Scientific Journal of Agricultural Sciences 3 (2): 145-160, 2021
Print (ISSN 2535-1796) / Online (ISSN 2535-180X) DOI: 10.21608/sjas.2021.97378.1156

Response of Some Agronomic, Physiological and Anatomical characters for Some Bread Wheat Genotypes Under Water Deficit in North Delta Region

Farhat, W. Z. E.[1], Rania A. Khedr[2] , Shimaa A. Shaaban*[3]

[1]Wheat Research Department, Field Crops Research Institute, ARC, Egypt
[2] Crops physiology Research Department, Field Crops Research Institute, ARC, Egypt
[3] Department of Agricultural Botany, Faculty of Agriculture, Cairo University, Giza, Egypt.
*Corresponding author: Email: sh.agribotany@gmail.com

Received on: 27-9-2021 Accepted on: 15-11-2021

ABSTRACT

Two field experiments were performed on Sakha Agricultural Research Station Farm during 2017/18 and 2018/19 growing seasons, to study the agronomic, physiological, and anatomical response of eleven bread wheat cultivar and lines for two irrigation regimes levels (i.e., five irrigations, (recommended as control) and only one irrigation after 21 days planting (water stress)). Results showed that the agronomic (i.e., number of days to maturity, plant height, grain yield and its components), physiological (i.e., relative water content, and chlorophyll a & b) and anatomocal estimates (i.e., thickness of leaf lamina, cuticle layer, upper epidermis, lower epidermis, mesophyll tissue, midrib, main vascular bundle dimension (length and width), collenchyma tissue, xylem tissue, phloem tissue and bulliform cells) were decreased under water stress conditions, except for proline and leaf temperature. Line 1, Line 2, Sids 14, Giza 171 and Sakha 95 were the most tolerant genotypes and may be suitable for water shortage conditions. High values of relative water content, chlorophyll and proline contents, low values of flag leaf temperature, in addition to the lowest reduction in leaf anatomical characters may be useful selection criteria for water stress tolerance in bread wheat.

KEYWORDS: Wheat, water deficit, tolerance index, physiology and leaf anatomy

1. INTRODUCTION

Wheat (*Triticum aestivum* L. em. Thell.) is one of the most important and widely cultivated cereal crops in Egypt and worldwide. Water stress is the most environmental limiting factor facing crop productivity (Mujeeb-Kazi *et al.*, 2019). In addition, global climate change is increasing the severity of water stress (Fang and Xiong 2015 and Senapati *et al.*, 2019). The development of tolerant genotypes using present genetic resources is an important strategy to increase wheat production in the semiarid areas and means to cope with water stress (Mwadzingeni *et al.*, 2016 and Wasaya *et al.*, 2021).

Water stress has harmful effects and brings morphological, physiological, biochemical, anatomical and molecular changes in plants. Generally, decreasing agronomic and morphological characters were observed under the water stress condition (Shalaby *et al.*, 2020, Shehab-Eldeen and Farhat, 2020, Morsy *et al.*, 2021, Mu *et al.*, 2021, Nehe *et al.*, 2021 and Wasaya *et al.*, 2021).

At the level of physiological response, there were decreasing effects on relative water and chlorophyll contents under water stress (Wasaya *et al.*, 2021). In contrast, proline and leaf temperature was reported to be increased under the water stress conditions (El-Gammaal, 2018, Din *et al.*, 2020 and Mu *et al.*, 2021).

Different plant features such as leaf anatomy have been considered as an indicator of stress symptoms and useful for water stress tolerance (Niinemets and Sack 2006). Furthermore, the anatomical changes in the leaf may help plants to maintain high levels of photosynthetic rates and high transpiration efficiencies (Evans *et al.*, 1994). Cuticle thickness (Rojas *et al.*, 1983) is believed to be useful for breeding for water stress-tolerant genotypes.

Water stress tolerance as a trait can be assessed from correlated traits with high yield under these conditions or from drought indices which accurately assess the genotypic yield response to drought stress (Al-Naggar *et al.*, 2020 Shehab-Eldeen and Farhat, 2020, El Gataa *et al.*, 2021, Morsy *et al.*, 2021, and Nehe *et al.*, 2021).

Consequently, this research aimed to: (1) understand water deficit effects on the agronomic, physiological and anatomical levels, (2) identify tolerant genotypes of bread wheat to water deficit (3) assess reliable multiple selection indices for water deficit tolerance in bread wheat.

2. MATERIALS AND METHODS

2.1. Plant materials and experimental design

This study was conducted on Sakha Agricultural Research Station Farm (Egypt; 38°52′N 65°48′E, 6 m) with clay soil. Eleven Egyptian bread wheat cultivars and lines (Table 1) were evaluated using the flood irrigation method under two irrigation treatments the 1st one was normal (five irrigations including planting irrigation), while the 2nd one was water deficit (only one irrigation 21 days after the planting irrigation). The experiment was performed on 30th and 25th, November during 2017/18 and 2018/19 wheat growing seasons, respectively.

The genotypes were studied under each water treatment separately and the randomized complete blocks design with four replications was used. Each plot involved two rows 2.5 m long and 30 cm apart. Each experiment was enclosed by a 5 m border to reduce the lateral movement of irrigation water. Location of experiments was close to main drainage. Levels of the water table were measured at intervals through irrigation procedures. All cultural practices, except irrigation were applied as recommended by Wheat Research Department for Delta region of Egypt. The previous crop was maize in the two growing seasons. Data of Sakha meteorological station and Water amounts of irrigations across two seasons are presented in Tables 2 and 3.

Table 1. Names and pedigrees of the studied wheat genotypes.

Name	Pedigree and selection history*	Origin
Giza 168	MRL / BUC // SERI CM93046-8M-0Y-0M-2Y-0B-0GZ	EGYPT
Giza 171	SAKHA 93/GEMMEIZA 9 S. 6-1GZ-4GZ-1GZ-2GZ-0S	EGYPT
Sakha 95	PASTOR // SITE / MO /3/ CHEN / AEGILOPS SQUARROSA (TAUS) // BCN /4/ WBLL1. CMA01Y00158S-040POY-040M-030ZTM-040SY-26M-0Y-0SY-0S.	EGYPT
Gemmeiza 12	OTUS/3/SARA/THB//VEE CMSS97Y00227S-5y-010M-010Y-010M-2Y-1M-0Y-OGM	EGYPT
Shandweel 1	SITE/MO/4/NAC/TH. AC//3*PVN/3/MIRLO/BUC CMSS93B00567S-72Y-010M-010Y-010M-3Y-0M-0HTY-0SH	EGYPT
Sids 12	BUC//7C/ALD/5/MAYA74/ON//1160.147/3/BB/GLL/4/CHAT"S"/6/MAYA/VUL//CMH74 A. 630/4*SX SD7096-4SD-1SD-1SD-0SD	EGYPT
Sids 14	Bow"s"/Vee"s"//Bow's'/Tsi/3/BANI SUEF 1 SD293-1SD-2SD-4SD-0SD	EGYPT
Misr 3	ATTILA*2/PBW65*2/KACHU CMSS06Y00582T-099TOPM-099Y-099ZTM-099Y-099M-10WGY-0B-0EGY	EGYPT
Line 1	CHEN/AEGILOPS SQUARROSA(TAUS) // BCN /3/ 2* KAUZ /4/ GEN*2 // BUC / FLK /3/ BUCHIN. S. 16280-020S-015S-4S-0S	EGYPT
Line 2	WBLL1*2/4/BABAX/LR42//BABA×/3/BABX/LR42//BABAX. CMSS06Y00885T-099TOPM-099Y-099ZTM-099NJ-099NJ-26WGY-0B-0EGY	CIMMYT
Line 3	BAJ1/3/KIRITATI//ATTILA*2/PASTOR. CMSS07Y00288S-0B-099Y-099M-099Y-1M-0WGY-0EGY	CIMMYT

* Source: Wheat Research Department

Table 2. Monthly mean air temperature (At ^{O}C), mean relative humidity (RH %) and rainfed (mm/month) in winter seasons, 2017/18 and 2018/19 at Sakha site.

