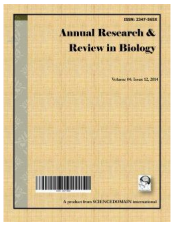

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The Effects of Genotype, Soil Water Deficit and Their Interaction on Agronomic, Physiologic and Yield Traits of *Zea mays* L.

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The presence of genotypic differences in performances under soil water deficit would help plant breeders in initiating successful breeding programs to improve drought tolerance. The objectives of the present study were: (i) to assess the effects of genotype, water stress and their interaction on maize agronomic, physiologic and yield traits and (ii) to identify drought tolerant genotypes for use in future breeding programs. Fifteen commercial hybrids and seven breeding populations were evaluated in the field for two seasons under water stress at flowering (WSF) and grain filling (WSG) compared to well watering (WW). A split plot design with three replications was used. Data analysed across seasons revealed a significant reduction in grain yield/plant (28.69 and 20.26%), grain yield/ha (35.53 and 25.51%), chlorophyll concentration index (30.18 and 44.07%) and 100-kernel weight (6.75 and 12.36%) due to water stress under WSF and WSG, respectively, a significant reduction in ears/plant (11.58%), kernels/row (14.23%), kernels/plant (24.85%) due to water stress under WSF and in upper stem diameter (18.46%) due to water stress under WSG, but a significant increase in days to silking (3.50%), anthesis silking interval (21.17%) and barren stalks

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(26.18%) due to water stress under WSF. Rank of genotypes differed from one irrigation regime to another for most studied traits. The highest yielding genotypes were Eg-77, P-3444, SC-128 and HT-2066 under WSF and P-3444, SC-128, TWC-324 and SC-166 under WSG, in a descending order. These genotypes could be offered to maize breeding programs for developing drought tolerant inbred and hybrids.

Keywords: Maize; drought; ASI; barren stalks; chlorophyll content.

1. INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops in the world as well as in Egypt. According to FAOSTAT [1], maize acreage in Egypt in 2014 was 750,000 hectares produced 5.8 million tons of grains, with an average yield of 7.73 tons ha^{-1}. However, the local production of maize covers only about 50% of the local consumption and Egypt imports every year more than six million tons of maize grains mainly for poultry industry. To reach self-sufficiency of maize production in Egypt, efforts are devoted to extend the acreage of maize in the desert. Growing maize in the sandy soils of low water-holding capacity would expose maize plants to drought stress, which could result in the reduction of grain yields. Moreover, the expected future shortage in irrigation water necessitates that Egyptian breeders should pay great attention to develop drought tolerant maize cultivars that could give high grain yield under soil water deficit conditions.

Water is basic requirement for plant growth and development. Without water, the plant goes under drought conditions and severely affects its growth stages and ultimately yield of crops is reduced. Thus, the development of maize cultivars with high and stable yields under drought is an important priority, as access to drought-adapted cultivars may be the only affordable alternative to many small-scale farmers [2].

Maize is considered more susceptible than most other cereals to drought stresses at flowering when yield losses can be severe through barrenness or reductions in kernels per ear [3]. Maize is particularly susceptible to drought at the flowering stage [4,5]. The studies showed that the sensitive period extended from around one week before to two weeks after 50% silking. Yield losses per day of comparable stress, before and after flowering, were around 45 and 60%, respectively, of the peak loss at silking itself [4]. Studies of more recent hybrids suggest that this period of susceptibility may have moved towards early grain filling. Grant et al. [6] reported that although yields were most severely reduced (70%) by stress coinciding with silking, yields were reduced by 40-54% from stresses occurring in the period 10 to 31 days after mid-silk, and kernel number was reduced below control for stresses occurring up to 22 days after silking. NeSmith and Ritchie [7] observed that kernel numbers per plant were reduced 8-20% when the plants were stressed in the period 18 to 31 days after silking, while weight per kernel declined by a significant 21-25%.

Recent studies have shown considerable genetic variation in the response of commercial hybrids to drought stress imposed during reproductive growth [8] and in one study, a well-known drought tolerant hybrid, P3223, displayed no additional susceptibility to stress imposed at flowering and it appeared that these responses vary considerably among hybrids [9].

Several investigators emphasised the role of maize genotypes in drought tolerance. Tolerant genotypes of maize were characterised by having shorter anthesis-silking interval (ASI) [3, 10], more ears/plant [11,12] and greater number of kernels/ear [12,13]. The presence of genotypic differences in drought tolerance would help plant breeders in initiating successful breeding programs to improve such a complicated character. There is good evidence suggesting that hybrids maintain their advantage over open pollinated varieties in both stress and non-stress environments [14-16].

To start a successful breeding programme for improving drought tolerance, available maize populations and commercial single and tree-way cross hybrids should be screened under drought stress to identify the best ones for further use in extracting the best parental inbred lines for developing drought tolerant hybrids. The objectives of the present study were: (i) to assess the effect of drought at silking and grain filling stages, genotype and their interaction on maize agronomic, physiological and yield traits and (ii) to identify drought tolerant genotypes for use in future breeding programs.

2. MATERIALS AND METHODS

This study was carried out in the two successive growing seasons 2016 and 2017 at the Agricultural Experiment and Research Station of the Faculty of Agriculture, Cairo University, Giza, Egypt (30° 02'N latitude and 31° 13'E longitude with an altitude of 22.50 meters above sea level).

2.1 Plant Materials

Seeds of 22 maize (*Zea mays* L.) genotypes obtained from Agricultural Research Center-Egypt (13 genotypes), Hi-Tec Company (3 genotypes), DuPont Pioneer Company (3 genotypes), Fine Seeds Company (one genotype), Egaseed Company (one genotype), and Watania Company (one genotype) were used in this study (Table 1). These genotypes represent three groups of maize genotypes of narrow- (10 commercial single crosses), medium- (5 commercial 3-way crosses) and broad- (7 populations) genetic base backgrounds and could be used as sources to extract inbred lines for developing drought tolerant hybrid varieties.

