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Evaluation of some bread wheat genotypes for grain yield and components under water stress conditions

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ABSTRACT

Water scarcity is one of the most significant constraints to wheat production in Egypt and around the world. Therefore, twenty genotypes and four cultivars of bread wheat were tested under normal irrigation (six irrigations including planting irrigation) and water deficit stress (two irrigations at 21 and 45 days after the planting irrigation) during the 2020/2021 and 2021/2022 growing seasons at Shandaweel Agricultural Research Station, Sohag, Egypt. Each irrigation treatment was considered a separate experiment in the randomized complete block design. The two seasons and two water treatments showed sufficient genetic variability among the studied genotypes. The number of days to heading and maturity, plant height, yield and its components traits significantly decreased under water deficit stress. The genotypes G13 and G17 significantly outperformed all studied genotypes and checked cultivars for grain yield under normal irrigation and water stress conditions. The genotypes G16, G2, G12, G9, G17, G20, G18, G8, G10 and G5 as well as cultivars Sids 14, Sokoll and Kasuko showed stress susceptibility index (SSI) <1 and they can be used as a source of water deficit tolerance in a breeding program. Genotypic main effect plus genotype by environment interaction (GGE) Biplot analysis revealed that the genotypes G13 and G17 had high yielding ability but genotype G17 showed more stability and tolerance under water stress conditions. Therefore this study concluded that the genotypes G13 and G17 were suitable genotypes to be cultivated under water shortage conditions and could be used to enhance the wheat breeding program for water deficit stress tolerance.

Keywords: Bread wheat, Water deficit, Grain yield, Stress susceptibility index

INTRODUCTION

Wheat is one of the most important and widely cultivated cereal crops in Egypt and worldwide and it takes a big consideration for its importance in sustainable food security. The cultivated area, yield, and total production of wheat in Egypt were 1.53 million hectares, 6.41 metric tons/hectare and 9.80 million metric tons, respectively in January 2022/2023 (USDA, 2023). However, the total annual production of wheat in Egypt is still far below the annual consumption. This gap could be limited by increasing the cultivated area or increasing production per unit area by developing new varieties with high-yielding ability. Irrigation water limitation is one of the most constraints for increasing the cultivated area and crop production in Egypt. Water scarcity in Egypt has crossed the threshold value of 1000 m^3/capita/year (Radwan, 2017). Considering the population predictions for 2025, Egypt will be down to an absolute scarcity level of 500 m3/capita/year, (FAO, 2016). This will further exaggerate the problems associated with water allocation for agriculture. In addition, global climate change is increasing the severity of water stress (Fang and Xiong, 2015; Senapati *et al.,* 2019). The water deficit stress has been reported in number of days to heading and maturity, plant height, number of spikes m^{-2}, number of grains spike^{-1} and 1000-kernel weight, and grain yield in wheat (Farhat, 2015; Hamza *et al.,*2018; Seleiman and Abdel-Aal, 2018; Abd El-Kreem*et al.,*2019; Abd El-Hamid et al., 2019; Henian*et al.,*2020; Shehab-Eldeen and Farhat, 2020; Farhat *et al.,*2021; Mahdavi, *et al.*2022). So, reducing the amount of water utilized for irrigation will help to solve this problem and will maximize the benefits from the available irrigation water. The development of high-yield genotypes with stable performance under limited water environments using present genetic resources is an important strategy to increase wheat production in semiarid areas and a means to cope with water stress and save the irrigated area (Mwadzingeni *et al.,*2016; Mkhabela *et al.,*2019; Thungo *et al.,*2019; Wasaya *et al.,*2021). Several stress indices have been proposed to screen genotypes for water stress tolerance. The stress susceptibility index (Fischer and Maurer, 1978) is commonly used in earlier studies to detect tolerant genotypes for water stress (Abd El Kreem *et al.,*2019; Henian *et al.,*2020; Shehab-Eldeen; Farhat, 2020; Farhat *et al.,*2021). Multi environments trials (MET) help estimate G x E interaction and accordingly select the most stable genotype/s with the lowest G x E interaction. Many researchers have introduced the GGE biplot as an efficient method for studying the interaction of genotype ×environment. GGE biplot is an effective method based on principal component analysis (PCA) to fully explore MET data. It allows visual examination of the relationships among the test environments, genotypes, and GE interactions (Yan *et al.,* 2007). GGE is a powerful and informative graphical technique for the illustration and identification of superior and stable genotype/s in a specific environment (Yan and Tinker, 2006). The objective of this study was to identify high-yielding bread wheat genotypes tolerant to water deficit stress to cultivate under water shortage conditions and integrate them into breeding programs to develop drought-tolerant wheat genotypes in Egypt.

MATERIALS AND METHODS

Experimental site:

The present study was carried out at the experimental farm of Shandaweel Agricultural Research Station, Agricultural Research Center (ARC), Sohag (31° 42 E, 26° 33 N, and 61 m altitude), Egypt during the two consecutive growing seasons of 2020/2021 to 2021/2022. The weather data were obtained from the Central Laboratory of Meteorology, Ministry of Agriculture, Egypt Table (1).

Table 1. The average data of monthly minimum and maximum temperature and precipitation, during 2020/2021 and 2021/2022 growing seasons.

Item	Seasons	Month						
		November	December	January	February	March	April	May
Minimum temperature (°C)	2020/2021	17.70	12.10	9.81	9.86	13.97	20.60	27.00
	2021/2022	14.00	10.81	7.71	9.11	11.58	21.50	23.87
maximum temperature (°C)	2020/2021	32.10	24.45	23.00	24.25	29.52	39.93	40.29
	2021/2022	25.07	23.61	20.87	25.25	28.32	34.20	39.68
Precipitation (mm)	2020/2021	0	0	0	0	0	0	0
	2021/2022	0	0	0	0	0	0	0

Experimental design and treatments:

Twenty four bread wheat genotypes included elite twenty genotypes selected from CIMMYT materials and four cultivars Sids 14, Giza 171 “local checks”, Sokoll “drought and heat tolerant cultivar” and Kasuko “high yielding cultivar” Table (2) were evaluated using the flood irrigation method under two irrigation treatments. The 1st one was normal (six irrigations including planting irrigation, N), while the 2nd one was water deficit stress (two irrigations at 21 and 45 days after the planting irrigation, S). Each irrigation treatment in each season was considered as a separate experiment. The experimental design for each irrigation treatment was the Randomized Complete Block Design (RCBD) with three replications. Each plot consists of 6 rows, spaced 20 cm and of 3.5 m long with a total area of 4.2 m^2. The seeding rate was 350 seed/m^2. All the wheat recommendation packages in Upper Egypt were applied.

Studied traits:

The studied traits included number of days to heading (DH), number of days to maturity (DM), plant height in cm (PH), number of spikes m^{-2} (SM), number of kernels spike^{-1} (KS), thousand kernel weight in gram (TKW), grain yield in ardab feddan^{-1} (GY).

Stress susceptibility index (SSI) and Yield reduction ratio (YR%) were calculated using a generalized formula of Fisher and Maurer, (1978) and Golestani–Araghi and Assad (1998), respectively, in which:

$$\mathrm{SSI} = [1 - (Y_s/Y_p)]/[1 - (\bar{Y}_s/\bar{Y}_p)]$$

$$\mathrm{YR\%} = 1 - (Y_S/Y_p)$$

Where:

$\boldsymbol{Y_p}$ and $\boldsymbol{Y_s}$: grain yield of each genotype under non-stress and stress conditions, respectively.

$\boldsymbol{\bar{Y}_p}$and $\boldsymbol{\bar{Y}_s}$: mean grain yield of all genotypes in non-stress and stress conditions, respectively.

Statistical analysis:

The analysis of variance was performed according to RCBD. Combined analysis across the two water treatments in the two seasons was performed when the assumption of errors homogeneity cannot be rejected (Levene, 1960) according to Gomez and Gomez (1984) using GenStat 18 computer software program (Payne et al., 2017). Means of genotypes were compared using LSD at 0.05 probability level according to Steel *et al.,*(1997). Seasons were random, while the water treatments and genotypes were fixed. The means of the studied genotypes were used to Perform the genotype and genotype by environment interaction GGE biplot using GenStat 18 according to Yan and Tinker, (2006).

Table 2. Code, source, pedigree, selection history and origin of the twenty-four bread wheat genotypes.

