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GENETIC VARIATION AND INTERRELATIONSHIPS AMONG AGRONOMIC TRAITS IN BREAD WHEAT GENOTYPES UNDER WATER DEFICIT AND NORMAL IRRIGATION CONDITIONS

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ABSTRACT: Water deficit is one of the major stresses that reducing wheat production particularly under current climate change. The aim of this study was to investigate the genotypic variation of thirty bread wheat genotypes under water deficit and normal irrigation conditions. In addition, to clarify the association between grain yield and the other important agronomic traits, and to determine the interrelationships among the tested traits under both conditions. Two field experiments were carried out in New Valley, Agricultural Research Station conditions, Agricultural Research Center, Egypt during 2014-2015 and 2015-2016 growing seasons. Thirty bread wheat genotypes were evaluated under two irrigation regimes. The normal irrigation was used every 15 days (NI) with total nine irrigation times per season (2900 m^3/fad.). The other irrigation regime was applied every 30 days giving in total five irrigation times (1900 m^3/fad.) providing water deficit conditions (WD). The experimental design was laid out in a spilt-plot in which irrigation treatments were in the main plots and genotypes were randomized in the sub-plots, in three replications. All evaluated traits were affected significantly by irrigation treatments. The genotypes; G1, G2, G17, G21, G22, G23, G24 and G27 exhibited good grain yield/plant and its components under both conditions. Tolerance indices; mean productivity (MP), geometric mean productivity (GMP), stress tolerance index (STI) and yield index (YI) were calculated based on grain yield/plant under both conditions. The highest indices were observed for G21, G2 and G1 genotypes followed by G23, G27 and G24 genotypes. Based on these indices, the genotypes were classified into three groups A (drought tolerant), B (moderate drought-tolerant) and C (drought-sensitive) with 8, 18 and 4 genotypes, respectively. Furthermore, phenotypic and genotypic correlation coefficients were estimated and it was observed strong and significant positive correlation between grain yield and 100-grain weight, grain weight/spike, biological yield/plant and harvest index under both conditions. Additionally, path analysis was calculated and it was found that biological yield and harvest index exhibited the highest positive direct effect on grain yield under both conditions. On the other hand, the highest indirect effects on grain yield were assigned for number of spikes/plant followed by flag leaf area, grain weight/spike and 100-grain weight under both conditions. Which demonstrates the importance of these traits in improving grain yield under both conditions.

Key words: Bread wheat genotypes, drought stress, genotypic and phenotypic coefficients of variation, genotypic and phenotypic correlation coefficients and path analysis

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important cereal crop and significant staple food in the world. Its total cultivation area in 2016 was 220.1 million hectares produced 749.5 million tons. Egypt was involved in these values with cultivation area 1.4 million hectares (3.3

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million faddan) produced 9.0 million tons (**FAOSTAT, 2018**). In spite of this, Egypt is considered one of the biggest wheat importer, imports annually around 10 million tons. In addition, the gap between production and consumption is increasing due to population growing. For that reason, cultivated area and productivity should be increase to limit this gap.

Wheat needs sufficient water to achieve good yield and acceptable quality. Water deficit is one of the major limitations of wheat production particularly in low rainfall and poorly irrigated regions (**Ryan *et al.*, 2008; Mursalova *et al.*, 2015; Mohammadi and Abdulahi, 2017; Mujtaba *et al.*, 2018**). Moreover, importance of drought has become more serious with increasing climate changes and global warming (**Izabela *et al.*, 2013; Khan *et al.*, 2015; Mwadzingeni *et al.*, 2016**). Accordingly, wheat yield losses are expected to be increased since temperature rises and rainfall distribution changes (**Gourdji *et al.*, 2013; Reynolds *et al.*, 2016; Liu *et al.*, 2017**).

Developing drought tolerant and high-yielding genotypes assists in decreasing the gap between yield potential of water-limited and well-watered conditions (**Khan and Naqvi, 2012; Edmeades, 2013; Khan and Hassan, 2017**). Consequently, screening genotypes under drought stress and identifying genotypes use water more efficiently, is very important concern and essential for water saving (**Mwadzingeni *et al.*, 2016; Sheikh *et al.*, 2017**).

The efficiency of breeding programs is determined by direction and magnitude of the association between grain yield and the other agronomic traits. In addition, the relative importance of each trait involved in contributing to grain yield (**Dao *et al.*, 2017**). Selection for grain yield by considering other related traits as indirect selection criteria is an alternative breeding approach (**Zarei *et al.*, 2013**). Therefore, genotypic and phenotypic correlations among traits could help in breeding through indirect selection for important traits by selecting least important traits that are easier to measure (**Pordel-Maragheh, 2013**). Moreover, path analysis is a useful statistical model in breaking down the correlations of agronomic traits with grain yield into their direct and indirect effects (**Williams *et al.*, 1990; Janmohammadi *et al.*, 2014**).

The objectives of this study were to: (i) Investigate the genotypic variation of thirty bread wheat genotypes under water deficit and normal irrigation conditions in addition to identify suitable genotypes for drought-stress and favorable conditions, (ii) To clarify the association between grain yield and the other important agronomic traits under both conditions and (iii) To determine the amount of direct and indirect effects of some agronomic traits on grain yield, also to study the interrelationships among the tested traits under both conditions. Which could provide valuable information for breeding new drought tolerant and high-yielding wheat genotypes.

MATERIALS AND METHODS

Site Description

Two field experiments were performed in 2014-2015 and 2015-2016 growing seasons in New Valley Agricultural Research Station conditions, Agricultural Research Center, Egypt (25°27' N and 30°32' E). Trials were sown on 21, 23 November in the two seasons, respectively. Based on soil analysis, the soil of the experimental site is characterized by loamy sand (Table 1). New Valley desert has been defined with hot and dry climate with temperatures ranging in winter between 20 to 35 degrees Celsius, and in summer rise between 40 or 45 degrees, with extremely rare annual rainfall (Table 2).

Plant Material and Experimental Design

Thirty bread wheat genotypes were evaluated under two irrigation regimes. The investigated genotypes included twenty advanced breeding lines (G1- G20) developed by Prof. Dr. M.A. Elmorshidy, Agronomy Dep. Assiut University, one exotic genotype from ICARDA (G29) and nine Egyptian bread wheat check verities (Table 3). The experimental design was laid out in a spilt-plot in which irrigation treatments were in the main plots and genotypes were randomized in the sub-plots, in three replications. The two irrigation treatments were separated by 6 m away from each other to avoid the horizontal seepage. Each plot consisted of six rows 20 cm apart, 2-m long and plants were spaced 10 cm on the row. Ammonium nitrate (33% N), Calcium

Table 1. Some physical and chemical properties of the experimental soil and irrigation water

Characteristic	Depth (cm)			Irrigation water
	0-20	20-40	40-60	
Sand (%)	81.31	59.11	54.18	
Silt (%)	8.57	5.44	4.93	
Clay (%)	10.12	35.45	40.89	
Soil texture	Loamy Sand	Sandy clay	Sandy clay	
Water saturation (%)	41.73	47.86	49.11	
Field capacity (%)	24.15	27.57	27.81	
Wilting point (%)	11.34	14.00	13.94	
Available water%	12.81	13.57	13.87	
Bulk density (g cm^{-3})	1.59	1.36	1.33	
$CaCO_3$ (%)	3.60	0.80	0.70	
pH	7.62	7.85	7.68	6.76
EC (dS m^{-1})	0.44	0.76	2.86	0.48
Ca^{+2} meq l^{-1}				1.09
Mg^{+2} meq l^{-1}				1.13
Na^{+1} meq l^{-1}				1.43
K^{+1} meq l^{-1}				1.07
CO_3^{-2} + HCO_3^{-1} meq l^{-1}				2.30
Cl^{-1} meq l^{-1}				1.64
SO_4^{-2} meq l^{-1}				0.75
SAR				1.35
Fe (ppm)				1.29
Mn (ppm)				0.1

Table 2. Meteorological data for the two growing seasons in the experimental site

Month	Min. Temp. (°C)	Max. Temp. (°C)	Mean Temp. (°C)	Mean humidity (%)	Wind speed (ms^{-1})	Precip. (mm)
			2014 - 2015			
November	19.8	33.7	27.0	34.1	3.2	0.0
December	13.9	28.6	21.4	43.7	2.6	0.0
January	6.4	22.2	14.4	46.9	2.2	0.0
February	9.1	25.2	17.3	41.5	2.6	0.0
March	14.5	29.6	22.6	31.8	3.4	0.0
April	15.1	32.0	24.5	25.5	3.4	0.0
			2015-2016			
November	22.9	35.4	29.3	36.2	3.4	0.0
December	14.9	28.4	22.0	47.1	2.7	0.0
January	6.8	20.9	14.0	49.3	2.6	0.0
February	15.0	35.2	24.6	32.0	2.6	0.0
March	15.9	28.8	22.2	34.0	6.0	0.0
April	21.3	37.4	28.7	24.0	3.0	0.0

