INTERNATIONAL JOURNAL OF MODERN AGRICULTUREAND ENVIRONMENT

VOLUME 3, ISSUE 2, 2023, p 77 – 100

Print ISSN 2974-4407

Online ISSN 2974-4415

Evaluation Stability of Some Bread Wheat Genotypes under Various Egyptian conditions

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Abstract:

Water shortage is one of the most significant difficulties to wheat production in Egypt, especially after establishment the Grand Ethiopian Dam. Eight promising bread wheat lines were estimated under recommended irrigation (5 irrigations with 2150 m^3) and two water deficit stress (3 irrigations with 1275m^3 as a low, 4 irrigations with 1750 m^3 as a medium) during the 2017/2018, 2018/2019 and 2019/2020 growing seasons in three different field conditions at the experimental farm of El-Amel (First time sown at Sainai), Kafer- El Hammam (El-Sharkia governorate) and El-Nubaria (old reclaimed area), Agricultural Research Center, ARC, Egypt. Each experiment represented a type of soil, sandy, clay and calcareous soil at El-Amel, Kafer-EL Hammam and El-Nubaria respectively. Seasonally, three field experiments had conducted with eight genotypes in each location. Each experiment represented an irrigation regime. The experimental design was Randomized Complete Block Design in three replicates. The nine environments (three seasons* three locations) and three irrigation regimes revealed sufficient genetic variability among the studied genotypes. The plant height, no. of spikes/m^2, no. of kernels/spike, 1000-kernel weight and grain yield ard/fed recorded significantly decreased under water deficit stress. The results revealed that water stress had a significant adverse impact on all characters which contributed to overall yield losses El Hamam recorded lowest loss (7.17%) under medium water deficit conditions. Genotype **Line 3** recorded lowest loss (9.48%) under water deficit conditions compared with recommended one. Genotypic main effect plus genotype by environment interaction (GGE) biplot analysis for yield trait showed the percentages of total variation explained by the first two principal components were more than 70% of the total variation. Graphs illustrated that highly stable genotypes were **Line 3 and Line5,** under low irrigation **Shandweel1 and Giza171** under medium, irrigation and **Line3** under recommended irrigation.

Therefore, results detected **Line3** as an ideal genotype for normal and water deficit conditions and it could be improving the bread wheat breeding program under water shortage as a stress tolerance.
Keywords: Bread wheat, Grain yield, stability, Water stress.

Introduction

Egypt's climate is semi-arid zone. The climate is extremely dry all over the country. Thus, it reflects the important of Nile River which provides Egypt with 98.26% of the available fresh water. (**Khayry, 2022; and FAO 2020**). Egypt is experiencing a rising water deficit due to Grand Ethiopian Dam. Egypt expected to fall even further below the UN water poverty line due to top of the reduction in the flow of Nile water to the country after the construction Ethiopian Dam. This water reduction could reduce the national product per capita in Egypt and considered as the main challenge that facing agricultural sector (**Kamara et. al.,2022**; and **Khayry,2022**).

Wheat (Triticum aestivum L.) is the main food for Egyptian people. Currently Egypt is the largest wheat-importing country in the world (**FAO 2020**). Efforts have been paid to increasing wheat production and reduced wheat importing. Shortage/Insufficient water supply in canal could cause drought in irrigated areas (**Hafeez et al., 2003**). Moreover, scarcity of irrigation water could be the main challenge that facing sown wheat in new reclaimed area. Shortage in irrigation water has been a severe problem facing wheat production. Water shortage has impact on plant growth, morphology, physiology, biochemistry and finally yield productivity (**Jones et al., 2003; Hafiz et al., 2004**). Mild water shortage causes 20–30% of yield reduction whereas severe drought stress can cause more than 70% yield reduction (**Behera and Sharma 2014**). Several researchers studied the reproductive stage, they reported that drought stress has a direct effect on wheat productivity. Thus, grain yield considered to be the main criterion that can used as indicator for drought tolerance (**Hussain & Jatoi, 2021; Mwadzingeni et al.;2016 Farooq et al., 2011**).

Conceptually, the phenotype of any plant is a result of the genotype (G), the environment(E), and the genotype x environment interaction (GEI). Based on this concept, reducing negative impact of the drought could be occurred by altering the environment or using drought tolerant genotypes.

INTERNATIONAL JOURNAL OF MODERN AGRICULTUREAND ENVIRONMENT
VOLUME 3, ISSUE 2, 2023, p77 – 100
Print ISSN 2974-4407
Online ISSN 2974-4415

Exploring highly adapted local genotypes to identify drought tolerant wheat genotypes is the first step to start a wheat breeding program for water stress (**Gadallah, *et al*., 2017; Mohamed and Said 2014 and Al-Otayk 2010**).Plant breeders always look for genotypes that performed better across environments with minimal GE interaction, especially under the different conditions (the fluctuations in the environmental conditions from year to year and location to location). Thus, measuring the stability of a new promising line is an essential criterion before releasing it. Selecting superior genotypes using stability measurements instead of average performance is highly recommended because genotypes selected using stability measures are more dependable across environments with a minimized GE interaction, or the provide a predictable response across environments. Studies have shown that stability analyses according to various measures can result in better identification of stable genotypes, even when there were no interactions among the measures **(Al-Otayk 2010 and Jha *et al*., 2013**). Stability and GE measurements classified into parametric and non-parametric measurements. The additive main effects and multiplicative interaction model (AMMI) and the genotype main effect plus GE interaction (GGE) are the most frequently utilized non-parametric methods. Both AMMI and GGE biplot analyses are based on the principal component analysis (PCA). However, GGE biplot is based on environment-centered principal component (PCA), whereas AMMI analysis is a double centered PCA method **(Akcura, and Kaya 2017; Yan, 2014 and Farshadfar and Sadeghi, 2014)**.
In the current study, eight wheat genotypes that represent 5 promising lines + 3commercial wheat cultivars in Egypt (based on 2017/2018 grown wheat cultivars) evaluated under recommended, high, and low irrigation regime. Thus, the main objectives of this study were to; 1- evaluate eight wheat genotypes under recommended irrigation and water stressed to identify high – yielding genotypes under drought stress and conditions across nine environments (3 location x 3 years). 2- Study the relationships among relevant genotypes and different treatments under normal and water stress conditions.

Material and Methods

Breeding materials

Eight Egyptian bread wheat genotypes consisting of five promising lines and three varieties (local checks) had obtained from wheat Research Department, Field Crops Research Institute, Agricultural Research Center

INTERNATIONAL JOURNAL OF MODERN AGRICULTUREAND ENVIRONMENT
VOLUME 3, ISSUE 2, 2023, p77 – 100
Print ISSN 2974-4407
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(ARC), Egypt as descript in **Table (1)**. The five- bread wheat promising lines produced from Low Input Program at El-Gemmiza Station.

Table 1. Code, pedigree and description of eight bread wheat genotypes used in this study.