Code	Source	Pedigree and selection history	Origin
G1	3 SAWYT 2019/20	SOKOLL/3/PASTOR//HXL7573/2*BAU*2/6/OASIS/5*BORL95/5/CNDO/R143//ENTE/MEXI75/3/AE.SQ/4/2*OCI CMSA10M00159T-050Y-099ZTM-099NJ-099NJ-5WGY-0B	CIMMYT
G2	8 SAWYT 2019/20	SLVS/ATTILA//WBLL1*2/3/GONDO/CBRD/4/BORL14 CMSS12Y00583S-099Y-099M-099NJ-099NJ-12Y-0WGY	CIMMYT
G3	18 SAWYT 19/20	MUU/KBIRD//2*KACHU/KIRITATI CMSS12Y01082T-099TOPM-099Y-099M-099NJ-099NJ-6Y-0WGY	CIMMYT
G4	77 SAWYT 2019/20	ELVIRA/5/CNDO/R143//ENTE/MEXI75/3/AE.SQ/4/2*OCI/6/VEE/PJN//KAUZ/3/PASTOR/7/KIRITATI/4/2*SERI. 1B*2/3/KAUZ*2/BOW//KAUZ/8/ELVIRA/5/CNDO/R143//ENTE/MEXI75/3/AE.SQ/4/2*OCI/6/VEE/PJN//KAUZ/ 3/PASTOR/9/BORL14 CMSS13B00475S-099M-0SY-5M-0WGY	CIMMYT
G5	94 SAWYT 2019/20	KACHU/BECARD//WBLL1*2/BRAMBLING*2/3/FRNCLN*2/TECUE #1 CMSS13Y01289T-099TOPM-099Y-099M-0SY-21M-0WGY	CIMMYT
G6	13 HTWYT 2019/20	PBW65/2*PASTOR//TACUPETO F2001*2/BRAMBLING/3/TACUPETO F2001*2/BRAMBLING/6/2* SHORTENED SR26 TRANSLOCATION/4/ATTILA/3*BCN//BAV92/3/PASTOR/5/MUNAL CMSS12Y01034T-099TOPM-099Y-099M-099NJ-099NJ-54Y-0WGY	CIMMYT
G7	25 HTWYT 2019/20	NADI#1*2/3/MUTUS/AKURI #1//MUTUS CMSS12B00767T-099TOPY-099M-099NJ-099NJ-30Y-0WGY	CIMMYT
G8	35 HTWYT 2019/20	KACHU/BECARD//WBLL1*2/BRAMBLING*2/3/KACHU/KINDE CMSS13Y01290T-099TOPM-099Y-099M-0SY-2M-0WGY	CIMMYT
G9	54 HTWYT 2019/20	BECARD/FRNCLN*2//BORL14 CMSS13Y01254T-099TOPM-099Y-099M-0SY-17M-0WGY	CIMMYT
G10	64 HTWYT 2019/20	SUNCO.6/FRAME//PASTOR/3/NAVJ07/4/1447/PASTOR//KRICHAUFF/5/BORL14 CMSS13B00579S-099M-0SY-5M-0WGY	CIMMYT
G11	92 HTWYT 2019/20	WBLL1*2/BRAMBLING//VORB/FISCAL/3/BECARD/4/MUCUY/5/MUCUY CMSS12Y01130T-099TOPM-099Y-099M-099NJ-099NJ-14Y-0WGY	CIMMYT
G12	12 WYCYT 2019/20	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY PTSS14Y00329S-0B-099Y-099B-33Y-020Y	CIMMYT
G13	13 WYCYT 2019/20	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1/5/MUCUY PTSS14Y00329S-0B-099Y-099B-40Y-020Y	CIMMYT
G14	20 WYCYT 2019/20	SOKOLL/3/PASTOR//HXL7573/2*BAU/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA //TSI/VEE#5/4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA(320)/3/CUNNINGHAM/4/VORB PTSS15Y00023S-099B-099Y-099M-22Y-020Y	CIMMYT
G15	5 CWYT 2019/20	MUNAL*2/WESTONIA CMSS08Y00833T-099TOPM-099Y-099M-099NJ-099NJ-14WGY-0B	CIMMYT
G16	32 CWYT 2019/20	CHEN/AE.SQ//2*OPATA/3/FINSI/5/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00152S-0SHB-099B-099Y-099B-099Y-17Y-020Y-0B	CIMMYT
G17	47 WYCYT 2019/20	WBLL4//OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5 /4/FRET2/6/D67.2/PARANA66.270//AE.SQUARROSA (320)/3/CUNNINGHAM/4/VORB PTSS15Y00024S-099B-099Y-099M-17Y-020Y	CIMMYT
G18	61 CWYT 2019/20	SOKOLL/WBLL1/4/PASTOR//HXL7573/2*BAU/3/WBLL1 PTSS11Y00144S-0SHB-099SHB-099Y-099B-099Y-19Y-020Y-0B	CIMMYT
G19	75 CWYT 19/20	NADI/COPIO//NADI#2 CMSS11B00910T-099TOPY-099M-099NJ-099NJ-37WGY-0B	CIMMYT
G20	36 IBSWN 2012/13	QUAIU/5/FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ CMSS06B00109S-0Y-099ZTM-099NJ-099NJ-13WGY-0B-0SH	CIMMYT
G21	KASUKO Cultivar	KASUKO CMSS11B00123S-099M-099NJ-099NJ-2RGY-0B-69M-0RGY	CIMMYT
G22	SOKOLL Cultivar	Sokoll CMSS97M00316S-0P20M-0P20Y-43M-010Y	CIMMYT
G23	SIDS 14 Cultivar	Bow"s"/Vee"s"// Bow"s"/TSI/3/BaniSewef 1 SD293-1SD-2SD-4SD-0SD	Egypt
G24	GIZA 171 Cultivar	SAKHA 93/GEMMEIZA 9 GZ.2003-101-1GZ-4GZ-1GZ-2GZ-0GZ	Egypt

27thSAWYT: Semi arid wheat yield trail, 18thHTWYT: High temperature wheat yield trail, 7thWYCYT: Wheat yield consortium yield trial, 2ndCWYT: Consortium wheat yield trial, 45thIBSWN: International bread wheat screening nursery.

RESULTS

Analysis of variance:

The results of the Levene test proved the homogeneity of the separate error variances for all the studied traits that allow performing the combined analysis across the two water treatments in the two growing seasons Table (3). Mean squares due to seasons, water treatments and genotypes were highly significant for all the studied traits. Variances of seasons, water treatments and genotypes interaction were significant or highly significant for all studied traits, except the interaction of seasons × water treatments for DH, DM, KS and GY; seasons × genotypes for DH and season ×water treatments × genotypes for DH, DM, PH, SM, TKW and GY.

Table 3. Analysis of variance for the studied traits across the seasons, water treatments and studied wheat genotypes.

SOV	df	DH	DM	PH	SM	KS	TKW	GY
Season (S)	1	561.13**	60.5**	1339.03**	19883.5**	815**	1344.49**	401.39**
Water Treatment (W)	1	1005.01**	1369.39**	2707.25**	564010.5**	1384.8**	1336.21**	784.74**
S x W	1	0.06 ns	24.5 ns	30.03*	7739.75**	15.41 ns	131.96**	1.08 ns
Reps/W/S = Error (a)	8	2.2	4.8	5.4	309.7	36.4	11.25	4.28
Genotypes (G)	23	63.66**	59.36**	155.41**	1253.39**	128.01**	37.46**	26.08**
S x G	23	3.94 ns	6.45**	31.03**	377.05*	49.26**	17.64**	3.27**
W x G	23	5*	6.47**	13.37**	536.4**	15.58**	6.97*	2.83**
S x W x G	23	0.72 ns	2.77 ns	5.67 ns	213.43 ns	8.67*	4.03 ns	1.79 ns
Polled Error b	184	2.9	2.7	5.41	206.9	5.11	4.174	1.39
CV		1.8	1.2	2.2	3.4	3.7	3.8	5.8

DH: number of days to heading, DM: number of days to maturity, PH: plant height (cm), SM: number of spikes m^{-2}, KS: number of kernels $spike^{-1}$, TKW: thousand kernel weight (g), GY: grain yield (ard fed^{-1}) and G: genotype.
*,** and ns refer to $P<0.05$, $P<0.01$ and non-significant, respectively**.**

Effect of seasons:

Highly significant differences were detected between the two growing seasons for all studied traits Table (4).The highest mean values were observed for all studied traits in 2021/2022 season.

Effect of water treatments:

Results in Table 4 showed highly significant differences between normal irrigation and water deficit across the two sowing seasons for all studied traits. The normal irrigation treatment recorded the highest mean values for all studied traits. Reduce number of irrigations from six to three irrigations (water stress) significantly decreased days to heading, days to maturity, plant height, number of spikes m^{-2}, number of kernels $spike^{-1}$, thousand kernel weight and grain yield by. 3.89%, 2.90%, 5.62%, 18.94 %, 6.86%, 7.77% and 15.03% respectively.

Effect of genotypes:

The means performance of the studied traits across seasons and water treatments are presented in Table 4. Regarding number of days to heading and maturity, G11 was the earliest genotypes, while Sids 14 and G20 were the latest genotypes for number of days to heading and maturity, respectively. The values of plant height ranged from 100.08 cm (G 9) to 116.67 cm (G13). Besides, the number of spikes m^{-2} were in the range of 399.50 spikes (G8) to 443.17 spikes (G17). The greatest number of kernels $spike^{-1}$ was obtained by G7, while the least was belonging to G19. The maximum value of thousand kernels weight was recorded by G19, whereas the minimum value was recorded by G 3. With respect to grain yield, the highest values 24.00 and 23.54 ard fed^{-1} were obtained by G13 and G17, respectively. While the lowest values of grain yield 18.01, 18.63 and 18.75 ard fed^{-1} were obtained by G2, G6 and G14,respectively.

Effect of interaction between seasons and water treatments:

The results in Table 5 indicated that the highest values for all traits were obtained by normal irrigation treatment in the second season. In contrast, the lowest values were exhibited under water stress treatment in the first season.

Table 4. The mean performance of seasons, water treatments and genotypes for the studied traits.

