84% and 85.2% for bread and durum data sets, respectively. However, genotypes percentage of variation are 1.0% and 2.2%, while GE interaction contributed 9.5 % and 7.5 % for bread and durum wheat genotypes, respectively.

The sum of square (SS) of noise GE_N and signal GE_S of GEI had 16.4 and 83.5% of bread wheat data. and 24.35% and 75.65% of durum wheat data, respectively. Accordingly, compared signal values GE_S with genotypes sum of square SS the GE_S is equal eight times and three times as large as Genotype SS for GY of two wheat experiments, these likely AMMI analyses to be worthwhile.

The AMMI analyses give an idea about GEI partitioned into IPCAs three IPCAs called AMMI3. The IPCA1 share with 49.4% and 61.6 of total GEI variation for bread and durum wheat sets, respectively .The Gollob's F-tests showed highly significant differences in all sources of variation particularly IPCAs, Table 3.

AMMI mega-environment and genotype winners

AMMI Analyses represents the winner genotypes and mega-environment based on the model family ordered in IPCA1 (AMMI-1). The scores AMMI-1 delineates four mega-environments with genotypes G11, G4, G7, and G12 as winners of bread group, and two mega-environments of durum with G17 and G16 genotypes. In contrast, AMMI-F deals with the row data, based on it identified seven mega-environments with several winners' genotype and the same note of durum trail. Moreover, that three bread genotypes and five durum entries never win for GY of any mega-environment (data not shown). Genotypes, AMMI-1, and AMMI-F ranks (Table 4). These models important because the first is capable of mega-environment delineation, and the other model reveals row data of high-yielding five genotypes throughout the environments. Corresponding AMMI-1, the most accurate member of this family, the data set of bread wheat labeled into four mega-environments (i) E8 with winner G11, (ii) E10 and E11 had winner G4, (iii) E2 E3 E4 E6 and E7 possess G7, and (iv) E1, E5, and E9 with winner G12. However, durum wheat had divided into two mega-environments, the first one is E8, E4, and E3 with winner G17, and the other mega-environment comprised of remaining environments and G16 winner. Matching to the AMMI-F model, the same mega-environments had characterized in both data sets, but the dissimilar the several seven genotypes from 12 are a win of bread and durum also (Table 4).

Table 3. AMMI analysis of variance for grain yield of 12 bread and 12 durum wheat genotypes across 11 environments

Source	DF	SS	MS	SS%	Noise	Signal	F-test Gollob
Bread wheat							
Genotypes (G)	11	26221433	2383767**	1.0			
Environments(E)	10	2219112660	221911266**	84.6			
Block	22	37448474	1702203**				
Interactions (GE)	110	250314556	2275587**	9.5	41265180[a]	209049376[b]	4.68**
IPCA 1	20	123700446	6185022**	49.4[c]			12.7**
IPCA 2	18	42837871	2379882**	17.1			4.9**
IPCA 3	16	36009037	2250565**	14.4			4.6**
Residuals	56	47767202	852986**	19.1			
Error	242	90783434	375138	3.5			
Durum wheat							
Source	DF	SS	MS	SS%	Noise	Signal	F-test Gollob
Genotypes (G)	11	58834939	5348631**	2.2			
Environments(E)	10	2316751623	231675162**	85.2			
Block	22	24348677	1106758**				
Interactions (GE)	110	207501443	1886377**	7.6	50536970[a]	156964473[b]	3.6**
IPCA 1	20	127922133	6396107**	61.6[c]			12.41**
IPCA 2	18	31997222	1777623**	15.4			3.4**
IPCA 3	16	17497003	1093563**	8.4			2.1**
Residuals	56	30085084	537234NS	14.5			
Error	242	111181349	459427	4.1			

*** and ** significant at 0.05 and 0.01 respectively**
a calculated by (DF GE*MS error) = 16.4% for bread wheat and 24.3% of durum GEI ss
b calculated as (SS GE-a) = 83.5%= 8 times of G SS for bread wheat and =75.6%= 3 times G ss of GEss
c calculated by (SS IPC/SS GE)