Table 3. Code, origin and pedigree of the bread wheat genotypes used

Code	Genotype	Pedigree	Origin	Year of release
G1	Sel-160	Genara 88 × Sonora 64	Assiut, Egypt	-
G2	Sel-188	Yecora Reja × Sonora 64	Assiut, Egypt	-
G3	Sel-190	Tokwie × Sonora 64	Assiut, Egypt	-
G4	Sel-506	134x5.69/303/1/393/3 × Yecora Reja	Assiut, Egypt	-
G5	Sel-509	Seria 82 × Sonora 64	Assiut, Egypt	-
G6	F7-187	134x5.69/365/1 × Local 221-C	Assiut, Egypt	-
G7	F7-220	CN1737=Chester × 5500-10-21-29	Assiut, Egypt	-
G8	F7-273	India 66R × 5500-10-21-29	Assiut, Egypt	-
G9	H-39	134x5.69/193/4/378/2 × India 66R	Assiut, Egypt	-
G10	H-222	134x5.69/193/4/378/2 × Çenara 81	Assiut, Egypt	-
G11	H-258	CI4397 Emerald × Genara 81	Assiut, Egypt	-
G12	H-280	134x5.69/186/3/368/7 × 5500-10-21-29	Assiut, Egypt	-
G13	Mk1-6	PI383308 Rageni 15 × 5500-10-21-29	Assiut, Egypt	-
G14	Mk15-119	Local 2052 × CN1740=Rescue	Assiut, Egypt	-
G15	As-130	Kvz/Buha"s"Kal/Bb × Maxi Pack	Assiut, Egypt	-
G16	As-202	Shenab70xG.155 × 5500-10-21-29	Assiut, Egypt	-
G17	As-232	Kvz/Buha"s"Kal/Bb × Bacanora 88	Assiut, Egypt	-
G18	As-238	Kvz/Buha"s"Kal/Bb × PI37743CANDUMI IRAN	Assiut, Egypt	-
G19	As-706	Sonora 64 × Local 235-C	Assiut, Egypt	-
G20	R-207	CN1739=Cypress × 134x5.69/186/3/368/7	Assiut, Egypt	-
G21	Sids-1	HD2173/PAVON"S"//1158.57/MAYA 74 "S"SD46-4SD-2SD-1SD-0SD	Egypt	1996
G22	Sids-11	MAYA"S"/MON"S"//CMH74A.592/3/GIZA 157×2SD10001-2SD-3SD-2SD-0SD	Egypt	2008
G23	Gemiza-11	Bow"s"/Kvz"s"//7c/seri82/3/Giza168/Sakha61C GM7892-2GM-1GM-2GM-1GM-0GM	Egypt	2010
G24	Gemiza-12	OTUS/3/SARA/THB//VEE CCMSS97Y00227S-5Y-010M-010Y-010M-2Y-1M-0Y-0GM	Egypt	2013
G25	Shandawel-1	SITE//MO/4/NAC/TH.AC//3×PVN/3/MIRLO/BUC CMss93B00567S-72Y-010M-010Y-010M-3Y-0M-0THY-0SH	CIMMYT	2013
G26	Giza-168	MIL/BUC//SeriCM93046-8M-0Y-0M-2Y-0B	CIMMYT	1999
G27	Misr-1	OASIS/KAUZA//4×BCN/3/2×PASTOP CMss00Y 01881T-050M-030Y-030M-030WGY-33M-0Y-0S	CIMMYT	2010
G28	Sakha-93	SAKHA 92/TR 810328S8871-1S-2S-1S-0S	Egypt	1999
G29	Icarda-2	ICB97-0727-0AP	ICARDA	-
G30	Sids-12	BUC//7C/ALD/5/MAYA74/ON//1160-147/3/BB/GLL/4C/HAT"S"/6/MAYA/VUL//CMH 74A.630/4×SX.SD7096-4SD- ISD- ISD-OSD	Egypt	2008

Superphosphate (15.5% P_2O_5) and Potassium Sulphate (48% K_2O) fertilizers were applied at the recommended rates 100 kg N/fad., 31 kg P_2O_5/fad., and 24 kg K_2O/fad. The other agronomic practices including, pest, disease and weed control were applied as recommended for wheat production in the region.

Irrigation Treatments

The common irrigation used by farmers in New Valley region is surface irrigation every 15 days. It was used as normal irrigation (NI) with total nine irrigation times providing 2900 m^3/fad. The other irrigation regime was used every 30 days as water deficit conditions with total five irrigation times and 1900 m^3/fad. The experimental field was irrigated using underground water and the water amount was estimated using V-notch weir under surface irrigation system according **Parshall (1950)** equation.

$$Q\,(m^3\,hr.^{-1}) = 4969\,H^{2.5}$$

Where Q is discharge ($m^3\,h^{-1}$) and H is the water elevation from weir rim (m).

Measurements

Ten plants were chosen randomly from the middle rows of each sub plot to measure number of spikes/plant (NSP), grain number/spike (GNS), grain weight/spike (GWS, g), 100-grain weight (100GW, g), Spike length (SL, cm), grain yield/plant (GYP, g) and biological yield/ plant (BYP, g). Flag leaf area (FLA, cm^2) was measured on 10 randomly main stems at the anthesis as flag leaf length × flag leaf width × 0.75. Plant height (PH) was measured as the distance (cm) from the base of the plant to the tip of the spike, excluding owns. Days to heading (DH) were recorded as the number of days from sowing date up to 50% of the spikes were fully headed in each plot. Days to maturity (DM) were scored as the number of days from sowing to physiological maturity, when 50% of the peduncles were ripe and showed complete lass of green color. In addition, harvest index (HI, %) was calculated by dividing grain yield/ plant by biological yield/plant.

Drought Tolerance Indices

Drought tolerance indices were calculated using the following parameters:

Mean productivity $MP = \frac{Ys+Yp}{2}$ **(Hossain *et al.*, 1990).**

Geometric mean productivity $GMP = \sqrt{(Ys \times Yp)}$ **(Fernandez, 1992).**

Stress tolerance index $STI = \frac{Ys \times Yp}{(\bar{Y}p)^2}$ **(Fernandez, 1992).**

Yield index $YI = \frac{Ys}{\bar{Y}s}$ **(Gavuzzi *et al.*, 1997).**

Where Ys is yield under water deficit conditions, Yp is yield of under normal irrigation, $\bar{Y}s$ is the average of all genotypes under water deficit conditions and $\bar{Y}p$ Average of all genotypes under normal irrigation.

Cluster analysis based on tolerance indices using squared Euclidian distance were performed using the statistical software SPSS version 16.0 (**SPSS Inc., 2007**).

Data Analysis

Combined analysis of variance (ANOVA) was applied according to **Gomez and Gomez (1984)** after testing the homogeneity of variance over the two years. The analysis was performed to test the significance of genotype (G), irrigation treatments (I), and the interaction effect for all investigated traits. Least significant difference (LSD) values were calculated at the 5% probability level. Variance components included phenotypic (σ^2_P) and genotypic (σ^2_G) components were estimated according to **Kwon and Torrie (1964)** based on combined data of the two growing seasons. Genotypic (GCV) and phenotypic (PCV) coefficients of variation was estimated according to **Burton and Devane (1953)**. Genotypic and phenotypic correlation coefficients were computed among the studied traits according **Kwon and Torrie (1964)**. Path analysis of above listed traits on grain yield was also performed according to **Dewey and Lu (1959)**. Microsoft Excel program, SPSS and SAS 9.1 Computer program for Windows were used for the statistical analysis.

