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EVALUATION OF EGYPTIAN WHEAT LANDRACES (*TRITICUM AESTIVUM* L.) FOR DROUGHT TOLERANCE, AGRONOMIC, GRAIN YIELD AND QUALITY TRAITS

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Abstract

To increase the genetic progress in wheat yield, breeders search for germplasm of high genetic diversity, one of them is the landraces, which are traditional varieties with a good tolerance to biotic and abiotic stresses. The objectives of the present investigation were to (i) assess the effects of deficit irrigation and genotype on studied traits of wheat landraces, (ii) identify landrace(s) showing drought tolerance, high yield, and/or carrying one or more desirable trait and (iii) identify the most correlated traits to drought tolerance. Twenty bread wheat landraces and two checks were planted in the field for two seasons under water stress (WS) and non-stress (WW) conditions using a split plot design with four replications and their agronomic, grain yield and quality traits (13) were recorded. Water stress caused a significant reduction of 9.54 % in grain yield, which was associated with a reduction in all studied traits, except grain protein content (GPC), which significantly increased by 13.99%. Our study recommended that landrace G17; the highest in GPC (20.87%) could be crossed to one of the highest yielding genotypes Sakha 64 cultivar, landraces G2 or G3 to select in their segregating generations some transgressive segregates of high grain yield and high GPC. The highest drought tolerant genotypes in this study were Sakha 63 and the landraces G2, G3, G4, G7, G12 and G15. These genotypes were the most drought tolerant, the highest yielders under WS as well as WW and could therefore be recommended to future wheat breeding programs. The results indicated that drought tolerant landraces are characterized by early maturity, short grain filling period, short plant height and high grain yield/plant. These traits could be considered as selection criteria for drought tolerance in wheat if they proved high heritability.

Key words: Bread wheat, Landraces, Drought tolerance, Grouping, Correlations, Grain composition

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops of the world and provides over 20% of calories and protein for human nutrition for over 35% of the world's population in more than 40 countries including Egypt. In 2017, the harvested area of wheat in Egypt was 1,342,805 ha (3,195,875 fed), the annual consumption of wheat grains was about 19 million tons, while the local production was about 8.8 million tons with an average grain yield of 18.35 ardab/fed (6.55 t/ha) (FAOSTAT, 2017). Therefore, the gap between annual local production and consumption is about 10.2 million tons. This gap could be narrowed by increasing local production of wheat *via* two ways. The first way is through vertical expansion, *i.e.* increasing wheat production per unit area through the development of new cultivars of high yielding ability, resistance to biotic and abiotic stresses, and the adoption of recommended cultural practices for growing these cultivars. The second way is through the horizontal expansion, *i.e.* by increasing the area cultivated with wheat. Horizontal expansion in Egypt is available only in the desert, where the soil is of low water holding capacity and thus needs improved wheat cultivars to tolerate drought stress, which could result in obtaining low grain yields under such conditions. Moreover, the expected future shortage in irrigation water necessitates that wheat breeders should pay great attention to develop drought tolerant wheat cultivars that could give high grain yield under both water-stress and non- stress conditions.

Yield plateaus of wheat were reported in some European countries (Grassini *et al.*, 2013) as well as in

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Egypt. However, a significant increase in wheat yield will be required in Egypt if demand from the growing human population, is to be met. The challenge for wheat breeders is to increase the rate of genetic gain in yield at a rate not lower than the rate of growing human population. Most current breeding programs of wheat are aimed at increasing field potential, but environmental stresses, such as drought, salinity, cold, and fungi pathogens, remain severe challenges for sustainable production (Mondal *et al.,* 2013). Soil–water deficiency has been reported to reduce about half of the wheat production, and fluctuations in annual precipitation lead to a direct influence on wheat output worldwide (Parry *et al.,* 2004).

Water deficit decreases grain yield by affecting anthesis and grain-filling period. Drought stress may decrease leaf water potential, consequently lowering turgor, stomatal conductance, and photosynthesis, and, finally, lessening growth and yield of wheat (Chen *et al.*, 2012). Drought stress during flowering and grain filling affects the number of seeds per spike and kernel weight, two important components of grain yield. As grain yield is a complex trait controlled by many genes, breeders often use indirect selection and use well-correlated traits with the yield for improving grain yield in dry environments (Sallam *et al.,* 2014**)**. Yield traits that breeders have used for assessing drought stress on wheat plants include plant height, days to heading, days to maturity, spike length, number of spikelets per spike, number of grains per spike, thousand kernel weight, grain yield per spike, grain yield, biological yield, and harvest index. Drought tolerance index can accurately assess the genotypic yield response to drought stress (Fernandez, 1992).

The wheat grain comprises three parts, bran (outer layer), endosperm (site of most food reserves), and germ (embryo); the main constituent of endosperm is starch which varies from 60 to 75% on a dry weight basis, the protein content of wheat grain (dry) falls within 10–18% and grain lipid content is around 1.5% which contains the essential fatty acids in varying amounts (Ashraf 2014). Shortage of water imposes multiple effects on plant growth and development. All these drought-induced effects not only cause stunted growth and reduced seed yield, but also bring about considerable changes in grain composition and quality. For example, while assessing the influence of drought stress on the grain quality of some salt-tolerant genotypes of durum wheat, Houshmand *et al.,* (2005) reported that although drought stress decreased significantly grain weight and test weight of the genotypes, it resulted in increased protein content by 12%, wet gluten content by 20%, and dry gluten content by 20%.

For wheat breeders, to increase the genetic progress in yield, they search for germplasm of high genetic diversity, one of them is the landraces. A wheat landrace was defined by Zeven (1998) as a traditional variety with a good tolerance to biotic and abiotic stresses. It has high stability, but shows moderate yield under poor environment. It is generally thought that during the process of wheat domestication, new adaptive traits suitable for the new environments were selected (Peng *et al.*, 2011). Probably traits such as easy harvest, large seeds, non-shattering plants were considered as main aims of the ancient farmers (Fuller, 2007), or ûowering time to fit with the prevailing environmental conditions of the region (Cockram *et al.,* 2009). Many other characteristics had also been selected by farmers, such as plant height, number and weight of spikes and grains (Peng *et al.*, 2011). Wheat landraces cultivated in the Saharan oases have been subjected during centuries to drought, heat and salinity and are expected to have developed tolerance to these stresses; most landraces may have been introduced from Egypt, possibly during wet climatic episodes (Zaharieva *et al.,* 2010). Previous research has indicated that modern wheat cultivars start flowering at an earlier stage compared to older cultivars and landraces (Isidro *et al.,* 2011). Identifying high yielding, drought tolerant and early-maturing genotypes should consequently be a priority in wheat-breeding programs aimed at areas experiencing drought stress.

The objectives of the present investigation were to (*i*) assess the effects of deficit irrigation and genotype on studied agronomic, grain yield and quality traits, (*ii*) identify landrace(s) showing drought tolerance, high yield and/or carrying one or more desirable trait for use in future breeding programs and (*iii*) identify the most correlated traits with drought tolerance.

Materials and Methods

Plant materials

Seeds of 20 bread wheat (*Triticum aestivum* L.) Egyptian landraces, obtained from the National Gene Bank, Agricultural Research Center (ARC), Egypt along with two checks, namely Sakha 64 (an Egyptian cultivar) and Yakora Kogo (drought tolerant variety) obtained from CIMMYT were used in the present investigation (Table 1).

Experimental procedure

The present investigation was carried out in the field of the experimental research station of ARC at Gemmieza (Gharbia Governorate) during the seasons 2015/2016 and

Table 1: Wheat landraces and check varieties used in this study.

Genotype No.	Accession No.	Landrace/ Variety	Country of Origin	Gover-norate
G1	9226	Landrace	Egypt	Giza
G2	9227	Landrace	Egypt	Giza
G3	9234	Landrace	Egypt	Giza
G4	9235	Landrace	Egypt	Giza
G5	9236	Landrace	Egypt	Giza
G6	9311	Landrace	Egypt	Giza
G7	9331	Landrace	Egypt	Giza
G8	9373	Landrace	Egypt	Giza
G9	9361	Landrace	Egypt	Giza
G10	9144	Landrace	Egypt	Giza
G11	9120	Landrace	Egypt	Giza
G12	9266	Landrace	Egypt	Giza
G13	9286	Landrace	Egypt	Qalyubia
G14	9287	Landrace	Egypt	Qalyubia
G15	9222	Landrace	Egypt	Qalyubia
G16	9290	Landrace	Egypt	Dakahlia
G17	9150	Landrace	Egypt	Monufia
G18	9293	Landrace	Egypt	Beheira
G19	9243	Landrace	Egypt	Sharqia
G20	9110	Landrace	Egypt	Gharbia
G21	Yakora Kojo	DT-Variety	CIMMYT -Mexico	-
G22	Sakha 64	Cultivar	Egypt	-

DT=Drought tolerant, NGB=National Gene Bank, CIMMYT=International Maize and Wheat Improvement Center.

2016/2017. The station is located at Gemmeiza (30º 48' 0" N, 31º 7' 30" E and Altitude = 12 m above sea level). Sowing date was on 21st and 27th of November in the first and second season, respectively.

A split plot design in randomized complete blocks arrangement was used with four replications. Main plots were devoted to two irrigation regimes, *i.e.* normal irrigation by giving the recommended number (five) of irrigations (sowing irrigation, the second one after 21 days and the next ones after each 25 days) and deficit irrigation by giving only two irrigations (sowing irrigation and the next one after 21 days) after which irrigation was stopped till the end of the season. A border of 30 meters' width was done between the two main plots, besides digging a canal in the middle of this border of a 5 m width and 1 m depth. The purpose of making this border was to prevent water interference from the full-irrigated main plot to the stressed one. Moreover, the whole experiment was isolated by a border of at least 14 m width far away from any source of irrigation water. Sub-plots were devoted to 22 wheat genotypes (20 Egyptian landraces and two check varieties).

The seeds were sown in individual hills in rows. Each row length was 2.5 meter and row to row distance was 20 cm and hill to hill distance was 20 cm (plot size was 3.0 m^2). The fertilization was applied as recommended by ARC, for commercial production using 15 kg P_2O_5 (100 kg Mono-Super Phosphate 15.5%) + 75 kg Nitrogen (225 kg Ammonium Nitrate 33.5%) for acre split in three times, first 20% with seeds, second 40% with first irrigation and third time 40% with second irrigation. Weeds, aphids and diseases were controlled when needed according to the recommendations of the ARC, Egypt.

Soil analysis of the experimental site was done in Analysis and Studies Unit (ASU), Soil, Water and Environment Res. Inst. (SWER) of ARC and data combined across two seasons is presented in Table 2. The meteorological data each season were recorded by Meteorological Station at Gemmeiza (Table 3).

Data recorded:

1. Days to anthesis (DTA): It was estimated as the number of days from sowing date to the date at which 50% of plants/plot had started to emerge anthers from their spikelets. **2. Days to maturity (DTM):** It was recorded as the number of days from sowing to the date at which 50% of main peduncles/plot have turned to yellow color (physiological maturity). **3. Grain filling period (GFP):** Number of days from 50% anthesis to 50% physiological maturity (on a per plot basis taken

Table 2: Physical and chemical analyses of soil at Gemmeiza station across two seasons.

Physical Analysis		Chemical Analysis					
Clay %	46.70	pH		7.81	Soluble Anions (mEqu/l)	Cl^-	41.1
Silt %	37.60	EC (dSm^{-1})		4.90		SO_4	7.3
Fine Sand %	11.30	SP		56.30		$HCP3^-$	0.7
Coarse Sand%	4.40	Soluble Cations (mEqu/l)	Ca^{+2}	10	Macro Elements (ppm)	N	71.3
Soil type	Clayey		Mg^{+2}	6.7		P	8.3
Organic Matter %	0.44		Na^+	32		K	2.5
		K^+	1.3				

Source: Analysis and Studies Unit, Soil, water and Environment Res. Inst., ARC, Egypt.