Factors	Traits						
	DH	DM	PH	SM	KS	TKW	GY
Seasons							
2020/2021	92.88	141.51	103.89	414.78	60.12	51.65	19.13
2021/2022	95.97	142.43	108.20	431.40	63.49	55.97	21.49
LSD 0.05	0.41	0.59	0.63	4.78	1.64	0.91	0.56
Treatments							
Normal irrigation(N)	96.15	144.15	109.11	467.34	64.00	55.96	21.96
Water stress (S)	92.41	139.97	102.98	378.83	59.61	51.61	18.66
Reduction (%)	3.89	2.90	5.62	18.94	6.86	7.77	15.03
LSD 0.05	0.41	0.59	0.63	4.78	1.64	0.91	0.56
Genotypes							
G1	92.08	139.08	102.25	422.33	61.58	53.97	21.38
G2	91.83	142.08	106.42	431.42	61.21	54.28	18.01
G3	93.33	140.58	104.25	426.42	66.76	51.40	21.46
G4	96.00	143.67	102.50	429.50	59.84	55.05	20.13
G5	95.58	142.08	103.25	409.17	60.10	55.26	19.13
G6	93.58	138.33	103.00	414.33	62.24	52.06	18.63
G7	92.92	141.83	105.08	421.42	70.28	52.07	20.25
G8	94.92	141.83	103.67	399.50	61.19	55.07	19.67
G9	92.58	140.08	100.08	411.42	62.80	53.33	19.29
G10	90.83	140.58	105.17	433.83	63.23	52.13	19.04
G11	88.42	138.25	103.08	420.67	67.53	53.31	19.05
G12	96.75	144.50	105.92	425.75	62.37	55.42	20.58
G13	97.25	144.92	116.67	433.33	62.85	55.01	24.00
G14	95.25	139.42	103.50	429.83	59.25	54.68	18.75
G15	92.67	141.42	107.17	418.00	60.92	52.97	21.96
G16	94.83	139.75	108.17	404.92	63.44	55.10	19.83
G17	94.83	142.33	108.42	443.17	58.48	53.76	23.54
G18	96.75	143.75	105.58	430.33	58.29	54.68	20.96
G19	93.25	141.08	106.25	416.33	54.63	59.37	20.33
G20	95.50	145.83	111.83	432.75	61.79	54.13	20.42
Kasuko	93.83	144.08	109.08	431.00	59.47	52.53	19.71
Sokoll	97.33	144.50	107.42	425.75	61.68	51.77	19.04
Sids 14	98.33	145.33	110.83	423.67	64.28	52.19	21.04
Giza 171	94.00	142.00	105.50	419.25	59.05	51.87	21.23
LSD 0.05	1.37	1.33	1.87	11.59	1.82	1.65	0.95

DH: number of days to heading, DM: number of days to maturity, PH: plant height (cm), SM: number of spikes m^{-2}, KS: number of kernels spike^{-1}, TKW: thousand kernel weight (g) and GY: grain yield (ard fed^{-1}).
*and ** refer to $P<0.05$ and $P<0.01$, respectively**.**

Table 5. The mean performance of the studied traits as affected by interaction between seasons and water treatments.

Seasons	Treatments	Traits						
		DH	DM	PH	SM	KS	TKW	GY
2020/ 2021	Normal irrigation(N)	94.76	143.40	107.28	453.85	62.08	53.13	20.84
	Water stress (S)	91.00	139.63	100.50	375.71	58.16	50.17	17.42
2021/ 2022	Normal irrigation(N)	97.53	144.90	110.94	480.83	65.91	58.80	23.08
	Water stress (S)	93.82	139.96	105.46	381.96	61.06	53.14	19.90
LSD 0.05		--	--	0.90	6.76	--	1.29	--

DH: number of days to heading, DM: number of days to maturity, PH: plant height (cm), SM: number of spikes m^{-2}, KS: number of kernels spike^{-1}, TKW: thousand kernel weight (g) and GY: grain yield (ard fed^{-1}).

Effect of interaction between seasons and genotypes:

The means of the studied traits across the two water treatments in the two seasons are presented in Table 6. The highest values of a number of days to heading were obtained by Sids 14, while the lowest values were recorded by G11 in both seasons. Genotype 20 had the highest number of days to maturity in both seasons, while G11 and G6 had the lowest number in the first and second seasons, respectively. The highest value of plant height was recorded by G13 in both seasons, whereas the shortest values were recorded by G1 in the first season and G4 in the second season. The greatest values of number of spikes m^{-2} 435.6 and 450.6 were obtained by G17, while the lowest number of spikes m^{-2} 391.0 and 408.0 were recorded by G8 in the first and second seasons, respectively. Besides, number of kernels spike^{-1} were in the range from 52.10 kernels in G19 and 55.65 kernels in G17 to 65.29 and 75.27 kernels in

G7 in the first and second seasons, respectively. The maximum thousand kernels weight was recorded by G19, while the lowest was recorded by Giza 171 in the first season and G3 in the second season. The highest grain yield was 23.67 ard fed^{-1} for G13 in the first season and 25.50 ard fed^{-1} for G17 in the second season, while the lowest values were 17.42 and 18.60 ard fed^{-1} for G2 in the first and second seasons, respectively.

Effect of interaction between water treatments and genotypes:

The means of all studied traits combined over the two seasons for the same water treatment are exhibited in Table 7. The highest values of all genotypes for all studied traits were obtained under normal irrigation treatment. Regarding number of days to heading G11 was the earliest genotype, while cultivar Sids 14 was the latest genotypes in both water treatments. The lowest values of number of days to maturity were recorded by G6 under normal irrigation and G11 under water stress, while the highest values were obtained by G20 under both water treatments. Plant height estimates ranged from 102.67 and 97.50 cm in G9 to 120.33 and 113.00 cm in G13 under normal and water stress conditions, respectively. The highest number of spikes m^{-2} were obtained by G17 in both water treatments, while the lowest number of spikes m^{-2} was found by G9 under normal irrigation and G8 under water stress conditions. The greatest values of number of kernels spike^{-1} were recorded by G7, while the lowest values were recorded by G19 under both water treatments. The Maximum thousand kernel weight was obtained by G19 under both water treatments. In contrast, G3 and G6 gave the minimum thousand kernel weight under normal and water stress conditions, respectively. Under normal irrigation conditions, G13 produced the highest grain yield 26.25 ard fed^{-1} and it was statically similar to G17 (25.08 ard fed^{-1}), while G2 gave the lowest grain yield (19.08 ard fed^{-1}). On the other side, under water stress conditions G17 produced the highest value of grain yield (22.00ard fed^{-1}) and it was at par with G13 (21.75 ard fed^{-1}), while G 6 gave the lowest value (16.42 ard fed^{-1}) of grain yield.

Effect of interaction between seasons, water treatments and genotype:

The mean performance of the studied traits for the interaction between seasons, water treatments and genotypes are presented in Tables (8 & 9). The interaction effect between the three factors was insignificant for all studied traits except number of kernels spike^{-1}. The earliest genotype was G11, while the latest genotype was cultivar Sids 14 in both seasons under both water treatments. The lowest number of days to maturity was belonged to G11, while the highest numbers belonged to G20 in the first season under both water treatments. In the second season, G6 and G16 had the lowest number of days to maturity, while G20 and G13 had the highest numbers under normal and water stress conditions, respectively. For plant height, G13 was the tallest genotype under normal irrigation conditions in the first season and both irrigation conditions in the second season, while the shortest genotypes were G1 and G8 in the first season and G9 and G4 in the second season under normal and water stress treatments, respectively. Besides, the least number of spikes m^{-2} was recorded by G16 and G8 in the first season under normal and water stress conditions, respectively and by G8 in the second season under both water conditions. The highest number of spikes m^{-2} was recorded by G17 and G4 in the first season and by G14 and G13 in the second season under normal and water stress treatments, respectively. Moreover, the lowest number of kernels spike^{-1} was detected by G19 in the first season under both water treatments and by G17 and G19 in the second season under normal and water stress treatments, respectively. Whereas, the highest number of kernels spike^{-1} was obtained with G3 and G12 in the first season under normal and water stress treatments, respectively and by G7 under both water conditions. The maximum thousand kernel weight was recorded by G19 under all conditions, while the minimum was recorded by G3 under normal irrigation and G6 under water stress in both seasons. The highest grain yield was produced by G13 in the first season and G17 in the second season under both water irrigation conditions. In contrast, the lowest grain yield was produced by G2 and G6 in the first season and by G2 and G14 in the second season under normal and water stress treatments, respectively.

Drought tolerance indices:

The water stress susceptibility index (SSI) was calculated using the grain yield (ard fed^{-1}) under normal and water stress conditions Table (10). The SSI values represent tolerance or sensitivity if they were less than or above unity, respectively. The SSI and yield reduction ratio (YR%) values among genotypes ranged from 0.58 and 8.71% for Sids 14 to 1.58 and 23.71% for G1, respectively. Averaging the mean of SSI values across the two seasons, Sids 14, G16, Sokoll, G2, G12, G9, Kasuko , G17, G20, G18,G8, G10 and G5 had values less than the unity while,G7, G3, Giza 171, G15, G13, G19, G14, G4, G11, G6 and G1 had values higher than the unity. Moreover, genotype 17 showed SSI<1 and had grain yield significantly higher that all genotypes and checks under normal and water stress conditions.

Table 6. The mean performance of the studied traits as affected by interaction between seasons and genotypes.