Code	Genotype	Status	Pedigree or selection history	Remark
G_1	Line 1	Promising line	KIRITATI/2*WBLL1 CGSS02B00118T-099B-099Y-099M-099Y-099M-18WGY-OB-OGM	Obtained from Low Input Program
G_2	Line 2	Promising line	WBLL1*2/VIVITTSI//AKURI/3/WBLL1*2/BRAMBLING CMSS07Y01066T-099TOPM-099Y-099M-099Y-7M-OWGY-OGM	Obtained from Low Input Program
G_3	Line 3	Promising line	PFAU/SERI.IB//AMAD/3/WAXWING*2/4/TECUE#1 CMSS07B00614T-099TOPY-099M-099Y-099M-49WGY-OB-OGM	Obtained from Low Input Program
G_4	Line 4	Promising line	WHEAR/VIVITIS//WHEAR. CGSS03-B00069T-099Y-099M-34WGY	Obtained from Low Input Program
G_5	Line 5	Promising line	SIDS 1/ATTILA/3/KAUZ//BOW/NKT S.16494-032S-031S-14S-0S	Obtained from Low Input Program
G_6	Giza 171	Released variety	SAKHA 93 / GEMMEIZA 9 Gz 2003-101-1Gz-4Gz-1Gz-2Gz-0Gz	Commercial, wide adaptability
G_7	Shandaweel 1	Released variety	Site/Mo/4/Nac/Th.Ac//3*Pvn/3/Mirlo/Buc CMSS93 B00S 67S-72Y-010M-010Y-010M-3Y-0M-0THY-0SH	Commercial, heat tolerance
G_8	Misr 2	Released variety	SKAUZ/BAV92 CMSS96M03611S-1M-0105Y-010M-010SY-8M-OY-OS	Commercial, high yielding

Multi-Environment Experiments

The experiments were conducted at three locations during three seasons (3 locations x 3seasons).The studied materials had sown in three successive growing seasons2017/2018, 2018/2019 and 2019/2020 under three different field conditions at the experimental farm of El-Amel (First time sown at Sainai), Kafer- El Hammam (El-Sharkia governorate) and El-Nubaria (old, reclaimed area).The details of these factorial environments and their codes had described in **Table (2).**

Field experimental treatments and design

Seasonally, in each environment, three experiments had been planted in randomized complete blocks design with three replications. Each experiment represented an irrigation regime. the three irrigation regimes (low, medium, and recommended) water requirements. Low irrigation (L), where wheat plants had irrigated three times at germination, at tillering and at booting with 1275m^3 water. Medium Irrigation (M), where four times of irrigation had done at germination, at tillering, at booting and at heading with 1750 m^3, and recommended

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Print ISSN 2974-4407

Online ISSN 2974-4415

irrigation (R) five times of irrigation at germination, at tillering, at booting, at heading, and at grain filling stage with 2150 m^3. The amount and time of irrigation depends on weather conditions. Each experimental field divided into plots with size 10.5m^2 (3 m x 3.5 m). Each plot including fifteen rows, row was 3.5 m long, and the spaces apart rows were 20 cm. All cultural practices for growing wheat applied as recommended.

Studied locations analysis and description.

Climate characters, and soil properties description, and rainfall at the different environments, which affect the crop yields represented in **Table (2)**. Rainfall data during the crop growing period had provided. Meanwhile, three regimes of irrigations had applied at different growth stages. Borders had made around the plants to prevent the effect of ground water logging others different conditions. Data had collected for Plant height cm. (PH), number of spikes per square meter(sp/m^2), number of kernels/spike (NK) and 1000-kernels weight (Kw). Grain yield had weighed and adjusted to ardabs per fed.

Table 2. Description of the studied environments and their codes under each irrigation treatment.

Location	Season	Env. code	Geographic position		Soil properties		Temperature (°C)	Rain-fall (mm)
			Latitude (N)	Longitude (E)	Texture	pH		
Al-Amal	2017/18	E1	29° 8' 36.66''	34° 9' 11.5''	sandy	7.4	14.18	1.1
	2018/19	E2			sandy	7.4	15.11	1.4
	2019/20	E3			sandy	7.4	16.23	1.5
Kafer-Hamam	2017/18	E4	30° 36' 46''	31° 30' 33''	clay	7.5	17.56	3.58
	2018/19	E5			clay	7.5	14.96	1.9
	2019/20	E6			clay	7.5	24.98	10.8
Nubaria	2017/18	E7	30° 40'	30° 04'	sandy clay	7.5	15.18	57
	2018/19	E8			sandy clay	7.5	15.96	99.12
	2019/20	E9			sandy clay	7.5	16.46	61.1

Statistical Analysis

Collected data of agronomic characters were employed for different separate and combined analyses (ANOVA). Homogeneity of the residual variances in different environments had done to teste prior to a combined analysis using **Leven's Test (1960)**. Means had compared using least significance difference (LSD at 5%) test according to **Steel and Torrie (1987).** Correlation coefficients had conducted using Pearson correlation coefficient model and graphic analysis had done by Past software (Version 8) **Hammer *et al.*, (2001).**

Stability Analysis

Obtained grain yield data from nine environments (3 locations×3 seasons) under each irrigation level had pooled and evaluated the presence of significant G×E by using analysis of variance. Then, additive main effects and multiplicative interaction analysis (AMMI) described by **Gauch *et al* (2008)** had applied for each irrigation treatment separately and after combing them. The genotype main effect and G×E interaction (GGE biplot) had performed to visualize the G×E interaction. The stability and G×E analysis had conducted using GenStat software (Version 18) **Payne *et al.*, (2017).**

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Results and Discussion

Combined analysis of variances

Results of the **Leven test** for homogeneity of variance error detected that, the mean square for grain yield of bread wheat genotypes across environments were homogenous in most cases. The analysis of variance for plant height (PH), number of spikes/m^2 (Sp/m^2), number of kernels/spike (NK), 1000-kernels weight (Kw) and grain yield (Gy) had presented in **Table** (**3**). Results show that significant differences had detected between the nine environments for all studied characters, indicating that the three locations among three seasons differed in the environmental conditions. These findings agreed with those reported by **Mahgoub *et al.* (2022a and b) and Mohammadi *et al.* (2023)** who suggested that the differences between genotypes could be due to location to location and year to year.

In respect to irrigation regimes, significant differences had detected for all characters, which demonstrated an existence of high effect of different treatments. The results in this experiment agree with the results of other researchers such as **Karaman (2019).**

The existence of significant difference among the genotypes was the presentation of the differences of genetic potentiality of the genotypes for the evaluated characters; also, the existence of significant difference among the studied regions represents the significant genotypes effect in the additive structure of data for the evaluated characters among the regions. Similar result had recorded by **Mahgoub *et al.* (2022a and b)**.

Regarding interactions, significant variations were detected due to interactions between environments x irrigation treatments and environments x genotypes for all characters except for number of kernels/spike. The variations due to environments were important effects

INTERNATIONAL JOURNAL OF MODERN AGRICULTUREAND ENVIRONMENT

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Print ISSN 2974-4407

Online ISSN 2974-4415

on genotypes and irrigation regimes. Meanwhile, irrigation x genotype revealed significant differences for 1000-kernel weight and grain yield ard/fed only. Significance of the interactions is a result of the different abilities of genotypes to adjust their grain yield to the irrigation regime and environments (seasons and locations). Thus, it obtained the importance of different genotype's responses to different irrigation regimes to identify the best ones under irrigation deficit.