RESULTS AND DISCUSSION

Analysis of Variance

The combined analysis of variance for evaluated traits is presented in Table 4. It was observed high significant differences among

Table 4. Mean squares of studied traits for 30 bread wheat genotypes under normal irrigation and water deficit conditions over two growing seasons

SV	df	FLA	DH	DM	PH	NSP	GNS
Irrigation (I)	1	850.79*	268.67**	1724.84**	6799.06**	79.05**	3094.08**
Error (I)	2	27.31	1.50	13.34	15.36	0.36	14.47
Genotype (G)	29	96.17**	257.57**	78.15**	315.45**	7.24**	502.31**
I×G	29	12.16NS	1.50NS	6.36*	35.90*	0.63*	29.84*
Error (G)	116	10.01	1.46	2.73	24.16	0.42	46.99
Year (Y)	1	2647.07**	153.40**	122.50**	4495.11**	8.07**	2787.79**
I×Y	1	1.19NS	26.14**	62.50**	1341.35**	1.12NS	50.18NS
G×Y	29	87.94**	46.13**	6.49**	54.91NS	2.04**	195.26**
I×G×Y	29	13.38NS	2.27NS	3.73NS	18.53NS	0.65NS	37.13NS
Residual	120	10.59	1.60	2.66	44.56	0.48	40.70
Total	359	33.75	27.14	15.22	102.29	1.40	111.72
SV	**df**	**100GW**	**GWS**	**SL**	**GY**	**BY**	**HI**
Irrigation (I)	1	19.77**	13.49**	139.75*	811.77**	3362.76**	686.22*
Error (I)	2	0.09	0.07	2.14	0.37	8.83	12.64
Genotype (G)	29	1.68**	1.09**	11.01**	10.30**	68.82**	38.82**
I×G	29	0.14*	0.10NS	0.49NS	5.02**	27.96**	19.37**
Error (G)	116	0.08	0.09	0.69	1.17	7.32	6.87
Year (Y)	1	10.58**	1.91**	10.82**	215.93**	213.71**	1071.40**
I×Y	1	2.44**	1.41**	0.02NS	37.28**	37.85*	257.00**
G×Y	29	0.34**	0.39**	2.07**	7.94**	39.66**	31.72**
I×G×Y	29	0.13*	0.05NS	0.62NS	7.20**	20.72**	27.72**
Residual	120	0.09	0.07	0.81	0.89	6.93	6.25
Total	359	0.33	0.24	2.08	6.14	27.70	19.49

NS: Not-significant, * $P < 0.05$, ** $P < 0.01$

FLA (Flag leaf area, cm^2), DH (Days to heading), DM (Days to maturity), PH (Plant height), NSP (number of spikes/plant), GNS (grain number/spike), 100GW (100-grain weight), GWS (Grain weight/spike), SL (Spike length), GYP (Grain yield/ plant), BYP (Biological yield/plant), HI (Harvest index).

the studied genotypes as well as between the two irrigation treatments for all traits. This indicates to presence of genetic variability in the used genotypes and irrigation treatments. Additionally, the interaction between irrigation and genotypes had a smaller magnitude than the main effect of irrigation and genotypes but it was significant for all traits under investigation except flag leaf area, days to heading, grain weight/spike and spike length. This significant interaction reveals that the genotypes performed differently under different irrigation regimes. Notwithstanding, the significant difference between the two years could be attributed to weather conditions the three ways interaction between irrigation, genotypes and years was not significant for all studied traits except 100-grain weight. These results are in agreement with **Khan and Naqvi (2012), El-Rawy and Hassan (2014), Mansour *et al.* (2017) and Mujtaba *et al.* (2018).**

Mean Performance

Earliness traits

Days to heading was significantly affected by irrigation treatments. It varied from 64.3 to 81.8 days under water deficit, and 64.8 to 83.0 days under normal irrigation (Fig. 1 A). The genotypes; G1, G10 and G5 presented the earliest under both irrigation treatments, while G16, G27 and G19 showed the latest heading under both treatments. All genotypes had significant differences between the irrigation treatments except; G1, G2, G8, G13, G15, G18, G19, G22 and G27 (Fig. 1, A). Likewise, days to maturity was significantly varied between irrigation treatments as well as genotypes (Fig. 1, B). It ranged between 106.5 to 115.5 days under water deficit conditions, and 110.3 to 120.2 days under normal irrigation. The earliest maturity was observed for G9 and G5 under normal irrigation and water deficit conditions, respectively. While, the latest maturity was observed for G17 and G25 under both treatments, respectively. All genotypes presented significant differences among treatments except; G13 and G24 (Fig.1, B). Water deficit causes early heading and maturity in wheat genotypes compared with normal irrigation. Therefore, earliness could be reflected as an escape approach and resilient adaptation under drought stress (**Shavrukov *et al*., 2017**).

Morphological traits

Flag leaf area significantly decreased by water decreasing, and the genotypes exhibited different performances (Fig. 1, C). In this respect, it was decreased from 25.7 to 13.8 cm^2 on average under water deficit, while it ranged from 15.5 to 27.6 cm^2 under normal irrigation. The genotype G17 displayed the lowest values followed by G5 and G20 under both irrigation treatments, while G16 presented the highest value under both treatments. The genotypes; G1, G3, G4, G5, G8, G14, G21, G23, G24 and G27 showed significant differences between the irrigation treatments while the rest genotypes had no significant difference between both treatments (Fig. 1, C).

Plant height also was affected by water limitation, it decreased from 103.9 cm under normal irrigation to 64.4 cm under water deficit condition. The highest values were given by G29 and G20 under both treatments. While, the lowest values were assigned for G15, G26 and G13 under both irrigation treatments. All genotypes exhibited significant differences among the irrigation treatments except; G3, G13, G18 and G21 (Fig.1, D).

Moreover, spike length significantly affected by irrigation treatments (Fig.2.A). It ranged between 9.2 to 13.9 cm under water deficit, and 10.1 to 14.6 cm under normal irrigation. The highest values were shown by G23 and G21 while, the lowest values were assigned for G5 and G15 under both treatments. All genotypes presented significant difference between the irrigation treatments except; G12, G17, G18, G20 and G23 (Fig.2. A).

Grain yield and its components

Number of spikes/plant was significantly affected by irrigation treatments (Fig. 2, B). It ranged between 4.3 to 6.9 under water deficit, and 4.5 to 8.1 spikes/plant under normal irrigation. Lowest values were assigned for G2 and G30, while the highest values were presented by G17 and G13 under both irrigation treatments. All genotypes had significant differences between both irrigation treatments except G1, G2, G8, G13, G14, G16, G18, G23 and G30 had no significant differences between irrigation treatments (Fig.2, B).

Likewise, grain number/spike significantly differed in the response to irrigation treatments (Fig. 2, C). It ranged between 49.2 to 75.2 under water deficit, and 51.8 to 77.5 under normal irrigation (G30). The genotypes; G29 and G13 presented the lowest grain number/spike under water deficit and normal irrigation, respectively while G30 exhibited the highest values under both conditions. The genotypes; G1, G2, G4, G5, G6, G7, G9, G10, G14, G18, G21, G22, G23, G24 and G26 varied significantly between irrigation treatments, while the other genotypes had no significant differences (Fig. 2, C).

Correspondingly, 100-grain weight differed significantly by irrigation treatments (Fig.2, D). It varied between 2.3 to 4.0 g under water deficit, and 3.0 to 4.7 g under normal irrigation. The lowest value was given by G26 under both treatments, while the highest values were displayed