Traits	DH		DM		PH		SM		KS		TKW		GY	
Seasons	**20/21**	**21/22**	**20/21**	**21/22**	**20/21**	**21/22**	**20/21**	**21/22**	**20/21**	**21/22**	**20/21**	**21/22**	**20/21**	**21/22**
Genotypes														
G1	91.33	92.83	139.17	139.00	99.83	104.67	424.67	420.00	58.23	64.93	50.30	57.63	20.58	22.17
G2	91.33	92.33	141.17	143.00	105.00	107.83	422.83	440.00	56.88	65.55	51.73	56.82	17.42	18.60
G3	92.67	94.00	139.50	141.67	103.33	105.17	419.83	433.00	63.15	70.38	50.33	52.47	19.83	23.08
G4	94.33	97.67	143.33	144.00	104.17	100.83	432.00	427.00	59.23	60.46	52.33	57.76	18.33	21.92
G5	93.83	97.33	142.17	142.00	101.83	104.67	404.17	414.17	58.46	61.75	50.88	59.64	18.17	20.08
G6	92.83	94.33	137.83	138.83	99.83	106.17	403.33	425.33	60.06	64.42	50.23	53.88	17.75	19.50
G7	91.50	94.33	141.33	142.33	104.67	105.50	417.67	425.17	65.29	75.27	50.87	53.28	20.00	20.50
G8	93.50	96.33	141.00	142.67	101.17	106.17	391.00	408.00	60.63	61.76	51.30	58.85	18.58	20.75
G9	91.17	94.00	137.67	142.50	99.50	100.67	404.83	418.00	62.35	63.24	53.50	53.17	17.58	21.00
G10	88.17	93.50	140.67	140.50	104.17	106.17	419.33	448.33	60.41	66.05	50.57	53.69	18.25	19.83
G11	86.00	90.83	136.67	139.83	101.00	105.17	407.83	433.50	63.43	71.62	52.60	54.02	17.68	20.42
G12	95.00	98.50	144.17	144.83	102.83	109.00	426.00	425.50	64.81	59.93	53.13	57.71	18.42	22.75
G13	96.17	98.33	144.00	145.83	111.33	122.00	421.83	444.83	61.66	64.05	51.70	58.32	23.67	24.33
G14	93.50	97.00	137.83	141.00	101.67	105.33	416.67	443.00	59.05	59.45	53.80	55.57	17.83	19.67
G15	92.17	93.17	142.00	140.83	102.17	112.17	417.33	418.67	55.68	66.17	52.03	53.91	20.33	23.58
G16	93.67	96.00	140.00	139.50	103.00	113.33	396.83	413.00	62.47	64.40	52.47	57.72	18.75	20.92
G17	93.33	96.33	142.00	142.67	104.50	112.33	435.67	450.67	61.31	55.65	51.30	56.22	21.58	25.50
G18	94.83	98.67	143.50	144.00	103.17	108.00	420.00	440.67	56.56	60.01	52.80	56.57	20.08	21.83
G19	91.83	94.67	141.50	140.67	104.83	107.67	395.50	437.17	52.10	57.16	54.53	64.20	18.75	21.92
G20	94.50	96.50	145.50	146.17	110.67	113.00	422.83	442.67	61.27	62.31	52.03	56.23	18.67	22.17
Kasuko	92.83	94.83	143.50	144.67	106.50	111.67	423.67	438.33	59.15	59.79	51.40	53.66	18.42	21.00
Sokoll	95.67	99.00	144.00	145.00	104.83	110.00	414.17	437.33	59.80	63.55	49.67	53.88	18.58	19.50
Sids 14	96.17	100.50	145.00	145.67	109.50	112.17	409.83	437.50	63.88	64.68	50.60	53.78	19.92	22.17
Giza 171	92.83	95.17	142.83	141.17	103.83	107.17	406.83	431.67	57.03	61.07	49.43	54.30	19.90	22.57
LSD 0.05	-----		**1.89**		**2.65**		**16.39**		**2.57**		**2.33**		**1.34**	

N: normal irrigation, S: water stress, DH: number of days to heading, DM: number of days to maturity, PH: plant height (cm), SM: number of spikes m^{-2}, KS: number of kernels spike^{-1}, TKW: thousand kernel weight (g) and GY: grain yield (ard fed^{-1}).

Table 7. The mean performance of the studied traits as affected by interaction between water treatments and genotypes.

Traits	DH		DM		PH		SM		KS		TKW		GY	
Treatments	**N**	**S**	**N**	**S**	**N**	**S**	**N**	**S**	**N**	**S**	**N**	**S**	**N**	**S**
Genotypes														
G1	95.50	88.67	141.17	137.00	103.67	100.83	465.00	379.67	63.77	59.38	55.65	52.28	24.25	18.50
G2	92.67	91.00	144.00	140.17	112.00	100.83	478.00	384.83	61.89	60.53	56.95	51.60	19.08	16.93
G3	95.17	91.50	143.83	137.33	106.00	102.50	470.00	382.83	70.50	63.02	52.66	50.14	23.25	19.67
G4	97.67	94.33	145.50	141.83	105.50	99.50	465.00	394.00	62.45	57.24	58.34	51.75	22.33	17.92
G5	97.00	94.17	143.83	140.33	105.00	101.50	448.67	369.67	62.35	57.85	56.36	54.17	20.67	17.58
G6	96.67	90.50	140.33	136.33	106.83	99.17	471.33	357.33	63.86	60.62	55.91	48.20	20.83	16.42
G7	95.17	90.67	143.50	140.17	107.50	102.67	469.33	373.50	72.46	68.10	53.20	50.94	21.92	18.58
G8	97.00	92.83	145.50	138.17	108.33	99.00	445.00	354.00	65.53	56.85	57.82	52.32	21.17	18.17
G9	94.33	90.83	142.00	138.17	102.67	97.50	444.00	378.83	65.18	60.41	55.49	51.17	20.50	18.08
G10	92.83	88.83	144.00	137.17	108.33	102.00	478.00	389.67	66.35	60.11	53.26	51.00	20.50	17.58
G11	90.33	86.50	141.17	135.33	106.00	100.17	479.67	361.67	71.83	63.22	55.70	50.92	21.25	16.85
G12	98.67	94.83	145.83	143.17	109.00	102.83	477.67	373.83	63.43	61.32	58.39	52.46	21.83	19.33
G13	98.00	96.50	146.50	143.33	120.33	113.00	477.33	389.33	67.11	58.60	56.52	53.50	26.25	21.75
G14	96.67	93.83	141.00	137.83	106.00	101.00	478.33	381.33	58.98	59.52	56.68	52.68	20.75	16.75
G15	94.50	90.83	143.17	139.67	110.00	104.33	461.00	375.00	62.58	59.27	55.03	50.91	23.92	20.00
G16	97.50	92.17	143.67	135.83	112.50	103.83	447.33	362.50	64.94	61.93	56.40	53.79	20.75	18.92
G17	96.00	93.67	144.67	140.00	111.50	105.33	488.00	398.33	60.44	56.52	55.88	51.64	25.08	22.00
G18	98.00	95.50	145.83	141.67	107.50	103.67	485.83	374.83	59.50	57.08	57.88	51.49	22.42	19.50
G19	95.67	90.83	143.67	138.50	109.00	103.50	461.67	371.00	57.09	52.17	60.83	57.90	22.25	18.42
G20	97.33	93.67	147.83	143.83	115.83	107.83	471.00	394.50	63.91	59.67	56.50	51.76	21.80	19.03
Kasuko	95.67	92.00	145.83	142.33	113.83	104.33	467.67	394.33	61.97	56.98	55.09	49.97	21.00	18.42
Sokoll	98.50	96.17	145.67	143.33	109.17	105.67	463.00	388.50	63.13	60.22	53.63	49.92	20.17	17.92
Sids 14	100.17	96.50	147.33	143.33	113.83	107.83	465.33	382.00	65.95	62.61	54.18	50.20	22.00	20.08
Giza 171	96.50	91.50	143.83	140.17	108.33	102.67	458.00	380.50	60.68	57.43	54.74	48.99	23.07	19.40
LSD 0.05	**1.94**		**1.89**		**2.65**		**16.39**		**2.57**		**2.33**		**1.34**	

DH: number of days to heading, DM: number of days to maturity, , PH: plant height (cm), SM: number of spikes m^{-2}, KS: number of kernels spike^{-1}, TKW: thousand kernel weight (g) and GY: grain yield (ard fed^{-1}).

Table 8. The mean performance of number of days to heading (DH), number of days to maturity (DM) and plant height (PH) traits as affected by Interaction between seasons, water treatments and genotypes.

Traits	DH				DM				PH			
Seasons	2020/2021		2021/2022		2020/2021		2021/2022		2020/2021		2021/2022	
Treatments	N	S	N	S	N	S	N	S	N	S	N	S
Genotypes												
G1	95.33	87.33	95.67	90.00	141.00	137.33	141.33	136.67	101.33	98.33	106.00	103.33
G2	92.00	90.67	93.33	91.33	143.67	138.67	144.33	141.67	111.67	98.33	112.33	103.33
G3	94.33	91.00	96.00	92.00	142.67	136.33	145.00	138.33	106.00	100.67	106.00	104.33
G4	96.33	92.33	99.00	96.33	145.00	141.67	146.00	142.00	106.67	101.67	104.33	97.33
G5	95.33	92.33	98.67	96.00	143.67	140.67	144.00	140.00	104.00	99.67	106.00	103.33
G6	96.00	89.67	97.33	91.33	139.33	136.33	141.33	136.33	103.00	96.67	110.67	101.67
G7	93.67	89.33	96.67	92.00	142.00	140.67	145.00	139.67	108.33	101.00	106.67	104.33
G8	95.33	91.67	98.67	94.00	144.67	137.33	146.33	139.00	106.00	96.33	110.67	101.67
G9	92.67	89.67	96.00	92.00	139.00	136.33	145.00	140.00	102.33	96.67	103.00	98.33
G10	90.33	86.00	95.33	91.67	143.33	138.00	144.67	136.33	107.67	100.67	109.00	103.33
G11	88.33	83.67	92.33	89.33	138.33	135.00	144.00	135.67	104.33	97.67	107.67	102.67
G12	96.67	93.33	100.67	96.33	145.33	143.00	146.33	143.33	106.00	99.67	112.00	106.00
G13	97.00	95.33	99.00	97.67	146.00	142.00	147.00	144.67	115.67	107.00	125.00	119.00
G14	95.00	92.00	98.33	95.67	139.67	136.00	142.33	139.67	104.67	98.67	107.33	103.33
G15	93.67	90.67	95.33	91.00	142.67	141.33	143.67	138.00	106.67	97.67	113.33	111.00
G16	96.33	91.00	98.67	93.33	143.33	136.67	144.00	135.00	107.33	98.67	117.67	109.00
G17	94.33	92.33	97.67	95.00	144.33	139.67	145.00	140.33	109.00	100.00	114.00	110.67
G18	96.00	93.67	100.00	97.33	145.67	141.33	146.00	142.00	105.67	100.67	109.33	106.67
G19	94.67	89.00	96.67	92.67	143.33	139.67	144.00	137.33	106.33	103.33	111.67	103.67
G20	96.33	92.67	98.33	94.67	147.33	143.67	148.33	144.00	115.00	106.33	116.67	109.33
Kasuko	94.33	91.33	97.00	92.67	145.67	141.33	146.00	143.33	111.67	101.33	116.00	107.33
Sokoll	97.00	94.33	100.00	98.00	145.00	143.00	146.33	143.67	107.00	102.67	111.33	108.67
Sids 14	98.00	94.33	102.33	98.67	146.67	143.33	148.00	143.33	111.67	107.33	116.00	108.33
Giza 171	95.33	90.33	97.67	92.67	144.00	141.67	143.67	138.67	106.67	101.00	110.00	104.33
$LSD_{0.05}$	---				---				---			