Figure 1 illuminates the AMMI-1 biplot, mean versus IPCA1. The value of this biplot refers to described GEI by genotypes means with environments effects and their IPCA1 score. Bread wheat analysis, showed that, The IPCA1 recorded 49.4% of genotype by environment interaction SS. Hence, it is suitable for interpreting GEI and mean effects. A consequence that E situated close to 0 line of IPCA1 had a low contribution of GEI across genotypes also recorded lower discrimination among Gs and *vis versa*. Therefore, the environment, i.e., E4, E10, E7, E6, E2, E3, and E11 possesses a low percentage of GEI variation. The environments E8 and E1 relished a high portion of GEI variation, but discriminate Es among Gs. The E3 and E4 followed by E2 noted high yielding along-with low variation sharing in GEI totally. The stable genotypes pointed in a situation close to the origin of the Figure (PC score zero) own low sharing of variation entirely GEI and *vice versa*. Additionally, genotypes G7, G8 followed by G 2 achieved high mean performance and stability compare with the other genotypes. The environments, i.e., E2, E3, E4, E5, E1, and E9 were favorable, but E2, E3, and E4 were desirable and high yielding.

Table 4. Mega-environments, AMMI-1 Ranks and AMMI-F Ranks of 12 bread and 12 durum genotypes over 11 environments

Environment	Ratio	AMMI-1 Ranks 1	2	3	4	5	AMMI-F Ranks 1	2	3	4	5
Bread Wheat											
ENV8	1.45	G11	G4	G6	G5	G8	G11	G4	G5	G6	G8
EN10	1.15	G4	G11	G8	G7	G6	G11	G6	G7	G8	G5
EN11	1.02	G4	G7	G11	G8	G2	G5	G4	G12	G2	G6
ENV6	1.00	G7	G2	G4	G12	G8	G2	G4	G6	G12	G8
ENV3	1.00	G7	G2	G4	G12	G8	G2	G4	G6	G10	G7
ENV7	1.00	G7	G2	G12	G4	G8	G8	G1	G2	G7	G11
ENV4	1.00	G7	G2	G12	G4	G10	G2	G4	G6	G7	G12
ENV2	1.00	G7	G2	G12	G4	G10	G12	G10	G11	G8	G7
ENV5	1.02	G12	G10	G2	G7	G3	G1	G3	G7	G2	G10
ENV9	1.03	G12	G10	G2	G7	G3	G8	G9	G12	G10	G1
ENV1	1.07	G12	G10	G3	G2	G7	G3	G7	G10	G12	G4
Durum Wheat											
ENV8	1.00	G17	G19	G21	G18	G22	G17	G19	G21	G18	G22
ENV4	1.00	G17	G21	G18	G19	G16	G17	G18	G15	G21	G24
ENV3	1.00	G17	G21	G18	G19	G16	G17	G18	G21	G15	G24
ENV9	1.01	G16	G17	G21	G18	G13	G18	G16	G12	G21	G19
EN11	1.06	G16	G17	G21	G18	G13	G17	G18	G16	G21	G19
EN10	1.09	G16	G17	G21	G18	G13	G17	G18	G24	G15	G19
ENV6	1.04	G16	G17	G21	G18	G13	G16	G24	G13	G17	G14
ENV7	1.04	G16	G17	G21	G18	G13	G22	G16	G22	G24	G17
ENV2	1.10	G16	G13	G24	G18	G21	G13	G16	G19	G14	G21
ENV1	1.09	G16	G13	G24	G18	G14	G21	G20	G16	G13	G14
ENV5	1.09	G16	G13	G24	G14	G18	G24	G22	G14	G16	G13

Regarding to AMMI-1 for durum means vs IPC1 (Figure 2), the IPC1 captured the highest variation of GEI SS with a value of 61.6% of the entire interaction. Likewise, genotypes G18 and G24 are stable genotypes and has a high grain yield performance more than farther entries, i.e., G17, G19 G13, G14, and G15. The environments, namely; E9, E3, and E4 observed high yielding and low contributor variation in GEI. Nevertheless, E8 (which had a long-distance from center) owned the highest portion of GEI over genotypes. Moreover, genotypes G7 and G8 bread wheat might be stable depending on AMMI stability value (ASV) Table 4. Although, G18 of durum stable from AMMI biplot view, but it was characterized four in the rank of ASV.