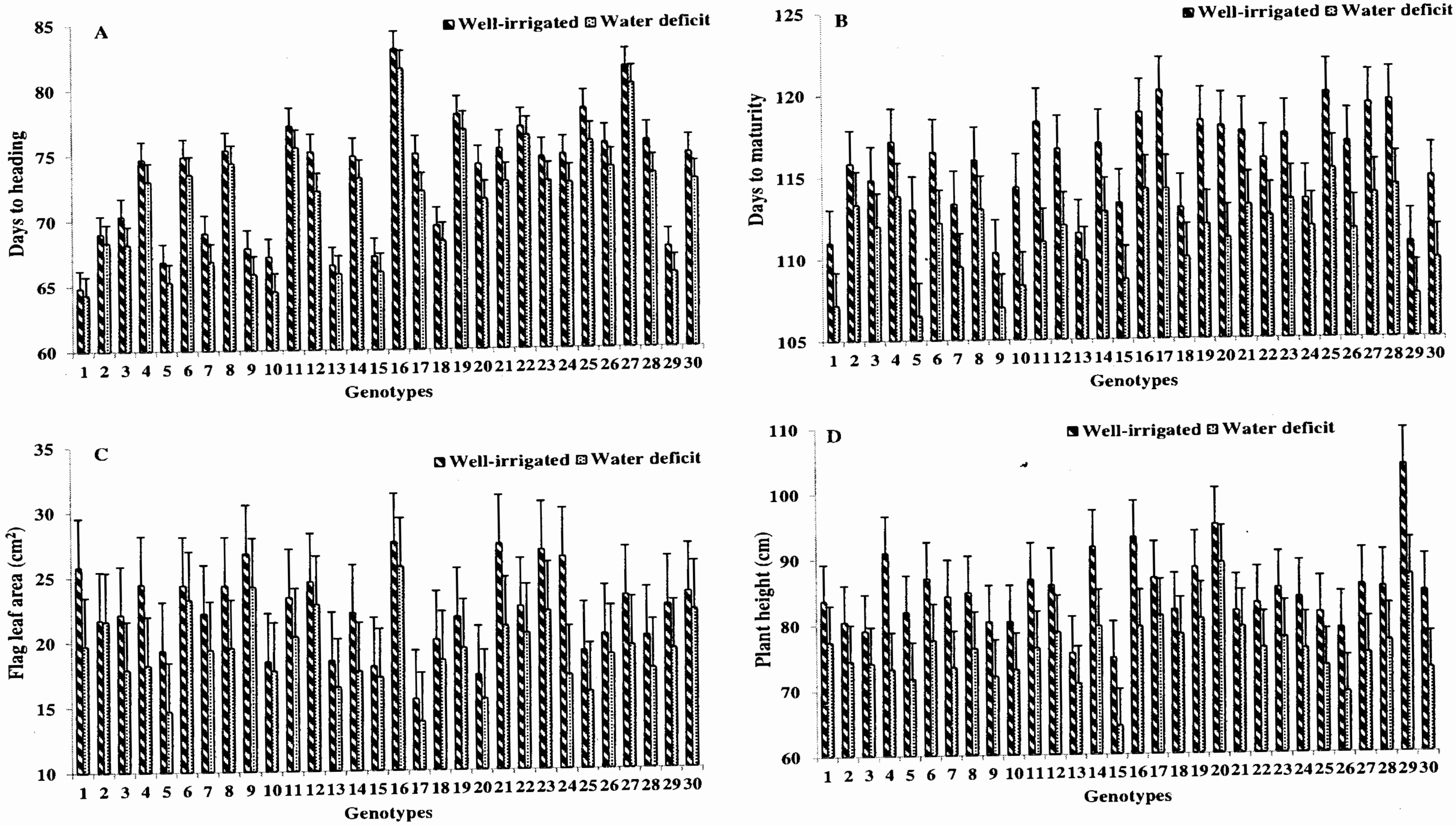

Fig. 1. Effect of irrigation treatments on days to heading (A), days to maturity (B), flag leaf area (C) and plant height (D), mean value of 30 wheat genotypes over 2 years. Legend of column is irrigation treatments, the bars on the top of the columns represent the LSD (0.05) for mean value comparison

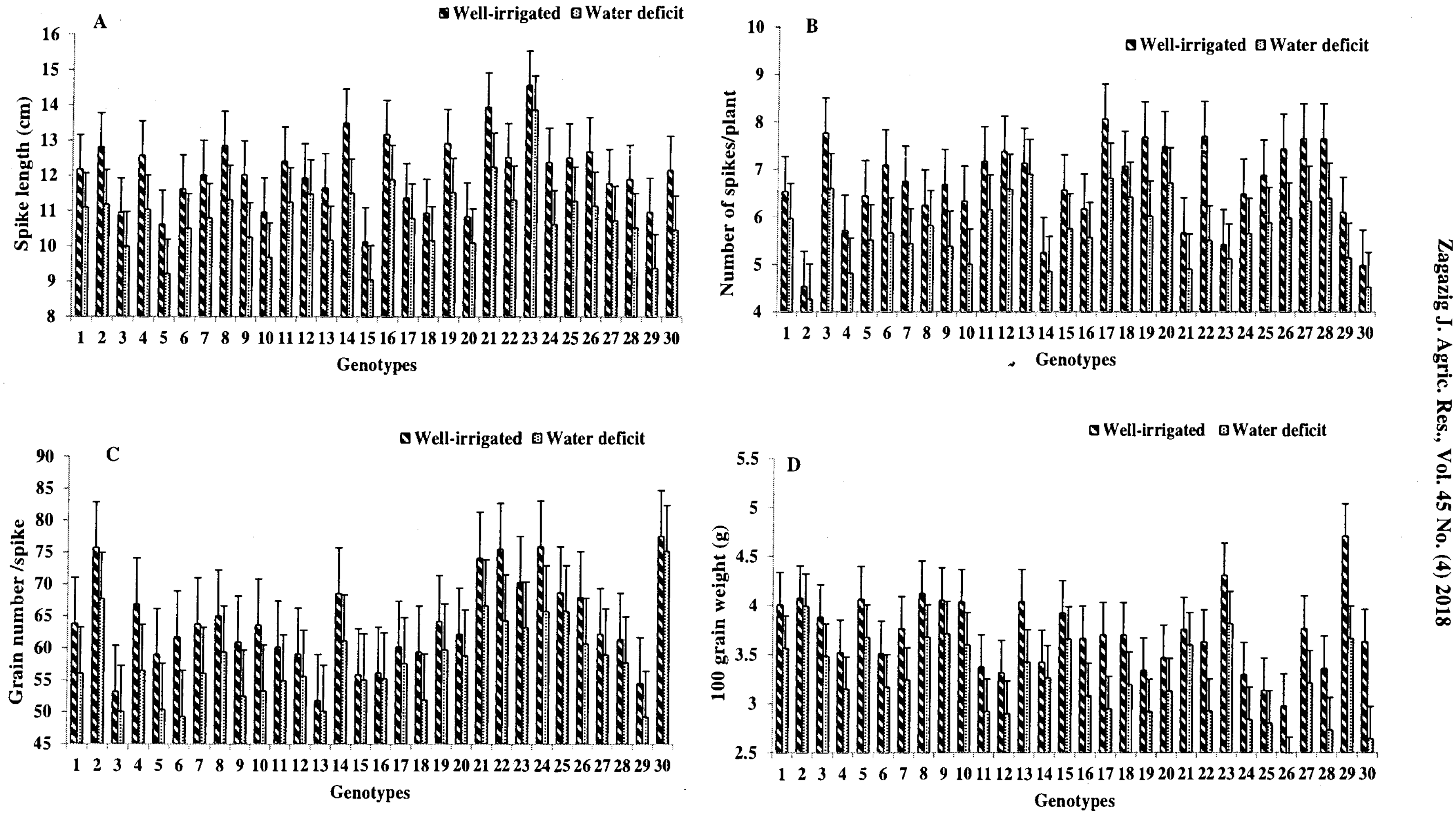

Fig. 2. Effect of irrigation treatments on Spike length (A), number of spikes/plant (B), grain number/spike (C), and 100 grain weight (D), mean value of 30 wheat genotypes over 2 years. Legend of column is irrigation treatments, the bars on the top of the columns represent the LSD (0.05) for mean value comparison

by G29 and G2 under normal and water deficit, respectively. All genotypes had significant differences between the irrigation treatments except; G2, G14, G15 and G21 had no significant differences between irrigation treatments (Fig. 2, D).

Besides, grain weight/spike varied significantly by irrigation treatments (Fig. 3, A). It varied between 1.8 to 3.0 g under water deficit, and 2.1 to 3.5 g under normal irrigation. The genotypes; G12 and G6 exhibited lowest values under normal irrigation and water deficit conditions, while G2, G23 and G21 showed the highest values under both conditions. All genotypes presented significant difference between irrigation treatments except; G3, G8, GG12, G15, G16, G18, G20, G28 and G29 had no significant differences between irrigation treatments (Fig. 3, A).

Furthermore, biological yield/plant significantly affected by irrigation treatments (Fig. 3, B). It ranged between 24.2 to 34.2 g under water deficit, while, it varied from 28.9 to 40.9 g under normal irrigation. The lowest biological yield/plant was presented by G4 and G16 under normal irrigation and water deficit conditions, respectively. While, the highest values were displayed by G22 and G21 under normal irrigation and water deficit conditions, respectively. All genotypes presented significant differences between the irrigation treatments except G2, G4, G8, G12, G13 and G20 (Fig. 3, B).

Additionally, harvest index changed significantly by irrigation treatments (Fig.3, C). it decreased from 41.3% under normal irrigation to 29.9% under water deficit. The genotypes; G18 and G14 exhibited the lowest values under normal and water deficit conditions, respectively. While, the highest values were assigned for G9 and G2 under both treatments, respectively. All genotypes presented significant difference between the irrigation treatments except; G2, G4, G6, G8, G10, G16, G17, G19, G20, G21, G25 and G29 (Fig. 3, C).

Finally, there were significant differences in grain yield/plant by irrigation treatments (Fig. 3, D). Grain yield/plant reduced from 15.1 g on average under normal irrigation to 7.9 g under water deficit due to decreasing of irrigation water. The lowest value was observed for G14 under both treatments, while the highest average was observed for G22 and G2 under normal irrigation and water deficit conditions. All genotypes showed significant difference between the irrigation treatments except; G18 and G20 had no significant difference between irrigation treatments (Fig. 3, D).