Table 9. The mean performance of number of spikesm^{-2} (SM), number of kernels spike^{-1} (KS), thousand kernel weight (TKW) and grain yield (GY) traits as affected by Interaction between seasons, water treatments and genotypes.

Traits	SM				KS				TKW				GY			
Seasons	2020/2021		2021/2022		2020/2021		2021/2022		2020/2021		2021/2022		2020/2021		2021/2022	
Treatments	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Genotypes																
G1	460.00	389.33	470.00	370.00	60.02	56.45	67.53	62.32	51.73	48.87	59.57	55.69	23.50	17.67	25.00	19.33
G2	456.00	389.67	500.00	380.00	57.10	56.66	66.69	64.41	53.33	50.13	60.57	53.06	18.50	16.33	19.67	17.53
G3	464.00	375.67	476.00	390.00	66.99	59.31	74.02	66.73	51.33	49.33	53.99	50.94	21.67	18.00	24.83	21.33
G4	464.00	400.00	466.00	388.00	62.25	56.21	62.64	58.27	54.53	50.13	62.16	53.37	20.50	16.17	24.17	19.67
G5	437.33	371.00	460.00	368.33	59.60	57.32	65.11	58.38	51.33	50.43	61.38	57.91	20.67	15.67	20.67	19.50
G6	452.67	354.00	490.00	360.67	62.60	57.51	65.11	63.72	53.33	47.13	58.49	49.27	20.67	14.83	21.00	18.00
G7	466.67	368.67	472.00	378.33	66.75	63.84	78.18	72.37	52.00	49.73	54.41	52.15	21.50	18.50	22.33	18.67
G8	434.67	347.33	455.33	360.67	64.68	56.57	66.39	57.13	52.67	49.93	62.98	54.72	20.50	16.67	21.83	19.67
G9	432.00	377.67	456.00	380.00	63.06	61.65	67.31	59.17	54.67	52.33	56.32	50.01	19.17	16.00	21.83	20.17
G10	456.00	382.67	500.00	396.67	62.19	58.63	70.52	61.59	51.33	49.80	55.18	52.21	20.00	16.50	21.00	18.67
G11	464.00	351.67	495.33	371.67	66.59	60.28	77.08	66.16	54.00	51.20	57.40	50.63	19.33	16.03	23.17	17.67
G12	469.33	382.67	486.00	365.00	65.56	64.07	61.30	58.56	54.67	51.60	62.10	53.32	19.67	17.17	24.00	21.50
G13	466.67	377.00	488.00	401.67	64.45	58.87	69.76	58.33	53.00	50.40	60.04	56.59	26.17	21.17	26.33	22.33
G14	450.67	382.67	506.00	380.00	60.53	57.57	57.43	61.48	54.93	52.67	58.44	52.70	19.00	16.67	22.50	16.83
G15	448.00	386.67	474.00	363.33	57.27	54.09	67.89	64.44	52.67	51.40	57.40	50.43	21.67	19.00	26.17	21.00
G16	432.00	361.67	462.67	363.33	64.60	60.35	65.28	63.51	53.53	51.40	59.26	56.19	19.83	17.67	21.67	20.17
G17	474.67	396.67	501.33	400.00	64.07	58.54	56.81	54.49	52.33	50.27	59.42	53.01	23.17	20.00	27.00	24.00
G18	473.67	366.33	498.00	383.33	58.34	54.79	60.66	59.37	54.27	51.33	61.48	51.65	21.67	18.50	23.17	20.50
G19	437.33	353.67	486.00	388.33	53.21	50.99	60.96	53.36	56.20	52.87	65.46	62.94	20.50	17.00	24.00	19.83
G20	456.00	389.67	486.00	399.33	63.36	59.19	64.47	60.15	54.67	49.40	58.33	54.13	20.10	17.23	23.50	20.83
Kasuko	455.33	392.00	480.00	396.67	61.37	56.94	62.57	57.02	52.73	50.07	57.45	49.86	20.00	16.83	22.00	20.00
Sokoll	448.00	380.33	478.00	396.67	61.44	58.16	64.82	62.29	51.47	47.87	55.79	51.96	19.67	17.50	20.67	18.33
Sids 14	450.67	369.00	480.00	395.00	65.61	62.14	66.29	63.07	52.67	48.53	55.69	51.86	21.08	18.75	22.92	21.42
Giza 171	442.67	371.00	473.33	390.00	58.35	55.71	63.00	59.14	51.60	47.27	57.88	50.71	21.65	18.15	24.48	20.65
$LSD_{0.05}$	------				3.6				---				---			

Table 10. Mean of grain yield under normal irrigation and water stress over the two growing seasons, and Water stress susceptibility index (SSI) and yield reduction ratio (YR%).

Genotypes	Grain yield (ardab/feddan)		SSI	YR%
	Normal irrigation	Water stress		
G1	24.25	18.50	1.58	23.71
G2	19.08	16.93	0.75	11.27
G3	23.25	19.67	1.03	15.41
G4	22.33	17.92	1.32	19.78
G5	20.67	17.58	0.99	14.92
G6	20.83	16.42	1.41	21.20
G7	21.92	18.58	1.01	15.21
G8	21.17	18.17	0.94	14.17
G9	20.50	18.08	0.78	11.79
G10	20.50	17.58	0.95	14.23
G11	21.25	16.85	1.38	20.71
G12	21.83	19.33	0.76	11.45
G13	26.25	21.75	1.14	17.14
G14	20.75	16.75	1.28	19.28
G15	23.92	20.00	1.09	16.38
G16	20.75	18.92	0.59	8.84
G17	25.08	22.00	0.82	12.29
G18	22.42	19.50	0.87	13.01
G19	22.25	18.42	1.15	17.23
G20	21.80	19.03	0.84	12.69
Kasuko	21.00	18.42	0.82	12.30
Sokoll	20.17	17.92	0.74	11.16
Sids 14	22.00	20.08	0.58	8.71
Giza 171	23.07	19.40	1.06	15.90

Genotype by genotype-environment biplot (GGE biplot):

The GGE biplot of grain yield for the studied wheat genotypes was done for the four environmental conditions, i.e., E1 (normal irrigation in 2020/2021 season), E2 (water stress in 2020/2021 season), E3 (normal irrigation in 2021/2022 season) and E4 (water stress in 2021/2022 season). GGE biplot analyses for comparison of genotypes were performed to detect the ideal and desirable genotypes (Figure 1). The biplot explained 87.75% of the total variation observed, of which 77.96% was explained by the first principal component (PC1), while the second principal component (PC2) explained 9.79%.On the other hand, G17, G13 and G15 were the desirable genotypes as they grouped in the centric circle. However, G2 and G6 seem to be undesirable.

Identification of high-yield and stable genotypes across environments was done byso-called the average environment coordinates (AEC) method (Yan and Tinker, 2006). The average environment is defined by the average values of PC1 and PC2 for all environments and it is presented with a circle. The average ordinate environment (AOE) is defined by the line which is perpendicular to the average environment axis (AEA) line and passes through the origin. The genotypes on the left side of the ordinate had a lower yield than mean yield but the genotypes on the right side of the ordinate had a higher yield than mean yield across environments. Thus, Figure 2 showed the rank of genotypes' performance. The highest yielder genotypes were G13 and G17 followed by G15, G3, G24, G1 and G18 but G24 (Giza 171), G18, G15, G3 and G17 showed more stability, respectively. In the contrast, G2 and G6 were the lowest.

A convex hull (Figure 3) has been drawn by connecting the furthest genotypes to form a polygon that encompasses all the genotypes. The convex hull was divided into sectors by drawing lines from the origin perpendicular to each side of the hull. If a genotype at an angular vertex of the polygon falls within one sector with an environment marker (or with several markers), that means that the yield capacity of this genotype was the highest in this particular environment. Another important feature of this biplot is that it indicates environmental groupings, which suggests the possible existence of different mega-environments. Mega environments were determined by drawing ellipses around the environments fall into the same sector. Environments that consistently shared the same best genotypes were considered mega-environments. Thus, our study “Which-Won–Where” polygon (Figure 3) showed that the four environments fell into two sectors with different winning genotypes. The first mega environment (ME1) contains normal irrigation and water stress conditions in 2020/2021 (E1 and E2), while the second mega environment (ME2) contains normal irrigation and water stress conditions in 2021/2022 (E3 and E4).