The GGE biplot results (Figure 3) illuminates mega-environments identified by partitioned the scatter plot into sectors commencing from the origin to outside. and winners' genotypes are placed on the vertices of the polygon. Accordingly, three mega-environments of bread wheat data recognize environments, i.e., E2, E3, E4 and E6 with genotypes G12 and G2, environments E8 and E10 with genotypes G11, and environments E5, E7, and E9 with genotypes G1.

Correspondingly, the durum wheat results divided environments into three mega- environments: (i) environments E3, E4, E8, E10, and E11 with genotypes G17 and G19, (ii)environments E2, E5, E6, E7, and E9 with genotypes G16, and (iii) environments E1 with genotypes G20 (Figure 4).

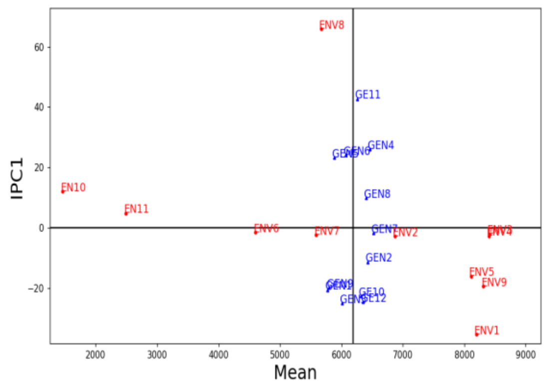

Figure 1. AMMI-2 biplot Mean kg ha-1 Vs IPCA for 12 bread wheat genotypes (GEN# and GE#) across 11 environments (ENV# and EN#).

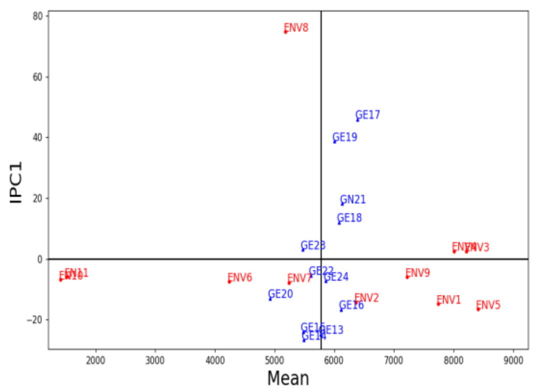

Figure 2. AMMI-2 biplot Mean kg ha-1 Vs IPCA for 12 durum wheat genotypes (GEN# and GE#) across 11 environments (ENV# and EN#)

According to a pattern of mean performance and stability, the stable genotypes had a short projection on the line with an arrow and over the other line (overall mean) cross it representing in Figure 5 and 6. genotypes G7 and G18 recorded high yield and stability of the bread and durum wheat groups, respectively. Nonetheless, genotypes like G4 and G2 of bread wheat and G17 and G16 of durum wheat possess high yielding but unstable genotypes.

The ideal genotypes point situates in the inner circle of the biplot graph. Consequently, G2 was an ideal bread wheat genotype followed by G4 and G6 are desirable. Whereas, G18 was the ideal durum wheat and G17 was desirable (Figures 7 and 8).