Table 3: Meteorological data during seasons of wheat growing at Gemmeiza.

	Air Temperature		Relative humidity (%)		Wind Velocity	Rain
Month	**Max**	**Min**	**7:30**	**13:30**	**(km/24hr)**	**(mm/day)**
2015/2016						
Nov.	24.8	14.2	86.6	63.9	75.5	52.4
Dec.	20.3	8.4	88.2	63.5	58.8	23.2
Jan.	18.7	6.9	87.8	61.1	95.6	58.9
Feb.	19.2	7.7	58.7	62.6	62.4	34.6
March	21.5	11.8	82.6	59.3	87.2	5.3
April	22.2	13.8	77.3	48.1	96.4	23.9
May	30.3	18.9	76	46	114.4	0
Total						198.3
2016/2017						
Nov.	20.0	13.8	52.8	33.8	67.8	0
Dec.	19.4	9.8	85.4	63	63	25.4
Jan.	18.1	6.3	84.9	62.5	63.2	18.6
Feb.	13.9	10.3	56.6	62.9	61.3	24.8
March	22.5	18.4	84.8	60.1	84.5	0
April	25.9	21.6	80.3	50.9	89.9	0
May	30.6	23.9	77.6	45.8	106.8	0
Total						68.8

Source: Meteorological Stations of Agric. Res. Centre at Gemmeiza. Nov. = November, Dec. = December, Jan. = Jan, Feb. = February.

from the 4 inner rows). **4. Plant height (PH):** It was measured as the height of plant at maturity, measured from the soil surface to the level of the tip of spike, excluding awns (average of 10 plants taken from the 4 inner rows). **5. Number of spikes/plant (SPP):** It was measured as the total number of fertile spikes per plant as an average of 10 plants taken from the 4 inner rows. **6. Number of spikelets/spike (SPS):** It was measured as the total number of spikelets per main spike as an average of 10 plants taken from the 4 inner rows. **7. Number of grains/spike (GPS):** It was measured as the total number of grains per main spike as an average of 10 spikes of 10 plants taken from the 4 inner rows. **8. Thousand grain weight (TGW):** It was measured as the weight of 1000 grains using an electronic balance. **9. Grain yield/plant (GYPP):** It was measured as the weight of grains per plant (adjusted at 14% grain moisture) as an average of 10 plants taken from the 4 inner rows. **10. Grain protein content (GPC). 11. Grain starch content (GSC). 12. Grain ash content (GAC) 13. Grain moisture content (GMC).** The grain quality traits (GPC, GSC, GAC and GMC) were measured on samples taken from the grain bulk of each wheat genotype by using INSTALAB 600 Near Infrared (NIR) Product Analyzer manufactured by DICKEY-john Corporation, Auburn, Illinois, USA.

Drought tolerance index (DTI)

Drought tolerance index; the factor used to differentiate between the genotypes from tolerance point of view was calculated following the equation suggested by Fageria (1992) as follows: DTI = (Y1/AY1) X (Y2/AY2). Where, Y1 = Mean grain yield of a genotype at well watering. AY1 = Mean grain yield of all genotypes at well watering. Y2 = Mean grain yield of a genotype at water stress. AY2 = Mean grain yield of all genotypes at water stress. When DTI is <1, it indicates that genotype is tolerant (T) to drought. If DTI is <1, it indicates that genotype is sensitive (S) to drought.

Biometrical analyses

Analysis of variance of the split plot design in a RCB arrangement was performed on the basis of individual plot observation using the MIXED procedure of MSTAT ®. Combined analysis of variance of the split plot across the two growing seasons was also performed if the homogeneity test was non-significant according to Steel *et al.,* (1997). Moreover, combined analysis of variance of randomized complete block design was performed for each environment; separately and combined across seasons. Least significant differences (LSD) were computed to compare means. Phenotypic correlation coefficients (Spearman) among studied traits and their significance were calculated according to Steel *et al.,* (1997) by using SPSS 20 computer software.

Results and Discussion

Analysis of variance

Analysis of variance of the split plot design combined across two seasons for agronomic and yield traits table 4 showed that mean squares due to seasons (S) were significant (≤0.01) for all studied traits, except for plant height (PH) and spikes/plant (SPP), indicating that climatic conditions prevailing during the first season were different from those during the second season (Table 3) and climatic conditions had a significant effect on the majority of studied traits. Mean squares due to irrigation (I) were significant (≤ 0.05 or ≤ 0.01) for all studied traits, except for PH, suggesting that the regime of irrigation (water stress) had a significant effect on all studied traits, except plant height trait. Mean squares due to genotypes (G) were significant (≤ 0.01) for all studied traits, indicating that the studied 22 genotypes (20 landraces and two check

Table 4: Combined analysis of variance of split plot design for agronomic and yield traits of 22 wheat landraces and varieties evaluated under two irrigation regimes across two seasons.

SV	df	Mean squares				
		DTA	**DTM**	**GFP**	**PH**	**SPP**
Season	1	2441.72**	2559.34**	10551.37**	5.16	37.81**
R(S)	4	3.124	13.093	10.26	33.68	0.44
Irrigation	1	194.95*	2909.71**	1651.20**	35.32ns	28.35**
S × I	1	59.32ns	1010.69**	549.16**	1723.60**	7.72**
Error	4	11.46	4.619	12.687	21.652	0.229
Genotypes	21	5.721**	121.088**	99.618**	553.392**	1.476**
S × G	21	2.301*	68.546**	60.255**	556.019**	0.769**
I × G	21	5.472**	29.502**	31.849**	121.574**	1.034**
S ×I × G	21	1.408 ns	38.977**	42.200**	153.789**	0.973**
Error	168	1.219	2.388	3.336	14.146	0.205
CV%		1.01	1.04	4.60	3.12	5.05
		GPS	SPS	TGW	GYPP	
Season	1	8284.19**	0.20 ns	115.51**	959.74**	
R(S)	4	23.572	0.978*	6.334 ns	5.691ns	
Irrigation	1	1936.89**	5.65**	572.68**	171.33**	
S × I	1	633.45*	6.88**	684.15**	474.19**	
Error	4	40.551	0.072	1.387	1.221	
Genotypes	21	135.39**	2.23**	81.09**	34.55**	
S × G	21	71.22**	1.71**	78.99**	30.17**	
I × G	21	74.95**	0.93**	18.86**	11.11**	
S ×I × G	21	61.58**	0.65ns	16.65**	9.88**	
Error	168	30.02	0.46	6.96	2.19	
		10.89	6.23	5.47	9.16	

ns, * and ** indicate non-significant and significant at 0.05 and 0.01 probability levels, respectively.

varieties) showed highly significant differences among them for all studied traits in the field experiment. Many investigators reported significant differences among wheat landraces and between them and the modern cultivars and varieties for phenological, agronomical and yield attributes (Cockram *et al*., 2009, Peng *et al*., 2011, Zaharieva *et al*., 2010). Mean squares due to all interactions were significant (≤ 0.05 or ≤ 0.01) for all studied traits, except S × I for days to anthesis (DTA) and G × S × I for DTA and spikelets/spike (SPS), indicating the differential response of genotypes for the majority of studied traits from season to season and from irrigation regime to another and from a combination of season and irrigation regime to another combination. Such a significant interaction suggests that selection would be effective under a specific environment (irrigation regime or a combination of season and irrigation regime); this conclusion was reported by previous investigators (Fischer and Maurer, 1978 and Al-Naggar *et al*., 2004, 2007, 2011, 2015 and 2016). It is worthy to note that coefficient of variation (CV) (Table 4) was very low (ranging from 0.99 to 10.89%), indicating the accuracy of implementing the experiment.

Analysis of variance of the split plot design for grain composition traits (Table 5) showed that mean squares due to irrigation (I) were significant (≤ 0.01) for all studied quality traits, suggesting that the regime of irrigation (water stress) had a significant effect on grain protein, starch, ash and moisture content traits. Many investigators reported significant effect of irrigation regime on grain chemical composition traits of bread wheat (Guttieri *at al*., 2000; Houshmand *et al*., 2005; Kiliç and Yaðbasanlar, 2010 and Ashraf 2014). Mean squares due to genotypes (G) were significant (≤ 0.01) for all grain quality traits, indicating that the studied 22 genotypes (20 landraces and two check varieties) showed highly significant differences among them for all studied grain composition traits. Many investigators reported significant differences among wheat landraces and between them and the modern cultivars for grain quality attributes (Ortiz-Monasterio *et al*., 1997; Le Gouisetal, 2000; Foulkes *et al*., 2006 and Barraclough *et al*., 2010). Mean squares due to genotype x irrigation interaction were not significant for all studied grain quality traits, indicating that the rank of genotypes for all studied grain quality traits did not change from one irrigation regime to another. It is also worthy to note that coefficient of variation (CV) (Table 5) was very low (ranging from

Table 5: Analysis of variance of split plot design for grain quality traits of 22 wheat landraces and varieties evaluated under two irrigation regimes in 2016/2017 season.

SV	df	Mean squares			
		GPC	**GSC**	**GAC**	**GMC**
Irrigation (I)	1	132.0**	132.0**	1.32**	3.525**
Error	2	0.01	0.01	0.01	0.274
Genotypes (G)	21	27.062**	93.423**	2.069**	0.359**
G × I	21	0.001	0.01	0.001	0.137
Error	84	132.00	132.00	1.32	0.092
CV%		1.70	1.03	7.31	2.30

** indicate significant at 0.01 probability level.

1.03 % for GSC to 7.31 % for GAC), indicating the accuracy of our experiment.

Effect of water stress

Stress irrigation (WS) caused a significant reduction (≤ 0.01) in all studied phenological, agronomic and yield traits (Table 6) of the studied germplasm (across all landraces and check cultivars), except plant height, which did not change significantly from WW to WS. In general, the reduction due to water stress was small and ranged from 1.56% for days to anthesis to 10.22% for grains/spike. Grain yield/acre showed a reduction of 9.54% due to water stress, which was associated with a reduction in grain yield/plant (9.49%), thousand grain weight (5.94%), spikelets/spike (2.61%), grains/spike (10.22 %) and spikes/plant (7.00%), *i.e.* all grain yield components.

Table 6: Means of studied agronomic and yield traits under WW and WS and reduction % from WW to WS across all genotypes and two seasons.

Trait	WW	WS	Reduction %
DTA (day)	110.19	108.47	1.56**
DTM(day)	152.51	145.87	4.35**
GFP (day)	42.19	37.19	11.85**
PH (cm)	120.17	120.91	-0.62^{ns}
SPP	9.28	8.63	7.00**
GPS	53.01	47.59	10.22**
SPS	11.11	10.82	2.61**
TGW (g)	49.70	46.75	5.94**
GYPP (g)	16.96	15.35	9.49**

**indicate significant at 0.01 probability level, ns indicates non-significant.

Shortage of water at any growth stage in the crop life cycle is likely to have consequences for yield and that there are several ways in which water stress can affect grain yield, the first by modification of early growth and ear development. The simultaneously occurring processes of tiller production and spikelets initiation are followed immediately before anthesis by a period in which a proportion of tillers and florets die. The second major yielding-determining process affected by stress is the production of fertile gametes and fertilization (Fischer, 1973), which determines the proportion of the potential grain number realized. These processes are probably responsible for determining the critical period before anthesis, during which water stress usually has the most detrimental effect on yield (Salter and Godge, 1967).