2.2 Experimental Procedures

Sowing date was April 24th in the 1st season (2016) and April 30^{ht} in the 2nd season (2017). Sowing was done in rows; each row was 4 m long and 0.7 m width. Seeds were over sown in hills 25 cm apart, thereafter (after 21 days from planting and before the 1st irrigation) were thinned to one plant/hill to achieve a plant density of 24,000 plants/fed.

2.3 Experimental Design

A split-plot design in randomized complete blocks (RCB) arrangement with three replications was used. Main plots were allotted to three irrigation regimes, *i.e.* well watering (WW), water stress at flowering (WSF) and water stress at grain filling (WSG). Each main plot was surrounded with an alley (4 m width), to avoid water leaching between plots. Sub plots were devoted to 22 maize genotypes. Each experimental plot included two rows (plot size = 5.6 m^2). Total number of experimental plots = 3 irrigation treatments × 22 genotypes × 3 replications = 198.

Table 1. Designation, origin and grain color of maize genotypes under investigation

Genotype No.	Designation	Origin	Genetic nature	Grain colour
1	Hi-Tec-2031	Hi-Tec, Egypt	Single cross	White
2	P-30K09	DuPont Pioneer, Egypt	Single cross	White
3	Fine-1005	Fine Seeds, Egypt	Single cross	White
4	Egaseed-77	Egaseed Co., Egypt	Single cross	White
5	SC-10	ARC, Egypt	Single cross	White
6	SC-128	ARC, Egypt	Single cross	White
7	Hi Tec- 2066	Hi-Tec, Egypt	Single cross	White
8	P-3444	DuPont Pioneer, Egypt	Single cross	Yellow
9	SC-166	ARC, Egypt	Single cross	Yellow
10	P-32D99	DuPont Pioneer, Egypt	Single cross	Yellow
11	Hi Tec 1100	Hi-Tec, Egypt	Three-way cross	White
12	Watania 11	Watania Co., Egypt	Three-way cross	White
13	TWC-324	ARC, Egypt	Three-way cross	White
14	TWC-360	ARC, Egypt	Three-way cross	Yellow
15	TWC-352	ARC, Egypt	Three-way cross	Yellow
16	Giza Baladi	ARC, Egypt	Population	White
17	Population-45	ARC, Egypt	Population	Yellow
18	Nubaria	ARC, Egypt	Population	Yellow
19	Nebraska Midland	USA	Composite	Yellow
20	Midland Cunningham	Eldorado, Kansas, USA	Population	Yellow
21	Golden Republic	Beltsville, Kansas, USA	Population	Yellow
22	Sweepstakes 5303	USA	Population	Yellow

2.4 Water Regimes

1. **Well watering (WW):** Irrigation was applied by flooding, the second irrigation was given after three weeks and subsequent irrigations were applied every 12 days.
2. **Water stress flowering (WSF**): The irrigation regime was just like well watering, but the 4^{th} and 5^{th} irrigations were withheld, resulting in 24 days water stress just before and during flowering stage.
3. **Water stress grain filling (WSG):** The irrigation regime was just like well watering, but the 6^{th} and 7^{th} irrigations were withheld, resulting in 24 days water stress during grain filling stage.

2.5 Agricultural Practices

All other agricultural practices were followed according to the recommendations of ARC, Egypt. Nitrogen fertilisation at the rate of 120 kg N/fed was added in two equal doses of Urea 46 % before the first and second irrigation. Triple Superphosphate Fertiliser (46% P_2O_5) at the rate of 30 kg P_2O_5/fed, was added as soil application before sowing during preparation of the soil for planting. Weed control was performed chemically with Stomp 330-E herbicide (Pendimethalin 33% w/v), just after sowing and before the planting irrigation and manually by hoeing twice, the first before the first irrigation (after 21 days from sowing) and the second before the second irrigation (after 33 days from sowing). Pest control was performed when required by spraying plants with Lannate (Methomyl) 90% (manufactured by DuPont, USA) against corn borers.

2.6 Soil Analysis

Physical and chemical soil analyses of the field experiments were performed at laboratories of Soil and Water Research Institute of ARC, Egypt. Across the two seasons, soil type was clay loam: Silt (36.4%), clay (35.3%), fine sand (22.8%) and coarse sand (5.5%), pH (7.92), EC (1.66 dSm^{-1}), SP (62.5), $CaCO_3$(7.7 %), Soil bulk density (1.2 g cm^{-3}), HCO_3 (0.71 mEqu/l), Cl (13.37 mEqu/l), SO_4 (0.92 mEqu/l), Ca^{++} (4.7 mEqu/l), Mg^{++}(2.2 mEqu/l), Na^+ (8.0 mEqu/l), K^+ (0.1 mEqu/l), N, P, K, Zn, Mn and Fe (371, 0.4, 398, 4.34, 9.08 and 10.14 mg/kg, respectively).