In grain yield trait, the mean square of environments explained the largest proportion of total variation (79.29%) in the three growing seasons x three locations. Significant variations had detected due to interactions between genotypes and irrigation regimes (1.46%). The variations due to genotypes (0.78%) were higher than those of interactions between genotypes and irrigation regimes (0.41%).

From the obvious mentioned results, it noticed that variations due to environments were very higher than those of interactions between genotypes and irrigation regimes, indicating to high influence of the environments on the yield performance of wheat genotypes. Similar findings had reported that GE interaction with environments is more important than other ones **(Darwish, *et al* 2022**).

Table 3. Analysis of variance for studied characters under three irrigation regimes across nine environments (3seasons×3locations).

Source of variation	df	PH (cm)	Sp/m^2	NK	KW	Gy	Explained SS% of Gy
Environments (Env.)	8	19825.79**	853892.00**	5460.15**	2204.95**	2284.91**	79.29
Error$_1$	18	50.14	2535	68.31	57.19	74.30	
Irrigation (Irrig.)	2	2395.36**	85668.00**	1055.81**	1554.32**	382.15**	3.32
Env.x Irrig.	16	107.61	20138.82**	49.09	41.42**	26.45**	1.84
Error$_2$	36	26.68	1141.02	78.08	7.24	12.09	
Genotypes (Geno.)	7	926.68**	6884.45**	86.22*	65.96**	25.74**	0.78
Env. x Geno.	56	156.02**	3715.08**	53.41	49.84**	6.03**	1.46
Irrig.x Geno	14	30.61	1962.51	16.73	20.68*	6.78**	0.41
Env.x Irrigx Geno.	112	24.57	2225.20**	25.26	13.77	5.15**	2.50
Error$_3$	378	22.27	1235.47	39.95	11.11	1.65	

*** and ** significant at 0.05 and 0.01, respectively.**
Plant height (PH), number of spikes per square meter(sp/m^2), number of kernels/spike (NK), 1000-kernel weight (Kw) and grain yield ard/fed (GY).

Correlation among agronomic characters:

Data presented in **Fig. (1)** indicated clearly that the correlation coefficients between yield and agronomic characters (plant height, number of spikes/m^2, number of kernels/spike and 1000-kernels weight). Results showed positively corrected values between all studied characters.

Grain yield (Gy ard/fed) had strong positively and significantly corrected with plant height (PH), number of spikes/m^2 (Sp/m^2), number of kernels per spike (NK/sp) and1000-kernels weight. Positive and insignificantly correlation had found between number of spikes/m^2 (Sp/m^2) and number of kernels per spike (NK/sp). However, number of kernels per spike (NK/sp) recorded less positive and significantly corrected with 1000-kernels weight (Kw). These results may be confirming the importance of one or more or all these studied characters on the bread wheat development (**Mohammadi *et al*., 2023 and Mahgoub *et al.* 2022a**).

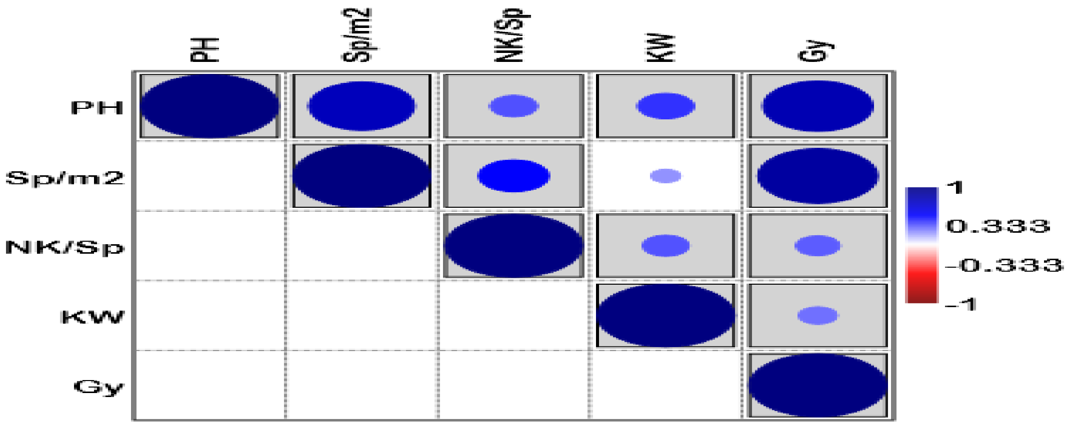

Fig. 1. Pearson correlation coefficient chart among all studied characters. Correlation key and the scale reads, blue circle: indicted positive correlation, red circle: indicted negative correlation and white circle: mean no correlation. Bigger boxed circle: indicted greater significance and smaller circle: indicted lesser significance. The color intensity and the size of the circle are relative to the correlation coefficients. Abbreviations of characters were PH: plant height, Sp/m^2: number of spikes/m^2, NK/Sp: number of kernels/spike, Kw: 1000-Kernel weight and (Gy): grain yield ard/fed.

Grain yield responses under different irrigation regimes

In view of the above significance mentioned of the irrigation x genotype interactions for grain yield ard/fed that indicated the importance of genotypes responses under different irrigation regime and locations to identify the best ones for deficit irrigation.

Mean performance:

The mean yields of eight bread wheat genotypes in nine environments (3irrigation and 3 locations) had revealed in **Table (3**). The mean of grain yield for genotypes over the environments revealed significant differences each environment (irrigation regime/location)

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Print ISSN 2974-4407

Online ISSN 2974-4415

and their interactions. **Table (4)** and **Fig (2)** showed the genotypes mean performance for grain yield trait among different environments.

Table 4. Grain Yield (ard/fed) response to the eight wheat genotypes under different irrigation regime across three locations.

Location		Al-Aml			Kafr-Hamam			Nubaria			Genotype mean
Irrigation		L	M	R	L	M	R	L	M	R	
Genotype											
Line 1		7.66	9.89	10.73	17.82	20.92	20.74	16.58	17.62	19.18	**15.68^{bc}**
Line 2		7.54	9.41	11.02	19.56	21.04	20.25	15.53	17.70	18.14	**15.58^{c}**
Line 3		8.63	10.29	10.94	21.16	21.98	23.16	18.41	19.40	20.56	**17.17^{a}**
Line 4		7.51	9.53	10.53	16.99	20.74	21.66	15.80	17.57	18.40	**15.41^{bc}**
Line 5		7.54	9.96	10.90	19.73	19.75	21.43	17.29	16.71	17.87	**15.68^{b}**
Giza 171		7.72	9.96	11.30	18.88	17.49	21.22	16.73	18.41	19.22	**15.66^{b}**
Shandaweel 1		8.37	9.85	11.03	18.74	17.64	21.69	17.13	17.23	20.26	**15.77^{b}**
Misr 2		7.78	9.58	11.15	19.83	20.33	22.27	17.02	17.88	20.13	**16.22^{b}**
$LSD_{0.05}$	**Geno.**	**0.71**	**0.88**	**0.70**	**1.46**	**1.92**	**1.17**	**1.19**	**1.48**	**0.95**	**Grand mean**
	G x Irg.	**0.84**			**2.41**			**1.24**			
Environmental mean		**7.84^{f}**	**9.81^{e}**	**10.95^{e}**	**19.09^{bc}**	**19.99^{ab}**	**21.55^{a}**	**16.81^{d}**	**17.82^{cd}**	**19.22^{bc}**	**15.90**

Recommended: (R), medium: (M) and low: (L) irrigation regimes for grain yield: (GY) across three locations (Al-Aml, Kafr-Hamam and Nubaria), Environmental mean: each irrigation mean.
*Mean values inside the same row or column for each characteristic with the same letter are not significantly different.