Various researchers reported similar trend of the evaluated traits and the reduction due to water deficit as **Ibrahim *et al.* (2010), Abd El-Kareem and El-Saidy (2011), El-Sarag and Ismaeil (2013), El-Rawy and Hassan (2014), Farhat (2015), Ali and El-Sadek (2016) and Milad *et al.* (2016)**.

Water deficit through wheat growth stages especially grain filling period leads to poor dry matter assimilation and high losses in grain yield (**Shpiler and Blum, 1991**). Therefore, the genotypes which produce high yield under water deficit as well as normal irrigation as G1, G2, G17, G21, G22, G23, G24 and G27 revealing that these genotypes are drought tolerant. And these genotypes could be used in future breeding programs to improve grain yield under normal and stress conditions.

Drought Tolerance Indices and Cluster Analysis

Tolerance indices; mean productivity (MP), geometric mean productivity (GMP), stress tolerance index (STI) and yield index (YI) were calculated based on grain yield/plant under normal irrigation and water deficit conditions (Table 5). The highest indices were observed for G21, G2 and G1 followed by G23, G27 and G24. While the lowest values were presented by G14 and G16 followed by G4 and G6. In addition, cluster analysis was estimated based on the tolerance indices. It classified the genotypes into three groups A, B and C with 8, 18 and 4 genotypes, respectively (Fig. 4). In this analysis, group A (G1, G2, G21, G17, G22, G23, G27 and G24) had the highest tolerance indices. Therefore, they are considered drought tolerant genotypes. Besides, group B (G11, G19, G12, G25, G10, G29, G28, G18, G20, G5, G30, G26, G15, G7, G13, G8, G9 and G3) had intermediate values, indicating that these genotypes are moderate drought-tolerant. While group C (G4, G6, G14 and G16) presented the lowest values, consequently, they are considered drought-sensitive genotypes. These results are in consonance

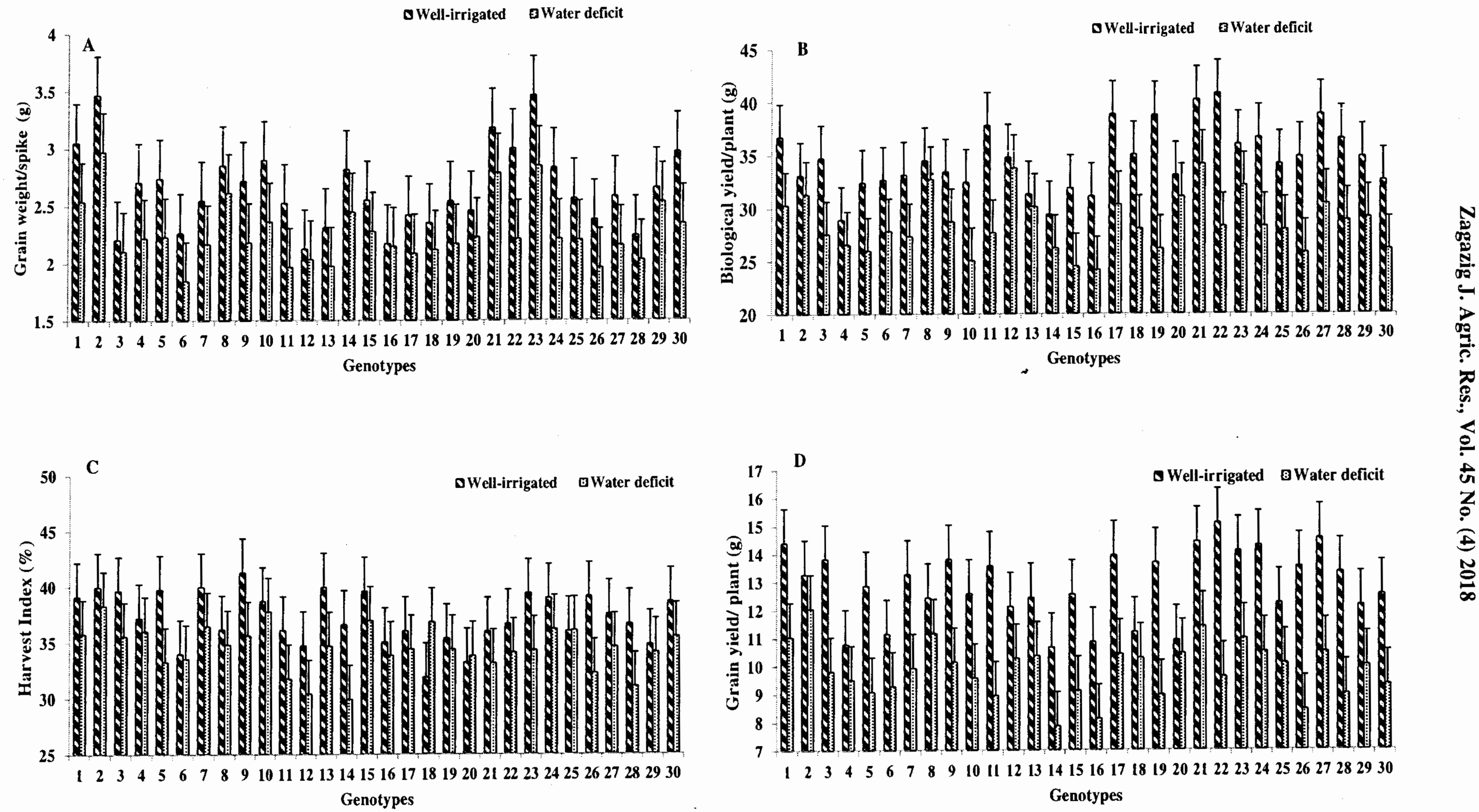

Fig. 3. Effect of irrigation treatments on grain weight/spike (A), biological yield/plant (B), harvest index (C), and grain yield/ plant (D), mean value of 30 wheat genotypes over 2 years. Legend of column is irrigation treatments, the bars on the top of the columns represent the LSD (0.05) for mean value comparison

Table 5. Drought tolerance indices for 30 bread wheat genotypes under normal irrigation and water deficit conditions (averaged over the two growing seasons)

Code	Genotype	MP	GMP	STI	YI
G1	Sel-160	12.73	12.62	0.96	1.12
G2	Sel-188	12.66	12.64	0.96	1.22
G3	Sel-190	11.82	11.64	0.82	0.99
G4	Sel-506	10.19	10.18	0.62	0.97
G5	Sel-509	10.97	10.81	0.70	0.92
G6	F7-187	10.21	10.17	0.62	0.94
G7	F7-220	11.60	11.48	0.79	1.00
G8	F7-273	11.90	11.88	0.85	1.15
G9	H-39	11.98	11.83	0.84	1.03
G10	H-222	11.07	10.97	0.73	0.97
G11	H-258	11.25	11.01	0.73	0.90
G12	H-280	11.19	11.15	0.75	1.04
G13	Mk1-6	11.39	11.34	0.78	1.05
G14	Mk15-119	9.25	9.14	0.50	0.79
G15	As-130	10.83	10.69	0.69	0.92
G16	As-202	9.48	9.38	0.53	0.82
G17	As-232	12.18	12.05	0.88	1.05
G18	As-238	10.74	10.73	0.69	1.04
G19	As-706	11.32	11.07	0.74	0.91
G20	R-207	10.68	10.67	0.69	1.06
G21	Sids-1	12.91	12.82	0.99	1.15
G22	Sids-11	12.35	12.04	0.87	0.97
G23	Gemiza-11	12.53	12.43	0.93	1.11
G24	Gemiza-12	12.40	12.25	0.90	1.06
G25	Shandawel-1	11.16	11.11	0.74	1.02
G26	Giza-168	10.98	10.68	0.69	0.85
G27	Misr-1	12.52	12.35	0.92	1.06
G28	Sakh-93	11.17	10.95	0.72	0.91
G29	Icarda-2	11.08	11.02	0.73	1.01
G30	Sids-12	10.93	10.81	0.70	0.94

MP (Mean productivity), GMP (Geometric mean productivity), STI (Stress tolerance index), and YI (Yield index)