Drought stress during flowering and grain filling affects the number of seeds per spike and kernel weight, two important components of grain yield. As grain yield is a complex trait controlled by many genes, breeders often use indirect selection and use well-correlated traits with the yield for improving grain yield in dry environments (Sallam *et al.*, 2014). When wheat plants are exposed to drought or heat stresses during grain filling, photosynthes is rapidly declines which reduces the available assimilates to the grain. Consequently, a dramatic reduction in kernel dry weight occurred (Wardlaw and Willenbrink, 2000).

Our results about reduction in wheat grain yield due to drought stress are also consistent with those reported by Solomon *et al*., (2003), and Al-Naggar *et al*., (2004, 2007, 2015a and 2017).

Several investigators also reported that water stress had a strong negative effect on number of spikes per plant (Kheiralla *et al*., 1997), grains/spike (Sharma and Bhargara, 1996), and 100-grain weight (Fischer and Maurer, 1978).

Reduction in previous studies was more pronounced than reduction in our study. The reason of small reduction in studied traits due to water stress in our experiment might be because the water stress was moderate, because the site of experiment was located in the north of Delta (lower Egypt), where rain might fall during the season of growing wheat, especially the first season.

Regarding grain quality traits, water stress caused a significant increase (≤ 0.05 or ≤ 0.01) in grain protein content (13.99%) and grain ash content (11.29%), but caused a significant decrease (≤ 0.05) in grain starch content (3.23%) and non-significant decrease in grain moisture content (2.52%) as shown in Table 7. Our results are in agreement with those reported by several investigators (e.g. Houshmand *et al.*, 2005; Ashraf 2014). Although drought stress typically depresses grain yield, it can elevate the value of other components of the economic yield, such as quality of grain protein (Guttieri *at al.*, 2000 and Kiliç and Yaðbasanlar, 2010).

Table 7: Means of studied grain quality traits under WW and WS and reduction % from WW to WS across all genotypes in 2016/2017 season.

Trait	WW	WS	Reduction %
Grain Protein Content %	14.29	16.29	-13.99**
Grain Starch Content %	61.75	59.75	3.23*
Grain Ash Content %	1.77	1.97	-11.29**
Grain Moisture Content %	13.05	12.72	2.52ns

* and ** indicate significant at 0.05 and 0.01 probability levels, respectively.

Stressful environments such as drought, salinity, extremes of temperature, etc., cause a multitude of changes in the metabolism of plants, although these changes overlap considerably in plants in response to different stresses (Ashraf 2014). These metabolic changes certainly lead to impaired growth and hence poor yield. It has been noted that the early pollen development stage in most cereals is highly sensitive to abiotic stress (Dolferus *et al.*, 2011). The impairment in this early reproductive phase may lead to improper grain development and hence considerable fluctuations in the components of grains. There are a few earlier studies which indicate that subjecting crops to different types of stress affects the level of several compounds within grains. For example, in triticale (Triticum × Secale), grain protein was negatively related to the rainfall that occurred during the entire crop growth period (Garcia del Moral *et al.*, 1995). This was ascribed to water deficit induced reduction in starch accumulation as well as grain yield during the grain filling stage.

The wheat grain comprises three parts, bran (outer layer), endosperm (site of most food reserves), and germ (embryo); the main constituent of endosperm is starch which varies from 60 to 75% on a dry weight basis, the protein content of wheat grain (dry) falls within 10–18% and grain lipid content is around 1.5% which contains the essential fatty acids in varying amounts (Ashraf 2014). Shortage of water imposes multiple effects on plant growth and development. The major effects of drought stress on plants are osmotic effects, imbalance in uptake and accumulation of nutrients, hormonal imbalance, and oxidative stress caused by the production of reactive oxygen species such as superoxide, singlet oxygen, hydroxyl radical, and hydrogen peroxide. All these drought-induced effects not only cause stunted growth and reduced seed yield, but also bring about considerable changes in grain composition and quality. For example, while assessing the influence of drought stress on the grain quality of some salt-tolerant genotypes of durum wheat, Houshmand *et al.*, (2005) reported that although drought stress decreased significantly grain weight and test weight of the genotypes, it resulted in increased protein content by 12%, wet gluten content by 20% and dry gluten content by 20%.

It is evident that carbohydrates are the major constituents of wheat grains. However, changes in the proportions of specific carbohydrates significantly affect the quality of grain composition and these changes frequently take place due to a variety of environmental factors. For example, drought stress is known to reduce contents of carbohydrates including sucrose and starch in cereal grains, the latter being 65% of cereal kernels (Barnabas *et al.*, 2008). Starch content in cereal grains is positively correlated with sucrose content and the activity of sucrose synthase (SuSy) and other related enzymes (Yan *et al.*, 2008). Thus, starch accumulation depends on sucrose content and activities of the enzymes involved in starch synthesis (Balla *et al.*, 2011). Labuschagne *et al.*, (2009) reported that dough quality depends on the amylose-to-amylopectin ratio.

Generally, it is known that drought-induced reduction in crop grain yield is associated with an increase in protein content (Garrido-Lestache *et al.*, 2005; Dupont *et al.*, 2006;). A study carried out in several regions of Spain showed moisture stress caused by low rainfall resulted in a significant increase in protein content in the grains of durum wheat (Rharrabti *et al.*, 2003). Another study conducted by Garrido-Lestache *et al.*, (2005) in southern Spain showed maximum values of protein content during the period when rainfall was lowest.

Although drought stress applied at any developmental stage adversely affects the grain composition and quality, in view of a number of reports it is evident that drought stress application, particularly at the grain filling stage has a substantial effect on wheat grain quality. Although it might appear intuitively that drought stress should have an adverse effect on grain quality, this is certainly not always the case, especially if the stress is applied at the grain filling stage. For example, drought stress applied during wheat grain development considerably reduced the SDS sedimentation volume and this was found to be mainly dependent on the timing of stress imposition (Gooding *et al.*, 2003).

From the above contrasting reports, it can be inferred that the varying effects of drought stress on wheat grain quality and protein composition depend on the variation in environmental conditions in which the studies had been conducted, intensity of stress, development stage at which stress was imposed, different protocols employed to appraise grain or flour quality, and different wheat varieties.

Effect of genotype

Means of each genotype across irrigation regimes and years of study for all studied traits are presented in Table 8. The twenty-two genotypes of bread wheat differed significantly for each studied trait. The ranges between minimum and maximum values were more pronounced (wide) in the traits DTM (140-155.3 days), GFP (30.5-44.8 days), PH (100.7-129.6 cm), GPS (44.2-56.5), TGW (40.9-51.9 g), GYPP (14.12-20.48 g) and GYPA (13.18-19.11 ard). Grain yield/plant ranged from 14.12 g for the Accession No. 9150 to 20.48 g for Sakha

Table 8: Means across irrigation regimes and seasons for agronomic and yield traits and drought tolerance index (DTI) of each genotype.

GenotypeNo.	AccessionNo.	DTA	DTM	GFP(day)	PH(cm)	SPS	GPS	SPS	TGW(g)	GYPP(g)
1	9226	109.3	150.2	40.9	116.9	9.32	45.5	10.7	50.0	14.87
2	9227	110.8	150.9	40.0	100.7	9.38	49.9	10.9	48.4	19.84
3	9234	109.2	147.3	38.0	121.8	8.6	44.2	11.0	51.1	18.26
4	9235	109.9	147.7	37.6	120.1	9.38	53.7	11.2	48.0	17.12
5	9236	109.3	148.3	38.9	122.2	9.32	56.5	11.0	48.0	15.74
6	9311	110.3	155.3	44.8	127.8	9.59	49.6	11.2	45.7	14.76
7	9331	108.5	149.8	41.1	116.1	8.87	48.1	10.4	51.1	16.73
8	9373	110.2	153.9	43.3	118.9	9.27	52.3	11.8	45.6	15.48
9	9361	108.6	148.2	39.4	125.8	8.63	49.8	11.4	49.8	16.41
10	9144	109.4	148.0	38.5	126.6	8.88	53.8	11.4	49.5	15.29
11	9120	109.5	150.2	40.6	129.6	8.86	47.5	10.8	44.9	14.4
12	9266	109.3	146.3	36.7	122.2	9.11	53.6	11.7	48.5	16.77
13	9286	108.5	146.0	37.3	123.8	8.68	49.9	10.3	51.8	14.5
14	9287	108.3	148.0	39.6	124.8	9.25	50.8	10.3	51.9	16.21
15	9222	108.6	149.0	40.3	125.6	8.48	51.7	11.1	48.3	16.61
16	9290	109.9	151.1	41.0	124.3	8.96	49.1	11.3	49.3	15.26
17	9150	108.9	149.8	40.8	122.7	9.11	46.2	10.8	40.9	14.12
18	9293	108.3	147.3	38.9	124.0	9.13	48.5	10.2	47.7	15.46
19	9243	110.1	151.5	41.3	110.0	8.49	48.2	10.6	50.3	15.04
20	9110	109.8	153.6	43.7	122.8	8.8	47.2	11.2	47.6	14.51
21	Yakora	109.6	149.9	40.2	110.8	8.5	54.8	11.0	46.8	17.49
22	Sakha 64	109.2	140.0	30.5	114.4	8.42	55.6	11.2	45.8	20.48
LSD$_{05}$		0.88	1.24	1.47	3.03	0.36	4.41	0.55	2.12	1.19
Min		108.3	140.0	30.5	100.7	8.42	44.2	10.2	40.9	14.12
Max		110.8	155.3	44.8	129.6	9.59	56.5	11.8	51.9	20.48

Several studies have also indicated that there is genotypic variation in grain yield of bread wheat under water stress and non-stress conditions (Al-Naggar *et al*., 2004 and 2007a).

64 (an Egyptian commercial cultivar). Sakha 64 had the highest grain yield/acre (19.11 ard) and was the earliest genotype in maturity (140.0 days) and had the highest number of grains/spike (56.54). Genotype G6 (Land race Accession No. 9311) had the longest grain filling period (44.79 day), the highest number of spikes/plant (9.59), but was the latest genotype in maturity (155.32 day).

Several workers also reported genotypic differences in wheat under both drought stress and non-stress conditions for number of spikes/plant (Kheiralla *et al*., 1997 and Al-Naggar *et al*., 2004), grains per spike (Sharma and Bhargava, 1996, 100-grain weight (Fischer and Maurer 1978 and Kheiralla *et al*., 1997) and plant height (Sharma and Bhargava, 1996, and Al-Naggar *et al*., 2004, 2007, 2015a and 2017).

Results on grain quality traits across irrigation regimes (Table 9) show that grain protein content ranged from 11.42% for G4 (Accession No. 9234) to 20.87% for G17 (Accession No. 9150). The landrace G11 (Accession No. 9120) came in the second rank for GPC (18.30%). Maximum grain starch content (67.03%) was shown by the landrace G2 (Accession No. 9227), but the minimum GSC (55.29%) was given by the landrace G11 (Accession No. 9120). The range for grain ash content was between 1.23% for G21 (Yakora) and 3.25% for G17 (Accession No. 9150). Grain moisture content ranged from 12.29% for G11 (Accession No. 9120) to 13.33% for G2 (Accession No. 9227). The landrace G2 (Accession No. 9227) had the highest contents of both grain starch and grain moisture. The landrace G17 (Accession No. 9150) had the highest contents of both grain protein and grain ash.