Among irrigation regimes, results illustrated that total genotypes mean across each of nine environments ranged from 21.55ard/fed as the highest response for recommended irrigation treatment in the Kafr-Hamam location to 7.84 ard/fed as the lowest response for low irrigation level in the Al-Aml location. Whereas each genotype recorded mean across nine environments ranged from 17.17ard/fed to 15.41 ard/fed for Line 3 and Line 4, respectively.

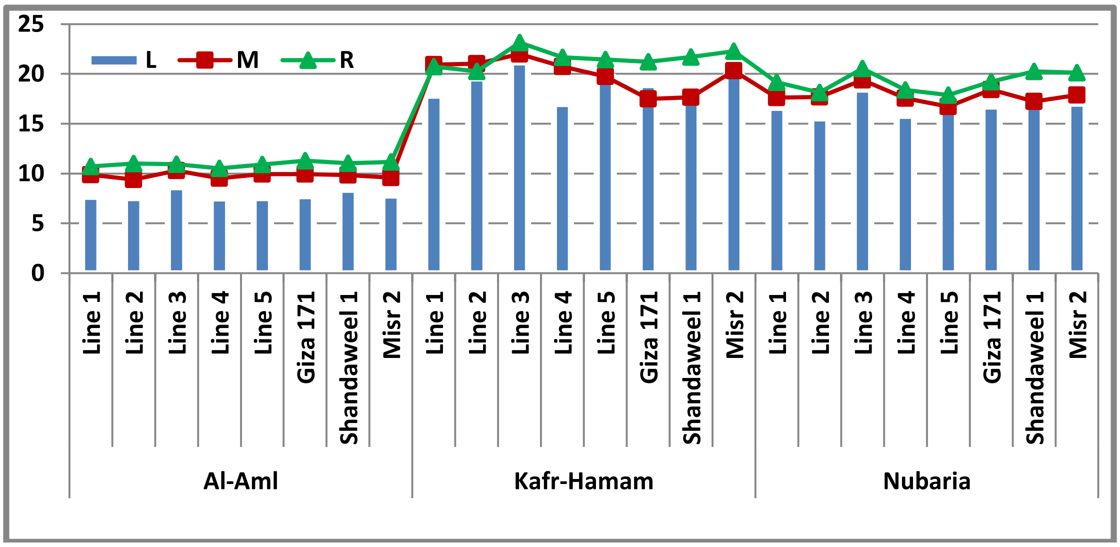

Fig2. Yield (ard/fed) response to the eight wheat genotypes under different irrigation levels across three locations.

Means obtained that Al-Aml location recorded the lowest performance compared to other two locations. Meanwhile, Kafr-Hamam location recorded the highest performance one. These may be due to climatic conditions such as evapotranspiration, soil fertility and soil characteristics which have a significant effect on influence of crop water requirement and consequently land productivities as reported by **Tellioglu (2017)**

Reduction% in grain yield

The grain yield under two irrigation regimes conditions (low and Medium) had compared with the recommended irrigation regime and the percent of reduction in grain yield had calculated. Reduction % in mean of grain yield (ard/fed) for the two irrigation regimes compared with the recommended irrigation across the three locations had shown in **Table (5)** and **Fig (3)**. Resulted means obtained that Al-Aml location as new sandy soil recorded the highest reduction%. Meanwhile, Kafr-Hamam location recorded the lowest reduction%.

In Al-Aml location, the maximum reduction under low (31.68%) and medium (14.61%) irrigation regimes obtained by Giza 171and Line 2, respectively. Meanwhile, the lowest reduction in yield had noticed by Line 3 under low and medium irrigation regimes, which estimated by 21.12%, and 5.94%, respectively.

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Print ISSN 2974-4407
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Table 5. Percent reduction in mean of grain yield (ard/fed) among low and medium irrigation regime compared with the recommended regime across the three locations.

Genotype	Grain reduction% at Al-Aml		Grain reduction% atKafr-Hamam		Grain reduction% atNubaria		Reduction means%
	L	M	L	M	L	M	
Line 1	28.61	7.83	14.08	-0.87	13.56	8.13	11.89
Line 2	31.58	14.61	3.41	-3.90	14.39	2.43	10.42
Line 3	21.12	5.94	8.63	5.09	10.46	5.64	9.48
Line 4	28.68	9.50	21.56	4.25	14.13	4.51	13.77
Line 5	30.83	8.62	7.93	7.84	3.25	6.49	10.83
Giza 171	31.68	11.86	11.03	17.58	12.96	4.21	14.89
Shandaweel 1	24.12	10.70	13.60	18.67	15.45	14.96	16.25
Misr 2	30.22	14.08	10.96	8.71	15.45	11.18	15.10
Mean of reduction%	**28.36**	**10.39**	**11.40**	**7.17**	**12.46**	**7.19**	

Medium: (M) and low: (L) irrigation regimes.

At Kafr-Hamam location, the maximum reduction in grain yield had computed by Line 4 (21.56%) and Shandaweel 1 (18.67%) under low and medium irrigation regime, respectively. and the lowest reduction had recorded by Line 2 (3.41%) under low irrigation regime. However, Line 2 and Line 1 registered increase in yield responses under medium irrigation by 3.90% and 0.87%, respectively.

At Nubaria location, the maximum reduction in grain yield had computed and revealed the (15.45% and 14.96%) by Shandaweel 1 and (3.25% and 2.43%) by Line 5 and Line 2 under low and medium irrigation, respectively.

The reduction in grain yield under water stress regimes was dependent on the amount of water irrigation and genotype. The highest losses of grain yield were of about 16.25% by Shandaweel 1and the lowest loss was about 9.48% by Line 3 under low and medium irrigation regimes, respectively compared with recommended one. These results were similar and accordance to those of **Moghaddam *et al.* (2012)** which resulted in approximately 39% yield losses.