2.7 Data Recorded

1. **Days to 50% silking (DTS):** The number of days taking from emergence to the day on which 50% of the plants in a treatment showing complete silk emergence.
2. **Anthesis-silking interval (ASI):** was calculated as the difference between 50% silking and 50% anthesis
3. **Plant height (PH):** The average height of five randomly selected plants measured in centimeter from the ground level to the tip of the tassel 15 days before harvest.
4. **Ear height (EH):** The average height of five randomly selected plants measured in centimeter from base of the plant to the node bearing the upper most ear of the same plants used to measure plant height 15 days before harvest.
5. **Barren stalks (BS):** measured as percentage (%) of plants bearing no ears relative to the total number of plants in the plot; an ear was considered fertile if it had one or more grains on the rachis.
6. **Ear leaf area (ELA):** It was measured in cm^2 on the ear leaf from five guarded plants/plot, according to Francis et al. [17] as follows: ELA = Leaf length x maximum leaf width x 0.75
7. **Chlorophyll concentration index (CCI):** It was measured in % on 5 guarded plants/plot by Chlorophyll Concentration Meter, Model CCM-200, USA, as the ratio of transmission at 931 nm to 653 nm through the ear leaf of the plant. (http://www.apogeeinstruments.co.uk/apogee-instruments-chlorophyll-content-meter-technical-information/)
8. **Lower stem diameter (SDL):** It was measured in mm with caliper from 5 guarded plants/plot as the stem diameter above second node; two measurements were taken. The first measurement was used as a base line with the second measurement recorded after a 90-degree turn of the caliper.
9. **Upper stem diameter (SDU):** It was measured in mm with caliper from 5 guarded plants/plot as the stem diameter on third internode below flag leaf.
10. **Number of ears $plant^{-1}$ (EPP):** It was estimated by dividing number of ears $plot^{-1}$ on number of plants $plot^{-1}$.
11. **Number of rows ear^{-1} (RPE):** Using 10 random ears $plot^{-1}$ at harvest.
12. **Number of kernels row^{-1} (KPR):** Using the same 10 random ears $plot^{-1}$

13. **Number of kernels plant^{-1} (KPP):** It was calculated by multiplying number of ears plant^{-1} by number of rows ear^{-1} by number of kernels row^{-1}.
14. **100-kernel weight (100KW) (g):** Adjusted at 155g water kg^{-1} grain.
15. **Grain yield plant^{-1} (GYPP) (g):** It was estimated by dividing the grain yield plot^{-1} (adjusted at 15.5% grain moisture) on number of plants plot^{-1} at harvest.
16. **Grain yield ha^{-1} (GYPH) (ton):** It was estimated by adjusting grain yield plot^{-1} at 15.5% grain moisture to grain yield ha^{-1}.

2.8 Biometrical Analyses

Analysis of variance of the split-split plot design in RCB arrangement was performed on the basis of individual plot observation using the MIXED procedure of MSTAT ®. Combined analysis of variance across the two growing seasons was also performed if the homogeneity test was non-significant. Moreover, combined analysis for each environment separately across seasons was performed as randomized complete block design. Least significant difference (LSD) values were calculated to test the significance of differences between means according to Steel et al. [18].

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance

Combined analysis of variance across seasons (S) of the split-split plot design for 16 agronomic, physiological and yield traits of 22 genotypes (G) of maize (10 single crosses + 5 three-way crosses + 7 open-pollinated populations) under three irrigation treatments; namely well watering (WW), water stress at flowering (WSF) and water stress at grain filling (WSG) (for DTS, ASI, PH, EH, BS, EPP, RPE, KPR, KPP, 100-KW, GYPP, GYPH traits) or four irrigation treatments, namely well watering at flowering (WWF), well watering at grain filling (WWG), water stress at flowering (WSF) and water stress at grain filling (WSG) for four traits (CCI, SDU, SDL, ELA traits) is presented in Table (2).

Mean squares due to seasons were significant ($P \le 0.05$ or 0.01) for 10 out of studied 16 traits, namely days to silking (DTS), anthesis-silking interval (ASI), ears/plant (EPP), 100-kernels weight (100KW), grain yield/plant (GYPP), grain yield/ha (GYPH), chlorophyll concentration index (CCI), lower stem diameter (SDL), upper stem diameter (SDU) and ear leaf area (LEA), indicating significant effect of climatic conditions on such traits.

Mean squares due to irrigation regime and genotype were significant ($P \le 0.05$ or 0.01) for all studied traits, except rows/ear (RPE) and ear leaf area (LEA) for irrigation regimes, indicating that irrigation regime has a significant effect on 14 out of 16 traits and that genotype has an obvious and significant effect on all studied agronomic, physiological and yield traits.

Mean squares due to the 1st order interaction, *i.e.* T×S, G×S and G×T were significant ($P \le 0.05$ or 0.01) for all studied traits, except for 8 traits for T × S, namely, DTS, EEP, RPE, KPP, GYPP, CCI, SDU, and SDL, one trait (ELA) for G x S, and two traits (SDL and ELA) for G x T (Table 2). Significance of G×T indicated that means of studied traits of genotypes varied with water supply, confirming previous results [19-23].

Mean squares due to the 2nd order interaction, i.e., G×S×T, were significant ($P \le 0.01$) for all studied traits, except for RPE, SDU and ELA (Table 2), indicating that genotype performance differ from a combination of season x treatment to another combination and that the rank of maize genotypes differ from irrigation regime to another, and from one season to another and the possibility of selection for improved performance under a specific water stress for most studied agronomic and yield traits as proposed by Al-Naggar et al. [24-30].

Combined analysis of variance of a randomized complete blocks design (RCBD) for all studied traits of 22 maize genotypes under each irrigation treatment, (data not presented) indicated that mean squares due to genotypes under all environments were highly significant for all studied agronomic and yield traits, indicating the significance of differences among studied genotypes for such traits under each of irrigation regimes. Such genotypic differences in studied traits under well watering as well as water stress at flowering and grain filling were also recorded by previous investigators in maize [14-16,22,23, 30-33].