Month	AT ^{O}C 2017/18		AT ^{O}C 2018/19		RH %		Rainfall (mm)	
	Max. *	Min. *	Max.	Min.	2017/18	2018/19	2017/18	2018/19
November	25.3	13.4	27.0	15.2	62.2	57.6	30.0	10.1
December	22.0	11.5	21.0	10.7	68.1	63.9	4.1	12.5
January	19.7	8.9	19.3	6.7	67.9	53.0	29.7	6.1
February	23.2	10.3	21.4	7.8	60.5	57.0	5.6	6.7
March	29.3	12.1	24.0	9.5	44.2	54.8	1.8	16.7
April	31.5	14.3	28.2	12.4	43.4	47.3	11.5	3.0
May	36.1	19.2	36.7	17.4	40.8	34.1	0.0	0.0

* Max = maximum and Min = minimum

Table 3. Amount of supplied water in m^3 fed^{-1}. during wheat growing seasons 2017/18 and 2018/19.

Supplied water	2017/18		2018/19	
	Normal	Deficit	Normal	Deficit
Planting irrigation	485.0		495.0	
Second irrigation	300.0		310.0	
Remaining irrigations	-	1010.0	-	1060.0
Total irrigation	1795.0	785.0	1865.0	805.0
Rainfall	347.3		231.2	
Total of water	2142.3	1132.3	2096.2	1036.2

2.2. Data recorded

Agronomic data were recorded on No. of days to maturity, plant height (cm), No. of spikes m^{-2}, No. of kernels $spike^{-1}$, 1000-kernel weight (g) and grain yield (kg m^{-2}). The physiological characteristics were estimated using randomly taken flag leaves samples from each plot at heading stage.

Relative water content (RWC %) were determined by Gonzalez and Gonzalez (2001) as follows:

$$\mathbf{RWC\% = \frac{FW - DW}{TW - DW}\ 100}$$

Where FW is the sample fresh weight, TW is the sample turgid weight, and DW is the sample dry weight

Proline content (mg g^{-1} FW,) was determined according to Bates *et al.* (1973) and Photosynthetic pigments of chlorophyll-a and b (µg ml^{-1}) were determined using the spectrophotometric method according to the equation

chl a = 12.64 A_{664}-2.99$_{A647}$

chl b = -5.6 A_{664} + 23.26 A_{647} as described by Moran, 1982.

Leaf temperature was estimated by a portable steady-state promoter (LI- COR model LI- 1600) on a central portion of fully expanded flag leaves from two randomly selected plants in each plot during the mid-day period, and in the absence of cloud cover. Air temperature ranged from 18.0 to 22.0 ^{O}C at the time of measuring in the seasons.

Stress susceptibility index (SSI) was calculated according to Fischer and Maurer (1978).

$$\mathbf{SSI = \frac{1 - \frac{Y_d}{Y_p}}{D}}$$

Where: Y_d = mean yield under water stress, Y_p = mean yield under normal, D = water stress intensity = 1 - (mean Y_d of all genotypes / mean Y_p of all genotypes).

Specimens of about 1 cm were taken from the central part of the flag leaf. Specimens were fixed in Formalin Alcohol Acetic acid mixture (FAA, 1:18:1 v/v), dehydrated in alcohol series. The dehydrated specimens were embedded in paraffin wax (52-54 °C). The embedded specimens were sectioned on a rotary microtome at a thickness of 20 µm. Staining sections with crystal violet and erthrosine, cleared in xylol and mounted in Canada balsam (Willey, 1971). Five reading from each slide were examined with an electric microscope (Leica DM LS) with a digital camera (Leica DC300), then photographed and calculated. The studied anatomical characters were average thickness of leaf lamina, cuticle layer, upper epidermis, lower epidermis, mesophyll tissue, midrib, main vascular bundle dimension (length and width), collenchyma tissue, xylem tissue, phloem tissue and bulliform cells.

The analysis of variance was performed according to RCBD. Combined analysis across the two water treatments in the two seasons was performed when the assumption of errors homogeneity cannot be rejected (Levene, 1960). Means of genotypes were compared using LSD at 0.05 probability level according to Steel *et al.* (1997). Seasons were random, while the water treatments and genotypes were fixed. Spearman rank correlation was also calculated. The statistical analyses were performed using the statistical routines available in Microsoft EXCEL (2016) and GenStat 18 (Payne *et al.*, 2017).

3. RESULTS

3.1. Analysis of variance:

Tables 4 and 5 show the analysis of variance for the studied characters across seasons and water treatments. Mean squares due to seasons, water treatments and genotypes were significant or highly significant ($P \leq 0.05$ or $P \leq 0.01$) for all the studied characters, except water treatments for 1000-kernel weight. These results indicated that the two seasons and two irrigation treatments behaved differently and detected sufficient genetic variability among the studied genotypes.

Variances of seasons, water treatments and

Table 4. Analysis of variance for the plant height, grain yield and its components across the seasons, water treatments and studied wheat genotypes.

SOV	df	DM	PH	SM	KS	KW	GY
Seasons (S)	1	27134.6**	14911.4**	159401.6**	1098**	2857.4**	2.49**
Water treatment (W)	1	1685.6**	2705.1**	192236.4**	174.4**	46.4	1.88**
S x W	1	266.7**	300.6**	35606.1**	24.7	0.7	0.38**
Reps/W/S = Error (a)	12	8.7	21.5	3091.7	18.6	15.2	0.01
Entry (E)	10	54.4**	601.9**	84462.1**	43.2**	211**	0.5**
S x E	10	23.1**	82.6**	5769.8	21.2	65.8**	0.08**
W x E	10	0.653	20.114	5097.677	1.155	1.321	0.02**
S x W x E	10	2.6	23.7*	2077.1	2.0	0.5	0.01*
Pooled error b	120	1.4	11	3238	16.8	4	0.005
Total	175						
CV (E)		0.86	3.35	11.65	7.07	4.28	7.71

*, ** = significant at 0.05 and 0.01, probability levels, respectively. DM = No. of days to maturity, PH = plant height, SM = No. of spikes m^{-2}, KS = No. of kernels $spike^{-1}$, KW = 1000-kernel weight (g) and GY = grain yield.

Table 5. Analysis of variance for the physiological characters across the seasons, water treatments and studied wheat genotypes.

SOV	df	RWC	pro	chl a	chl b	LT
Seasons (S)	1	611.2**	0.2**	1347.5**	57.8**	16.6*
Water treatment (W)	1	7614.4**	1.3**	280.5**	43.9**	185.1**
S x W	1	11.5	0.001	4.1	0.01	6.6
Reps/W/S = Error (a)	12	16.2	0.01	4.7	0.5	2.2
Entry (E)	10	111.6**	0.02**	24.7**	0.9**	5.5**
S x E	10	11.1**	0.01**	12.8**	0.6**	0.7**
W x E	10	15.749**	0.01**	2.768**	0.624**	1.383**
S x W x E	10	8.8**	0.001	1.9**	0.2**	0.8**
Pooled error b	120	2.7	0.001	0.3	0.04	0.2
Total	175					
CV (E)		2.17	10.75	4.03	5.28	2.28

*, ** = significant at 0.05 and 0.01, probability levels, respectively. RWC = relative water content percent, pro = proline (mg g^{-1} FW), chl a = chlorophyll-a, chl b = chlorophyll-b and LT = leaf temperature.

genotypes interaction were significant for all characters, except the interaction of seasons x water treatments for No. of kernels $spike^{-1}$, 1000-kernel weight, relative water content, proline content, chlorophyll-a and b and leaf temperature; season x genotypes for No. of spikes m^{-2} and No. of kernels $spike^{-1}$; water treatments x genotypes for No. of days to maturity, plant height, No. of spikes m^{-2}, No. of kernels $spike^{-1}$, and 1000-kernel weight; and season x water treatments x genotypes for No. of days to maturity, No. of spikes m^{-2}, No. of kernels $spike^{-1}$, 1000-kernel weight and proline content.

3.2. Mean performance

Averaging across the two seasons and water treatments are shown in Table 6. Number of days to maturity varied from 135.3 days in Line 1 to 140.5 days in Shandaweel 1. In addition, plant height estimates were in the range of 87.5 cm in Sids 12 and 107.5 cm in Sids 14. Besides, the highest and lowest No. of spikes m^{-2} (589.8 and 364.2 spikes) were detected by Line 2 and Sids 12, respectively. Moreover, No. of kernels $spike^{-1}$ ranged from 60.6 kernels (Misr 3) to 55.6 kernels (Giza 168). Also, the range of 1000-kernel weight varied from 52.1 g in Giza 171 to 40.8 g in Giza 168. Moreover, the highest grain yield was observed by Sakha 95 (1.193 kg) and Misr 3 (1.151 kg), while the lowest value was obtained by Sids 12 (0.593 kg).