The landrace G17 (Accession No. 9150) had the highest grain protien content (20.87%), but had the lowest grain yield/plant (14.12g). The landrace G11 (Accession No. 9120) had the tallest plant (129.56 cm), but the shortest genotype (100.74 cm) was the landrace G2 (Accession No. 9227), which had the highest starch content (67.97%). The genotype G18 (Accession No. 9293) was the earliest in anthesis and G14 (Accession No. 9287) had the highest grain moisture content (13.87%). This can be explained that not only some

Table 9: Means for grain quality traits of each genotype across two irrigation regimes in 2016/2017 season.

Genotype No.	Accession No.	Protein Content %	Starch Content %	Ash Content %	Moisture Content %
1	9226	16.44	61.55	1.37	13.00
2	9227	11.60	67.03	1.74	13.33
3	9234	12.94	63.39	1.49	12.87
4	9235	11.42	57.49	3.02	12.93
5	9236	17.06	60.75	2.13	13.10
6	9311	17.28	58.16	2.70	13.00
7	9331	15.72	60.23	1.52	12.87
8	9373	16.29	59.73	2.41	12.59
9	9361	14.48	60.26	1.42	12.80
10	9144	14.80	61.23	1.55	12.95
11	9120	18.30	55.88	2.83	12.29
12	9266	13.91	64.63	1.53	13.11
13	9286	16.25	61.63	1.50	12.64
14	9287	13.71	64.30	1.60	13.24
15	9222	15.54	62.48	1.74	13.06
16	9290	14.58	62.39	1.37	12.58
17	9150	20.87	55.29	3.25	12.92
18	9293	16.43	62.11	1.41	12.80
19	9243	15.23	61.73	1.96	12.80
20	9110	15.83	62.39	1.81	12.68
21	Yakora	14.39	63.01	1.23	12.80
22	Sakha 64	13.47	62.23	1.67	13.18
LSD_{05}		0.399	0.948	0.209	0.462
Min		11.42	55.29	1.23	12.29
Max		20.87	67.03	3.25	13.33

agronomically important traits but also grain quality traits which have been decreased during term breeding of modern cultivars (Newton *et al.*, 2010). The landrace G17(Accession No. 9150) can therefore be exploited in plant breeding programs for improving grain protein content of the modern bread wheat varieties. Our study recommends that landrace G17 (Accession No. 9150) could be crossed to one of the highest yielding genotypes (Sakha 64, G2 or G3) to select in their segregating generations some transgressive segrgants that accumulate genes of high grain yield and high grain protein content. Several investigators reported genotypic variation in grain protein content in wheat (Ortiz-Monasterio *et al.*, 1997; Le Gouisetal, 2000; Foulkes *et al.*, 2006 and Barraclough *et al.*, 2010 and Al-Naggar *et al.*, 2015b).

Effect of genotype × irrigation regime

Means of each genotype (from No. 1 to No. 22) under each environment for all studied traits are presented in Figs. (1 through 9) and Table 10. It is observed from table and figures that the rank of genotypes generally varied from one environment (WW) to another (WS) confirming the ANOVA results (Tables 4 and 5) that mean squares due to genotype x irrigation regime were significant for all studied traits, except for the grain quality traits GPC, GSC, GAC and GMC, where the rank of genotypes was approximately the same.

The earliest landrace for DTA was genotype No.18 under WW, but was No. 17 under WS and the latest genotype for DTA was No. 2 under WW, but was No. 16 under WS. For days to maturity, the earliest genotype under both WW and WS was the check Egyptian cultivar Sakha 64, but the latest one was the landrace No. 6 under WW and the landrace No. 8 under WS. For grain filling period (GFP), the shortest period was performed by the landrace No.2 under both WW and WS and the longest period was shown by landrace No. 6 under WW and No. 8 under WS. Regarding plant height, the shortest plant was exhibited by G2 under WW and G19 (Accession No. 9243) under WS. Moreover, the tallest plant was performed by the landrace No. 11 under WW, but was shown by the landrace No.4 under WS.

With respect of spikes/plant, the large number was given by the landrace No. 2 under WW, but by the landrace No.6 under WS. The lowest number of SPP was shown by genotype No. 22 (Sakha 64) under WW, but was exhibited by the landrace No. 13 under WS. Regarding spikelets/ spike, the lowest number was given by the landrace No. 14 under WW, but by the landrace No. 19 under WS. The highest number of SPS was given by the landrace No. 8, but was given by the landrace No. 12 under WS. For thousand grain weight, the heaviest grain was shown by the landrace No. 14 under WW, but was exhibited by the landrace No. 2 under WS. The lightest

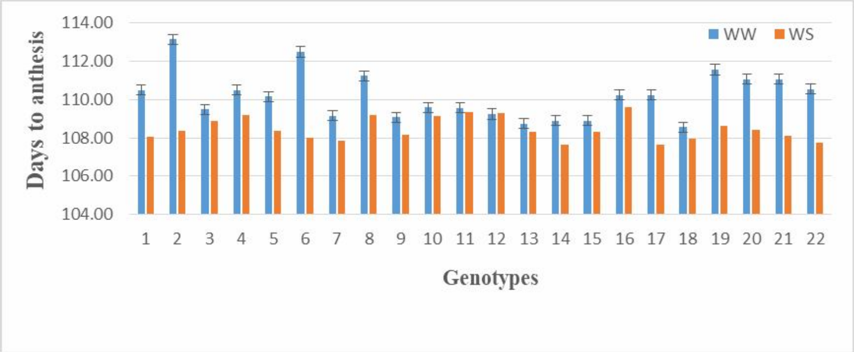

Fig. 1: Mean number of days to anthesis of genotypes from No. 1 to No. 22 under well watering (WW) and water stress (WS) across two seasons.

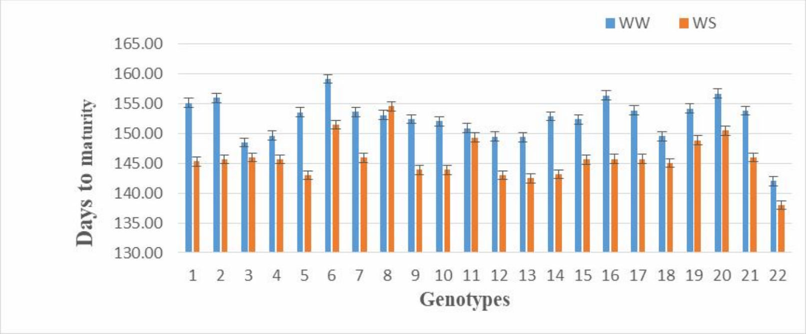

Fig. 2: Mean number of days to maturity of genotypes from No. 1 to No. 22 under well watering (WW) and water stress (WS) across two seasons.

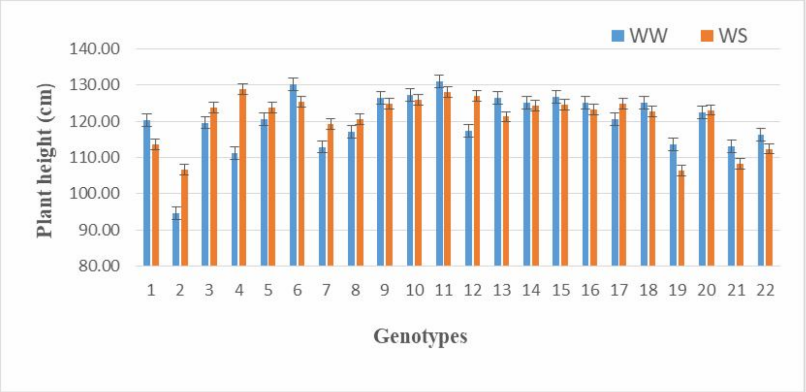

Fig. 3: Mean plant height of genotypes from No. 1 to No. 22 under well watering (WW) and water stress (WS) across two seasons.

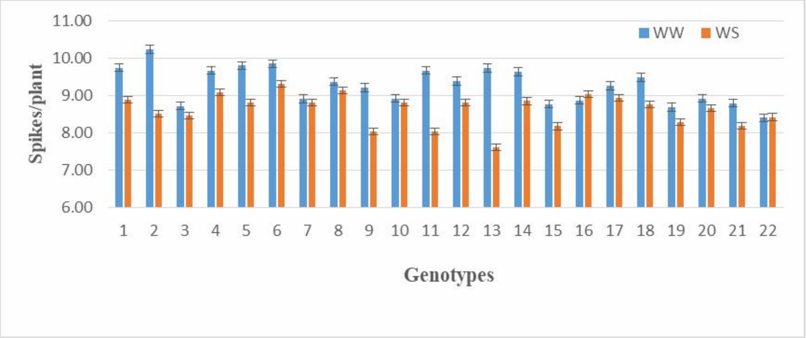

Fig. 4: Mean number of spikes/plant of genotypes from No. 1 to No. 22 under well watering (WW) and water stress (WS) across two seasons.

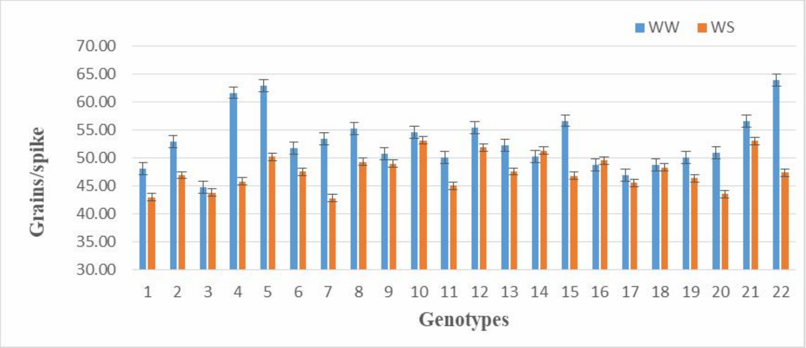

Fig. 5: Mean number of grains/spike of genotypes from No. 1 to No. 22 under well watering (WW) and water stress (WS) across two seasons.

grain was shown by the landrace No. 17 under both WW and WS environments.

Regarding grain yield per plant, the highest yielding genotype was the landrace No. 2 under WW, but was the Egyptian check cultivar Sakha 64 (G22) under WS conditions. The lowest yielding landrace was G6 under WW, but was G19 (Accession No. 9243) under WS.

The highest grain yielding genotypes was the landrace G2 followed by Sakha 64, Yakora and landrace G4, in a descending order under WW and Sakha 64 followed by the landraces G3, G2 and G15 (Accession No. 9222), in a descending order under WS (Table 10 and Fig. 7). The landraces G6, G15 (Accession No. 9222), G1 (Accession No. 9226) and G18 (Accession No. 9293) showed increments in grain yield due to water stress, ranging from 1% to 8.1%. Moreover, the landrace G10 (Accession No. 9144) showed the lowest reduction (0.5%) due to water stress followed by G11 (Accession No. 9120) (1.8%) and G13 (Accession No. 9286) (4.5%). On the contrary, the greatest reduction (25.8%) in grain yield due to water stress, was exhibited by Yakora (the international drought tolerant check variety), which was not expected and might be explained by its negative interaction with the environment in Egypt under deficit irrigation conditions. In the 2nd ,3rd and 4th place regarding the greatest reduction in grain yield came the landrace G8 (25.3%), G19(Accession No. 9243) (24.9%) and G2 (Accession No. 9227) and G4 (Accession No. 9235) (21.9%).