The best-performing genotypes under ME1 were G13 while the best genotype under ME2 was G 17. The rest of genotypes were not belonging to any sector because their performance was lower than the average performance of any test environments.

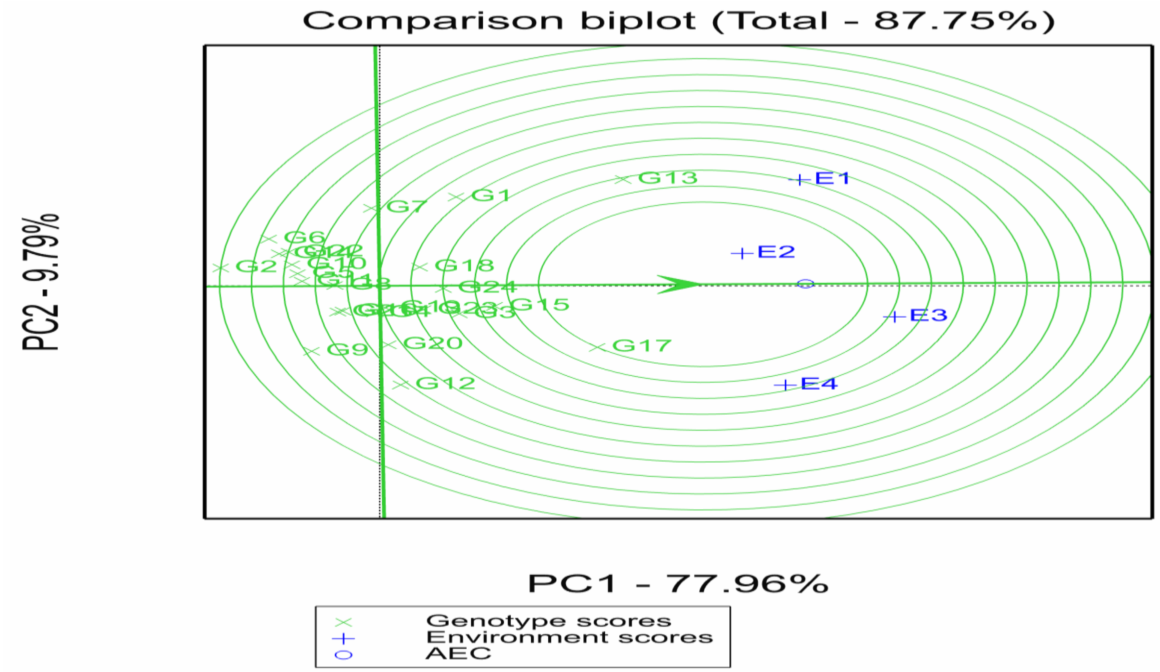

Fig. 1. GGE-biplot focused scaling for comparison of the genotypes. E1 – E4 are the environments; G1 – G24 are the genotypes.

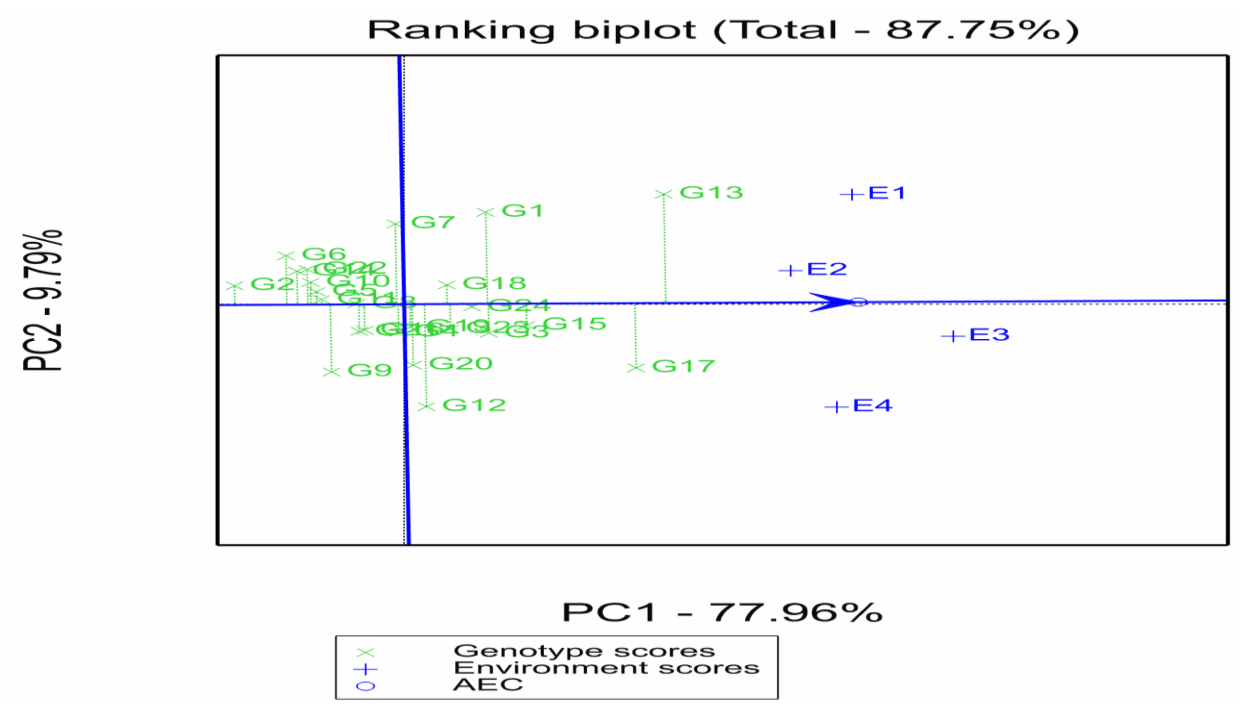

Fig. 2. Identification of winning genotypes across 4 environments. E1- E4 are the environments; G1 – G24 are the genotypes.

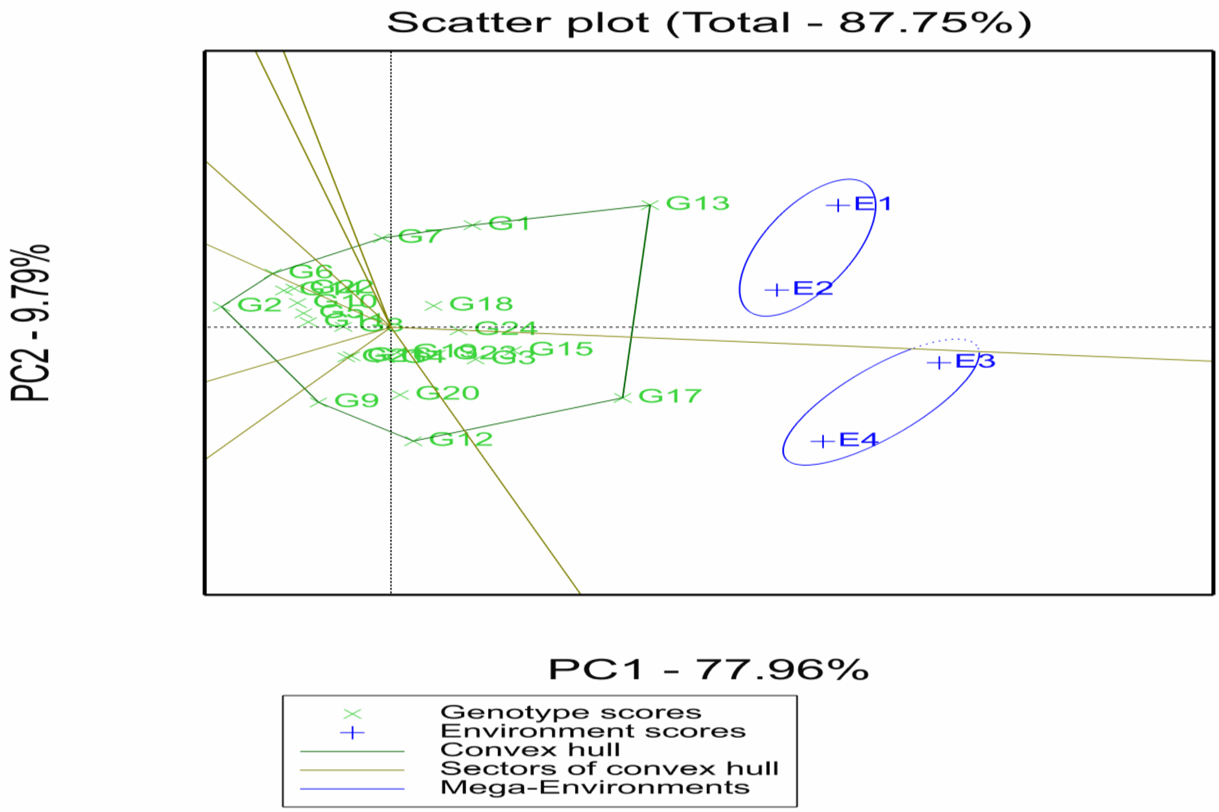

Fig. 3. The which–won–where a view of the GGE biplot to show which genotypes performed better in which environment for grain yield. E 1 – E4 are the environments; G1 – G24 are the genotypes.