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VOLUME 3, ISSUE 2, 2023, p77 – 100
Print ISSN 2974-4407
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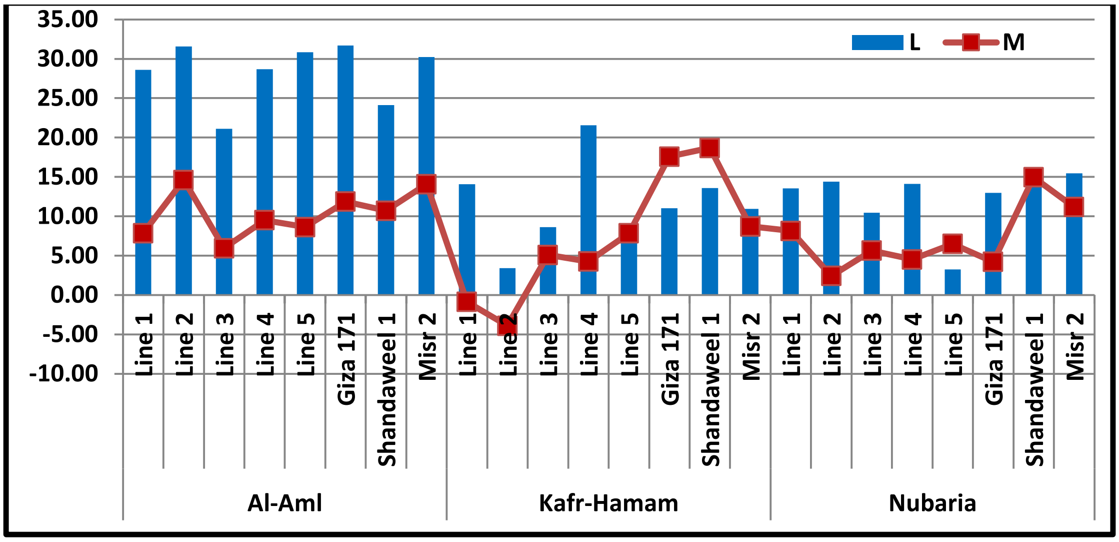

Medium: (M) and low: (L) irrigation levels for grain yield.

Fig3. Reduction percent for grain yield (ard/fed) under low and high irrigation regime as compared with recommended regime.

Genotype by Environment Interaction (GEI) for Grain Yield

Grain yield is a quantitative and complex character that has high responsive to genotype by environment interaction (GEI). Additionally, grain yield was the most important parameter that used to determine approve genotype by breeders. Thus, in this study, we performed stability analysis on the grain yield. Genotype by environment (GEI) under each irrigation treatment had further investigated using the additive main effect and multiplicative interaction (AMMI) analysis and genotype main effect plus genotype x environment interaction (GGE). Finally, GGE biplot was performed to combined data of three irrigation regimes against environments means to detect adaptation under different condition (**Mohammadi *et al*., 2021 and Mahgoub *et al.* 2022a and b**).

AMMI Analyses of variance.

The first model was running by AMMI analysis across (3seasons × 3locations) within each irrigation treatment, i.e., nine environments. Results in **Table (6)** revealed the analyses of variance for AMMI model for grain yield (ard/fed) of eight wheat genotypes across nine environments under different irrigation regimes.

Firstly, under low irrigation regime, ANOVA for AMMI model indicated significant effect of the environments, genotypes, and GEI. Whereas the variance of the environment was 92.71%, while the variance due to genotypes was 1.75% and that for GEI was 5.54%. However,

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the variance of the AMMI model for the medium irrigation regime was 92.13%, 1.47% and 6.41% for the environment, genotypes, and GEI, respectively. Moreover, the variance of the AMMI model for the recommended irrigation treatment was 96.81%, 0.98% and 32.22% for the environment, genotypes, and GEI, respectively. It had noted that, genotypes under recommended irrigation recorded the lowest response (0.98%) compared with others two (low and medium) irrigation regimes. However, the GEI was highly significant (p-value<0.00) implying differential response of genotypes to environments. Substantial variance for the environment in the third model compared with the first and second one had detected, which indicates an amplification effect of water deficient on the environmental effect.

The variance explained by GE interaction was greater about 3.17, 4.36 and 2.27 times than genotype effect for Low, medium, and recommended irrigation, respectively. The magnitude of the environment was greater than the genotype several times, implying that most of the variation in grain yield was due to the environment. This indicated that the considerable influence of environment caused most of the variation in yield performance of wheat genotypes across all seasons and locations, while the contribution of GEI to the total variation showed a different effect. Similar results were reported on wheat by **Mohammadi *et al*., (2021) and Mahgoub *et al.* (2022 a and b)**.

Based on AMMI analysis, the GEI divided into two main principal components that explain (63.48% - 17.63%) of the total variance under the first model (medium irrigation), revealing non-significant for residuals of variance. Furthermore, the first two principal components explained (44.54% - 33.61% and 33.54% - 32.30%) of the interaction between genotype and environment under 1st and 3rd (low and recommended) irrigation conditions, respectively.

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Table 6. Analyses of variance for AMMI model for yield (ard/fed) of eight wheat genotypes across nine environments (3seasons×3locations) under each irrigation.

Irrigation type	SOV	d.f.	S.S.	M.S.	Explained SS %
Low Irrigation (L)	**Treatments**	71	6445.00	**90.78****	**88.20**
	Genotypes (G)	7	113.00	**16.14****	**1.75**
	Environments (E)	8	5975.00	**746.90****	**92.71**
	Interactions (GE)	56	357.00	**6.38****	**5.54**
	IPCA 1	14	159.00	**11.37****	**44.54**
	IPCA 2	12	120.00	**9.99****	**33.61**
	Residuals	30	78.00	**2.61***	**21.85**
	Error	126	187.00	1.49	**2.56**
Medium Irrigation (M)	**Treatments**	71	6197.00	**87.28****	**87.96**
	Genotypes (G)	7	91.00	**13.02****	**1.47**
	Environments (E)	8	5709.00	**713.62****	**92.13**
	Interactions (GE)	56	397.00	**7.09****	**6.41**
	IPCA 1	14	252.00	**17.98****	**63.48**
	IPCA 2	12	70.00	**5.80****	**17.63**
	Residuals	30	75.00	**2.52** ns	**18.89**
	Error	126	308.00	2.45	**4.37**
Recommended Irrigation (R)	**Treatments**	71	7250.00	**102.10****	**91.33**
	Genotypes (G)	7	71.00	**10.10****	**0.98**
	Environments (E)	8	7019.00	**877. 30****	**96.81**
	Interactions (GE)	56	161.00	**2.90****	**2.22**
	IPCA 1	14	54.00	**3.90****	**33.54**
	IPCA 2	12	52.00	**4.30****	**32.30**
	Residuals	30	55.00	**1.80***	**34.16**
	Error	126	129.00	1.00	**1.63**

* and ** significant at 0.05 and 0.01, respectively.
Low irrigation (L): wheat plants were irrigated 3 times with 1275m^3 water, medium irrigation (M): 4 times with 1750 m^3, and recommended irrigation (R): 5 times with 2150 m^3 regime.

The previous AMMI analysis of variance revealed to variable response of the genotypes under the three irrigation levels. Therefore, the stability GGE biplot had run on the irrigation levels and combined data.