For grain quality traits, the genotype x irrigation interaction was not significant, indicating that the rank of genotypes was similar under both environments (WW and WS). Grain protein content and grain ash content increased due to water deficit, with a slight difference among genotypes with regard of such increments (Figures 8 and 9). On the contrary, grain starch content and grain moisture content decreased due to water stress; with a slight difference among genotypes with regard of such decreases. The highest GPC (21.87%) was given by the landrace No. 17 under WS and the lowest

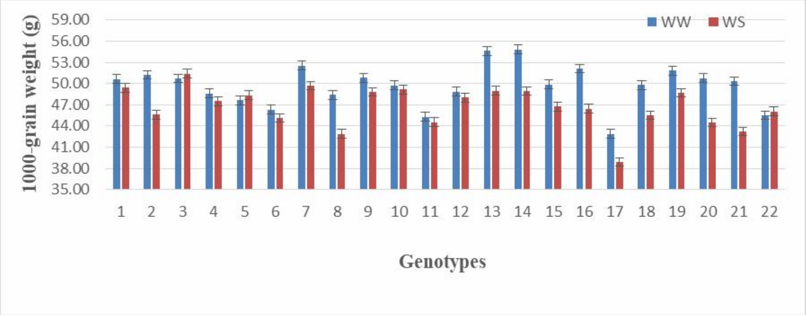

Fig. 6: Mean weight of 1000 grains of genotypes from No. 1 to No. 22 under well watering (WW) and water stress (WS) across two seasons.

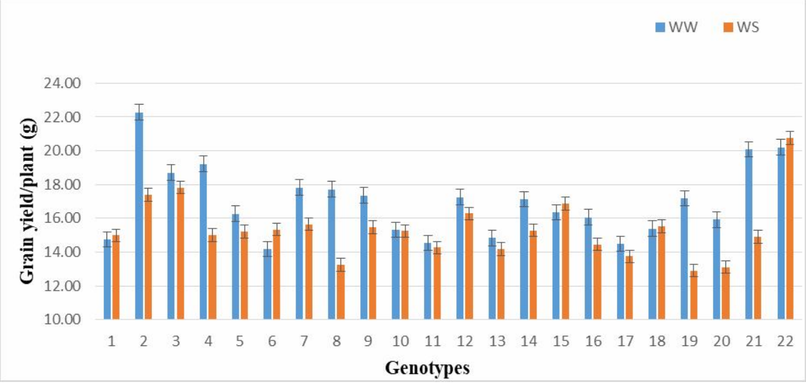

Fig. 7: Mean grain yield/plant of genotypes from No. 1 to No. 22 under well watering (WW) and water stress (WS) across two seasons.

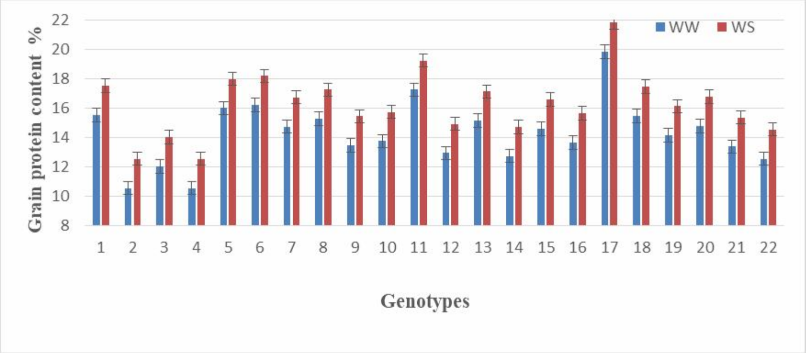

Fig. 8: Mean grain protein content of genotypes from No.1 to No.22 under well watering (WW) and water stress (WS) across two seasons.

GPC (10.54%) was given by the landraces G2 and G4 under WW conditions. For GSC, the highest value (67.97%) was shown by landrace No.2 under WW and the lowest value (54.34%) was given by the landrace No. 17 under WS. For GAC, the largest value (3.34%) was given by landrace No.17 under WS and the lowest value (1,14%) was given by the check cultivar Yakora (No. 21) under WW. The highest GMC (13.87%) was given by the landrace No. 14 under WW and the lowest GMC (11.93%) was given by the landrace G11(Accession No. 9120) under WW conditions.

Changes in protein content with application of different irrigation levels differ with cultivar (Clarke *et al.*, 1984, Fowler *et al.*, 1990 and Al-Naggar *et al.*, 2015b and 2016). Semidwarf wheat cultivars show a smaller increase in grain protein with small applications of N fertilizer than do cultivars of conventional height due to greater yield potential of semidwarf wheats (Clarke *et al.*, 1984). The rank of wheat genotypes for GPC, GSC, GMC and CAC was similar in the two environments, indicating less effect of interaction between genotype and irrigation level on these traits. A similar conclusion for GPC was reported by Al-Naggar *et al.*, (2015 b and 2016).

Generally, it is known that drought-induced reduction in crop grain yield is associated with an increase in protein content (Garrido-Lestache *et al.*, 2005; Dupont *et al.*, 2006). A study carried out in several regions of Spain showed moisture stress caused by low rainfall resulted in a significant increase in protein content in the grains of durum wheat (Rharrabti *et al.*, 2003). Another study conducted by Garrido-Lestache *et al.*, (2005) in southern Spain showed maximum values of protein content during the period when rainfall was lowest. Drought stress is known to reduce contents of carbohydrates including sucrose and starch in cereal grains, the latter being 65% of cereal kernels (Barnabas *et al.*, 2008).

Drought tolerance index

Drought tolerance index (DTI) values of studied genotypes estimated using the equation suggested by Fageria (1992) under the stressed environment WS are presented in Table (10 and Fig. 10). According to our scale, when DTI is ≥1.0, it indicates that genotype is tolerant (T), if DTI is 1.0, it indicates that genotype is moderately tolerant (MT) and if DTI is <1.0, it indicates that genotype is sensitive (S).

Based on DTI values, the 22 studied wheat genotypes were grouped into three categories under water stress, namely tolerant (9 genotypes; 7 landraces and the two checks), moderately tolerant (one genotypes; the landrace G14) and sensitive (12 landraces) (Table 10).

The drought tolerant landraces were G2, G3, G4, G7, G9, G12 and G15. The highest DTI (1.61) under the stressed environment (WS) was exhibited by the local commercial

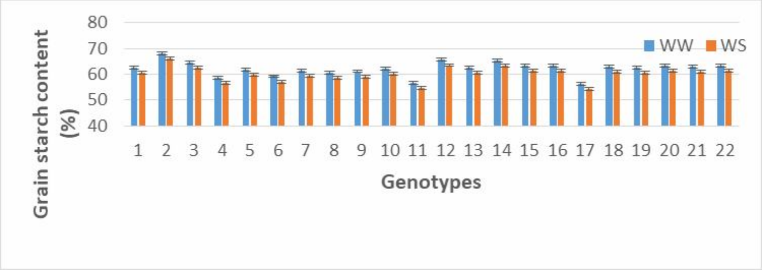

Fig. 9: Mean grain starch content of genotypes from No.1 to No.22 under well watering (WW) and water stress (WS) across two seasons.

Table 10: Means of each genotype under each environment across two seasons for grain yield/plant (GYPP), grain yield/acre (GYPA), reduction (Red) and drought tolerance index (DTI).

Geno-type	Access-ion No.	GYPP(g)		GYPA(ard)		Red(%)	DTI
		WW	WS	WW	WS		
1	9226	14.8	15.0	13.8	14.0	-1.6	0.85
2	9227	22.3	17.4	20.8	16.2	21.9	1.49
3	9234	18.7	17.8	17.5	16.6	4.7	1.28
4	9235	19.2	15.0	18.0	14.0	21.9	1.11
5	9236	16.3	15.2	15.2	14.2	6.4	0.95
6	9311	14.2	15.3	13.2	14.3	-8.1	0.84
7	9331	17.8	15.6	16.6	14.6	12.3	1.07
8	9373	17.7	13.2	16.5	12.4	25.3	0.90
9	9361	17.4	15.5	16.2	14.4	10.9	1.03
10	9144	15.3	15.3	14.3	14.2	0.5	0.90
11	9120	14.5	14.3	13.6	13.3	1.8	0.80
12	9266	17.3	16.3	16.1	15.2	5.7	1.08
13	9286	14.8	14.2	13.9	13.2	4.5	0.81
14	9287	17.1	15.3	16.0	14.3	10.8	1.01
15	9222	16.4	16.9	15.3	15.8	-3.2	1.06
16	9290	16.1	14.5	15.0	13.5	9.9	0.89
17	9150	14.5	13.7	13.5	12.8	5.2	0.77
18	9293	15.4	15.5	14.4	14.5	-1.0	0.92
19	9243	17.2	12.9	16.0	12.0	24.9	0.85
20	9110	15.9	13.1	14.9	12.2	17.7	0.80
21	Yakora	20.1	14.9	18.7	13.9	25.8	1.15
22	Sakha 64	20.2	20.8	18.9	19.4	-2.7	1.61
Aver.		17.0	15.4	15.8	14.3	9.54	1.01
Min		14.2	12.9	13.2	12.0	-8.1	0.77
Max		22.3	20.8	20.8	19.4	25.8	1.61
LSD$_{.05}$		1.9	1.4	1.8	1.3		
LSD$_{.01}$		2.6	1.9	2.4	1.8		

wheat variety (Sakha 64) used as a check. The 2nd and 3rd highest genotypes in DTI (DTI=1.49 and 1.28) were the landraces G2 (Accession No.) and G3 (Accession No.), respectively. For productivity (grain yield) under WS, the three genotypes Sakha 64, the landraces G3 and G2 ranked 1st, 2nd and 3rd, respectively, indicating that these three genotypes were the most drought tolerant and the highest yielding under drought stress environment. These three genotypes should be recommended to bread wheat breeding programs aiming at improving drought tolerance.

On the contrary, the most drought sensitive genotype was the landrace G17 (Accession No 9150.) (Table 10); its grain yield under drought stress was the 4th lowest (Table 10). Several investigators reported genotypic variation in grain yield and grain protein content in wheat (Van Sanford and MacKown,1986, Ortiz-Monasterio *et al.*, 1997; Foulkes *et al.*, 2006 and Barraclough *et al.*, 2010 and Al-Naggar *et al.*, 2015b and 2016).

Several authors described the negative relationship between the percentage of grain protein and grain yield (Löffler and Busch, 1982). Implications to overcome the negative correlation between the percentage of grain protein and grain yield were reviewed by Feil (1997).

Grouping landraces based on drought tolerance and grain yield

Drought tolerance index (DTI) of studied landraces and check cultivars was plotted against mean grain/plant of the same genotypes under water stress (WS) Fig. 2 and under well watering (WW) Fig. 11, which made it possible to distinguish between four groups, namely tolerant high-yielding, tolerant low-yielding, sensitive high-yielding and sensitive low-yielding according to Al-Naggar *et al.*, (2015a and 2017).

Under water stress (WF), the genotype G22 (the check commercial cultivar Sakha 64) and the landraces G2 (Accession No.9227) and G3 (Accession No.9234) followed by G15 (Accession No.9222), G12 (Accession No.9266), G7 (Accession No.9331), and G9 (Accession No.9361), in a descending order were classified as drought tolerant and high yielding genotypes, *i.e.* they could be considered as the most water stress tolerant and the most responsive genotypes to water stress in this study Fig. 12. There was only one genotype belonging to the group of sensitive and high yielding genotypes under WS; namely G18 (Accession No.9293). The genotype G21 (Yakora) and landraces G4 (Accession No.9235) and G14 (Accession No.9287) were classified as tolerant and low-yielding (3rd

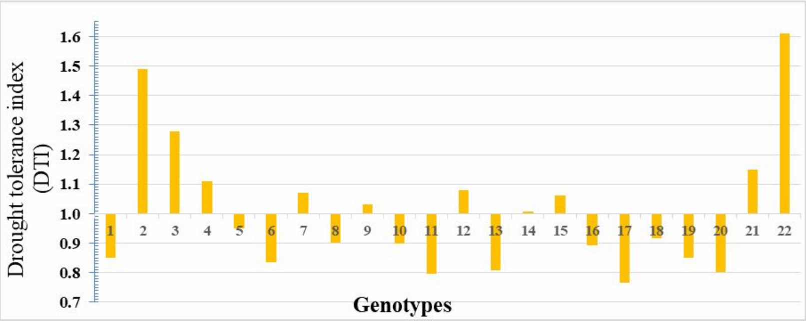

Fig. 10: Drought tolerance index (DTI) of genotypes from No.1 to No.22 under water stress (WS) across two seasons.

group). The genotypes No. 1 and 3 occupied the group of tolerant and low yielding under WSF. The landraces No 20, 19, 17, 8, 11, 13, 16, 1, 5, 10 and 6 were classified as water stress sensitive and low yielding and therefore could be considered sensitive and low yielding Fig. 12.