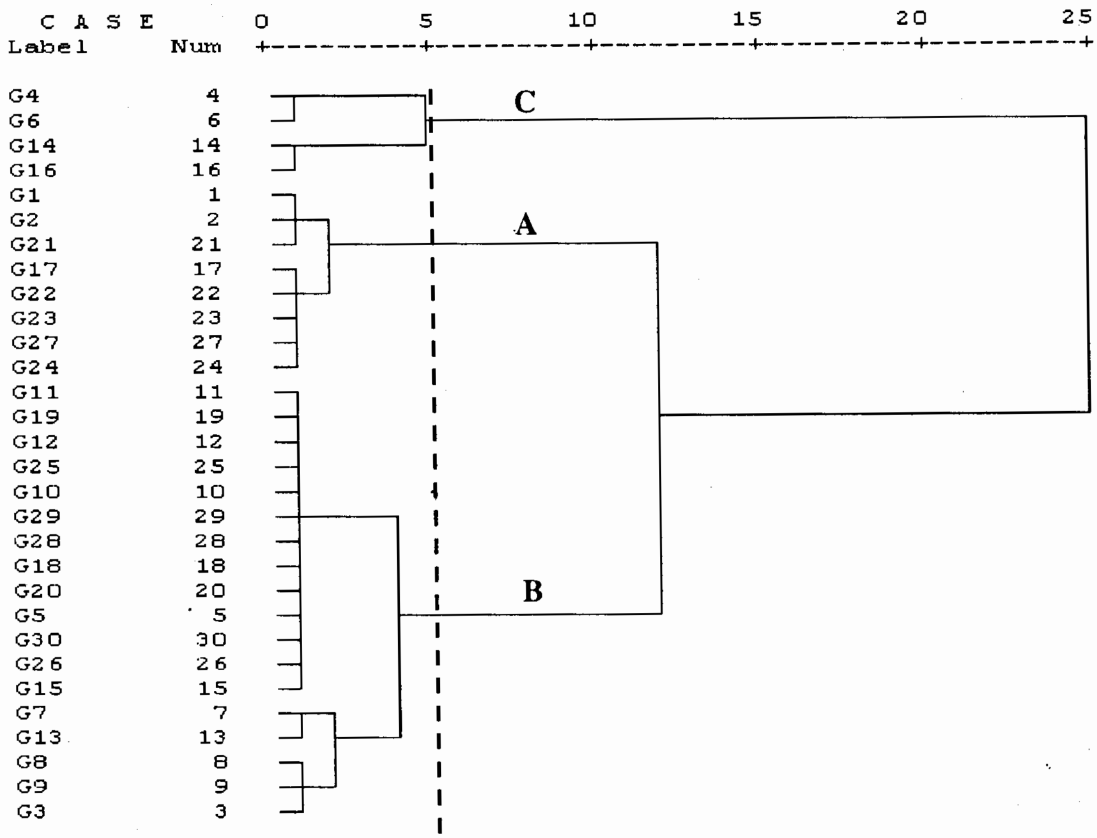

Fig. 4. Hierarchical clustering of the phenotypic distances among 30 bread wheat genotypes under normal irrigation and water deficit conditions based on grain yield and the drought tolerant indices. With cutting dendrogram obtained from Ward method in distance five, the genotypes were classified into three groups A (drought-tolerant, 8 genotypes), B (moderate drought-tolerant, 18 genotypes) and C (drought-sensitive, 4 genotypes)

with that found by **Mohammadi *et al.* (2011), El-Rawy and Hassan (2014), Ali and El-Sadek (2016), Mohammadi (2016), Mariey and Khedr (2017)** and **Mohammed and Kadhem (2017)**.

Genetic Variability Parameters

The phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) in all investigated traits under normal irrigation and water deficit conditions (Table 6). Nevertheless, the values of phenotypic and genotypic coefficients of variation differed slightly. The difference between PCV and GCV was very low for days to heading and days to maturity under both conditions. Which demonstrates to minor environmental effects in these traits. However, the difference was relatively higher for flag leaf area, grain number/spike, grain yield/plant and harvest index under both conditions. Which indicates to greater effect of the environment in the expression of these traits. Furthermore, broad-sense heritability values ranged between 42.45% (harvest index) to 97.39 (days to heading) under water deficit. While, under normal irrigation it ranged between 60.48% (harvest index) to 96.03 (days to heading). The highest values were assigned for days to heading followed by days to maturity, 100-grain weight and number of spikes/plant. The highest values of these traits suggest that the majority of additive gene action and possibility of selection to improve yield under both conditions. These results are in line with that reported by **Abd El-Kareem and El-Saidy (2011), Soleymanifard *et al.* (2012), Ijaz *et al.* (2015), Dao *et al.* (2017), Sabit *et al.* (2017)** and **Sharma *et al.* (2018)**.

Table 6. Genetic variability parameters for the studied traits in 30 bread wheat genotypes under normal irrigation (NI) and water deficit conditions (WD)

Trait	σ^2g		σ^2p		GCV		PCV		h^2b	
	NI	WD	NI	WD	NI	WD	NI	WD	NI	WD
FLA	8.54	6.18	13.56	11.17	13.09	12.91	16.49	17.36	62.96	55.32
DH	21.58	21.11	22.47	21.68	6.35	6.43	6.48	6.51	96.03	97.39
DM	7.79	5.39	8.78	7.13	2.41	2.08	2.56	2.40	88.71	75.55
PH	30.77	19.74	42.79	31.87	6.54	5.83	7.71	7.41	71.89	61.94
NSP	0.74	0.44	0.97	0.62	12.88	11.51	14.79	13.74	75.88	70.18
GNS	40.29	32.73	64.47	55.55	9.93	9.85	12.56	12.84	62.50	58.92
100GW	0.13	0.15	0.19	0.17	9.52	11.97	11.20	13.33	72.15	80.73
GWS	0.11	0.06	0.16	0.09	12.25	11.07	15.19	13.55	65.00	66.77
SL	0.92	0.76	1.22	1.15	7.94	8.05	9.14	9.90	75.48	66.10
GYP	1.41	0.76	1.97	1.36	9.21	8.81	10.91	11.79	71.28	55.78
BYP	7.58	6.11	12.19	8.82	7.94	8.67	10.08	10.41	62.15	69.35
HI	4.53	2.88	7.49	6.79	5.71	4.92	7.34	7.55	60.48	42.45

σ^2g (Genotypic variance), σ^2p (Phenotypic variance), GCV (Genotypic coefficient of variation), PCV (Phenotypic coefficient of variation) h^2b (heritability in broad sense)

Phenotypic and Genetic Correlation Coefficients

Under water deficit

It was observed that days to heading exhibited positive and significant genotypic and phenotypic correlation with flag leaf area, days to maturity, grain number/spike and grain weight/spike (Tables 7 and 8). Furthermore, days to maturity displayed significant and positive correlation coefficients with grain number/spike, spike length and biological yield. Grain weight/spike showed positive and significant correlation coefficients with grain number/spike, 100-grain weight, spike length, grain yield, biological yield and harvest index. Spike length demonstrated positive and significant correlation coefficients with flag leaf area, grain number/ spike and biological yield. Biological yield presented positive and significant correlation coefficients with plant height, 100-grain weight, and grain yield.

On the other hand, days to heading proved negative and significant correlation coefficients with 100-grain weight, grain yield and harvest index. Number of spikes/plant exhibited negative and significant correlation coefficients with flag leaf area, grain number/spike, 100-grain weight, grain weight/ spike and harvest index. 100-grain weight showed negative and significant correlation coefficients with days to maturity, number of grain/spike. Spike length showed negative and significant correlation coefficients with harvest index.