DISCUSSION

The highly significant among seasons, water treatments and genotypes indicates that the two seasons and two water treatments behaved differently and detected sufficient genetic variability among the studied genotypes. Similar results were found by Farhat *et al.,* (2021). The highest values in the second season for all studied traits Table (3) can be attributed to the rise in temperature of the first season compared to the second season Table (1). Similar results were obtained by Farhat *et al.,* (2021) and Shehab-Eldeen and Farhat, (2020).

The significant reduction of days to heading and maturity under water stress compared to normal irrigation may be due to the water deficit was occur at end of elongation stage and relatively high temperature until early flowering and speed up maturation. These results coincide with the findings of Abd El-Rady, (2016); GabAlla *et al.,* (2019) and Shehab-Eldeen and Farhat (2020). Reduce irrigation numbers significantly decreased number of spikes m^{-2}, number of kernels $spike^{-1}$, 1000-kernel weight and grain yield of wheat (Farhat, 2015; Abd El-Rady, 2017, Abd El-Rady *et al.,* 2020 and Farhat *et al.,* 2021). The reduction in kernels number under the water deficit may be due to premature abortion of florets (Dolferus *et al.,* 2013) and male and female sterility (Onyemaobi *et al.,* 2017). Additionally, the reduction of grain weight under the water deficit may be due to the decrease of grain-filling duration and then lower dry matter accumulation or a reduced rate and duration of starch accumulation in the endosperm (Zhao *et al.,* 2020). Grain yield was reported to be decreased under water stress due to the decrease of number of spikes m^{-2}, number of kernels $spike^{-1}$ and thousand kernel weight (Abd El-Rady *et al.,* 2020 and Mahdavi *et al.,* 2022).

The significant differences between genotypes for all traits Table (4) might be attributed to their genetic backgrounds and indicated that the differences among genotypes were sufficient to provide a scope to characterize the effect of water stress. The significant interaction between seasons and sowing dates for all traits Table (5) suggest that the agroecological conditions of the growing seasons were extremely different and accounted for most of the variation of the traits. The significant variance component for the interaction between seasons and genotypes Table (6) suggests a different ranking of genotypes across water treatments under the two growing seasons. Selection for water stress tolerance should be done in more than one year in the target environments (Sallam*et al.,* 2019) because water stress tolerance usually has low heritability.

The reduction in number of days to heading and maturity, plant height, grain yield and its components under water stress Table (7) was also reported in many earlier studies (Farhat, 2015; Abd El-Rady, 2017; Hamza *et al.,* 2018; Seleiman and Abdel-Aal, 2018; Abd El-Kreem *et al.,* 2019; Abd El-Hamid *et al.,* 2019; Abd El-Rady *et al.,* 2020). Water stress generally decreased the days required to initiate heading or flowering due to the early start of the reproductive (Menshawy *et al.,* 2006 and El-Hag, 2017). A decreasing number of irrigations led to a significant reduction in number of days to maturity. This may be due to water stress retards photosynthesis and translocation of photosynthates and affects plant development which shortens days to maturity. Moreover, water stress imposed at post-flowering reduced the grain-filling period hence decreasing days to maturity (Abd El-Rady *et al.,* 2020). The decrease in plant height in response to water stress may be attributed to a reduction of inflammation and protoplasm water loss, which contributes to the reduction of turgor pressure and cell division, as well as the decrease in cell size and number (Mehraban *et al.,* 2019). Tillers are initiated in the first growth stage, but the fertile tillers are controlled by the availability of nutrients, moisture, and weather conditions throughout the entire growing period from emergence through tillering and stem elongation up to the stages of spike development, as evidenced by our results, which show that the number of spikes m^{-2} increases gradually with an increasing number of irrigations. Similar results were reported by El-Hag, (2017) and Abd El-Rady *et al.,*(2020). The reduction in number of kernels spike^{-1} under water deficit may be due to the negative effect of water stress on floret formation and fertility (Mehraban *et al.,* 2019). Similar results were found by El-Hag, (2017), Senapati *et al.,* (2019), Abd El-Rady *et al.* (2020) and Farhat *et al.* (2021). The reduction of thousand kernel weight under the water deficit was observed by Gab Alla *et al. (*2019); Abd El-Rady *et al.,* (2020); Shehab-Eldeen and Farhat, (2020) and Zhao *et al.,* (2020). The hypothesised cause of grain weight reduction under water stress could be drought impacting emergent florets and reducing the weight of the carpel at pollination. Furthermore, moisture stress during grain filling may limit photosynthates delivery from leaves to spike, hence decreasing seed size. Bashir *et al.,* (2017); Si *et al.,*(2020) and Khan *et al.,* (2022) reported that decreasing number of irrigations and amount of water decreased wheat grain yield at the different growth stages. Low grain yield under water stress was mainly due to the obvious reduction in the yield components such as spikes number, kernels number and 1000-kernel weight during the critical growth stages.

The significant effect of interaction between season, water treatment and genotype for number of kernels spike^{-1} Table (8 and 9) suggest a different ranking of genotypes across seasons and water treatments.

Results of water stress susceptibility index Table (10) indicate that the genotypes Sids 14, G16, Sokoll, G2, G12, G9, Kasuko, G17, G20, G18, G8, G10 and G5 were the most tolerant ones under water deficit. Moreover, genotype 17 showed SSI<1 and had grain yield significantly higher that all genotypes and checks under normal and water stress conditions. Therefore, it can be labeled a good source of drought tolerance in a breeding program. On the other side, G7, G3, Giza 171, G15, G13, G19, G14, G4, G11, G6 and G1 had values higher than the unity and they can be considered asdrought–sensitive genotypes.

Identifying stable, high-yielding genotypes is a very important task for breeding programs and food security. An ideal genotype should have both high mean yield performance and high stability across environments (Kaya *et al.,* 2006 ; Yan and Tinker, 2006). Both GGE biplot analyses and ranking of genotypes Figures (1 and 2) confirmed the superiority of the two genotypes G13 and G17 followed by G15, G3, G24, G1 and G18 but G24 (Giza 171), G18, G15, G3 and G17 showed more stability, respectively. One of the most attractive features of GGE biplot is its ability to show the "which-won-where" pattern of a genotype by environment dataset as it graphically addresses important concepts such as cross-over GE, mega-environment differentiation, specific adaptation, etc. (Yan and Tinker, 2006). The polygon view of GGE biplot Figure (3) showed that G13 and G17 genotypes were suitable for planting under normal and water stress conditions, while the rest of genotypes were not belonging to any sector because their performance was lower than the average performance of any test environment.

CONCLUSION

Reduce number of irrigations (water stress) harmed the agronomic traits of wheat. Genotypes 13 and 17 significantly outperformed all studied genotypes and checked cultivars for grain yield under normal irrigation and water stress. The genotypes Sids 14, G16, Sokoll, G2, G12, G9, Kasuko, G 17, G20, G18, G8, G10 and G5 showed SSI<1 and it can be used as a source of drought tolerance in a breeding program. GGE biplot analysis revealed that G17 was an ideal genotype in terms of yielding ability and stability. This study concluded that G13 and G17 were suitable genotypes to be cultivated under water shortage conditions.

REFERENCES

Abd El-Hamid, E. A. M., Aglan, M. A. & Hussein, E. (2019). Modified method for the analysis of genotype by trait (GT) biplot as a selection criterion in wheat underwater stress conditions. *Egyptian Journal of Agronomy*, 41(3), 293-312.

Abd El-KreemThanaa, H. A., Abdel-Hamid, E. A. M. &Elhawary, M. N. A. (2019).Tolerance indices & cluster analysis to evaluate some bread wheat genotypes under water deficit conditions. *Alexandria Journal of Agricultural Sciences*, 64(4), 245-256

Abd El-Rady, A. G. (2016). Selection for grain yield under normal & deficit irrigation regimes in bread wheat. *Egyptian Journal of Agricultural Sciences*, 67(4), 295-306.

Abd El-Rady, A. G. (2017). Selection efficiency for grain yield under normal irrigation & water stress conditions in bread wheat. *Assiut Journal of Agricultural Science*, 48(5), 1-20.

Abd El-Rady, A. G., Soliman, G. M. M. &Koubisy, Y. S. I. (2020). Effect of irrigation scheduling on some agronomic & physiological traits of some wheat cultivars. *Journal of Plant Production*, 11(10), 907-920.

Bashir, M.U., Wajid, S.A., Ahmad, A., Awais, M., Raza, M. A. S.,Tahir, G. M., Saeed, U., Ur Rehman, M. H., Waqas, M. & Abbas S.(2017). Irrigation scheduling of wheat at different nitrogen levels in semi-arid region. *Journal of Field Crops*, 22(1), 63-70.

Dolferus, R., Powell N., JI., X., Ravash, R., Edlington, *Journal*, Oliver, S., Dongen, *Journal*V. &Shiran, B. (2013). The physiology of reproductive-stage abiotic stress tolerance in cereals. *Molecular stress physiology of plants*, 193-216.

El-Hag, Dalia A.A. (2017). Effect of irrigation number on yield & yield components of some bread wheat cultivars in North Nile Delta of Egypt. *Egyptian Journal of Agronomy*, 39, (2), 137-148.

Fang, Y. & Xiong, L. (2015). General mechanisms of drought response & their application in drought resistance improvement in plants. *Cellular and molecular life sciences*, 72(4), 673-689

FAO, (2016). AQUASTAT Country Profile-Egypt.

Farhat, W. Z. E. (2015).Response of 21 spring bread wheat genotypes to normal & reduced irrigation in North Delta. *Journal of Plant Production*, 6(6), 943-963.