Under well watering (WW), the landrace G2 (Accession No.9227) followed by the check Egyptian cultivar Sakha 64 (G22) and the international check G21 (Yakora), and the landraces G4 (Accession No.9235), G3 (Accession No.9234), G7 (Accession No.9331), G9 (Accession No.9361), G12 (Accession No.9266) and G14 (Accession No.9287), in a descending order, were classified as drought tolerant and high yielding Fig. 12; they could be considered as the most water stress tolerant and the most responsive genotypes to water stress in this study. Only two landraces (G8 and G9) belonged to the 2nd group (sensitive and high-yielding). The 3rd group involved only one landrace; namely G15 (Accession No.9222). On the contrary, landraces No. 17, 11, 6, 13, 1, 20, 10, 16, 18 and 5 were classified as water stress sensitive and low yielding Fig. 12.

Summarizing the above-mentioned classifications, it is apparent that the landraces G2 (Accession No.9227) followed by G3 (Accession No.9234), G12 (Accession No.9266), G7 (Accession No.9331) and G9 (Accession No.9361), in a descending order, were the best genotypes that occupied the first group (best one) in all classifications; they are the most efficient, most drought tolerant, the highest yielder under WS as well as WW. These landraces could be recommended to future wheat breeding programs for use in developing drought tolerant and high

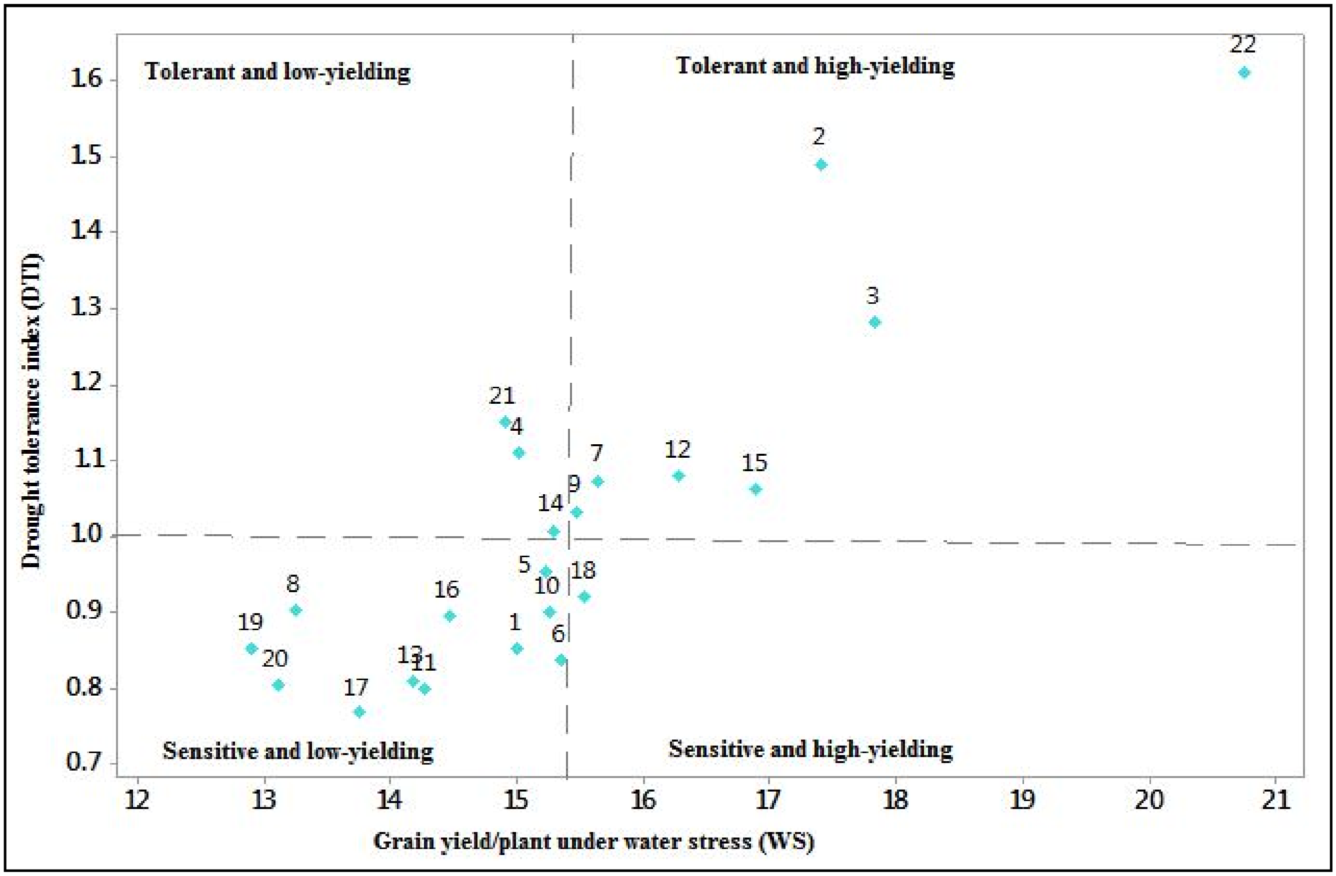

Fig. 11: Relationships between drought tolerance index (DTI) and means of grain yield/plant (GYPP) of genotypes (from No. 1 to No. 22) under water stress (WS) across seasons. Broken lines represent mean GYPP and DTI.

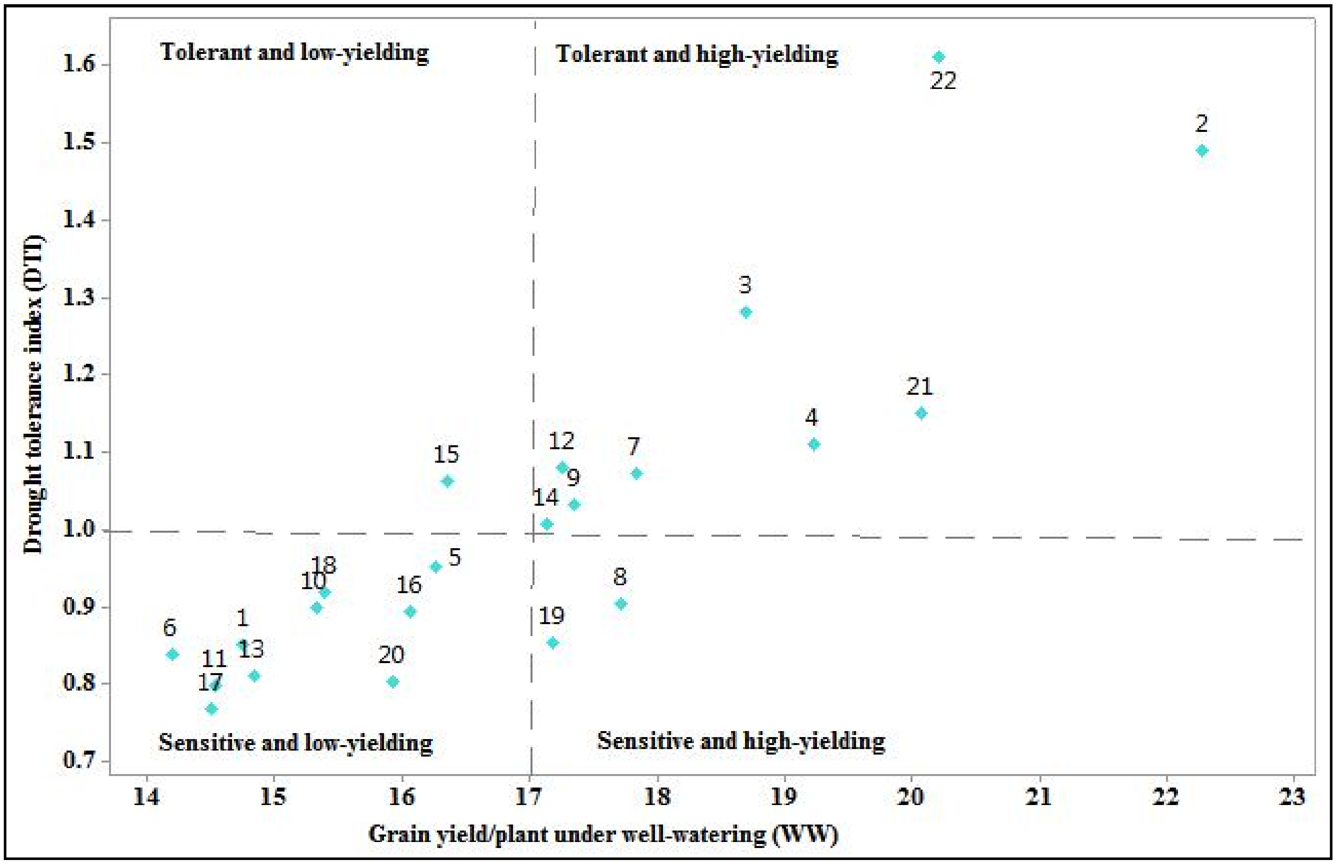

Fig. 12: Relationships between drought tolerance index (DTI) and means of grain yield/plant (GYPP) of genotypes (from No. 1 to No. 22) under well watering (WW) across seasons. Broken lines represent mean GYPP and DTI.

yielding genotypes, because they might possess genes for both drought tolerance and high grain yield.

Advantages and disadvantages of selected landraces

Landrace G2 (Accession No. 9227): The highest yielding under WW, the third highest yielding under WS, the second highest drought tolerant genotype, the highest grain starch content under WW and WS, but the lowest grain protein content under WW and WS.

Landrace G3 (Accession No. 9234): The second highest grain yield under WS and the third highest drought tolerant.

Landrace G4 (Accession No. 9235): The third highest grain yield under WW, the fifth highest drought tolerant genotype, but the lowest grain protein content under WW and WS.

Landrace G12 (Accession No. 9266): The second highest in grain protein content and the second highest in grain starch content.

Landrace G17 (Accession No. 9150): The highest in grain protein content under WW and WS, the highest in grain ash content, but the lowest in grain yield under WW, the most sensitive to drought, the lowest in grain starch content.

The advantages of the above-mentioned land races could be

Table 11: Phenotypic correlation coefficients (Spearman) among studied traits of 22 wheat landraces and check cultivars across two irrigation regimes and two seasons.