Identification of high-yielding stable genotype

GGE biplot had performed by the individual data under each irrigation level. Then, the combined genotypes mean for three irrigation regimes against environments means had used to detect the general and specific adaptation under different condition. It is obvious from **Figs. (4, 5 and 6)** that GGE biplot graphs for yield trait showed the percentages of total variation explained by the first two principal components (PC_1 and PC_2) were more than 70 %. Considering low irrigation level, grain yield influenced by environment accounted for 79.12% of the total variation while, PC_1 and PC_2 explained 49.92% and 29.20% of the variation,

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respectively.PC_1 and PC_2explained 62.98% and 15.40% of the variation, respectively under medium level, grouped as 78.38% of the total variation. Meanwhile, recommended irrigation level recorded 47.40% (PC_1) and 23.23%(PC_2), accounting for 70.63% of the total variation. Overall, the biplot graph of combined data across environments indicated that PC_1 and PC_2 explained 44.40% and 30.87% of the variation, respectively and accounted for 75.27% of the total variation.

GGE biplot Polygon view identification of adaptable genotype:

Regarding to Polygon biplot view in **Fig (4**) that illustrated which genotype won stable in where environment pattern of a GEI analysis. vertices genotypes farthest from the biplot origin. Sectors dividing polygon sides facilitated visual comparisons between neighboring genotypes. Environments fell into the right biplot sector were broad adaptability, but other environments fell into one of other sectors were specific adaptability. Under each irrigation level, three biplots had generated for low, medium, and recommended irrigation levels (**Figs 4A, B, and C**) and **Fig (4D)** for combined data. For the three biplots, genotypes that were further away from the biplot origin had connected (the vertices) to create the polygon. Genotypes allocated on the polygon vertices with the longest distance from the origin of biplot performed either the best (on the right side) or the poorest (on the left side) in one or more locations/seasons.

The vertex genotypes of the first GGE biplot in **Fig (4A)** (low irrigation level) were Line 3 and Line 5. While the best right sector with vertex genotype contained all environments except for Kafr-Hamam 1and Al-Amal 2. Under the medium irrigation level in the **Fig (4B),** the vertex genotypes were Shandweel1 and Giza171, however the best right sector included Al-Amal 1, Nubaria1 and Kafr-El Hamam 2 environments. Moreover, the vertex genotypes for the recommended irrigation were Line 3 and Shandweel1 (**Fig 4C**) at the right side that concluded all environments except for Am 1 and Am 3. The best genotype for combined irrigation levels was Line 3 (**Fig 4D**) especially, under Nubaria in the 1st and 3rd seasons, Kafr-Hamam in the 1st and 2nd seasons and Al-Amalin the 3rd and 2nd seasons (**Abd El-Rady and Koubisy 2023; Mohammadi *et al*., 2021 and 2023; and Mahgoub *et al.* 2022 a and b)**.

The best right sector with vertex genotype contained all environments except for Ham1 and Am2 under the low irrigation level, Am1, Nub1and Ham2 under medium, all environments except for Am1

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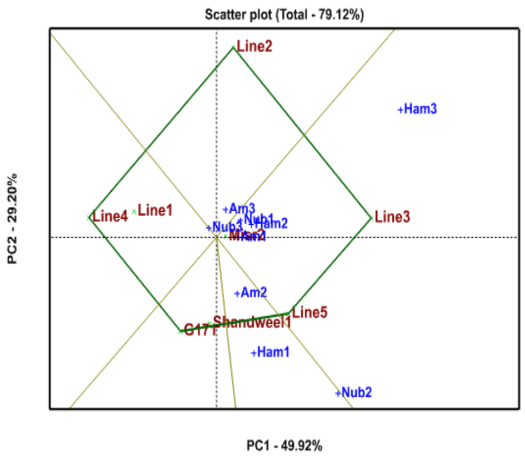
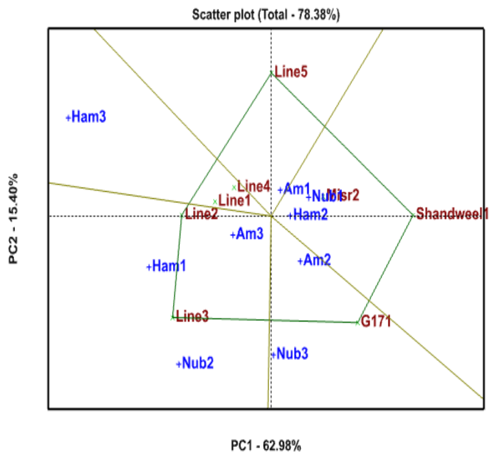
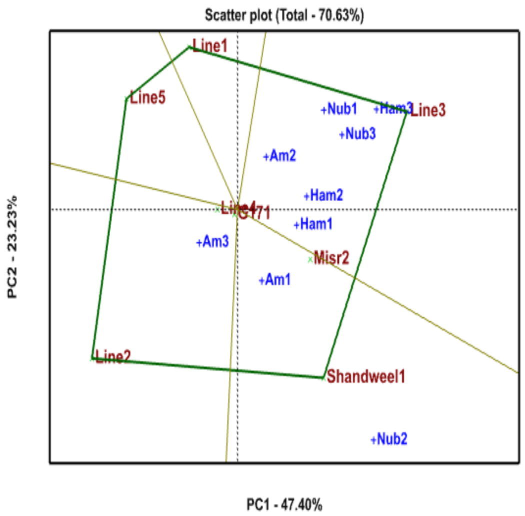
and Am3 under recommended and all environments for combined irrigation levels.



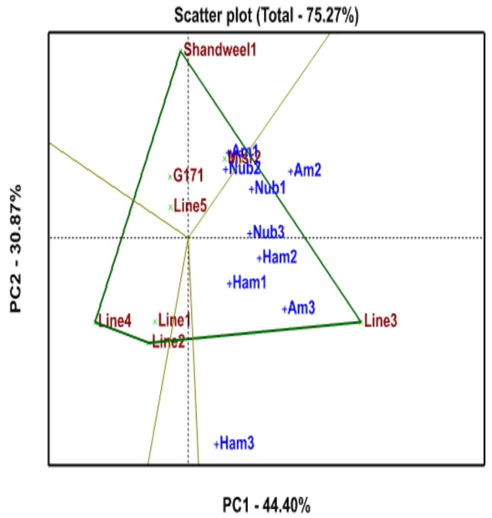
A: low Irrig 1



B: medium Irrig 2



C: recommended Irrig 3



D: combined irrigation data

Fig 4. GGE biplot Polygon view identification of adaptable genotypes across 9 environments (Am1, 2 and 3: Al-Aml, Ham1, 2 and 3: Kafr-Hamam and Nub1, 2 and 3: Nubaria during 2017/18, 2018/19 and 2019/20, respectively) under each irrigation levels low (A), medium (B) and recommended irrigation levels (C), addition to its combined data (D).

GGE biplot view for mean yield vs. stability:

The ranking of eight bread wheat genotypes based on their mean yield and stability for nine environments had shown in **Fig. (5)**. line that through the average of environments and the origin of the biplot had called the average environmental coordinate (AEC) axis.