3.2 Effect of Deficit Irrigation

Water stress conditions imposed during flowering and grain filling stages caused a significant reduction, of 28.69 and 20.26% in grain yield/plant and 35.53 and 25.51% in grain yield/ha, respectively (Table 3 and Fig. 1). These results indicate that drought stress at flowering stage had more severe effect on yield than drought at grain filling. This result is in

Table 2. Combined analysis of variance of split-split plot design for 22 maize genotypes (G) under three/four irrigation regimes (T) across 2016 and 2017 seasons (S)

SOV	df	Mean squares			
		DTS	ASI	PH	EH
Season (S)	1	644**	18.3**	49.9	939.3
R(S)	4	3.5	0.1	53.9	54.2
Treatment (T)	2	48.1*	13.8**	22341.4**	5318.6**
T x S	2	7.3	4.5**	18508.9**	9057**
Error (a)	8	7.7	0.3	785.8	425.3
Genotype (G)	21	165.6**	12.1**	5990.6**	2385.6**
G x S	21	23.6**	1.7**	713**	265.5**
G x T	42	6.8**	2.5**	307.9**	132.7**
G x S x T	42	6.1**	2.5**	263.2**	134.6**
Error (b)	252	1.6	0.7	148	51.6
		BS	EPP	RPE	KPR
Season (S)	1	1882.9**	0.8**	0.1	150.1
R(S)	4	88.5	0.1	1.9	2.0
Treatment (T)	2	1520.2**	0.7**	2.7	1284.5**
T x S	2	1026.6*	0.01	0.1	321.2*
Error (a)	8	149.6	0.1	1.5	54.9
Genotype (G)	21	269.5**	0.1**	24.2**	245.6**
G x S	21	136.9**	0.1**	1.*	48.4**
G x T	42	102.3**	0.04**	1.1**	26.5**
G x S x T	42	87.7**	0.1**	0.7	28.6**
Error (b)	252	50.8	0.02	0.6	7.8
		KPP	100KW	GYPP	GYPH
Season (S)	1	100284.5	302.3**	26041.5*	124.7**
R(S)	4	13216.3	1.6	5318.3	2.4
Treatment (T)	2	735325.9**	590.5**	47158.4**	2041.1**
T x S	2	32895.6	182.1**	3864.3	225.5**
Error (a)	8	36955.1	5.6	4686.9	5.2
Genotype (G)	21	67129.7**	274.3**	12428.3**	707.3**
G x S	21	26213.3**	24.9**	3439.6**	46.4**
G x T	42	18826.3**	18.1**	1335.8**	34.8**
G x S x T	42	14581.2**	17.7**	1383.5**	19.6**
Error (b)	252	7281.6	4.9	219.5	2.1
		CCI	SDL	SDU	ELA
Season (S)	1	3458.3**	300.3**	1585.6**	342312.8**
R(S)	4	172.5	37.9	8.4	7319.7
Treatment (T)	3	4432.6**	120.9*	156.**	63074.7
T x S	3	374.6	21.4	37.6	94133.1*
Error (a)	12	152.3	31.4	14.2	27629.3
Genotype (G)	21	498**	79**	18.5**	101407.4**
G x S	21	94.8**	5.7*	4.9**	12628.8
G x T	63	148.3**	2.8	3**	8554.9
G x S x T	63	56.2**	4.8*	2.2	6414.7
Error (b)	336	18.36	3.6	1.7	8882.2

*DTS = days to 50% silking, ASI = anthesis-silking interval, PH = plant height, EH = ear height, EPP = number of ears per plant, RPE = Rows per ear, KPR = Kernels per row, KPP = Kernels per plant, 100-KW = 100-kernel weight, GYPP = Grain yield/plant, GYPH = grain yield/ha, CCI= Chlorophyll concentration index, SDL= Lower stem diameter, SDU= Upper stem diameter, ELA= Ear leaf area, * and ** indicate significance at 0.05 and 0.01 probability levels, respectively.*

accordance to Denmead and Shaw [5] and Chapman et al. [19], who noted that water stress during the vegetative stage of corn production reduced grain yield by 25%, water stress during silking reduced grain yield by 50%, while water stress during grain fill reduced grain yield by 21%. El-Ganayni et al. [31] also reported 33% yield reduction due to water stress at flowering. On the contrary, Al-Naggar et al. [30] found that drought stress at grain filling stage had more severe effect on yield than drought at flowering. They attributed that to stopping irrigation after flowering stage till the end of the season in their experiment. Differences in results of different investigators might be due to differences in soil properties and climate conditions prevailed during the seasons and locations of different studies.

Yield reductions were accompanied by significant ($p \leq 0.05$ or 0.01) losses in number of ears/plant by 11.58%, kernels/row by 14.23%, kernels/plant by 24.85% and 100-kernel weight by 6.75% due to drought at flowering and 100-kernel weight by 12.36% due to drought at grain filling stage. It is observed that reduction in kernel weight was more pronounced due to drought at grain filling than that at flowering. Number of kernels per row and per plant was significantly reduced due to drought at flowering, but was not affected with drought at grain filling. This is because number of fertilised eggs (later become grains) is determined at flowering stage, but accumulation of assimilates in grains (which affects grain weight) occurs during grain filling stage. This conclusion is in agreement with that reported by El-Ganayni et al. [31].

Table 3. Means of studied agronomic, physiological and yield traits under WW (or WWF and WWG), WSF and WSG and change % from WW to WSF and WSG combined across all genotypes and across 2016 and 2017 seasons

Trait	Parameter		WW	WSF	WSG
Days to 50% silking	Mean		63.96	66.08	64.33
	Change %			-3.31*	-0.58
Anthesis-silking interval	Mean		2.6	3.53	2.53
	Change %			-35.77**	1.54
Plant height (cm)	Mean		252.25	244.22	249.66
	Change %			3.18*	1.03
Ear height (cm)	Mean		127.03	120.18	119.25
	Change %			5.39**	6.12**
Barren stalks%	Mean		0.94	7.22	1.84
	Change %			-665.3**	-95.02
Ears per plant	Mean		0.95	0.83	0.97
	Change %			11.85*	-2.65
Rows per ear	Mean		14.02	13.74	13.85
	Change %			2.0	1.24
Kernels per row	Mean		38.08	32.66	38.05
	Change %			14.23**	0.07
Kernels per plant	Mean		499.05	375.02	508.96
	Change %			24.85**	-1.99
100-kernel weight (g)	Mean		34.18	31.88	29.96
	Change %			6.75**	12.36**
Grain yield/plant (g)	Mean		128.17	91.39	102.2
	Change %			28.69**	20.26**
Grain yield/ha (ton)	Mean		9.02	5.82	6.72
	Change %			35.53**	25.51*
		WWF	**WWG**	**WSF**	**WSG**
Chlorophyll concentr. index %	Mean	34.2	17.11	23.88	9.56
	Change %		49.98**	30.18**	44.07**
Lower stem diameter (mm)	Mean	24.73	23.79	23.91	22.42
	Change %		3.79	3.29	5.76
Upper stem diameter (mm)	Mean	9.97	9.46	10.05	7.72
	Change %		5.11	-0.77	18.46**
Ear leaf area (cm^2)	Mean	708.9	666.1	691.1	662.7
	Change %		6.04	2.52	0.51