Trait	DTA	DTM	GFP	PH	SPP	GPS	SPS	TGW
DTM	0.659**							
GFP	0.417	.941**						
PH	-0.232	-0.05	0.028					
SPP	0.306	0.264	0.154	0.046				
GPS	0.085	-0.317	-0.467*	-0.096	0.042			
SPS	0.449*	0.083	-0.038	0.130	-0.023	0.366		
TGW	-0.355	-0.31	-0.228	-0.083	-0.144	-0.142	-0.295	
GYPP	-0.042	-0.401	-0.488*	-.495*	-0.136	0.491*	0.217	0.174
GMC	-0.128	-0.299	-0.355	-0.206	0.282	0.385	-0.028	0.140
GPC	-0.09	0.388	0.502*	0.370	0.189	-0.358	-0.249	-0.504*
GSC	-0.094	-0.211	-0.258	-0.199	-0.247	0.080	-0.021	0.399
GAC	0.346	0.326	0.295	0.016	0.346	0.009	0.037	-.509*
DTI	-0.077	-0.439*	-0.523*	-0.485*	-0.139	0.491*	0.178	0.196

* and ** indicate non-significant and significant at 0.05 and 0.01 probability levels, respectively

Continue Table 11.

Trait	GYPP	GMC	GPC	GSC	GAC
GMC	0.497*				
GPC	-0.810**	-0.354			
GSC	0.439*	0.342	-0.556**		
GAC	-0.278	0.135	0.329	-0.512*	
DTI	0.998**	0.501*	-0.808**	0.444*	-0.304

* and ** indicate non-significant and significant at 0.05 and 0.01 probability levels, respectively

utilized in the future breeding programs to develop high grain quantity and quality wheat varieties under well watering and water stress conditions. Morphological traits are very important for grouping wheat genetic resources, such as landraces, and also are essential and useful for plant breeders seeking to improve existing germplasm by introducing novel genetic variation for certain traits into the breeding populations (Salem *et al.,* 2008 and Najaphy *et al.,* 2012).

Trait Interrelationships

Phenotypic correlation coefficients between all studied traits and drought tolerance index (DTI) across the two seasons, the two irrigation regimes and across all landraces and check cultivars were estimated and presented in Table 11. Drought tolerance index (DTI) showed a perfect positive and significant (≤ 0.01) correlation coefficient (r= 0.998) with grain yield/plant or grain yield/acre, indicating that high grain yield is a perfect trait to select for high drought tolerance; this conclusion was previously reported by several investigators (Al-Naggar *et al.,* 2004, 2011, 2016, 2017).

DTI showed a positive and significant correlation coefficient (≤ 0.05 or ≤ 0.01) with each of grains/spike (GPS), grain starch content (GSC) and grain moisture content (GMC) and a negative and significant correlation coefficient (≤ 0.05 or ≤ 0.01) with each of days to maturity (DTM), grain filling period (GFP), plant height (PH) and grain protein content (GPC).

Grain yield/plant showed perfect positive association with DTI for combined data across WW and WS environments, that is why the estimates of correlation coefficients between GYPP and other traits are very close to those between DTI and the same traits (Table 16). Grain yield/plant showed a positive and significant correlation coefficient (≤ 0.05 or ≤ 0.01) with each of grains/spike (GPS), grain starch content (GSC) and grain moisture content (GMC) and a negative and significant correlation coefficient (≤ 0.05 or ≤ 0.01) with each of grain filling period (GFP), plant height (PH) and grain protein content (GPC). A negative correlation between the yield and protein content of wheat grain was also reported by other authors (e.g. Balla *et al.*, 2011). In maize, Ortiz-Monasterio *et al.*, (1997) and Sinebo *et al.*, (2004) reported negative associations of grain yield with protein content. Similar conclusion was reported by Gorny *et al.*, (2011) and Al Naggar *et al*., (2015b and 2016) in wheat.

The strongest correlation was observed between GYPP and DTI (r= 0.998), between grain filling period (GFP) and days to maturity (DTM) (r= 0.941), and between grain protein content (GPC) and each of DTI (r= -0.808) and GYPP (r= -0.810) across all genotypes, irrigation regimes and seasons of study.

Number of days to physiological maturity (DTM) had a positive and significant correlation coefficient with each of days to anthesis (DTA), spikelets/spike (SPS) and grain filling period (GFP). Grain filling period had a positive and significant correlation with grain protein content and a negative and significant correlation with number of grains/spike (GPS). Thousand grain weight (TGW) showed a negative and significant correlation with each of grain protein content (GPC) and grain ash content (GAC).

A negative and significant correlation was found between GPC and grain starch content (GSC) and between GSC and GAC. An inverse correlation between the protein content and B-type starch granules in wheat grains was reported by Balla *et al*., 2011.The significant negative correlation between starch and grain protein content in the case of drought may indicate an important interaction between starch granules and proteins in determining the bread making properties of flour (Balla *et al*., 2011).

There is an increased pressure on plant breeders to improve grain protein and yield simultaneously. The feasibility of this simultaneous improvement, however, is a subject of controversy. Numerous genetic studies have shown the existence of major genes conferring enhanced grain protein concentration without adverse effects on yield (Johnson *et al.,* 1973 and Al-Naggar *et al.*, 2015b). Nevertheless, plant breeders' experience shows that simultaneous selection of grain protein concentration and yield is only occasionally successful at enhancing both characters (Loffler and Busch, 1982).

While the observed variation in grain protein concentration in wheat is large (6-22%, Johnson and Lay 1974), much of this variation is environmental rather than genetic in origin. The protein concentration is determined by the genetic background, but also, to a large extent, by environmental factors such as nitrogen, water access, and temperature conditions. Consequently, selection for high grain protein concentration, especially in the early generations of a breeding program, is likely to be ineffective. Secondly, many studies have shown a negative correlation (r typically between -0.4 and -0.6) between grain protein concentration and overall yield (e.g. Johnson *et al.*, 1985).

Both processes, *i.e.* grain yield and grain protein content appear to be governed by different genetic factors (Gallais and Hirel, 2007). For instance, results of extensive molecular studies, on wheat and maize (Habash *et al*., 2007 and Laparche *et al*., 2007) revealed that different sets of genes (QTL regions) controlled various components of the two processes. Hence, the appearance of the above mentioned negative relationship between grain yield and grain protein content in the examined landraces may be a genetic quandary.

The results of this study indicate that drought tolerant genotypes under WS as well as WW conditions are characterized by early DTM, short grain filling period, short plant height and less GPC %, high grain yield/plant, and high grain moisture content, *i.e.* high ability to retain water in their cells. This conclusion is in accordance with other investigators (Al-Naggar *et al*., 2004, 2011, 2015b and 2016). These traits could be considered as selection criteria for drought tolerance in maize.

Significant correlations under drought stress were found between maize grain yield and grain filling period, and number of grains spike^{-1} (Chapman and Edmeades 1999 and Banziger *et al.,* 2002).

Significant and negative r value detected between GYPP of genotypes and plant height in WS environment indicated that shorter plants of genotypes are of high yielding, under drought conditions. This conclusion is in agreement with other investigators (Sangoi *et al.,* 2002) who reported that shorter genotypes are higher yielding than taller genotypes under both WW and water stress conditions. Simane *et al.,* (1993), using path analysis, found that the number of grains per spike and grain weight had significant, positive, direct effects on grain yield under moisture stress conditions, as well as under well-watered conditions. These traits could be considered as selection criteria for drought tolerance in wheat if they proved high heritability and high predicted genetic advance from selection. Drought tolerance as a trait can be assessed from any of these traits or from drought indices which accurately assess the genotypic yield response to drought stress (Fernandez, 1992 and Sallam *et al.,* 2014). This conclusion is in accordance with other investigators (Al-Naggar *et al.,* 2004, 2007, 2011, 2015a, 2016 and 2017).

Conclusion

The two studied factors; *i.e.* irrigation regime (I) and genotype (G) had significant effects on the majority of studied traits. The interaction effect (G × I) was significant for agronomic and grain yield traits, but was not significant for all the four grain quality traits; *i.e.* grain protein, starch, ash and moisture contents. Our study recommends that landrace G17 (the highest in grain protein content) could be crossed to one of the highest yielding genotypes (Sakha 64, G2 or G3) to select in their segregating generations some transgressive segrgants that accumulate genes of high grain yield and high grain protein content. The highest drought tolerant genotypes in this study were Sakha 64 and landraces G2, G3, G4, G7, G12 and G15. Thus, the two landraces G2 and G3 are drought tolerant and high yielding. These landraces could be recommended to future wheat breeding programs for use in developing drought tolerant and high yielding genotypes. The results concluded that drought tolerant genotypes are characterized by early maturity, short grain filling period, short plant height, high and grain yield/plant. It is evident that the best secondary traits for drought tolerance in our study are: GYPP and GPS traits.

References

Al-Naggar, A.M.M., R. Shabana, M.M. Abd-El-Aleem and Z. El-Rashidy (2017). Mode of inheritance of low-N tolerance adaptive traits in wheat (*Triticum aestivum* L.) under contrasting nitrogen environments. *Spanish Journal of Agricultural Research,* **15(2):** 1-11.

Al-Naggar, A.M.M., Kh.F. Al-Azab, S.E.S. Sobieh and M.M.M. Atta (2015a). Variation induction in wheat via gamma-rays and hybridization and gains from selection in derived heterogeneous populations for drought tolerance. *Scientia Agriculturae,* Vol.9 **(1):** 1-15.

Al-Naggar, A.M.M., M.M.M. Atta, A.M. Shaheen and K.F. EL-Azab (2007). Gamma rays and EMS induced drought tolerant mutants in bread wheat. *Egypt. J. Plant Breed.,* **11(3):** 135-165.

Al-Naggar, A.M.M., A.E.I. Ragab, S. Youssef Sawsan and M.R. Al-Bakry (2004). New genetic variation in drought tolerance induced *via* irradiation and hybridization of Egyptian cultivars of bread wheat. *Egypt. J. Plant Breed.,* **8:** 353–370.

Al-Naggar, A.M.M., R. Shabana, M.M. Abd El-Aleem and A. El-Rashidy Zainab (2015b). Diallel analysis of wheat grain protein content and yield in F_1 and F_2 generations under contrasting nitrogen conditions. *American Research Journal of Agriculture,* Vol.1**(4):** 12-29.

Al-Naggar, A.M.M., S.M. Soliman and M.N. Hashimi (2011). Tolerance to drought at flowering stage of 28 maize hybrids and populations. *Egypt. J. Plant Breed.,* **15(1):** 69-87.

Al-Naggar, A.M.M., M.M.M. Atta, M.A. Ahmed and A.S.M.

Younis (2016). Grain protein, oil and starch contents and yields of maize (*Zea mays* L.) as affected by deficit irrigation, genotype and their interaction. *International Journal of Plant and Soil Science,* **10(1):** 1-21.

Ashraf, M. (2014). Stress-Induced Changes in Wheat Grain Composition and Quality Critical Reviews in *Food Science and Nutrition.,* **54:** 1576–1583.

Balla, K., M. Rakszegi, Z. Li, F. B ekes, S. Bencze and O. Veisz (2011). Quality of winter wheat in relation to heat and drought shock after anthesis. *Agric. Res. Inst. Hung. Acad. Sci.,* **29:** 117–128.

Barnabas, B., K. J ager and A. Feh er (2008). The effect of drought and heatstress on reproductive processes in cereals.*Plant Cell Environ.,* **31:** 11–38.

Barraclough, P.B., J.R. Howartha, J. Jonesa, R. Lopez-Bellido, S. Parmara, Shepherda and M.J. Hawkesforda (2010). Nitrogen efficiency of wheat: Genotypic and environmental variation and prospects for improvement. *Eur. J. Agron.,* **33:** 1–11.

Chapman, S.C. and G.O. Edmeades (1999). Selection improves drought tolerance in tropical maize populations. II. Direct and correlated responses among secondary traits. *Crop Sci.,* **39:** 1315–1324. doi:10.2135/cropsci1999.3951315x.