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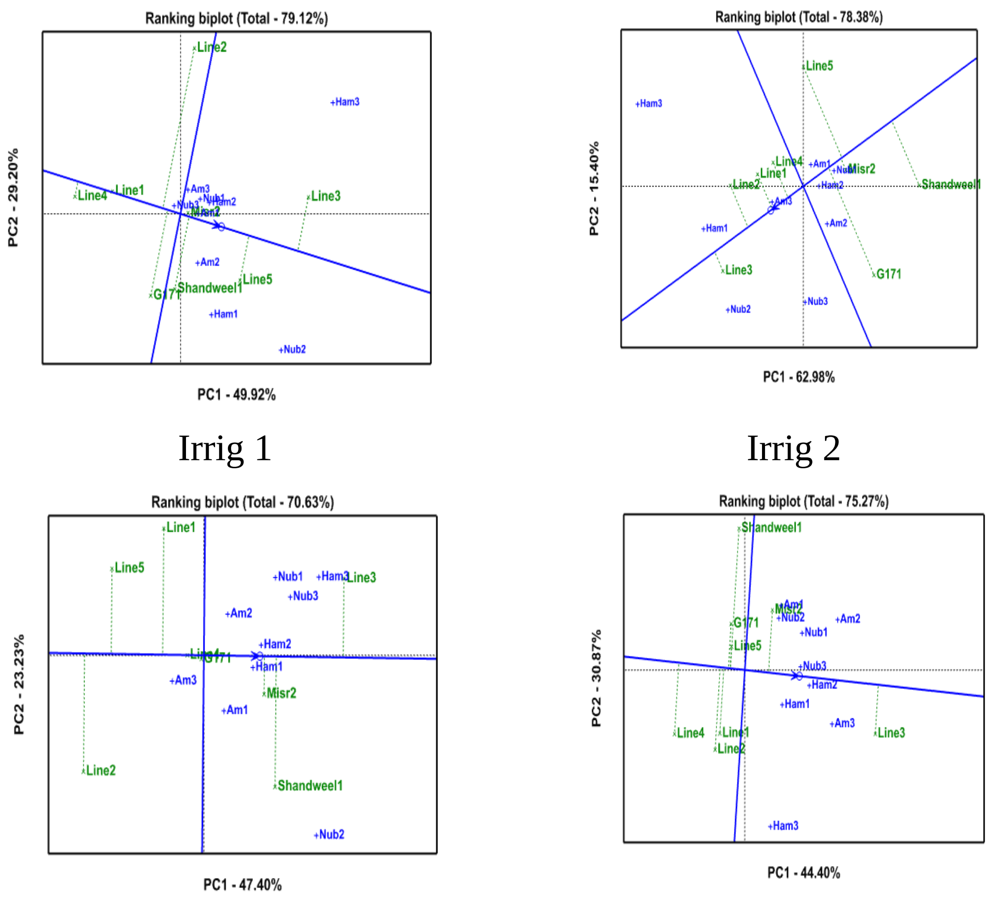
This AEC ordinate separated high-yielding genotypes in the right side and low-yielding genotypes in the left side. The genotype Line 3 and Line 5 recorded a highest yield (above environmental average) and more closeness to the AEC axis (more stable ones). Shandweel1, Line 5, Misr 2 and Giza171 that placed to the right side of the origin point (grand mean), but these genotypes were unstable except Misr 2 because they allocated far from AEC axis. However, Line 3 and Misr 2 were located above (grand mean) and closest to AEC line reflecting its stability under recommended level. Therefore, the Line 3 had placed over grand mean and closest to AEC line, confirming its stability with high yielding. These results agreed to the others obtained with **da Silva *et al.* (2021), Mohammadi *et al*., (2023) Abd El-Rady and Koubisy (2023).**



Irrig. 3 combined irrigation

Fig.5. The mean performance and stability view of the GGE biplot with scaling focused on eight genotypes across nine environments (Am1, 2 and 3: Al-Aml, Ham1, 2 and 3: Kafr-Hamam and Nub1, 2 and 3: Nubaria during 2017/18, 2018/19 and 2019/20, respectively).

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GGE-biplot view showing the ideal genotype:

The evaluation of the ideal genotype that had both a high mean yield and high stability was detected. Although such an ideal genotype may not actually exist, it can used as a reference for comparing genotypes (**Yan and Kang 2003**). The ideal genotype had placed at the center of the concentric circles in **Fig (6**) and had considered as a desirable genotype. Results presented that Line 3 genotype was the ideal genotype followed by Line 5 and Misr 2 that were close to ideal one and could considered desirable genotypes under low irrigation level **Fig (6A**). Meanwhile, Line 2 and Line 1 were the nearest genotypes to the Line 3 (ideal one) under medium irrigation level **Fig (6B**). However, the best genotype under the recommended level **Fig (6C**) was Line 3 followed by Misr 2. Finally, the best genotype for combined irrigation regimes was Line 3 **Fig (6D)** that assumed ideal genotype with high and stable yield (**Abd El-Rady and Koubisy 2023**).

It also provided a meaningful and useful summary of GE interaction data and helped in assessing the relationships of test locations and variations in genotypes performance across environments. The GGE biplot has successfully detected promising genotypes for stability and high mean yield performance in various crops (**Yan *et al.* 2021)**