*WW = well watering, WWF= well watering at flowering, WWG= well watering at grain filling, WSF = water stress at flowering, WSG= water stress at grain filling, * and ** indicate significance at 0.05 and 0.01 probability levels, respectively. Change %= 100 (WW-WS)/WW.*

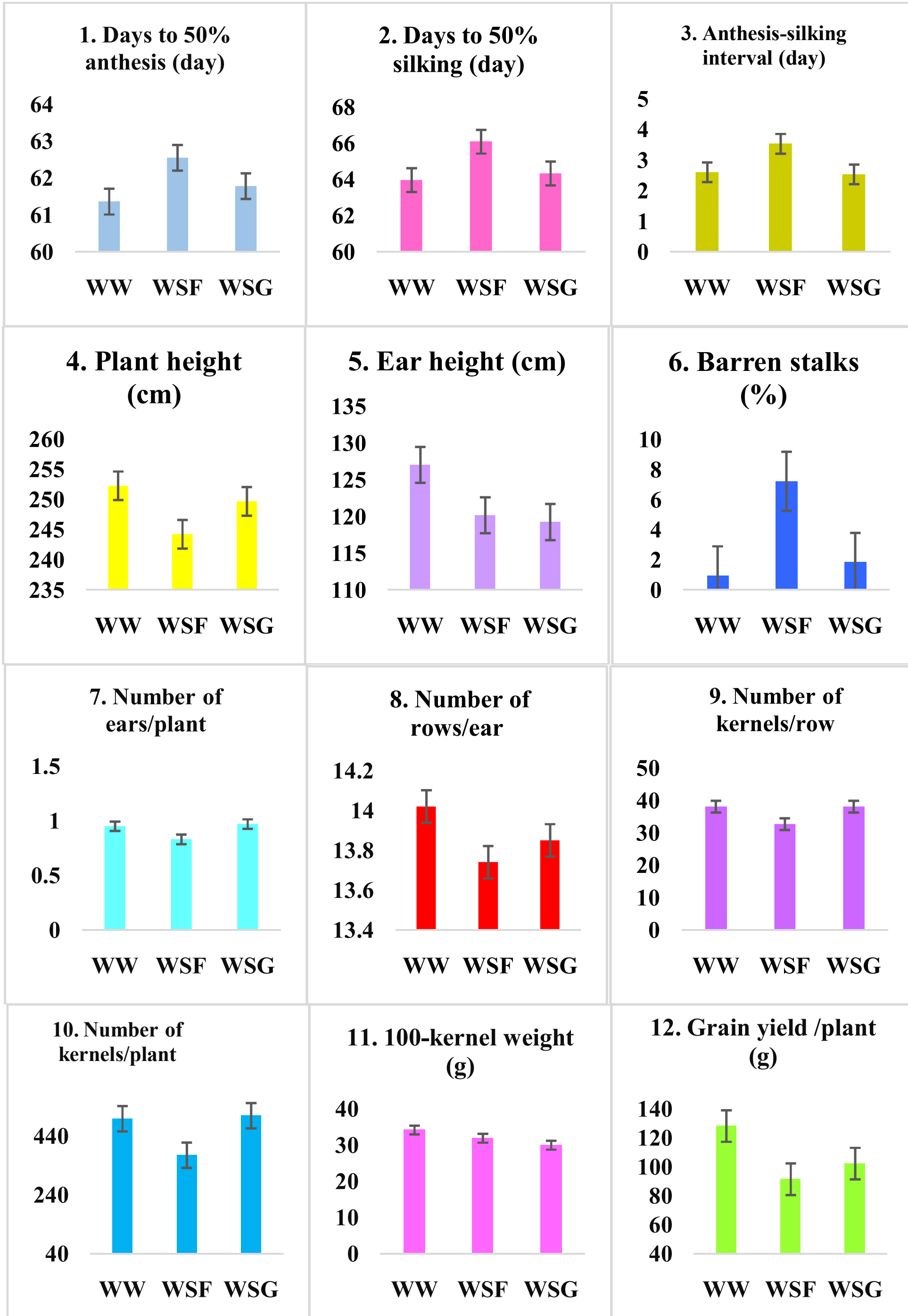

Fig. 1. Means of studied agronomic and yield traits (1 through 12) under well watering (WW), water stress at flowering (WSF) and at grain filling (WSG) across all maize genotypes and across two seasons

Reduction in grain yield and its components due to water deficit at flowering and grain filling stages is in agreement with those of several investigators [3,6,23,30,31,34]. A significant decrease due to water stress at flowering and grain filling was also recorded in plant height

(3.18 and 1.03%) and ear height (5.39 and 6.12 %), respectively. This result is in agreement with that reported by Al-Naggar et al. [30].

On the contrary, a significant increase due to water stress at flowering stage only was shown for anthesis-silking interval (35.77%), days to silking (3.31%) and barren stalks (BS) (665.3 %) (Table 3). Elongation of ASI and increase of BS in maize because of drought stress were reported by several investigators [2,3,10,22-25, 27,30,31,35].