Under normal irrigation

The results clearly indicated that days to heading had positive and significant genotypic and phenotypic correlation with flag leaf area, days to maturity, plant height, grain number/ spike, spike length and biological yield (Tables 7 and 8). Additionally, days to maturity revealed significant and positive correlation coefficients with plant height, grain number/spike, 100-grain weight, spike length, biological yield and harvest

Table 7. Phenotypic correlation coefficients for the grain yield and its components in 30 bread wheat genotypes under normal irrigation (below diagonal) and water deficit (above diagonal) conditions

Trait	FLA	DH	DM	PH	NSP	GNS	100GW	GWS	SL	GYP	BYP	HI
FLA		0.26*	0.06^{NS}	-0.03^{NS}	-0.28*	0.16^{NS}	0.04^{NS}	0.17^{NS}	0.39**	-0.01^{NS}	0.06^{NS}	-0.05^{NS}
DH	0.23*		0.73**	0.18^{NS}	0.08^{NS}	0.34*	-0.51**	0.48**	-0.15^{NS}	-0.21*	0.01^{NS}	-0.29*
DM	-0.12^{NS}	0.80**		0.1^{NS}	0.1^{NS}	0.35**	-0.27*	0.06^{NS}	0.5**	0.08^{NS}	0.23*	-0.14^{NS}
PH	0.12^{NS}	0.27*	0.20*		0.1^{NS}	-0.02^{NS}	-0.03^{NS}	0.1^{NS}	0.14^{NS}	0.13^{NS}	0.29*	-0.17^{NS}
NSP	-0.27*	0.17^{NS}	0.16^{NS}	-0.1^{NS}		-0.34*	-0.26*	-0.5**	-0.11^{NS}	0.03^{NS}	0.16^{NS}	-0.21*
GNS	0.21*	0.24*	0.22*	-0.04^{NS}	-0.36**		-0.25*	0.41**	0.42**	0.16^{NS}	0.11^{NS}	0.09^{NS}
100GW	0.07^{NS}	-0.51**	-0.47**	0.06^{NS}	-0.32*	-0.17^{NS}		0.56**	-0.05^{NS}	0.4**	0.23*	0.3*
GWS	0.17^{NS}	-0.17^{NS}	-0.10^{NS}	-0.05^{NS}	-0.53**	0.62**	0.41**		0.31*	0.48**	0.35*	0.23*
SL	0.48**	0.47**	0.34*	0.08^{NS}	-0.32*	0.47**	-0.13^{NS}	0.45**		0.11^{NS}	0.36**	-0.28*
GYP	0.13^{NS}	-0.04^{NS}	-0.03^{NS}	-0.34*	0.25*	0.26*	0.08^{NS}	0.39**	0.17^{NS}		0.77**	0.5**
BYP	0.12^{NS}	0.26*	0.20*	-0.01^{NS}	0.41**	0.21*	-0.08^{NS}	0.19^{NS}	0.14^{NS}	0.76**		-0.15^{NS}
HI	-0.01^{NS}	-0.40**	0.20*	-0.24*	-0.2*	0.09^{NS}	0.22*	0.3*	0.05^{NS}	0.44**	-0.24*	

NS = Not significant and *, ** = significant at $p < 0.05$ and $p < 0.01$, respectively.

FLA (Flag leaf area, cm^2), DH (Days to heading), DM (Days to maturity), PH (Plant height), NSP (number of spikes/plant), GNS (grain number/spike), 100GW (100-grain weight), GWS (Grain weight/spike), SL (Spike length), GYP (Grain yield/plant), BYP (Biological yield/plant), HI (Harvest index).

Table 8. Genetic correlation coefficients for the grain yield and its components in 30 bread wheat genotypes under normal irrigation (below diagonal) and water deficit conditions (above diagonal)

Trait	FLA	DH	DM	PH	NSP	GNS	100GW	GWS	SL	GYP	BYP	HI
FLA		0.31*	0.06^{NS}	0.07^{NS}	-0.45**	0.09^{NS}	0.13^{NS}	0.15^{NS}	0.52**	0.04^{NS}	0.14^{NS}	-0.1^{NS}
DH	0.27*		0.81**	0.25*	0.07^{NS}	0.44**	-0.58**	0.61**	-0.21*	-0.3*	-0.01^{NS}	-0.49**
DM	-0.08^{NS}	0.87**		0.26*	0.06^{NS}	0.49**	-0.4**	-0.01^{NS}	0.69**	0.02^{NS}	0.24*	-0.32*
PH	0.22*	0.34*	0.21*		0.17^{NS}	-0.04^{NS}	-0.05^{NS}	0.19^{NS}	0.23*	0.16^{NS}	0.48**	-0.5**
NSP	-0.48**	0.19^{NS}	0.24*	-0.1^{NS}		-0.53**	-0.37**	-0.73**	-0.25*	-0.06^{NS}	0.22*	-0.31*
GNS	0.38**	0.31*	0.22*	-0.11^{NS}	-0.55**		-0.32*	0.5**	0.52**	0.27*	0.22*	0.04^{NS}
100GW	0.11^{NS}	-0.63**	-0.63**	0.09^{NS}	-0.4**	-0.34*		0.69**	-0.1^{NS}	0.56**	0.29*	0.5**
GWS	0.41**	-0.20*	-0.18^{NS}	-0.12^{NS}	-0.81**	0.77**	0.41**		0.39**	0.65**	0.45**	0.34*
SL	0.72**	0.53**	0.42**	0.12^{NS}	-0.49**	0.68**	-0.2*	0.51**		0.22*	0.41**	-0.27*
GYP	0.20*	-0.01^{NS}	-0.05^{NS}	-0.45**	0.23*	0.32*	0.12^{NS}	0.37**	0.19^{NS}		0.83**	0.39**
BYP	0.10^{NS}	0.34*	0.32*	-0.09^{NS}	0.48**	0.25*	-0.1^{NS}	0.12^{NS}	0.22*	0.8**		-0.16^{NS}
HI	0.14^{NS}	-0.49**	0.32*	-0.45**	-0.3*	0.15^{NS}	0.34*	0.44**	0.02^{NS}	0.52**	-0.11^{NS}	

NS = Not significant and *, ** = significant at $p < 0.05$ and $p < 0.01$, respectively index. Number of spikes/plant exhibited positive and significant correlation coefficients with grain yield, biological yield and harvest index. Grain number/spike showed positive and significant correlation coefficients with flag leaf area, grain weight/spike, spike length and grain yield. 100-grain yield had positive and significant correlation coefficients with grain weight/spike and harvest index. Grain weight/ spike presented positive and significant correlation coefficients with spike length, grain yield and harvest index. Spike length demonstrated positive and significant correlation coefficients with flag leaf area. Grain yield presented positive and significant correlation coefficients with both biological yield and harvest index.

Conversely, flag leaf area showed negative and significant correlation coefficients with number of spikes/plant. Days to heading presented negative and significant correlation coefficients with 100-grain weight. Plant height exhibited negative and significant correlation coefficients with both grain yield and harvest index. Number of spikes/plant displayed negative and significant correlation coefficients with grain number/spike, 100-grain weight, grain weight/spike, spike length and harvest index.

From the obtained results of phenotypic and genetic correlation, it was observed strong and significant positive phenotypic and genotypic correlation between grain yield and 100-grain weight, grain weight/spike, biological yield/ plant and harvest index under both conditions. Which proves the importance of these traits in improving grain yield under both conditions. On the other hand, it was observed negative phenotypic and genotypic correlation between grain yield and days to heading under water deficit. Which indicates the possibility of using early heading to escape from the effects of drought stress. Similar trends were found by **Marappa *et al.* (2010), Baloch *et al.* (2013), Ata *et al.* (2014), Suleiman *et al.* (2014), Sabit *et al.* (2017) and Sharma *et al.* (2018)**.

Path coefficient analysis

Direct and indirect effects of studied traits on grain yield under normal irrigation and water deficit conditions are presented in Tables 9 and 10, respectively. All studied traits presented positive direct effect on grain yield/plant except days to maturity and spike length which had a negative effect under normal irrigation (-0.016 and -0.011 respectively). While under water deficit, days to maturity, number of spikes/ plant, flag leaf area, and spike length had a negative direct effect on grain yield (-0.026, -0.013, -0.012 and -0.012, respectively). Biological yield and harvest index exhibited highest positive direct effect on grain yield (0.85 and 0.69 under normal irrigation and 0.71 and 0.62 under water deficit, respectively). Furthermore, the correlation coefficients between these two traits and grain yield were positive and highly significant under normal irrigation and water deficit conditions. The previous results confirm the effectiveness of direct selection of these traits for achieving high grain yield under both conditions.

The highest indirect effects on grain yield were assigned for number of spikes/plant (0.35) and flag leaf area (0.31), through biological yield/plant and grain weight/spike (0.19) and 100-grain weight (0.18) with harvest index under normal irrigation. While the highest indirect effects under water deficit were grain weight/spike (0.27), flag leaf area (0.22), spike length (0.21) through biological yield/plant and by 100-grain weight (0.30) and grain weight/ spike (0.26) through harvest index.

Form the found results it could be concluded that the presence of true relationship between grain weight/spike, 100-grain weight, biological yield, harvest index and grain yield. This indicates that direct and indirect selection through these traits is very useful for developing high yielding under normal irrigation and water deficit. These results are in agreement with that reported by **Talebi *et al.* (2010), Khan and Naqvi (2012), Zarei *et al.* (2013), Abderrahmane *et al.* (2013), Naghavi and Khalili (2017) and Sharma *et al.* (2018)**.