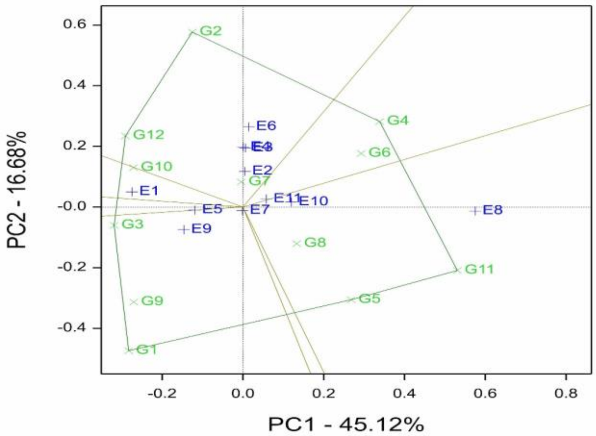

Figure 3. which-own-where pattern of GGE biplot for grain yield of 12 bread wheat genotypes (G) over 11 environments

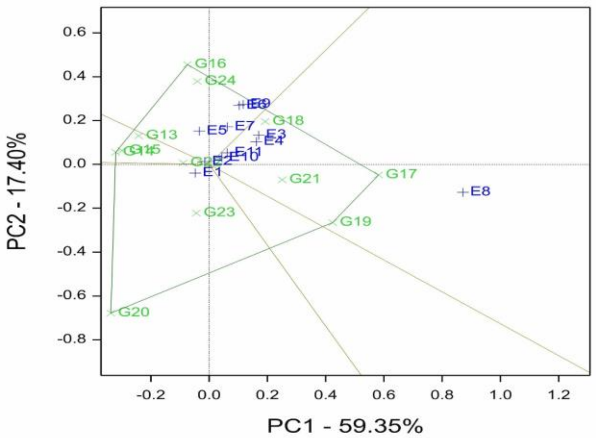

Figure 4. Which – own- where pattern of GGE biplot for grain yield of 12 durum wheat genotypes (G) over 11 environments (E)

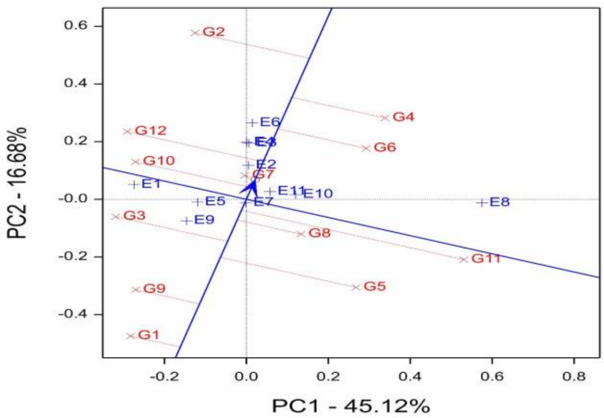

Figure 5. GGE biplot, Mean vs Stability for grain yield of 12 bread wheat genotypes (G) over 11 environments

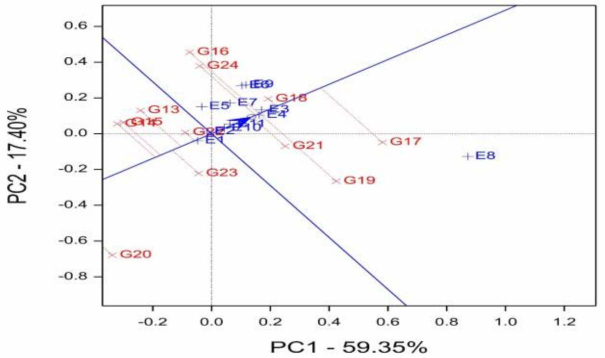

Figure 6. GGE biplot, Mean vs Stability for grain yield of 12 durum wheat genotypes (G) over 11 environments

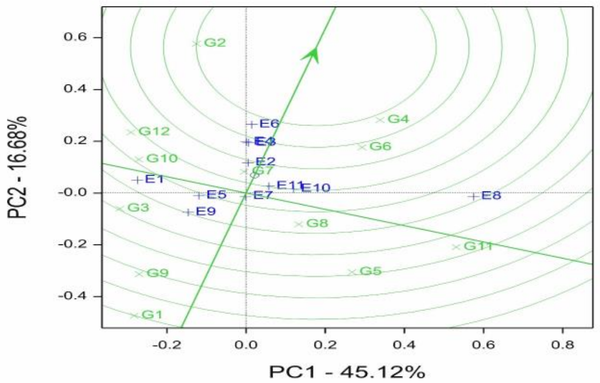

Figure 7. GGE biplot, ideal genotype for grain yield of 12 bread wheat genotypes (G) over 11 environments