Farhat, W. Z. E.1, Khedr Rania A. & Shaaban Shimaa, A. (2021). Response of some agronomic, physiological & anatomical characters for some bread wheat genotypes under water deficit in north delta region. *Scientific Journal of Agricultural Sciences*, 3(2),145-160.

Fischer, R. A. & Maurer, R. (1978). Drought resistance in spring wheat cultivars I. Grain yield responses. *Australian Journal of Agricultural Research*, 29(5), 897-912.

Gab Alla, M. M. M., Abdelkhalek, A. A., Eryan, N. L. & Farag, S. A. (2019). Response of some bread wheat genotypes to less irrigation water. *Journal of Plant Production*, 10(11), 917-927.

Golestani-Araghi, S. & Assad M.T. (1998). Evaluation of four screening techniques for drought resistance & their relationship to yield reduction ratio in wheat. *Euphytica*, 103, 293–299.

Gomez, K. M. & Gomez, A. A. (1984). Statistical procedures for agricultural research. *John Wily and Sons.*

Hamza Doaa, A., Milad Sanaa, I., Barakat, M. N., Ageez, A. &Nawar, A. I. (2018). Evaluation of drought tolerance indices for screening some wheat (*Triticumaestivum*L.) genotypes under drought conditions. *Middle East Journal of Agriculture Research*, 7(4), 1234-1244.

Henian Manal, M., Bakheit, B. R., Ali, M. B. M., El-Morshidy, M. A. &Amro, A. M. (2020). Assessment of bread wheat genotypes under normal irrigation &waterstress. *Assiut Journal of Agricultural Science*, 51(1), 26-26.

Kaya, Y., Akcura, M. &Taner, S. (2006). GGE-biplot analysis of multi-environment yield trials in bread wheat. *Turkish Journal of Agriculture*, (30), 325-337.

Khan, F. Y., Khan, S. U., Gurmani, A. R., Khan, A., Ahmed, S. & Zeb, B. S. (2022). Effect of water stress through skipped irrigation on growth & yield of wheat. *Polish Journal of Environmental Studies*, 31(1), 713-721.

Levene, H. (1960). Levene test for equality of variances. Contributions to probability & statistics, 278-292.

Mahdavi, Z., Rashidi, V., Yarnia, M., Aharizad, S., &Roustaii, M. (2022). Evaluation of yield traits & tolerance indices of different wheat genotypes under drought stress conditions. *Cereal Research Communications*, 1-11.

Mehraban, A., Tobe,A., Gholipouri,A.,Amiri, E.,Ghafari, A. &Rostaii, M. (2019).The effects of drought stress on yield, yield components, & yield stability at different growth stages in bread wheat cultivar (*Triticumaestivum*L.). *Polish Journal of Environmental Studies*, 28(2), 739-746.

Menshawy, A.M. M., El-Hag, A. A. & El-Sayed Soaad, A. (2006). Evaluation of some agronomic & quality traits for some wheat cultivars under different irrigation treatments. *In Proceeding First Field Crops Research Institute Conference, Giza, Egypt* (pp. 22-24).

Mkhabela ,S. S., Shimelis,H., Odindo, A. O. &Mashilo, *Journal* (2019). Response of selected drought tolerant wheat (*Triticum aestivum*L.) genotypes for agronomic traits & biochemical markers under drought-stressed & non-stressed conditions. *Acta Agriculturae Scandinavica, Section B—Soil and Plant Science*, 69(8), 674-689

Mwadzingeni, L., Shimelis, H., Dube, E.,Laing, M.D. &Tsilo, T.*Journal* (2016). Breeding wheat for drought tolerance: Progress & technologies. *Journal of Integrative Agriculture*, 15(5), 935-943

Onyemaobi. I., Liu. H., Siddique., K. H. & Yan G (2017). Both male & female malfunction contributes to yield reduction under water stress during meiosis in bread wheat. *Frontiers in Plant Science*, 7, 2071.

Payne, R. W.. Murray D. A. & Harding S. A. (2017). An introduction to the GenStat command language. *Hemel Hempstead, UK: VSN International*.

Radwan, H.G. (2017). Water saving from improved on-farm irrigation projects in Egypt. *International Journal of Scientific and Engineering Research*, 8 (8), 871-883

Sallam, A., Alqudah, A. M.,Dawood Mona, F. A., Baenziger, P. S. &Börner, A. (2019).Drought stress tolerance in wheat & barley: advances in physiology, breeding & genetics research. *International journal of Molecular Sciences*, 20(13), 1-36

Seleiman, M. F. & Abdel-Aal, M. S. M. (2018). Response of growth, productivity & quality of some Egyptian wheat cultivars to different irrigation regimes. *Egyptian Journal of Agronomy*, 40(3), 313-330.

Senapati, N., Stratonovitch, P., Paul, M. *Journal*& Semenov MA (2019). Drought tolerance during reproductive development is important for increasing wheat yield potential under climate change in Europe. *Journal of Experimental Botany*, 70(9), 2549-2560.

Shehab-Eldeen, M.T. & Farhat, W.Z.E. (2020). Response of some exotic bread wheat genotypes to reduced irrigation in north delta region of Egypt. *Egyptian Journal of Plant Breeding*, 24(4), 799-821.

Si, Z., Zaina, M., Mehmood, F., Wang, G., Gao,Y.& Duan, A. (2020). Effects of nitrogen application rate & irrigation regime on growth, yield, & water-nitrogen use efficiency of drip irrigated winter wheat in the North China Plain. *Agricultural Water Management*, 231, 106002

Steel, R. G. D., Torrie, *Journal* H. & Dicky, D.A. (1997). Principles & procedures of statistics, *A biometrical approach. 3rd Edition, McGraw Hill, Inc. Book Co., New York*, 352-358.

Thungo, Z., Shimelis,H., Odindo, A. O. &Mashilo, *Journal* (2019). Genotype by environment interaction of elite heat & drought tolerant bread wheat (*Triticum aestivum*L.) genotypes under non-stressed & drought-stressed conditions. *Acta Agriculturae Scandinavica, Section B-Soil and Plant Science*, 69,725-733.

USDA, United States Department of Agriculture. World Agricultural Production. January (2023). Available online: https://apps.fas.usda.gov/psdonline/circulars/production.pdf (accessed on 27 Jan 2023).

Wasaya, A., Manzoor, S., Yasir, T. A., Sarwar, N., Mubeen,K., Ismail, I. A., Raza, A., Rehman, A.,Hossain, A. & El Sabagh, A. (2021). Evaluation of fourteen bread wheat (*Triticum aestivum*L.) genotypes by observing gas exchange parameters, relative water & chlorophyll content, and yield attributes under drought stress. *Sustainability*, 13, 1-15.

Yan, W. & Tinker, N. A. (2006). An integrated biplot analysis system for displaying, interpreting, & exploring genotype x environment interactions. *Crop Science*, 45, 1004 - 1016.

Yan, W. K., Kang, M. S., Ma, B., Woods, S. & Cornelius, P. L. (2007). GGE Biplot vs. AMMI analysis of genotype-by-environment data. *Crop Science*, 47(2), 643-653.

Zhao, W., Liu, L., Shen, Q., Yang, *Journal*, Han, X., Tian, F. & Wu, *Journal* (2020). Effects of water stress on photosynthesis, yield, & water use efficiency in winter wheat.*Water*,12(8) 2127.

تقييم بعض التراكيب الوراثية من قمح الخبز لمحصول الحبوب ومكوناته تحت ظروف الإجهاد المائي

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يُعد نقص مياه الري أحد أهم معوقات إنتاج القمح في مصر والعالم. وفي ضوء ذلك تم تقييم أربعة وعشرون تركيب وراثي منها أربعة أصناف من قمح الخبز تحت ظروف الري العادي (ستة ريات تشمل رية الزراعة) وتحت ظروف الإجهاد المائي (رية الزراعة بالإضافة إلى رية بعد 21 ورية بعد 45 من الزراعة) خلال موسمي الزراعة 2021/2020 و2022/2021 بمحطة البحوث الزراعية بشندويل- سوهاج- مصر. كل معاملة ري كانت في تجربة منفصلة في تصميم القطاعات الكاملة العشوائية. أظهر موسما الزراعة ومعاملتا الري اختلافا في استجابة التراكيب الوراثية المدروسة. تناقصت صفات عدد الأيام حتى طرد السنابل والنضج الفسيولوجي، طول النبات، المحصول ومكوناته تحت الإجهاد المائي. تفوق التركيبان الوراثيان 13و17 بصورة معنوية لصفة محصول الحبوب بالمقارنة مع جميع التراكيب الوراثية تحت الدراسة وأصناف المقارنة تحت ظروف الري العادي والإجهاد المائي. أظهرت التراكيب الوراثية 16، 2، 12، 9، 17، 20، 18، 8، 10و5 كذلك الأصناف سدس 14، SokollوKasuko دليل حساسية للجفاف اقل من الواحد. وبالتالي يمكن استخدامها كمصدر لتحمل الإجهاد المائي في برنامج التربية. أظهر تحليل GGE Biplot أن التركيبان الوراثيان 13 و17 امتلكا قدرة محصولية مرتفعة ولكن كان التركيب الوراثي 17 أكثر ثباتا وتحملا لظروف الإجهاد المائي. لذلك خلصت هذه الدراسة إلى أن التركيبان الوراثيان 13و17 مناسبة للزراعة تحت ظروف نقص المياه ويمكن استخدامها لتعزيز برنامج تربية القمح لتحمل إجهاد نقص المياه.

الكلمات المفتاحية: قمح الخبز، نقص المياه، محصول الحبوب، دليل الحساسية للإجهاد.