For the physiological characters, RWC % varied from 72.1 % in Giza 168 to 79.9 % in Sids14. Moreover, free proline content in flag leaves were in the range of 0.258 mg g^{-1} fresh weight in Giza 168 and Line 3 and 0.362 mg g^{-1} F W in Sids14. In addition, the concentrations of chlorophyll-a extended from 10.32 µg ml^{-1} in Giza 168 to 14.53 mg L^{-1} in Sids 14, while chlorophyll-b fluctuated from 3.36 mg L^{-1} in Line3 to 4.05 µg ml^{-1} in Giza 168 and Sakha 95. Moreover, mean values of leaf temperature ranged from 19.66 $^{\circ}$C in Sids 14 to 21.88 $^{\circ}$C in Line 2.

Table 6. Mean performance of studied genotypes for the studied characters combined over seasons and water treatments.

Genotype	DM	PH	SM	KS	KW	GY	RWC	pro	chl a	chl b	LT
Giza 168	140.1	91.9	532.1	55.6	40.8	0.958	72.1	0.258	10.32	4.05	20.57
Giza 171	140.1	101.9	428.5	59.0	52.1	1.009	78.0	0.305	13.54	3.56	20.98
Sakha 95	136.3	105.9	580.4	58.0	50.1	1.193	77.5	0.313	14.43	4.05	20.38
Gemmeiza 12	137.6	97.5	452.5	59.0	42.3	0.848	73.4	0.307	13.22	3.57	21.05
Shandaweel 1	140.5	95.6	499.0	56.6	42.0	0.828	75.6	0.307	13.38	3.77	20.93
Sids 12	136.7	87.5	364.2	60.1	46.3	0.593	76.1	0.298	13.63	3.50	21.25
Sids 14	139.3	107.5	479.2	58.5	47.2	1.054	79.9	0.362	14.53	3.79	19.66
Misr 3	140.1	94.4	396.7	60.6	47.7	1.151	78.8	0.348	14.47	3.87	20.29
Line 1	135.3	102.2	510.0	57.7	45.9	1.067	75.2	0.307	13.46	3.65	20.64
Line 2	138.4	98.4	589.8	56.4	48.0	1.127	73.5	0.279	12.16	3.45	21.88
Line 3	139.9	103.4	540.8	56.1	50.0	1.107	72.4	0.258	12.31	3.36	21.19
Minimum	135.3	87.5	364.2	55.6	40.8	0.593	72.1	0.258	10.32	3.36	19.66
Maximum	140.5	107.5	589.8	60.6	52.1	1.193	79.9	0.362	14.53	4.05	21.88
Mean	138.6	98.8	488.5	58.0	46.6	0.994	75.7	0.304	13.22	3.69	20.80
$LSD_{0.05}$	0.8	2.3	39.8	2.9	1.4	0.049	1.2	0.023	0.37	0.14	0.33

DM = No. of days to maturity, PH = plant height (cm), SM = No. of spikes m^{-2}, KS = No. of kernels $spike^{-1}$, KW = 1000-kernel weight (g), GY = grain yield (kg m^{-2}), RWC = relative water content percent), pro = proline (mg g^{-1} FW), chl a = chlorophyll-a (µg ml^{-1}), chl b = chlorophyll-b (µg ml^{-1}) and LT = leaf temperature (^{O}C).

3.3. The effect of season and genotypes interaction

Tables 7 and 8 show means of all studied characters across the water treatments and seasons. Values of No. of days to maturity ranged from 122.3 and 148.3 days in Line 1 to 130.6 days in Misr 3 and 153.4 days in Shandaweel 1 in the first and second seasons, respectively. Plant height estimates varied from 78.1 and 96.9 cm in Sids 12 to 98.8 and 116.3 cm in Sids 14 in the first and second season, respectively. Besides, No. of spikes m^{-2} were in the range of 327.1 and 401.3 spikes in Sids 12 and 551.7 in Sakha 95 and 648.8 spikes in Line 2 in the first and second seasons, correspondingly. Values of No. of kernels $spike^{-1}$ varied from 52.5 in Shandaweel 1 and 57.2 kernels in Line 3 in the first season and 58.2 in Gemmeiza 12 and 64.1 kernels in Sids 12 in the second season. In addition, the lowest 1000-kernel weight was 35.0 g in Giza 168 and 42.2 g in Gemmeiza 12 and the highest values were 46.3 and 57.8 g in Giza 171 in the first and second season, respectively. The highest grain yields were 1.064 kg m^{-2} for Misr 3 and 1.334 kg $m^{-2}$for Sakha 95, while the lowest values were 0.470 and 0.715 kg m^{-2} for Sids 12in the first season and second season, respectively.

Table 7: Mean performance of interaction between seasons and genotypes for days to maturity, plant height, grain yield and its components characters combined over water treatments.

Genotype	DM		PH		SM		KS		KW		GY	
	17/18	18/19	17/18	18/19	17/18	18/19	17/18	18/19	17/18	18/19	17/18	18/19
Giza 168	128.3	152.0	82.5	101.3	514.6	549.6	53.9	57.4	35.0	46.7	0.694	1.221
Giza 171	128.4	151.9	92.5	111.3	437.5	419.6	55.3	62.8	46.3	57.8	0.778	1.240
Sakha 95	123.6	148.9	96.9	115.0	551.7	609.2	55.4	60.6	44.3	56.0	1.053	1.334
Gemmeiza 12	124.9	150.4	87.5	107.5	430.4	474.6	58.2	59.8	42.4	42.2	0.809	0.887
Shandaweel 1	127.6	153.4	82.5	108.8	476.7	521.3	52.5	60.8	38.8	45.1	0.734	0.921
Sids 12	122.5	150.9	78.1	96.9	327.1	401.3	56.0	64.1	44.3	48.3	0.470	0.715
Sids 14	127.0	151.6	98.8	116.3	426.3	532.1	56.6	60.5	45.0	49.4	0.999	1.108
Misr 3	130.6	149.6	83.8	105.0	378.3	415.0	57.9	63.3	41.4	54.1	1.064	1.238
Line 1	122.3	148.3	96.9	107.5	471.7	548.3	54.8	60.6	41.7	50.0	0.958	1.175
Line 2	124.9	152.0	93.1	103.8	530.8	648.8	54.7	58.2	43.2	52.8	1.034	1.219
Line 3	127.8	152.1	92.5	114.4	497.1	584.6	55.0	57.2	45.7	54.3	1.032	1.183
$LSD_{0.05}$	**1.2**		**3.3**		**NS**		**NS**		**2.1**		**0.070**	

DM = No. of days to maturity, PH = plant height (cm), SM = No. of spikes m^{-2}, KS = No. of kernels $spike^{-1}$, KW = 1000-kernel weight (g), GY = grain yield (kg m^{-2}) and NS = not significant.