Table 9. Direct and indirect effect of agronomic traits on grain yield in wheat under normal irrigation conditions (the last column shows genotypic correlation)

Trait	FLA	DH	DM	PH	NSP	GNS	100GW	GWS	SL	BYP	HI	GYP
FLA	**0.011**	0.018	0.002	0.002	0.005	0.003	0.004	0.004	-0.059	0.31	-0.03	0.27^{**}
DH	0.002	**0.011**	-0.003	0.002	0.005	0.001	-0.004	-0.004	-0.005	0.17	-0.27	-0.09^{NS}
DM	-0.002	0.007	**-0.011**	0.002	0.002	0.001	-0.030	-0.009	-0.043	0.11	0.00	0.03^{NS}
PH	0.002	0.002	-0.035	**0.009**	-0.026	-0.080	0.004	-0.016	-0.010	0.01	0.04	-0.10^{*}
NSP	-0.002	0.002	-0.001	-0.001	**0.026**	-0.003	-0.003	-0.011	0.003	0.35	-0.14	0.23^{**}
GNS	0.003	0.001	-0.002	-0.001	-0.008	**0.010**	-0.001	0.016	-0.007	0.17	0.08	0.26^{**}
100GW	0.005	-0.005	0.003	0.003	-0.007	-0.001	**0.010**	0.009	0.001	-0.04	0.18	0.15^{NS}
GWS	0.002	-0.002	0.004	-0.001	-0.012	0.007	0.003	**0.025**	-0.006	0.14	0.19	0.34^{**}
SL	0.004	0.003	-0.003	0.001	-0.005	0.004	-0.001	0.010	**-0.016**	0.16	-0.02	0.14^{NS}
BYP	0.003	0.002	-0.0014	0.001	0.011	0.002	-0.001	0.004	-0.003	**0.85**	-0.14	0.73^{**}
HI	-0.005	-0.004	0.002	-0.002	-0.005	0.001	0.002	0.007	0.004	-0.18	**0.69**	0.52^{**}

NS = Not significant and *, ** = significant at $p < 0.05$ and $p < 0.01$, respectively

FLA (Flag leaf area, cm^2), DH (Days to heading), DM (Days to maturity), PH (Plant height), NSP (number of spikes/plant), GNS (grain number/spike), 100GW (100-grain weight), GWS (Grain weight/spike), SL (Spike length), GYP (Grain yield/ plant), BYP (Biological yield/plant), HI (Harvest index).

Table 10. Direct and indirect effect of agronomic traits on grain yield in wheat under water deficit conditions (the last column shows genotypic correlation)

Trait	FLA	DH	DM	PH	NSP	GNS	100GW	GWS	SL	BYP	HI	GYP
FLA	**-0.012**	0.005	-0.006	-0.005	-0.004	0.001	0.002	0.003	-0.037	0.22	0.11	0.28^{**}
DH	-0.003	**0.019**	-0.006	-0.002	-0.001	0.001	-0.004	-0.003	-0.005	0.02	-0.17	-0.16^{NS}
DM	-0.026	0.010	**-0.026**	-0.003	-0.003	0.001	0.002	0.004	-0.049	0.19	0.17	0.28^{*}
PH	-0.004	0.002	-0.010	**-0.014**	0.001	0.001	0.002	0.003	-0.002	0.19	0.16	0.33^{*}
NSP	0.002	0.002	-0.001	0.001	**-0.013**	-0.001	-0.002	-0.005	0.004	0.19	-0.08	0.09^{**}
GNS	-0.003	0.003	-0.010	-0.002	0.003	**0.005**	0.001	0.009	-0.005	0.20	0.19	0.39^{**}
100GW	-0.003	-0.008	-0.001	-0.004	0.003	0.004	**0.001**	0.009	0.001	0.20	0.30	0.50^{**}
GWS	-0.002	-0.004	-0.005	-0.002	0.004	0.003	0.005	**0.017**	-0.003	0.27	0.26	0.54^{**}
SL	-0.004	0.007	-0.010	-0.002	0.004	0.002	-0.005	0.005	**-0.012**	0.21	-0.05	0.15^{NS}
BYP	-0.003	0.0005	-0.007	-0.004	-0.004	0.001	0.003	0.006	-0.004	**0.71**	0.09	0.79^{**}
HI	-0.002	-0.005	-0.005	-0.003	0.002	0.001	0.004	0.007	0.001	0.11	**0.615**	0.72^{**}

NS = Not significant and *, ** = significant at $p < 0.05$ and $p < 0.01$, respectively.

FLA (Flag leaf area, cm^2), DH (Days to heading), DM (Days to maturity), PH (Plant height), NSP (number of spikes/plant), GNS (grain number/spike), 100GW (100-grain weight), GWS (Grain weight/spike), SL (Spike length), GYP (Grain yield/ plant), BYP (Biological yield/plant), HI (Harvest index).

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التباين الوراثي والعلاقة المتبادلة بين الصفات المحصولية في تراكيب وراثية من قمح الخبز تحت ظروف نقص الماء والري العادى

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يعتبر نقص الماء أحد الإجهادات الهامة التي تؤدى إلى قلة إنتاج القمح خاصة في ظل التغيرات المناخية الحالية. الهدف من هذه الدراسة هو تقييم التنوع الوراثي لثلاثين تركيباً وراثياً من قمح الخبز تحت ظروف نقص الماء والري الطبيعي. بالإضافة لذلك دراسة العلاقة بين محصول الحبوب والصفات المحصولية الهامة، وتحديد العلاقة المتبادلة بين الصفات تحت الدراسة تحت ظروف الإجهاد المائي والري الطبيعي، ولتحقيق ذلك تم إجراء تجربتين حقليتين في محطة البحوث الزراعية بالوادي الجديد، مركز البحوث الزراعية، مصر، خلال الموسميين ٢٠١٤-٢٠١٥ و٢٠١٥-٢٠١٦، لتقييم ثلاثين تركيباً وراثياً من قمح الخبز تحت نظامين ري، أحدهما استخدام الري العادي كل ١٥ يوم بإعطاء تسع ريات في الموسم الواحد (بإجمالي ٢٩٠٠م^3/للفدان)، وكان نظام الري الآخر كل ٣٠ يوم بإعطاء خمس ريات في الموسم (بإجمالي ١٩٠٠م^3/للفدان) مما يوفر ظروف نقص الماء، كان التصميم التجريبي المستخدم القطع المنشقة مره واحدة حيث تم وضع معاملات الري في القطع الرئيسية وتم توزيع التراكيب الوراثية بشكل عشوائي في القطع المنشقة، باستخدام ثلاث مكررات، أوضحت النتائج تأثر جميع الصفات تحت الدراسة بشكل كبير بمعاملات الري، وأظهرت التراكيب الوراثية G1، G2، G17، G21، G22، G23، G24 و G27 محصول جيدًا تحت كلا نظامى الري، وتم حساب مقاييس تحمل الجفاف: متوسط الإنتاجية (MP)، ومتوسط الإنتاجية الهندسى (GMP)، دليل تحمل الإجهاد (STI) ودليل المحصول (YI)على أساس محصول الحبوب للنبات تحت ظروف الإجهاد والري العادي، وأظهرت التراكيب الوراثية G21، G2 و G1 متبوعة بـ G23، G27 وG24 أفضل القيم لمقاييس الجفاف، وبناء على مقاييس التحمل تم تقسيم التراكيب الوراثية باستخدام التحليل العنقودي إلى ثلاث مجموعات: المجموعة الأولى مكونة من ثمانية تراكيب وراثية (متحملة للجفاف)، المجموعة الثانية مكونة من ثمانية عشر تركيب وراثي (متوسطة تحمل الجفاف) والمجموعة الثالثة مكونة من أربعة تراكيب وراثية (حساسة للجفاف)، علاوة على ذلك، تم تقدير معامل الارتباط المظهري والوراثي ولوحظ وجود علاقة موجبة قوية بين محصول الحبوب ووزن ١٠٠ حبة وكذلك وزن حبوب السنبلة والمحصول البيولوجي للنبات ودليل الحصاد تحت كلا نظامى الري، بالإضافة إلى ذلك، تم حساب معامل المرور ووجد أن المحصول البيولوجي ودليل الحصاد أظهرا أعلى تأثيراً إيجابياً مباشراً على محصول الحبوب تحت ظروف الإجهاد والظروف الطبيعية، ومن ناحية أخرى، كان أعلى تأثير غير مباشر على محصول الحبوب من عدد السنابل/النبات، مساحة ورقة العلم، وزن حبوب السنبلة ووزن ١٠٠ حبة تحت كلا نظامى الري، ويدل ذلك على أهمية هذه الصفات في تحسين محصول الحبوب تحت ظروف الإجهاد المائى وكذلك الرى العادى.

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