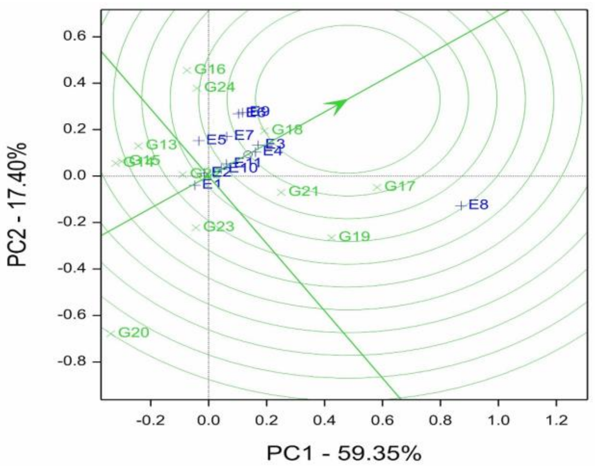

Figure 8. GGE biplot, ideal genotype for grain yield of 12 durum wheat genotypes (G) over 11 environments

Discussion

Wheat breeders encounter with the challenge of environmental factors to release a new cultivar. So, they rely on a variety trails to achieve this target (Yan, 2014). To identify these goals, breeders use AMMI and GGE methods. The main differences between them are that methods depend on principal component analyses (PCA) proposed by (Gabriel, 1971). Hence, AMMI determines that for GE to divide it into PCA1, PCA 2, and PCAn and reveals it in the ANOVA table, but GGE estimate the PCA from G + GE the source of variations for the studied trait for graphically showing (Yan *et al*., 2007 and Yan, 2019). The fundamental purposes of these analyses are Mega-environments delineation and genotypes evaluation(Gauch, 2013 and Yan, 2015)by components G and GE, which are reasonable for the breeders and influence of the genotypes rankings(Gauch, 2013).

This study amid to categorize mega-environments for 12 bread and 12 durum wheat genotypes across the multi-location-year experiments in Egypt (11 variable environments) and recommend the stable (winner) genotypes to be released a new wheat cultivar. The significant G × E effects witnessed in this paper table 3 indicate that the genotypes evaluated do not perform constant performance over examined environments (Zaïm *et al*., 2017; Rezende *et al*., 2020b and Thungo *et al*., 2020) and variation among genotypes across environments allowed to investigate of the nature and magnitude of G × E, which cannot be achieved by ordinary combined analysis of variance *(*Purchase, 2000; Gauch, 2013; Horn *et al*., 2018). Generally, the main findings of AMMI multivariate ANOVA represent the same trend of previous studies. Environment main effects of both wheat data sets, which interpret the influence of environmental conditions on wheat had an enormous contribution of total variations, which reached 84% and 85% (Mohammadi *et al*. 2018 and 2021). So, the whole region has to delineation into sub-regions or mega environment of wheat-growing area (Yan, 2014 and 2015 and Paderewski *et al*. 2016). (Gauch and Zobel, 1997) informed that in multi environments experiments MET data analyses, environment contributes approximately 80 percent of the total variation. For bread wheat data set, (Kaya *et al*., 2006) stated that the environment produced roughly 81% of total variation. The same trend was detected by (Mohammadi *et al.* 2021) for durum wheat yield trials in Iran. (Mohammadi *et al.*, 2015) reported about 81% of the total variation attributed by environments, whereas, genotype main effect contributed 2.5% of the total variation. They witnessed 16.3% contribution of GE interaction to the total variation in analyzing 25 durum wheat in 21 environments. In our study, the three-component had similar trend, particularly, genotypes variation percentage are 1.0% and 2.2%, but GE interaction contributed 9.5 % and 7.5 % for bread and durum wheats data sets, respectively. This may be true in Indian situation as well as in other sorghum cropping regions (Rakshit *et al*., 2012). hence, the sorghum breeders have to consider this notes while breeding in their respective situations (Rakshit *et al*., 2012). (Yan, 2019) identifies the purpose and importance of this delineation for plant breeder and crop production. In our case, four mega-environments of bread genotypes AMMI results were divided. However, the durum genotypes were separated to two sub-regions. These results comparable to a study on sugar beet (Hassani *et al*., 2018). The mega environments delineated according to the similarity of their conditions, in this recent study for bread wheat data set, only E8 categorized (West ElMynia, 2019-2020), refers to it is a newly reclaimed land with dripping irrigation, AMMI results in Table 4. While, Figure 4 of GGE biplot revealed that site along with E10 (East Owinat, 2018-2019) and E11(East Owinat 2019-2020) similar weather conditions with G11 (Sids 14) as a winner cultivar released from national breeding program. However, the other mega-environment consisted of E3 and E4 (Shandaweel in both seasons), E2 (Sakha 2019-2020), E6 and E7 (Nubariain both seasons) all located in middle and north of Egypt, with G7 (adapted promising line from CIMMYT material) as a winner of