Table 8. Mean performance of interaction between seasons and genotypes for physiological characters combined over water treatments

Genotype	RWC %		Pro		chl a		chl b		LT ºC	
	17/18	18/19	17/18	18/19	17/18	18/19	17/18	18/19	17/18	18/19
Giza 168	71.49	72.66	0.263	0.252	10.11	10.53	4.19	3.91	20.82	20.32
Giza 171	75.30	80.66	0.362	0.248	10.76	16.31	4.44	2.68	21.27	20.68
Sakha 95	75.37	79.60	0.347	0.280	11.47	17.39	4.59	3.51	20.60	20.17
Gemmeiza 12	72.10	74.77	0.347	0.267	10.37	16.06	4.31	2.84	21.45	20.65
Shandaweel 1	72.45	78.81	0.365	0.248	10.20	16.56	4.45	3.09	21.68	20.18
Sids 12	73.46	78.64	0.307	0.290	10.29	16.98	4.05	2.95	21.85	20.65
Sids 14	77.81	81.98	0.415	0.309	11.39	17.67	4.35	3.24	19.84	19.48
Misr 3	77.22	80.38	0.387	0.308	11.46	17.48	4.44	3.30	20.63	19.95
Line 1	73.79	76.69	0.358	0.255	9.87	17.04	4.32	2.99	20.70	20.58
Line 2	71.25	75.82	0.313	0.245	9.38	14.94	3.92	2.99	22.08	21.68
Line 3	71.78	73.02	0.288	0.228	9.72	14.91	3.88	2.84	21.28	21.10
$LSD_{0.05}$	1.63		0.032		0.53		0.19		0.47	

RWC = relative water content percent), pro = proline (mg g^{-1} FW), chl a = chlorophyll-a (µg ml^{-1}), chl b = chlorophyll-b (µg ml^{-1}) and LT = leaf temperature (^{O}C)

For the physiological characters, the relative water (RWC%) content had values from 71.25 % in line 2 and 72.66 % in Giza 168 to 77.81 and 81.98 % in Sids 14 in the first and second seasons, respectively. The Proline contents were ranged from 0.263 mg g^{-1} FW in Giza 168 and 0.228 mg g^{-1} FW in Line3 to 0.415 and 0.309 mg g^{-1} FW in Sids 14 in the first and second season, correspondingly.

Additionally, the concentrations of chlorophyll-a continued from 9.38 µg ml^{-1} in line 2 and 10.53 µg ml^{-1} in Giza 168 to 11.47 µg ml^{-1} in Sakha 95 and 17.67 µg ml^{-1} in Sids 14, while chlorophyll-b continued from 3.88 in Line 3 and 2.68 µg ml^{-1} in Giza 171 to 4.59 in Sakha 95 and 3.91 µg ml^{-1} in Giza 168 in the first and second season, respectively. The leaf temperature ranged from19.84 and 19.48^{O}C in Sids 14 to 22.08 and 21.68^{O}C in Line 2 in the first and second season, respectively.

3.4. The effect of water treatments and genotypes interaction

The means of all studied characters combined over the two seasons for the same water treatment are exhibited in Tables 9 and 10. Number of days to maturity ranged from138.6 and 132 days in Line 1 to 143.6 and 137.4 days in Shandaweel1 under normal and water stress conditions, respectively. Plant height estimates varied from 90.6and 84.4 cm in Sids 12 to 111.9 and 103.1 cm in Sakha 95 and Sids 14 under normal and water stress conditions, respectively. Besides, the number of spikes m^{-2} went in the range from 406.3 and 322.1 spikes in Sids 12 to 652.5 spikes in Sakha 95 and 565.4 spikes in Line 2 under normal and water stress conditions, respectively.

The number of kernel $spike^{-1}$ varied between 56.5 kernels in Giza 168 and 54.4 kernels in Line 3to 61.5 and 59.6 kernels in Misr 3 under normal and water deficit conditions, respectively. The lowest kernel weights were 41.3 and 40.4 g in Giza 168, while the highest values were 52.6and 51.5 g in Giza 171 under normal and water stress conditions, respectively.

The lowest values of grain yield were 0.721 and 0.464 kg m^{-2} for Sids 12, while the highest values were 1.287 and 1.099 kg $m^{-2}$for Sakha95 under normal and water stress conditions, respectively.

RWC % had values from 77.94 % in Line 3 and 64.65 % in Giza 168 to 85.43 and 74.36 % in Sids 14 under normal and water stress conditions, respectively.

Moreover, the proline contents ranged from 0.195 mg g^{-1} FW in Line 3 and 0.287 mg g^{-1} fresh weight in Giza 168 to 0.245mg g^{-1} FW in Misr 3 and 0.485 mg g^{-1} FW in Sids 14 under normal and water stress conditions, respectively.

The contents of chlorophyll-a extended from 11.70 and 8.94 µg ml^{-1} in Giza 168 to 15.53 µg ml^{-1} in Sakha 95 and 13.77 mg L^{-1} in Sids 14 and Misr 3, while chlorophyll-b extended from 3.66 µg ml^{-1} in Line 3 and 2.83 µg ml^{-1} in Line 1 to 4.80 µg ml^{-1} in Giza 168 and 3.53 µg ml^{-1} in Misr 3 under normal and water stress conditions, respectively.

Furthermore, the lowest leaf temperature was 18.60 and 20.73 ^{O}C in Sids 14, while the highest values were 20.88 and 22.88 ^{O}C in Line 2 under normal and water stress conditions, respectively.

Table 9. Mean performance of interaction between water treatments and genotypes for days to maturity, plant height, grain yield and its components characters combined over seasons

Genotype	DM		PH		SM		KS		KW		GY	
	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress
Giza 168	143.3	137.0	96.3	87.5	570.8	493.3	56.5	54.8	41.3	40.4	1.053	0.863
Giza 171	143.4	136.9	106.9	96.9	462.9	394.2	60.0	58.1	52.6	51.5	1.083	0.935
Sakha 95	139.1	133.4	111.9	100.0	652.5	508.3	59.2	56.8	50.9	49.4	1.287	1.099
Gemmeiza 12	140.6	134.6	101.3	93.8	499.6	405.4	59.8	58.2	42.7	41.8	1.016	0.679
Shandaweel 1	143.6	137.4	100.6	90.6	503.8	494.2	57.6	55.7	42.9	41.0	0.963	0.692
Sids 12	139.4	134.0	90.6	84.4	406.3	322.1	60.8	59.4	46.5	46.1	0.721	0.464
Sids 14	142.8	135.9	111.9	103.1	512.5	445.8	59.6	57.5	47.3	47.1	1.113	0.994
Misr 3	143.3	137.0	97.5	91.3	425.0	368.3	61.5	59.6	47.8	47.6	1.269	1.033
Line 1	138.6	132.0	105.0	99.4	523.3	496.7	58.5	56.9	46.6	45.1	1.143	0.991
Line 2	141.5	135.4	100.6	96.3	614.2	565.4	57.4	55.4	48.5	47.4	1.210	1.044
Line 3	143.0	136.9	106.9	100.0	565.8	515.8	57.8	54.4	50.7	49.4	1.212	1.003
$LSD_{0.05}$	NS		NS		NS		NS		NS		0.070	

DM = No. of days to maturity, PH = plant height (cm), SM = No. of spikes m^{-2}, KS = No. of kernels $spike^{-1}$, KW = 1000-kernel weight (g), GY = grain yield (kg m^{-2}) and NS = not significant.

Table 10. Mean performance of interaction between water treatments and genotypes for physiological characters combined over seasons.

Genotype	RWC		Pro		chl a		chl b		LT	
	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress
Giza 168	79.50	64.65	0.228	0.287	11.70	8.94	4.80	3.31	19.33	21.80
Giza 171	84.20	71.76	0.220	0.390	14.45	12.62	4.01	3.11	19.78	22.17
Sakha 95	84.82	70.16	0.210	0.417	15.53	13.33	4.75	3.35	18.93	21.83
Gemmeiza 12	81.82	65.05	0.228	0.385	14.59	11.84	3.97	3.18	19.78	22.32
Shandaweel 1	81.86	69.40	0.215	0.398	14.92	11.84	4.42	3.12	20.10	21.77
Sids 12	83.82	68.28	0.202	0.395	14.62	12.65	3.79	3.21	20.38	22.12
Sids 14	85.43	74.36	0.239	0.485	15.29	13.77	4.29	3.30	18.60	20.73
Misr 3	84.29	73.31	0.245	0.450	15.16	13.77	4.21	3.53	19.43	21.15
Line 1	81.40	69.08	0.203	0.410	14.79	12.12	4.48	2.83	19.48	21.80
Line 2	79.80	67.27	0.203	0.355	14.00	10.32	3.75	3.15	20.88	22.88
Line 3	77.94	66.87	0.195	0.322	14.27	10.35	3.66	3.06	20.83	21.55
$LSD_{0.05}$	1.63		0.032		0.53		0.19		0.47	

RWC = relative water content percent), pro = proline (mg g^{-1} FW), chl a = chlorophyll-a (µg ml^{-1}), chl b = chlorophyll-b (µg ml^{-1}) and LT = leaf temperature (^{O}C).