Because other four studied traits (CCI, SDL, SDU, ELA) were measured or scored at different plant ages as compared with controls at the end of each stress, so we had two controls, one for water stress at flowering (WWF) at plant age of 80 days and another one for water stress at grain filling (WWG) at plant age of 104 days, besides two water stress treatments (WSF and WSG). So these traits were analysed under four irrigation treatments (WWF, WWG, WSF, and WSG). The change in percentage from WWF to WSF and from WWS to WSG was calculated to study the effect of drought at flowering and grain filling, respectively on these traits; however the change from WWF to WWG was calculated to study the effect of plant ageing on such traits.Water stress at flowering and grain filling caused a significant reduction in chlorophyll concentration index (CCI) by 30.18 and 44.07%, respectively (Table 3 and Fig. 2). Water stress at grain filling only caused a significant reduction in upper stem diameter (SDU) by 18.46%. The two traits (SDL and ELA) were not affected significantly by water stress neither at flowering nor at grain filling. It is observed that the effect of WSG on these four traits was more severe than the effect of WSF. It is worthy to note that ageing of corn plant from 80 days to 104 days age caused a reduction in all four traits; such reduction reached significance ($p \leq 0.01$) for CCI trait (49.98%).

3.3 The Effect of Maize Genotype

Means of studied 16 traits of each of 22 genotypes across all irrigation treatments combined across two seasons are presented in Table (4). Means of each of the 22 maize genotypes showed wide ranges of performance (difference between minimum and maximum) for all studied traits across all irrigation treatments. Genotypes varied for grain yield/ha from 13.0 ton (Genotype No. 8) to 2.69 ton (Genotype No. 22), grain yield/plant from 158.5 g (Genotype No. 6) to 62.5 g (Genotype No. 22), ears/plant from 1.05 (Genotype No. 8) to 0.83 (Genotype No. 4), rows/ear from 15.9 (Genotype No. 14) to 11.9 (Genotype No. 1), kernels/row from 43.6 (Genotype No. 5) to 30.5 (Genotype No. 22), kernels/plant from 592.3 (Genotype No. 8) to 332.4 (Genotype No. 22), 100-kernel weight from 32.0g (Genotype No. 2) to 25.8g (Genotype No. 18), CCI from 31.1% (Genotype No. 7) to 13.5% (Genotype No. 22), SDL from 27.2 mm (Genotype No. 2) to 20.1 mm (Genotype No. 21), ELA from 773.6 cm^2 (Genotype No. 5) to 0.565.4 cm^2 (Genotype No. 9), DTS from 69.7 (Genotype No. 2) to 57.6 (Genotype No. 21), ASI from 4.78 day (Genotype No. 9) to 0.83 (Genotype No. 22), BS from 14.9% (Genotype No. 22) to 0% (Genotypes No. 2, 4, 7 and 11), plant height from 296.9 cm (Genotype No. 5) to 219.7 cm (Genotype No. 21), ear height from 142.2 cm (Genotype No. 5) to 100.2 cm (Genotype No. 9).

The genotype No. 8 (Pioneer-3444) exhibited the highest mean values for three traits [GYPH, KPP, EPP] and second highest for GYPP. The genotype No. 6 (SC-128) developed by ARC-Egypt was the highest in GYPP. The genotype No. 4 (Egaseed 77) developed by Fine Seed Co. showed the third highest in grain yield. The genotype No. 5 (SC-10) developed by ARC-Egypt showed the highest means for four traits (KPR, ELA, plant height and ear height); it was the fourth highest in grain yield per plant and per hectare.

In general, the commercial varieties P-3444, SC-128, Egaseed-77 and SC-10 were the best genotypes in our experiment, where they showed the highest grain yield across all studied irrigation treatments; they could be recommended for farmers use under a range of different environments as well as for maize breeding programs.

On the contrary, the genotype No. 22 (Pop. Sweepstakes 5303) exhibited the lowest means for six traits, namely GYPP, GYPH, KPP, KPR, CCI and ASI (desirable) and the highest mean (undesirable) for barren stalks%. The genotype No. 21 (Pop. Golden Republic) exhibited the lowest means for three traits, namely DTS, PH and SDL. The genotype No. 18 (Pop. Nubaria) showed the lowest means for 100-KW. It is observed that most of traits with undesirable mean values were exhibited by populations and the *vice versa* for traits with desirable means, which were mostly shown by the single crosses. Several investigators [14-16] suggested that hybrids maintain their advantage over open pollinated varieties across stress and non-stress environments.

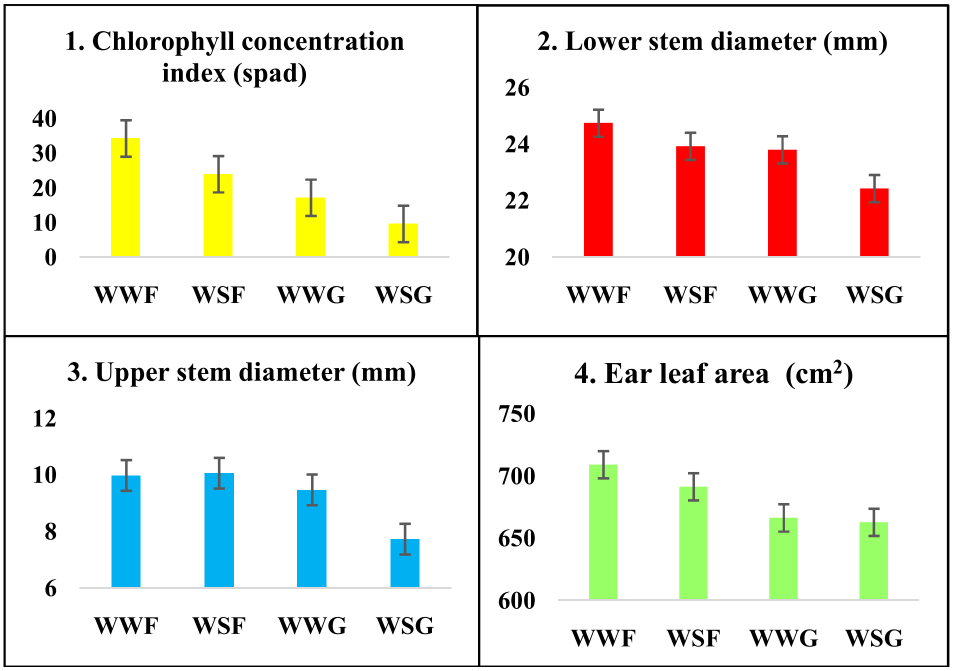

Fig. 2. Means of chlorophyll concentration index (1), lower stem diameter (2), upper stem diameter (3) and ear leaf area (4) across genotypes under well watering at flowering (WWF) and at grain filling (WWG), water stress at flowering (WSF) and at grain filling (WSG) across two seasons