AMMI family ranks. The durum wheat data set, separated into two sub-zone, first one is E8 (West El Mnyia, 2019-2020), E3 and E4(Shandaweel in both seasons) middle Egypt with winner G17 from both analyses models a promising breeding line. The second mega-environment including the remaining environments with G16 as a winner promising breeding line developed from national durum breeding program. To summarize that, GGE biplot results show that four mega-environments of bread wheat set with G11, G4, G2 as a winner from AMMI and GGE findings in addition to G7 and G11 AMMI and GGE deferent. While two sub-regions for durum with G17 and 16 as winners from both AMMI and GGE biplot. These results correlated with (Hassani *et al.,* 2018) and this significant by relevant contribution for wheat breeders (Gauch, 2013).These models have been revealed successfully in a range of other crops (Sabaghnia *et al*., 2008; Mohammadi *et al.,* 2015 and Acosta-Pech *et al*., 2017).Moreover, the GGE biplot analysis used to determine and characterize the adaptability and stability of germplasm in leaf rust resistance of bread wheat (Akcura *et al.,* 2017; Akan and Akcura, 2018). A grain yield character is a form of multi-location, multi-year, and numerous genotypes trials (Yan 2015a, 2016). The valuable outcome is the differentiation of stable from unstable genotypes in different crops (Phuke *et al*., 2017)

The concept of stability and adaptability (stable genotypes) of entries are fundamental in describing product potentiality and promotion value of cultivars. The high grain production and efficiency of increased production in widely variable environments can be considered to be a cultivar that continued to grow in agro-climatic regions. Hence, the advanced lines evaluation for adaptability and stability is important approaches to improve productive variety (Kaya *et al.,* 2006; and Yan *et al*., 2007; Hassani *et al*., 2018). In this study, AMMI-1 biplot, mean versus IPCA1, valuable of this relationship refers to described GEI by genotypes means with environments effects and their IPCA1 score (Gauch, 2013 and Hassani *et al*., 2018) Figure 1and 2. These methods are suitable for identify the stable genotype along with AMMI stability value (ASV) (data not shown), it depending on PCA scores and their SS(Purchase, 2000 and Solonechnyi *et al.* 2018) Table 1 bread wheat genotypes G7 and G8 along with G18 of durum set were considering a stable AMMI biplot view, but it was be number four in the ASV rank (data not shown). These findings correlated with (Mohammadi *et al.,* 2018; Abraha *et al*., 2019). The stable genotypes pointed in a situation close to the origin of Figure (PC score zero) own low sharing of variation entirely GEI and vice versa (De Vita *et al*., 2010 and Gauch, 2013). In our study, bread wheat G7 promising breeding line, might be stable and adaptable genotype of that set over tested 11 environments figure 1 and 5 of AMMI biplot and GGE biplot in addition to high yielding productivity. While, G18 a durum wheat entry, might be stable from both models across the examined environments figure 2 and 6. These findings similar with other research results (Horn *et al.,* 2018; Abraha *et al.,* 2019 and Yan, 2019). Thus, to select a stable genotype over all environments could be G7 and G18 of bread and durum, respectively. In contrast to select specific genotype to certain mega environment chose the winner from table4 and the genotypes situated on the vertices of polygon and the environments in the same sector Figure 4.