3.5. The effect of season, water treatments and genotypes interaction

The mean performance of the studied characters for the interaction seasons, water treatments and genotypes are demonstrated in Tables 11 and 12. The lowest number of days to maturity was belonged to Sids 12 and Sakha 95 under normal irrigation and to Line 1 under water stress in the two seasons, while the highest numbers were belonged to Misr 3 in the first season and to Shandaweel 1 in the second season. For plant height, Sids 12 and Giza 168 were the shortest genotypes, while Sids14, Sakha 95 and Line 3 were the tallest genotypes under most conditions. Besides, Sids 12 showed the least number of spikes m^{-2} under all conditions, however, Sakha95 revealed the highest number under normal conditions and Line 2 under water stress. Moreover, the lowest number of kernels $spike^{-1}$ was detected by Shandaweel 1 and Giza 168 and Line 3, while the highest number was given by Misr 3 and Gemmeiza 12 in the first season and Sids 12 in the second season, respectively. Additionally, the lowest weight of kernels was shown by Giza 168 in the first season and Gemmeiza 12 in the second season, while the highest weight was obtained by Giza 171 under all conditions. At the same time, Sids 12 had the least grain yield under all conditions, whereas Sakha 95 and Misr 3under all conditions and Giza 171 under water stress in the second season were the best ones.

Table 11. The mean performance of days to maturity, plant height and grain yield and its components characters as affected by interactions among seasons, water treatments and genotypes.

Genotype	DM				PH				SM				KS				KW				GY			
	2017/2018		2018/2019		2017/2018		2018/2019		2017/2018		2018/2019		2017/2018		2018/2019		2017/2018		2018/2019		2017/2018		2018/2019	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Giza 168	132.3	124.3	154.3	149.8	85.0	80.0	107.5	95.0	544.2	485.0	597.5	501.7	54.8	53.1	58.2	56.5	35.4	34.7	47.2	46.2	0.739	0.650	1.368	1.075
Giza 171	133.0	123.8	153.8	150.0	97.5	87.5	116.3	106.3	443.3	431.7	482.5	356.7	56.4	54.2	63.5	62.0	46.8	45.8	58.5	57.2	0.820	0.736	1.346	1.134
Sakha 95	128.5	118.8	149.8	148.0	101.3	92.5	122.5	107.5	598.3	505.0	706.7	511.7	57.3	53.5	61.0	60.2	44.9	43.7	57.0	55.0	1.129	0.976	1.445	1.223
Gemmeiza 12	129.3	120.5	152.0	148.8	88.8	86.3	113.8	101.3	444.2	416.7	555.0	394.2	59.4	57.1	60.3	59.3	42.8	42.0	42.7	41.7	0.883	0.735	1.150	0.624
Shandaweel 1	132.0	123.3	155.3	151.5	86.3	78.8	115.0	102.5	480.0	473.3	527.5	515.0	53.9	51.1	61.3	60.3	39.7	38.0	46.2	44.0	0.799	0.669	1.128	0.715
Sids 12	125.8	119.3	153.0	148.8	82.5	73.8	98.8	95.0	362.5	291.7	450.0	352.5	56.9	55.1	64.6	63.7	44.8	43.8	48.3	48.3	0.518	0.423	0.925	0.505
Sids 14	131.8	122.3	153.8	149.5	100.0	97.5	123.8	108.8	440.0	412.5	585.0	479.2	58.2	55.0	60.9	60.1	45.2	44.9	49.5	49.3	1.050	0.949	1.176	1.040
Misr 3	134.5	126.8	152.0	147.3	86.3	81.3	108.8	101.3	391.7	365.0	458.3	371.7	59.7	56.2	63.4	63.1	41.4	41.3	54.3	54.0	1.125	1.003	1.414	1.063
Line 1	126.7	118.0	150.5	146.0	98.8	95.0	111.3	103.8	475.0	468.3	571.7	525.0	55.3	54.3	61.8	59.5	42.0	41.4	51.3	48.8	1.000	0.916	1.285	1.065
Line 2	129.5	120.3	153.5	150.5	93.8	92.5	107.5	100.0	545.0	516.7	683.3	614.2	56.1	53.2	58.8	57.6	43.8	42.7	53.3	52.2	1.092	0.976	1.328	1.111
Line 3	132.3	123.3	153.8	150.5	93.8	91.3	120.0	108.8	525.0	469.2	606.7	562.5	57.5	52.5	58.2	56.3	46.5	44.9	54.9	53.8	1.100	0.964	1.324	1.043
LSD0.05	NS				4.7				NS				NS				NS				0.099			

N = normal, S = water stress, DM = No. of days to maturity, PH = plant height (cm), SM = No. of spikes m^{-2}, KS = No. of kernels $spike^{-1}$, KW = 1000-kernel weight (g), GY = grain yield (kg m^{-2}) and NS = not significant.

Table 12. The mean performance of the physiological characters as affected by interactions among seasons, sowing dates and genotypes.

Genotype	RWC				Pro				chl a				chl b				LT			
	2017/2018		2018/2019		2017/2018		2018/2019		2017/2018		2018/2019		2017/2018		2018/2019		2017/2018		2018/2019	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Giza 168	79.00	63.98	80.00	65.32	0.233	0.293	0.223	0.280	11.37	8.85	12.03	9.02	4.97	3.42	4.63	3.19	19.67	21.97	19.00	21.63
Giza 171	82.15	68.44	86.24	75.07	0.283	0.440	0.157	0.340	11.72	9.80	17.18	15.44	4.99	3.89	3.03	2.33	20.20	22.33	19.37	22.00
Sakha 95	83.30	67.44	86.34	72.87	0.247	0.447	0.173	0.387	12.52	10.42	18.54	16.24	5.15	4.02	4.34	2.67	19.20	22.00	18.67	21.67
Gemmeiza 12	79.84	64.37	83.80	65.73	0.273	0.420	0.183	0.350	11.39	9.34	17.79	14.34	4.69	3.92	3.25	2.43	20.53	22.37	19.03	22.27
Shandaweel 1	77.54	67.37	86.19	71.43	0.257	0.473	0.173	0.323	11.96	8.44	17.88	15.24	4.93	3.98	3.91	2.27	21.53	21.83	18.67	21.70
Sids 12	81.29	65.63	86.35	70.93	0.217	0.397	0.187	0.393	11.34	9.24	17.89	16.06	4.36	3.74	3.22	2.67	21.47	22.23	19.30	22.00
Sids 14	84.46	71.15	86.39	77.57	0.280	0.550	0.197	0.420	12.27	10.50	18.31	17.04	5.00	3.71	3.58	2.89	18.80	20.89	18.40	20.57
Misr 3	83.82	70.62	84.76	76.00	0.290	0.483	0.200	0.417	12.12	10.79	18.21	16.75	4.65	4.23	3.77	2.83	20.03	21.23	18.83	21.07
Line 1	80.86	66.72	81.94	71.43	0.247	0.470	0.160	0.350	11.19	8.55	18.39	15.70	5.20	3.44	3.75	2.22	19.53	21.87	19.43	21.73
Line 2	78.00	64.50	81.61	70.03	0.240	0.387	0.167	0.323	10.52	8.24	17.49	12.40	4.27	3.57	3.24	2.73	21.23	22.93	20.53	22.83
Line 3	76.93	66.64	78.95	67.10	0.237	0.340	0.153	0.303	10.80	8.63	17.74	12.08	4.15	3.62	3.18	2.51	20.87	21.70	20.80	21.40
LSD0.05	2.30				0.046				0.75				0.27				0.66			

RWC = relative water content percent), pro = proline (mg g^{-1} FW), chl a = chlorophyll-a (µg ml^{-1}), chl b = chlorophyll-b µg ml^{-1}) and LT = leaf temperature (^{O}C).

For the physiological characters, Sids 14 showed the highest relative water content under all conditions, while Line 3 and Giza 168 showed the lowest content under normal and water stress, respectively. The highest contents were produced by Misr 3 and Giza 168 under normal irrigation and Sids 14 under water stress conditions, while the least contents belonged to Sids 12 and Line 3 under normal irrigation and Giza 168 under water stress condition. In addition, Line 2 gave the least chlorophyll-a estimates in the first season and Giza 168 in the second season, while the highest estimates belonged to Sakha 95 under normal conditions and Misr 3 and Sids 14 under water treatments in the two seasons. Also, the lowest chlorophyll-b values belonged to Line 3, Giza 168, Giza 171 and Line1 in the two seasons, while Line 1 and Misr 3 had the highest values in the first season and Giza 168 in the second season. Also, the lowest leaf temperature was given by Sids 14 in the two seasons and the highest temperature belonged to Shandaweel 1 and Line 3 under normal irrigation and Line 2 under water stress conditions in the two seasons.