Table 4. Minimum and maximum values followed by genotype No. (Between brackets) of all studied traits combined across all irrigation regimes and across two seasons

Parameter	Traits					
	DTS	**ASI**	**PH (cm)**	**EH (cm)**	**BS%**	**EPP**
Min	57.6 (21)	1.78(9)	219.7 (21)	100.2 (9)	0.0(2,4,7,11)	0.83(4)
Max	69.7 (2)	4.78 (22)	296.9 (5)	142.2 (5)	14.9(22)	1.05(8)
$LSD_{.05}$	0.83	0.54	7.98	4.71	1.73	0.09
	RPE	**KPR**	**KPP**	**100-KW (g)**	**GYPP (g)**	**GYPH (ton)**
Min	11.9 (1)	30.5 (22)	332.4 (22)	25.8 (18)	62.5 (22)	2.69 (22)
Max	15.9 (14)	43.6 (5)	592.3 (8)	38.1(2)	158.5 (6)	13.0(8)
$LSD_{.05}$	0.5	1.83	56.02	1.45	9.72	0.40
	CCI (%)	**SDL (mm)**	**SDU (mm)**	**ELA (cm^2)**		
Min	13.5 (22)	20.1(21)	7.5(9)	565.4(9)		
Max	31.1(7, 4)	27.2(2, 3, 13)	11.4(4,6,5)	773.6(5,6)		
$LSD_{.05}$	2.43	1.07	0.74	53.52		

*DTS = days to 50% silking, ASI = anthesis-silking interval, PH = plant height, EH = ear height, EPP = number of ears per plant, RPE = Number of rows per ear, KPR = Number of kernel per row, KPP = number of kernels per plant, 100-KW = 100-kernel weight, GYPP = grain yield/plant, GYPH = grain yield/ha, CCI= Chlorophyll concentration index, SDL= Lower stem diameter, SDU= Upper stem diameter, ELA= Ear leaf area. *Minimum and Maximum values are followed by genotype number (between brackets).*

3.4 Genotype × Irrigation Regime Interaction

For agronomic and yield traits measured under WW, WSF and WSG (Table 5), it is observed that for DTS, the lowest mean was exhibited by genotypes No. 9, 21 and 21 and the highest mean by genotypes No. 4, 2 and 2, for ASI, the lowest mean by genotypes No. 7, 5 and 20 and the highest mean by genotypes No. 22, 22 and 6, for PH, the lowest mean by genotypes No. 21, 21 and 21 and the highest mean by genotypes No. 5, 5 and 5, for EH, the lowest by genotypes No. 21, 9 and 9 and the highest by genotypes No. 13, 5 and 5, for BS, the lowest mean by genotypes No. 2, 4, 7 and 11 and the highest mean by genotype No. 22, 22 and 17, for EPP, the lowest by genotypes No. 20, 16 and 4 and the highest by genotypes No. 8, 6 and 20, for RPE, the lowest by genotypes No. 1, 11 and 1 and the highest by genotypes No. 9, 9 and 18 , for KPR, the lowest by genotypes No. 22, 16 and 14 and the highest by genotypes No. 5, 5 and 6, for KPP, the lowest by genotypes No. 22, 16 and 22 and the highest by genotypes No. 8, 6 and 8, for 100-KW, the lowest by genotypes No. 18, 18 and 14 and the highest by genotypes No. 2, 2 and 1, for GYPP, the lowest by genotypes No. 19, 22 and 22 and the highest by genotypes No. 1, 6 and 8 and for GYPH, the lowest by genotypes No. 22, 22 and 22 and the highest by genotypes No. 8, 4 and 8, at WW, WSF and WSG, respectively.

For CCI, SDU, SDL and ELA traits (Table 6), data were measured under WWF, WWG, WSF and WSG. For CCI, the lowest mean was exhibited by genotypes No. 1, 19, 22 and 19 and the highest mean was shown by genotypes No. 6, 4, 7 and 7, for SDL, genotypes No. 21, 21, 21 and 21 and the highest mean was shown by genotypes No. 2, 3, 2 and 2, for SDU, genotypes No. 9, 9, 9 and 15 and the highest mean was shown by genotypes No. 4, 4, 4 and 5, for ELA, the lowest means by genotypes No. 22, 9, 22 and 9 and the highest mean by genotypes No. 6, 6, 1 and 5 under WWF, WWG, WSF and WSG, respectively.

Results from Tables (5 and 6) concluded that the best genotypes were No. 8 (P-3444) in 3 traits (KPP, GYPP, GYPH) under WSG, and 3 traits (EPP, KPP, GYPH) under WW, the genotype No. 6 (SC 128) in 3 traits (EPP, KPP, GYPP) under WSF and two traits (CCI, ELA) under WWF, the genotype No.5 (SC 10) in 4 traits (PH. EH, SDU, ELA) under WSG, 3 traits (PH, EH, KPR) under WSF, two traits (PH, KPR) under WW , respectively, the genotype No. 7 (Hi-Tec 2066) in one trait (BS) under WW, WSF and WSG, one trait (CCI) under WSG, the genotype No. 4 (Egaseed 77) in three traits (GYPH, BS, SDU) under WSF, two traits (CCI,SDU) under WWG and one trait (SDU) under WWF and the genotype No. 2 (30K09) in two traits (GYPH, SDL) under WSF.