Chen, X., D. Min, T.A. Yasir and Y.G. Hu (2012). Field crops research evaluation of 14 morphological, yield-related and physiological traits as indicators of drought tolerance in Chinese winter bread wheat revealed by analysis of the membership function value of drought tolerance (MFVD), *F. Crop Res.,* **137:** 195-201

Clarke, M., T. Towenley-Smith and T. McCaig (1984). Growth analysis of spring wheat cultivars of varying drought resistance. *Crop Sci.,* **24:** 537-541.

Cockram, J., C. Norris and D.M. O'Sullivan (2009). PCR-based markers diagnostic for spring and winter seasonal growth habit in barley. *Crop Science,* **49:** 403–410.

Dolferus, R., X. Ji and R.A. Richards (2011). Abiotic stress and control of grain number in cereals. *Plant Sci.,* **181:** 331–341.

Dupont, F.M., W. Hurkman, W. Vensel, C. Tanaka, K. Kothari, O. Chung and S. Altenbach (2006). Protein accumulation and composition in wheat grains: Effects of mineral nutrients and high temperature. *Eur. J. Agron.,* **25:** 96–107.

Fageria, N.K. (1992). Maximizing crop yields. Dekker. New York, 423.

FAOSTAT (2019). Food and Agriculture Organization, Statistical Division. Available online: http://www.fao.org/faostat/en/#data/QC (accessed on 20 November 2019).

Feil, B. (1997). The inverse yield-protein relationship in cereals: possibilities and limitation for genetically improving the grain protein yield. *Trends in Agronomy,* **1:** 103-119.

Fernandez, G.C.J. (1992). Effective Selection Criteria for Assessing Stress Tolerance. In Proceedings of the International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress, Taibei, Taiwan, 13–16 August 1992.

Fischer, R.A. and R. Maurer (1978). Drought resistance in spring wheat cultivars. I. Grain yield response. *Aust. J. Agric. Res.,* **29:** 897-907.

Fischer, R.A. (1973). The effect of water stress of various stages of development on yield processes in wheat. UNESCO: Plant Response to Climate Factors. Proc. Uppsala Symp. 1970, 233–241.

Flagella, Z., M.M. Giuliani, L. Giuzio, C. Volpi and S. Masci (2010). Influence of water deficit on durum wheat storage protein composition and technological quality. *Eur. J. Agron.,* **33:** 197–207.

Foulkes, J., M. Holdsworth, S. Kerr, S. Kightly, P. Barraclough, M. Hawkesford and S. Shewry (2006). Study of the scope for the application of crop genomics and breeding to increase nitrogen economy within cereal and rapeseed based food chains. Final Report for Project AR0714. Defra, London.

Fowler, D., J. Brydon, B.A. Darroch, M.H. Entz and A.M. Johnston (1990). Environment and genotype influence on grain protein concentration of wheat and rye. *Agron. J.,* **82:** 666-664.

Fuller, D.Q. (2007). Contrasting patterns in crop domestication and domestication rates: Recent archaeobotanical insights from the Old World. *Annals of Botany,* **100:** 903–924.

Garcia del Moral, L.F., A. Boujenna, J.A. Yanez and J.M. Ramos (1995). Forage production, grain yield and protein content in dual purpose triticalegrown for both grain and forage. *Agron. J.,* **87:** 902–908.

Garrido-Lestache, E.L., R.J. Lopez-Bellido and L. Lopez-Bellido (2005). Durum wheat quality under Mediterranean conditions as affected by N rate,timing and splitting, N form and S fertilization. *Eur. J. Agron.,* **23:** 265–278.

Gooding, M.J., R.H. Ellis, P.R. Shewry and J.D. Schofield (2003). Effectsof restricted water availability and increased temperature on the grain filling,drying and quality of winter wheat. *J. Cereal Sci.,* **37:** 295–309.

Gorny, A.G., Z. Banaszak, B. Lugowska and D. Ratajczak (2011). Inheritance of the efficiency of nitrogen uptake and utilization in winter wheat (*Triticum aestivum* L.) under diverse nutrition levels. *Euphytica,* **77:** 191–206.

Grassini, P., K.M. Eskridge and K.G. Cassman (2013). Distinguishing between yield advances and yield plateaus in historical crop production trends. *Nature Communications,* **4:** doi:10.1038/ncomms3918.

Guttieri, M.J., R. Ahmad, J.C. Stark and E. Souza (2000). End use quality of six hard red spring wheat cultivars at diûerent irrigation levels. *Crop Sci.,* **40:** 631-635.

Habash, D.Z., S. Bernard, J. Schondelmaier, J. Weyen and S.A. Quarrie (2007). The genetics of nitrogen use in hexaploid wheat: N utilisation, development and yield. *Theor. Appl. Genet.,* **114:** 403–19.

Houshmand, S., A. Arzani, S.A.M. Maibody and M. Feizic (2005). Evaluation of salt-tolerant genotypes of durum wheat derived from in vitro and field experiments. *Field Crops*

Res., **91:** 345–354.

Isidro, J., F. Álvaro, C. Royo, D. Villegas, D.J. Miralles and L.F. García del Moral (2011). Changes in duration of developmental phases of durum wheat caused by breeding in Spain and Italy during the 20th century and its impact on yield. *Ann. Bot.,* **107:** 1355–1366.

Johnson, V.A. and C.L. Lay (1974). Genetic improvement of plant protein. *J. Agric. Food Chem.,* **22:** 558-566.

Johnson, V.A., P.J. Mattern, J.W. Schmidt and J.E. Stroike (1973). Genetic advances in wheat protein quantity and composition. Proc. 4th Int. Wheat Genetic Symposium, Colombia, Missouri. pp. 547-556.

Johnson, V.A., P.J. Mattern, C.J. Peterson and S.L. Kuhr (1985). Improvement of wheat protein by traditional breeding and genetic techniques. *Cereal Chem.,* **62:** 350-355.

Kheiralla, K.A., A.A. Ismail and G.R. El-Nagar (1997). Drought tolerance and stability of some spring wheat cultivars. *Assiut J. of Agric. Sci.,* **28(1):** 75-88.

Kiliç, H. and T. Ya¢gbasanlar (2010). The Effect of Drought Stress on Grain Yield, Yield Components and some Quality Traits of Durum Wheat (*Triticum turgidum* ssp. durum). *Cultivars,* **38:** 164–170.

Labuschagne, M.T., O. Elago and E. Koen (2009). The influence of temperature extremes on some quality and starch characteristics in bread, biscuit and durum wheat. *J. Cereal Sci.,* **49:** 184–189.

Loffler, C.M. and R.H. Busch (1982). Selection for grain protein, grain yield, and nitrogen partitioning efficiency in hard red spring wheat. *Crop Sci.,* **22:** 591-595.

Mondal, S., R.P. Singh, J. Crossa, J. Huerta-Espino, I. Sharma, R. Chatrath, G.P. Singh, V.S. Sohu, G.S. Mavi, V.S.P. Sukuru and I.K. Kalappanavar (2013). Earliness in wheat: a key to adaptation under terminal and continual high temperature stress in South Asia. *Field Crops Res.,* **151:** 19–26.

Najaphy, A., R.A. Parchin and E. Farshadfar (2012). Comparison of phenotypic and molecular characterizations of some important wheat cultivars and advanced breeding lines. *Aust. J. Crop Sci.,* **6:** 326–332.

Newton, A.C., T. Akar, J.P. Baresel, P.J. Bebeli, E. Bettencourt, K.V. Bladenopoulos, J.H. Czembor, D.A. Fasoula, A. Katsiotis, K. Koutis, M. Koitsuka-Sotiriou, G. Kovacs, H. Larsson, MAAP de Carvalho, D. Rubiales, J. Russell, D.S. TMM and M.C. Vaz Patto (2010). Cereal landraces for sustainable agriculture. A review. *Agron Sustain Dev.* , **30(2):** 237–69.

Ortiz-Monasterio, J.I., K.D. Sayre, S. Rajaram and M. McMahon (1997). Genetic progress in wheat yield and nitrogen use efficiency under four nitrogen rates. *Crop Sci.,* **37:** 898-904.

Parry, M.L., C. Rosenzweig, A. Iglesias, M. Livermore and G. Fischer (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Glob. Environ. Change,* **14:** 53–67.

Peng, J., D. Sun and E. Nevo (2011). Wild emmer wheat, '*Triticum dicoccoides*', occupies a pivotal position in wheat domestication process. *Australian Journal of Crop Science,* **5(9):** 1127.

Rharrabti, Y., D. Villegas, C. Royo, V. Martos-N ìu Þnez and L.F. Garc ìýa del Moral (2003). Durum wheat quality in Mediterranean environments. II. Influence of climatic variables and relationships between quality parameters. *Field Crops Res.,* **80:** 133–140.

Salem, K.F.M., A.M. El-Zanaty and R.M. Esmail (2008). Assessing wheat (*Triticum Aestivum* L.) genetic diversity using morphological characters and microsatellite markers. *World J. of Agri. Sci.,* **4:** 538-544.

Sallam, A., E.S. Hamed, M. Hashad and M. Omara (2014). Inheritance of stem diameter and its relationship to heat and drought tolerance in wheat (*Triticum aestivum* L.). *J. Plant Breed. Crop Sci.,* **6:** 11–23.

Salter, P.J. and J.E. Godge (1967). Crop responses to water at different stages of growth. Commonwealth Bureau of Horticulture. East Mailing, Research Review No. 2.

Sangoi, L., M.A. Gracietti, C. Rampazzo and P. Bianchetti (2002). Response of Brazilian maize hybrids from different eras to changes in plant population. *Field Crops Res.,* **79:** 39-51.

Sharma, H.P. and S.C. Bhargava (1996). Relative sensitivity of wheat genotypes under moisture stress conditions. *Annals of Biology Ludhiana,* **12(1):** 39-42.

Simane, B., P.C. Struik, M.M. Nachit and J.M. Peacock (2003). Ontogenetic analysis of yield components and yield stability of durum wheat in water-limited environments. *Euphytica,* vol. **71:** no. 3, pp.211–219,1993.

Sinebo, W., R. Gretzmacher and A. Edelbaur (2004). Genotypic variation for nitrogen use efficiency in Ethiopian barley. *Field Crops Research,* **85(1):** 43-60 DOI: 10.1016/S0378-4290(03)00135-7.

Solomon, K.F., M.T. Labuschagne and A.T.P. Bennie (2003). "Responses of Ethiopian durum wheat genotypes to drought stress," *South African Journal of Plant and Soil,* vol. **20:** no. 2, pp.55–58.

Steel, R.G.D., J.H. Torrie and D. Dickey (1997). Principles and Procedure of Statistics. A Biometrical Approach 3rd Ed. McGraw Hill BookCo. Inc., New York. pp. 352-358.

Wardlaw, I.F. and J. Willenbrink (2000). Mobilization of fructan reserves and changes in enzyme activities in wheat stems correlate with water stress during kernel filling. *New Phytol.,* **148:** 413–422. [CrossRef].

Yan, J., M. Warburton and J. Crouch (2011). Association mapping for enhancing maize (*Zea mays* L.) genetic improvement. *Crop Science,* **51:** 433–449.

Zaharieva, M., N.G. Ayana, A.Al. Hakimi, S.C. Misra and P. Monneveux (2010). Cultivated emmer wheat (Triticum dicoccon Schrank), an old crop with promising future: A review. *Genet. Resour. Crop Evol.,* **57:** 937–62. https://doi.org/10.1007/s10722-010-9572-6.

Zeven, A.C. (1998). Landraces: a review of defnitions and classifcations. *Euphytica,* **104:** 127–139.