3.6. The effect of season, water treatments and their interaction

Tables 13 show means of seasons, water treatments and their interaction across all studied genotypes. Means of studied genotypes for all traits were significantly higher in 2018/19 compared to 2017/18, except for proline contents, chlorophyll-b and leaf temperature (Tables 4 and 5).

Averaging across the 11 entries, the water stress conditions reduced all studied characters, except for proline content and leaf temperature.

Table 13. The mean performance of seasons, water treatments and their interaction for the studied characters.

Season/treatment		DM	PH	SM	KS	KW	GY	RWC	pro	chl a	chl b	LT
2017/18		126.2	88.9	458.4	55.5	41.9	0.875	73.8	0.34	10.5	4.27	21.1
2018/19		151.0	108.0	518.6	60.5	50.2	1.113	77.5	0.27	16.0	3.12	20.5
F test		**	**	**	**	**	**	**	**	**	**	*
Normal (N)		141.7	102.2	521.5	59.0	46.3	1.097	82.3	0.22	14.5	4.19	19.8
Water deficit (S)		135.5	94.6	455.4	57.0	45.8	0.891	69.1	0.39	12.0	3.19	21.8
F test		**	**	**	**	NS	**	**	**	**	**	**
2017/18	**N**	130.5	91.3	477.2	56.8	42.1	0.932	80.7	0.25	11.6	4.76	20.3
	S	121.8	86.5	439.5	54.1	41.7	0.818	67.0	0.43	9.3	3.78	21.9
2017/18	**N**	152.9	113.2	565.8	61.1	50.5	1.262	83.9	0.18	17.4	3.63	19.3
	S	149.1	102.7	471.3	59.8	49.9	0.963	71.2	0.35	14.6	2.61	21.7
$LSD_{0.05}$		1.37	2.2	25.8	NS	NS	0.041	NS	NS	NS	NS	NS

DM = No. of days to maturity, PH = plant height (cm), SM = No. of spikes m^{-2}, KS = No. of kernels $spike^{-1}$, KW = 1000-kernel weight (g), GY = grain yield (kg m^{-2}), RWC = relative water content percent), pro = proline (mg g^{-1} FW), chl a = chlorophyll-a (µg ml^{-1}), chl b = chlorophyll-b µg ml^{-1}) and LT = leaf temperature (^{O}C) and NS = not significant.

3.7. Water stress susceptibility index

The water stress susceptibility index (SSI) was calculated using the grain yield kg m^{-2} under normal and water deficit conditions (Table 14). The SSI values represent tolerance, moderate tolerance or sensitivity and sensitivity if they were less than, equal or near to and above unity, respectively. Averaging the mean of SSI values across the two seasons, Line 1, Line 2, Sids 14, Giza 171 and Sakha 95 had values less than the unity, Misr 3, Line 3 and Giza 168 had values around the unity and Shandaweel 1, Gemmeiza 12 and Sids 12 had values higher than the unity. These results indicate that the genotypes Line 1, Line 2, Sids 14, Giza 171 and Sakha 95were the most tolerant ones under water deficit. In addition, these genotypes showed preferable values of grain yield, relative water, proline, chlorophyll-a contents and cooler leaf temperatures.

3.8. Reduction percentage and correlation

Reduction % due to water stress for the studied characters are shown in Table 15. The means of reduction were in the positive direction for all studied characters except for porline content and leaf temperature. The least affected characters with the water stress were 1000-kernel weight and No. of kernels $spike^{-1}$ (2.1 and 2.0 %) in the first and second season, respectively. On the contrary, the most affected characters were chlorophyll-b content (20.3 and 27.1 %), then chlorophyll-a and grain yield(19.3 and 24.7 in the first and second season, respectively.

Moreover, the increasing in average were 67.4 and 98.7 % for proline, 8.3 and 12.8 % for leaf

Table 14. Estimates of stress susceptibility index (SSI) based on grain yield kg m^{-2} for the studied genotypes in the two seasons.

Genotype	2017/18	2018/19	Mean
Giza 168	0.98	0.90	0.96
Giza 171	0.84	0.66	0.73
Sakha 95	1.10	0.65	0.77
Gemmeiza 12	1.37	1.93	1.76
Shandaweel 1	1.33	1.55	1.50
Sids 12	1.50	1.92	1.89
Sids 14	0.78	0.49	0.57
Misr 3	0.88	1.05	0.99
Line 1	0.68	0.72	0.71
Line 2	0.87	0.69	0.73
Line 3	1.01	0.90	0.91

Table 15. Means and ranges of reduction % due to water stress for the all studied characters during 2017/18 and 2018/19 seasons in addition to Spearman coefficient correlation among means of susceptibility index and the studied characters under normal and water deficit across the two seasons.

Characters	Reduction %						Correlation coefficient with water stress index	
	Mean		Range					
			Minimum		Maximum			
	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	Normal	Water stress
No. of days to maturity	6.6	2.4	5.2	1.2	7.6	3.1	0.15	0.23
Plant height	5.7	9.1	1.3	3.8	10.6	12.2	-0.69*	-.78**
No. of spikes m^{-2}	7.9	16.8	1.4	2.4	19.5	29.0	-0.48	-0.45
No. of kernels spike^{-1}	4.8	2.0	1.8	0.6	8.6	3.8	0.23	0.28
1000-kernel weight	2.1	2.3	0.1	0.1	4.3	5.0	-0.52	-0.48
Grain yield	12.6	24.7	8.4	11.6	18.4	45.8	-0.50	-0.58
Relative water content	16.9	15.1	13.1	10.2	19.4	21.6	-0.14	-0.41
Proline content	-67.4	-98.7	-96.4	-123.1	-25.7	-25.4	-0.03	-0.26
Chlorophyll-a content	19.3	16.6	10.9	6.9	29.5	31.9	-0.10	-0.10
Chlorophyll-b content	20.3	27.1	9.1	15.6	33.8	42.0	-0.19	0.26
Leaf temperature	-8.3	-12.8	-14.6	-17.0	-1.4	-2.9	0.32	0.16

* and ** = Significant and highly significant at 0.01 probability level, respectively

temperature, respectively. The range of the reduction % ranged from -96.4 for proline content in the first season to 11.6 % for grain yield in the second season. Table 12 shows Spearman correlation coefficients (r) among the mean of water stress susceptibility index and the studied characters under normal and water stress conditions. Significant (P-value < 0.01 or 0.05) and negative correlation coefficient was detected among water stress susceptibility index and plant height under normal and water stress conditions. Water stress susceptibility index showed moderate insignificant and negative correlations with grain yield, No spike m^{-2} and 1000-kernel weight under all conditions and relative water content under water stress. The correlation coefficient was insignificant and positive between water susceptibility index and leaf temperature under normal conditions. The correlation coefficient for water stress susceptibility index was insignificant and positive with No. of kernels spike^{-1} under normal and water stress conditions.

3.9. Leaf anatomy

Three cultivars (Sakha 95 as tolerant and high-yielding cultivars, Misr 3 as moderate tolerant cultivar and Shandaweel 1 as susceptible cultivar) were selected to perform the anatomical studies. The studied histological features and reduction percentage in transverse sections through flag leaf blade of Sakha 95, Misr 3 and Shandaweel 1 cultivars under normal and water stress conditions are shown in Table (16) and Figure (1). The histological features are the thickness of leaf lamina, cuticle layer, upper epidermis, lower epidermis, mesophyll tissue, midrib,

Table 16. Measurements in micron (μ)of certain histological features and the reduction percentage (D%) in cross-sections of flag leaf in Sakha 95, Misr 3 and Shandaweel 1wheat cultivars under normal (N) and water stress (S) conditions.