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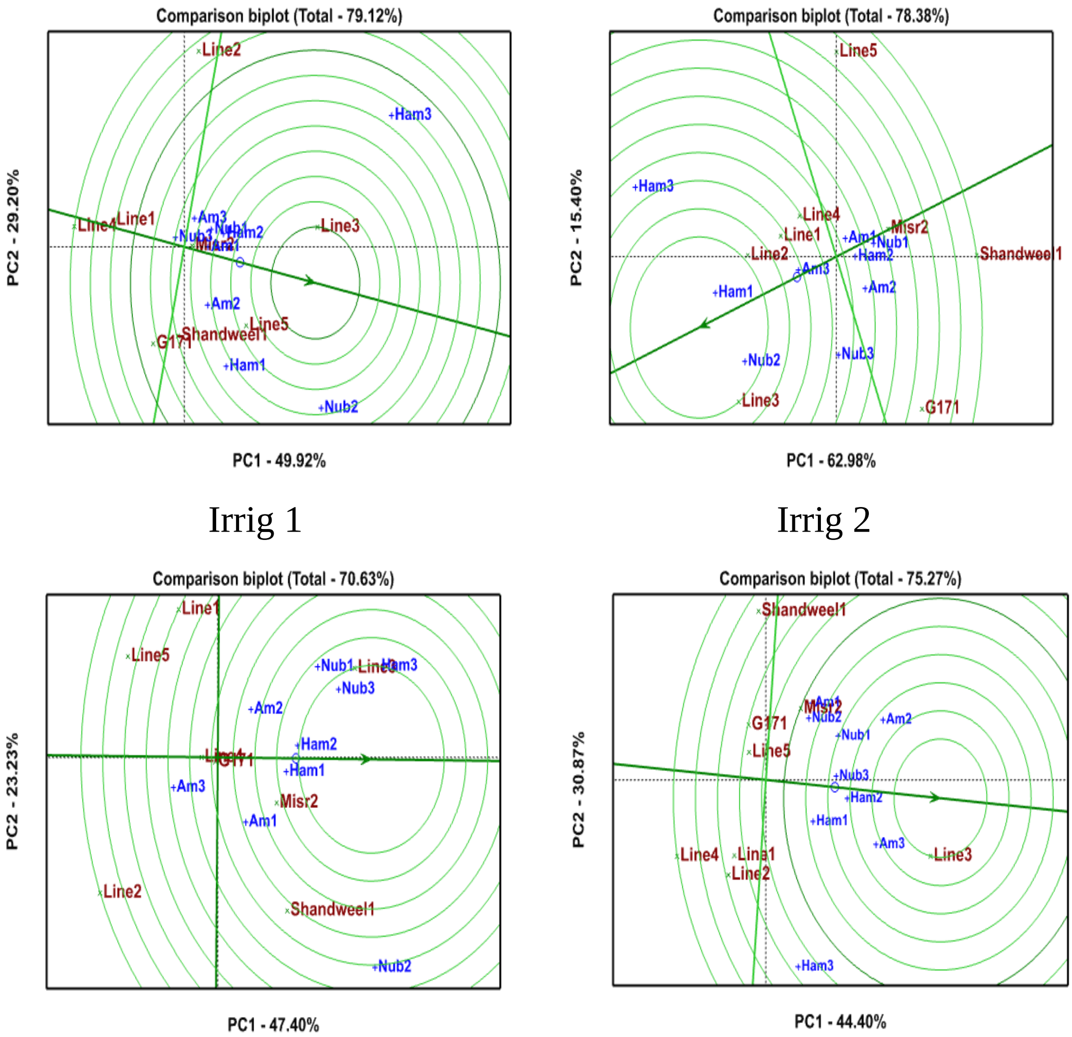

Irrig 1 Irrig 2

Irrig. 3 combined irrigation

Fig.6. GGE-biplot showing the ideal genotype for grain yield(ard/fed) among eight bread wheat genotypes across nine environments. (Am1, 2 and 3: Al-Aml, Ham1, 2 and 3 Kafr-Hamam and Nub1, 2 and 3: Nubaria during 2017/18, 2018/19 and 2019/20, respectively).

From obvious results, use of GGE biplot helped in identifying ideal promising genotype with high mean yield and stability performance across all environments and explore the GE interaction patterns in wheat breeding program (**da Silva *et al.*2021; Mohammadi *et al.*, 2023 and Mahgoub *et al.* 2022a and b**).

Relationship between genotypes across environments

To explain the relationships between the multivariate variables (genotypes under the studied environments), cluster heat map visualization as hierarchical clustering (Euclidean distance and average

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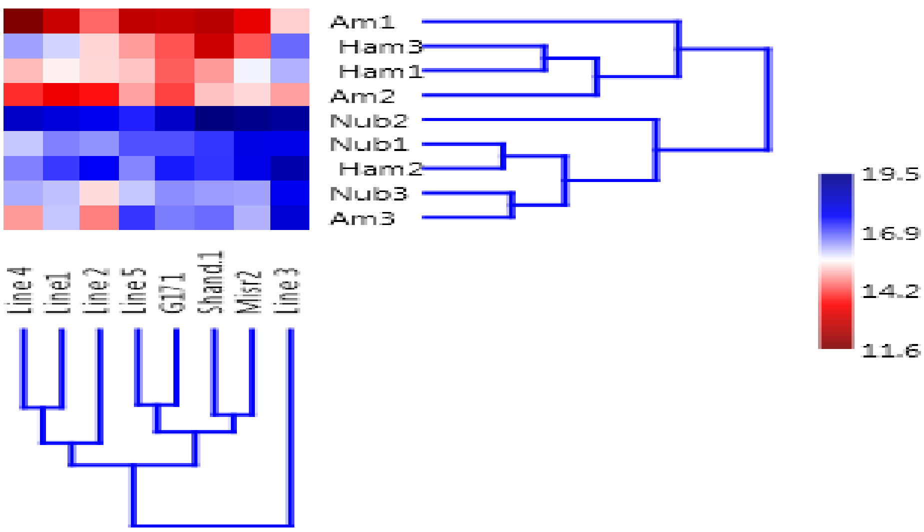
linkage) had done and graphically presented in **Fig. (7)**. A bi-dimensional cluster from the mean yield of environments and genotypes of each environment had generated to assess the contribution of the genotypes on the environments. The horizontal axis groups the genotypes based on phenotypic similarity across environments. The differences in the color intensity indicated the values of each feature with the blue color being the highest and red is the lowest.

Regarding grain yield, graphical representation of the genotypes across environments had shown in a heatmap graph **Fig** (**7**). The heatmap based on the different studied nine environments (3seasons x 3locations) and various eight bread wheat genotypes. Scaling color key ranged from 11.6 ard/fed as the lowest yield mean with the red color to 19.5 ard/fed as the highest yield performance with the blue color. Results showed three clusters of genotypes based on their correlation with one or more of the tested environments. First cluster contained only Line 3 genotype, second one concluded four genotypes (control varieties, Misr2; Shandweel1 and Giza171; addition to Line5). While the last other three genotypes (Line2, Line1 and Line4) contained the 3rd cluster. But environments divided into two clusters, 1st at lateral blow gathered 5 environments (Nubaria 1st, 2nd, 3rd seasons + Kafer-Hamam 2nd season+ Al-Amal at 3rd season). As well as the 2nd cluster grouped other 4 environments (Kafer-Hamam at 1st and 3rd seasons + Al-Amal at 1st and 2nd seasons).



Scaling color Environments: Am1, 2 and 3: Al-Aml, Ham1, 2 and 3: Kafr-Hamam and Nub1, 2 and 3: Nubaria during 2017/18, 2018/19 and 2019/20, respectively. key in the right side: meaning yield mean ranged from 11.6 to19.5ard/fed.

Fig. 7. Heatmap and grouping of 8 bread wheat genotypes based on different 9 environments.

Accordingly, based on similarity of most these environments, genotype Line 3 separated only as independent cluster (1st one at right horizontal). Whereas, it had the highest values across most these environments (all environments with blue color except for Al-Amal at the1st and 2nd seasons). The 2nd horizontal cluster containing 4 genotypes showed high performance contribution among 1st right lateral vertical cluster of environments in contrast another 2ndenvironmental cluster. However, 3rdcluster of genotypes showed some high contribution toward environments of cluster1 except for Al-Amal at 3rd season + Kafer-Hamam at 3rd, meaning these genotypes need the old soil. Therefore, line 3 could be selected as stable genotype with high yielding. These relationships in two directions (genotypes/environments) were grouped and investigated by many authors as **Mohammadi *et al*., (2023).**

Thus, these results displayed a clear picture of the associations between all the tested environments for all genotypes concomitantly.

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