The ideal genotypes situates in the inner circle of the biplot graph (Yan *et al.,* 2007). Consequently, G2 is an ideal bread wheat genotype followed by G4 and G6 are desirable under tested conditions. Whereas, G18 was the ideal durum wheat and G17 desirable (Figure 7 and 8). These results correlated with review findings (Rakshit *et al*,. 2012).

Despite the genotypes G7 of bread wheat and G16 and G17 of durum wheat winners and characterized as stable and adaptable across the investigated environments. But no genotype was released as a new cultivar because there are massive plant materials (local breeding program and exotic materials) in other experiments tested in the wheat research department to select and release new cultivars. However, Sakha 95 (stable and had yield performance in another multi-environment trial) and Misr 3 and Sids 14 have currently spread cultivars and represent most of the bread wheat production of Egypt. Durum wheat, on the other hand, in the case of cultivar Bani Suef 5, is sown in the most cultivated durum area in Upper Egypt (South).

CONCLUSION

The AMMI and GGE biplot findings revealed that some genotypes possess wide and narrow adaptability to environments. Bread wheat G7 is the winner in several environments and confirms this finding with it was a stable genotype from the view of AMMI and GGE biplot and ASV, but the ideal genotype was G2. The durum wheat winners were G16 and G17 of both mega-environments of AMMI and GGE biplot analyses. But the stable and ideal genotype was G18 for AMMI and GGE biplot across tested environments.

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تقدير الثبات الوراثي باستخدام AMMI, GGE لبعض تراكيب قمح الخبز و المكرونة

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يواجه مربي القمح عند استنباط ونشر صنف جديد من برنامج التربية الظروف والعوامل البيئية والذي تعتبر تحديا خاصة عند تغير المناخ. يعد تحليل التفاعل بين التركيب الوراثي والبيئة مفتاحا لانتخاب وإطلاق الصنف وكذلك تحديد بيئات الإنتاج والاختبار المناسبة. لذلك تم تقييم 12 تركيب وراثي من قمح الخبز و 12 تركيب وراثي من قمح المكرونة لصفة محصول الحبوب في ستة مواقع مختلفة من وادي النيل إلى الأراضي المستصلحة حديثا في الصحراء الغربية لمصر، في موسمين متتاليين 2019/2018 و 2020/2019. تم اختبار البيئة الكبيرة مع التراكيب الوراثية المتميزة، والتراكيب الوراثية الثابتة، والتراكيب المثالية الفريدة باستخدام طريقة التأثير الرئيسي الإضافي والتفاعل المضاعف (AMMI) ، والتأثير الرئيسي للتركيب الوراثي بالإضافة إلى التفاعل بين الوراثة والبيئة (GGE biplot). أظهرت النتائج أربعة بيئات كبيرة، واحدة منها تضمنت العديد من البيئات وكان التركيب الوراثى G7 هو الفائز والثابت بها ولكن كان التركيب الوراثي G2 هو التركيب المثالي بالنسبة لمجموعة التراكيب الوراثية لقمح الخبز. من ناحية أخرى قسمت مجموعة التراكيب الوراثية لقمح المكرونة إلى بيئتين كبيرتين وكان G16 وG17 هما التركيبين الوراثيين الفائزين في محصول الحبوب لتحليلات AMMI وGGE biplot ولكن كان G18 التركيب الوراثي المثالي وفقا لتحليلات AMMI وGGE biplot عبر البيئات المختبرة.