Characters Av	Sakha 95			Misr 3			Shandaweel 1		
	N (100%)	S	D %	N (100%)	S	D %	N (100%)	S	D %
Thickness of leaf lamina	365.3	322.3	11.8	454.3	370.2	18.5	368.3	289.6	21.4
Thickness of cuticle layer	7.6	6.8	10.5	6.1	4.4	27.9	6.7	4.6	31.3
Thickness of upper epidermis	22.4	18.5	17.4	30.1	22.9	23.9	30.1	21.7	27.9
Thickness of lower epidermis	18.5	17.3	6.5	26.3	21.1	19.8	24.3	19	21.8
Thickness of mesophyll tissue	330.9	280.9	15.1	406.5	322.8	20.6	303.1	235.2	22.4
Thickness of midrib	852.7	745.5	12.6	858.4	740.1	13.8	891.4	760.2	14.7
Main vascular bundle Length	166.9	156.4	6.3	210.4	190.9	9.3	188.6	166.9	11.5
Main vascular bundle Width	213.2	185.9	12.8	226.2	194.3	14.1	219.7	185.9	15.4
Thickness of collenchyma tissue	344.6	293.3	14.9	566.8	464.4	18.1	435.6	347.8	20.2
xylem tissue thickness	52.6	45.3	13.9	61.3	52.4	14.5	58.9	49.9	15.3
phloem tissue thickness	49.7	47.4	4.6	55.9	49.8	10.9	62.3	49.6	20.4
Thickness of the bulliform cells	48.1	41.1	14.6	55.2	45.3	17.9	55.9	44.9	19.7

main vascular bundle dimension (length and width), collenchyma tissue, xylem tissue, phloem tissue and bulliform cells. The obtained results showed that the means of the three cultivars for all leaf anatomical characters decreased under water stress. Relative to normal condition, the thinnest leaf lamina was found in Shandweel 1 (289.6μ) while the thickest one was found in Misr 3 (370.2μ). The reduction occurs in leaf lamina thickness accomplished by another reduction in mesophyll tissue. The maximum reduction percentage in mesophyll thickness was found in Shandaweel 1 (22.4%) followed by Misr 3(20.6%) and Sakha 95(15.1%). Misr 3 obtained the highest values for most leaf anatomical characteristics, followed by Shandaweel 1, and then Sakha 95 under normal and water stress conditions. Moreover, the most susceptible cultivar Shandaweel 1 obtained the highest deficiency percentages (11.5-31.3%) of all studied leaf anatomical characteristics due to water stress, followed by the moderate tolerant Misr 3 cultivar (9.3-27.9%), and then the more tolerant Sakha 95 cultivar (4.6-17.4%).

The anatomical characteristics of the more tolerant variety (Sakha 95) confirmed these results, as it was found that mesophyll cells were more compact compared to the other two genotypes. Moreover, the stomata in this genotype appear closed and sunken on both surfaces under water stress. In addition, this genotype showed an increased cuticle layer under the two conditions compared to the other two genotypes.

4. DISCUSSION

The studied genotypes were prevented from irrigation for about 130 days started from elongation stage in most genotypes until harvesting. Meantime, rainfall reached 347.3 m^3 fed^{-1} and 231.2 m^3 fed^{-1} in the first and second season, respectively. Moreover, the deepness of water table was more than 170 cm after 65 and 150 days from sowing under the water deficit and normal conditions, respectively in the two seasons. Consequently, water shortage allowed the comparisons of normal and water stress treatments**.**

Based on the analysis of variance, the two seasons and two irrigation treatments behaved differently and the studied genotypes had sufficient variability. According to the interactions among the studied factors, the studied genotypes responded differently to the water treatments and seasons, allowing to select the favorable genotypes. In this respect, the evaluation of wheat genotypes under well-watered compared to water-deficit conditions was proved to be useful to detect tolerant genotypes to water deficit (Morsy et al., 2021). In addition, the breeders could select the adaptive genotypes to water deficit using morphological and physiological indices (Shalaby et al. 2020). In this respect, Shehab-Eldeen and Farhat (2020) found significant genetic variability among the studied genotypes under the two studied seasons and the two water treatments.

The highest values in the second season may be a result of the lowest temperature and higher relative humidity than in the first one. Similar results were obtained by Farhat et al. (2020) and Shehab-Eldeen and Farhat (2020).

Averaging across the studied genotypes, the water deficit reduced all studied characters, except for proline content and leaf temperature. These results were confirmed by Shalaby et al. (2020), Shehab-Eldeen and Farhat (2020), Morsy et al. (2021), Mu et al. (2021) and Wasaya et al. (2021).

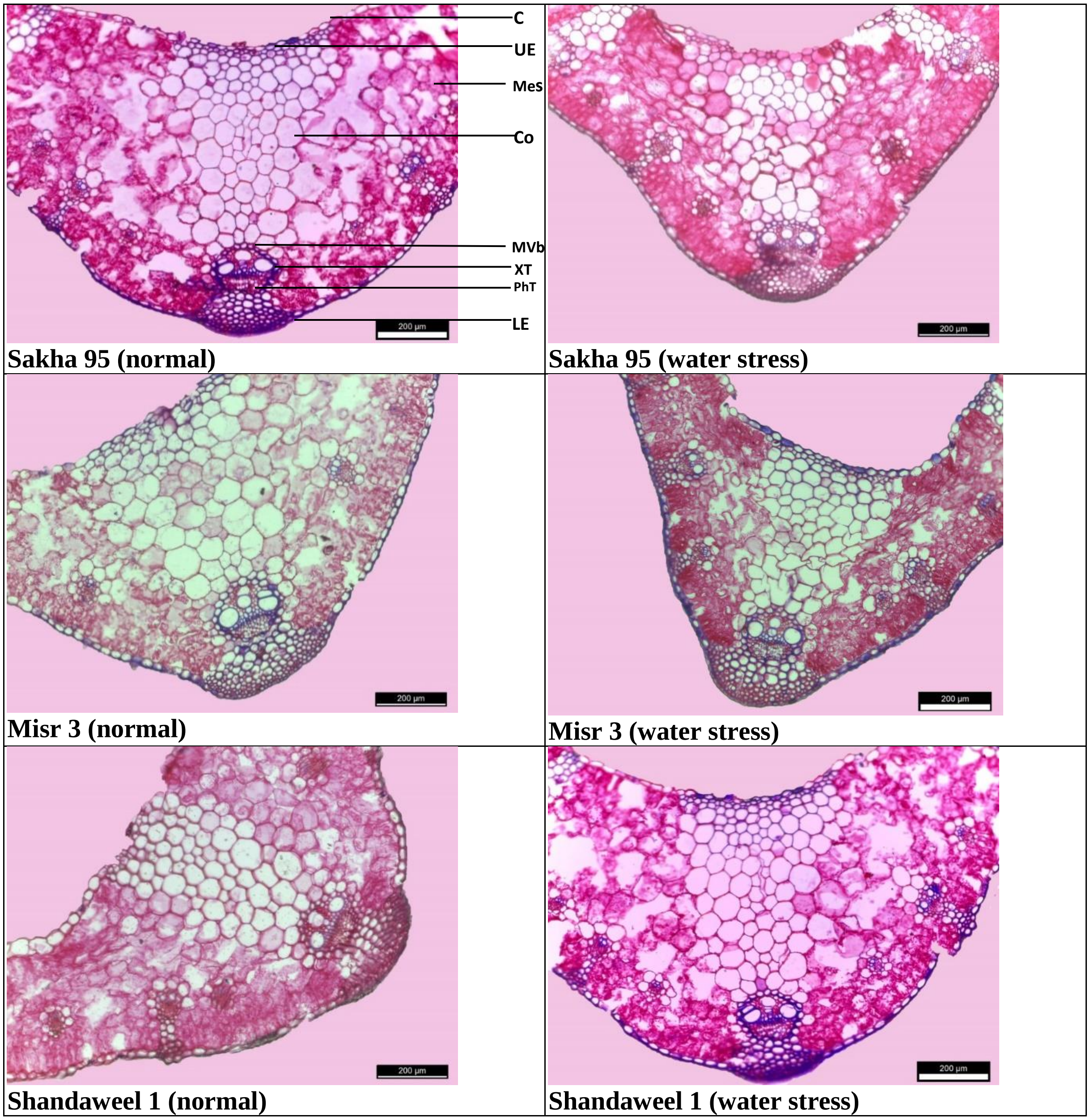

Figure 1. Transverse sections in the leaf of the wheat cultivars Sakha 95, Misr 3 and Shandaweel 1 under two irrigation levels. C: cuticle, UE: upper epidermis, LE: lower epidermis, MVb: main vascular bundle, XT: xylem Tissue, PhT: phloem tissue and Col: collenchyma tissue.

The grain number was reduced under water deficit and similar results were obtained by Senapati et al. (2019).The reduction in grain number may be due to premature abortion of florets (Dolferus et al., 2013) and male and female sterility (Onyemaobi et al., 2017). Additionally, the reduction of grain weight under the water deficit was observed by Zhao et al. (2020), who explained that for the shorter grain-filling times under water stress and then lower dry matter accumulation or a reduced rate and duration of starch accumulation in the endosperm.

In earlier studies, grain yield was reported to be decreased under water stress due to the decrease in grain weight per spike (Zhao et al., 2020), grain number per spike (Ehdaie et al., 2008) and spike number per square meter (Leilah and Al-Khateeb, 2005). The reduction % as a result of water stress was also detected by previous studies and reached 9.54 %

(Al-Naggar et al., 2020), 77.29, 76.44 and 76.78% (Shalaby et al., 2020) and 46.8% (Nehe et al., 2021).

Relative water content reveals plant water status and is considered an index of dehydration stress tolerance (Dehnavi et al., 2017 and Marček et al., 2019). In addition, Relative water content reveals is considered to be a good index to detect the water stress-tolerant genotypes (Din et al., 2020). The reduction in leaf relative water content ultimately leads to reducing growth and biomass production (Wasaya et al., 2021). Moreover, water deficit-tolerant genotypes maintained more water contents under limited water treatment (Allahverdiyev 2015andWasaya et al., 2021).

Belay et al. (2021) reported that proline content increased under water stress compared to normal irrigation. Where plants cope water stress by assembling high amounts of inorganic ions or producing low molecular weight organic solutes like proline for osmotic adjustments (Ben Rejeb et al., 2014). Proline and other osmotic adjustments increasing save the plants from dehydration under water stress conditions. Also, proline as an enzymatic antioxidant protects membranes from oxidative stress by ROS under water deficit.

The chlorophyll content parallels the photosynthesis and could be used to assess stress tolerance of genotypes (Shabala and Munns, 2017). The reduction in chlorophyll contents under water stress conditions may be mainly due to chloroplasts damage caused by the reactive oxygen species (ROS) which formed under water deficit stress conditions (Shalaby et al., 2020and Khayatnezhad and Gholamin, 2021). Reduced chlorophyll causes chlorosis and leads to a reduction in photosynthesis (Yang et al., 2001).

The lowest leaf temperature could be used as an indicator of plant water status and a possible mechanism of stress avoidance. The lowering leaf temperatures could be due to an increased root suction power, allowing plants to absorb water and transpire it, thereby cooling their leaves (El-Gammaal, 2018, Doneva et al., 2021 and Takashima et al., 2021). Similar results were reported by Zada et al. (2020) who stated that drought stress condition considerably reduced the leaf potential and relative water content and transpiration rate with an associated raised in leaf temperature. In general, leaf temperatures were cooler than air temperatures under well-watered conditions, while leaves were warmer than air temperatures under water-stressed conditions (Perera et al., 2019).

Based on the water stress susceptibility Line 1, Line 2, Sids 14, Giza 171 and Sakha 95 were the most tolerant ones under water deficit. In addition, these genotypes showed preferable values of grain yield, relative water content, proline, chlorophyll contents and cooler leaf temperatures. In this respect, El-Nagar (2019), concluded that Shandaweel 1 was the most drought-sensitive genotype compared to the other studied cultivars in their study.

Drought stress reduces crop yield because of some anatomical changes. In this study the means of the three cultivars (Sakha 95, Misr 3 and Shandaweel 1) decreased for all leaf anatomical characters under water stress. These results are in harmony with Ghanem (2008), Farhat (2009), Jafarian *et al*. (2012), and Hassan *et al*. (2017). They reported that water stress decreased most of the leaf anatomical characters.

The anatomical modification in leaf architecture of the plant plays an important role in resisting drought stress (Balsamo et al., 2006), where Sakha 95 (the most tolerant variety) showed compact mesophyll cells, sunken & closed stomata, thick cuticle layer and small vascular bundle under water deficiency. Cuticle plays a vital role in regulating water loss (Bi et al. 2017). And Mesophyll tissue appeared compacted because of absence of intercellular spaces, where this criterion is considered to be highly indicative of the resistance to water flow (David *et al.*, 2017). Moreover, the smallest vascular bundles are more efficient in water and nutrient conduction, Hameed et al. (2012). These results indicate that tolerant genotypes modify their leaf characters to adapt to drought stress similar observations of anatomical characters under drought stress have been reported (Jäger *et al.*, 2014, David *et al.*, 2017, and Hassan *et al.*, 2017). Therefore, changing the anatomical characteristics of leaves under stress is considered an indicator of the regulation of photosynthesis at the morphological level (Adhikary *et al.*, 2007). The reduction in mesophyll, xylem, and phloem tissues slows the rate of the translocation of photo-assimilatess and the accumulation of necessary water for photosynthesis (Hassan *et al.*, 2017).

5. CONCLUSION

This study concluded that Line 1, Line 2, Sids 14, Giza 171 and Sakha 95 were suitable cultivars to be cultivated under water shortage conditions. High values of relative water content, chlorophyll-and proline contents, low values of leaf temperature, in addition to lowest reduction in leaf anatomical characters may be a useful selection criterion for water stress tolerance in wheat genotypes.

6. ACKNOWLEDGEMENTS

This research was supported by Wheat Research Department, Field Crops research, ARC, Egypt.

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الملخص العربي

استجابة بعض الصفات الزراعية والفسيولوجية والتشريحية في بعض تراكيب قمح الخبز تحت الري المتناقص في منطقة شمال الدلتا

وليد ذكي اليماني فرحات[١]، رانيا أنور خضر[٢] وشيماء عبدالسلام شعبان[٣]

[١] قسم بحوث القمح، معهد بحوث المحاصيل الحقلية، مركز البحوث الزراعية، مصر،

[٢] قسم بحوث فسيولوجيا المحاصيل، معهد بحوث المحاصيل الحقلية، مركز البحوث الزراعية، مصر،

[٣] قسم النبات الزراعي، كلية الزراعة،جامعة القاهرة، مصر

أجريت تجربتان حقليتان في مزرعة محطة البحوث الزراعية بسخا خلال موسمي الزراعة ٢٠١٧/١٨ و٢٠١٨/١٩، لدراسة الاستجابة الزراعية والفسيولوجية والتشريحية لأحد عشر صنفا وسلالة من قمح الخبز تحت معاملتين من الري (خمس ريات (موصى به كمعاملة مقارنة) ورية واحدة فقط بعد ٢١ يومًا من الزراعة (إجهاد مائي)). وأظهرت النتائج أن الصفات الزراعية (عدد الأيام حتى النضج، ارتفاع النبات، محصول الحبوب ومكوناته)، الصفات الفسيولوجية (محتوى الماء النسبي، والكلوروفيل أ & ب) والصفات التشريحية (سمك نصل الورقة، طبقة الكيوتيكل، البشرة العليا، البشرة السفلى، نسيج الميزوفيل، العرق الوسطي، النسيج الكولنشيمي، نسيجا الخشب واللحاء، وطول وعرض الحزمة الوعائية الرئيسية وسمك الخلايا اللافة) انخفضت تحت ظروف الإجهاد المائي، باستثناء البرولين ودرجة حرارة الأوراق. وتعتبر السلالة ١، السلالة ٢، سدس ١٤، جيزة ١٧١، سخا ٩٥ أكثر التراكيب الوراثية المدروسة تحملاً للإجهاد المائي وبالتالي تكون مناسبة لظروف نقص المياه. وكذلك يمكن استخدام القيم المرتفعة للمحتوى المائي النسبي، ومحتوى الكلوروفيل والبرولين، والقيم المنخفضة لدرجة حرارة ورقة العلم، بالإضافة إلى انخفاض الصفات التشريحية لورقة العلم كدلائل انتخاب مفيدة لتحمل الإجهاد المائي في قمح الخبز.