Table 5. Minimum (Min) and maximum (Max) values of studied agronomic and yield traits of each genotype under each irrigation regime (well watering; WW, water stress at flowering; WSF and water stress at grain filling; WSG) across 2016 and 2017 seasons

Parameter	WW	WSF	WSG	WW	WSF	WSG
	Days to silking			Anthesis silking interval		
Min	57.8(21)*	57.8(21)	57 (21)	1.5(8)	1.67(15)	0.4(21)
Max	68.3(4)*	70.5(2)	70.3(2)	4.67(22)	6.33(22)	3.7(1,6)
LSD.05	1.49	1.2	1.54	0.8	1.02	.0.88
	Plant height			Ear height		
Min	214.5(21)	212.1(21)	232.4(21)	97.2(21)	96.5(9)	104.1(9)
Max	291.3(5)	277.2(5)	322.3(5)	136.5(13)	136.2(5)	160.4(5)
LSD.05	12.7	14.38	14.72	7.6	7.85	9.17
	Barren stalks (%)			Ears/plant		
Min	0	0	0	0.82(20)	0.72(3)	0.75(4)
Max	10.4 (22)	25.5(22)	8.8(22)	1.08(8)	1.0(6)	1.17(20)
LSD.05	3.99	13.0	3.90	0.16	0.16	0.16
	Rows/ear			Kernels/row		
Min	11.7(1)	11.6(11)	11.6(1)	30(22)	26.2(16)	32.3(14)
Max	16.5(9)	15.9(9)	15.9(18)	44.9(5)	40.9(5)	45(5)
LSD.05	1.02	0.88	0.88	3.8	3.18	2.48
	Kernels/plant			100-Kernel weight		
Min	361.8(22)	237.4(16)	349.8(22)	27.4(18)	23.4(18)	23.5(14)
Max	618(8)	515.9(6)	655(8)	42.3(2)	38.3(2)	38.2(1)
LSD.05	95.62	87.96	109.5	2.6	2.6	2.4
	Grain yield/plant			Grain yield/ha		
Min	82.9(19)	31.8(22)	58.9(22)	3.91 (22)	1.39 (22)	2.77 (22)
Max	168.191)	156.4(6)	179.7(8)	15.25 (8,5,6)	10.55 (4,8.6)	13.45 (8,6)
LSD.05	23	13.3	12.7	0.75	0.63	0.71

**Minimum and Maximum values are followed by genotype number (between brackets)*

Table 6. Minimum (Min) and maximum (Max) values of CCI, SDU, SDL and ELA traits for each genotype under well watering at flowering (WWF) and at grain filling (WWG), water stress at flowering (WSF) and at grain filling (WSG) and change % from WWF and WWG to WSF and WSG, respectively combined across two seasons

Parameter	WWF	WWG	WSF	WSG
		Chlorophyll Concentration index %		
Min	26.5(1)	4.4(19)	15.8(22)	2.6(19)
Max	42(6)	33.2(4)	36.2(7)	22.1(7)
LSD.05	6.4	4.1	4.4	4.4
		Lower stem diameter (SDL) (mm)		
Aver.	24.7	23.8	23.9	22.4
Min	20.5(21)*	20.1(21)	20.6(21)	19.4(21)
Max	28(2)*	27(3)	27.2(2)	27.2(2)
LSD.05	1.8	2.4	2.1	2.4
		Upper stem diameter (SDU) (mm)		
Aver.	10	9.5	10.1	7.72
Min	8.4(9)	7.6(9)	7.9(9)	6.(15)
Max	11.4(4)	13.5(4)	13(4)	11.1(5)
LSD.05	1.3	1	1.4	2
		Ear leaf area (ELA) (cm^2)		
Aver.	708.9	666.1	691.1	662.7
Min	586.3(22)	528.8(9)	568.4(22)	527.2(22)
Max	839.9(6)	809.4(6)	788.5(1)	786.2(1)
LSD.05	100.6	104.3	105	96.5

**Minimum and Maximum values are followed by genotype number (between brackets)*

On the contrary, the worst genotypes were No. 22 (Sweepstakes) in 3 traits (KPR,GYPP,GYPH) under WSG, 4 traits (GYPP, GYPH, CCI, ELA) under WSF and 4 traits (KPR, KPP, GYPH, ELA) under WW, the genotype No. 21 (Golden Republic) in 2 traits (PH, SDL) under WSG, 2 traits (PH,SDL) under WSF, one trait (SDL) under WWF and 2 traits (PH,EH) under WW, the genotype No. 19 (Nebraska) in one trait (CCI) under WSG, and the genotype No. 18 (Nubaria) in one trait (CCI) under WWG and one trait (GYPP) under WW.

The four highest and the four lowest performing genotypes under water stress at flowering (WSF) and grain filling (WSG) across seasons are presented in Table (7). Under WSF conditions, the highest mean grain yield/ha was achieved by the single cross Egaseed-77 (developed by Egaseed Co.), followed by P-3444 (developed by Pioneer Co.), SC 128 (developed by ARC, Egypt) and HT-2066 (developed by Hi Tec Co.) in a descending order. The single cross Egaseed-77 was among the four highest genotypes under WSF for GYPH, GYPP, CCI, SDL, SDU and the four lowest genotypes for BS (barren stalks%). The single cross P-3444 was among the four highest genotypes under WSF for GYPH, GYPP, EPP, and KPP. The single cross SC-128 was among the four highest genotypes under WSF for GYPH, GYPP, EPP, KPP, 100-KW, SDU and the four lowest genotypes for DTS and ASI (favorable). The single cross HT-2066 was among the four highest genotypes under WSF for GYPH, GYPP, KPR, KPP, CCI and the four lowest genotypes for BS and EH.

Under WSG conditions, the highest mean grain yield/ha was achieved by the single cross P-3444 (developed by Pioneer) followed by SC-128 (developed by ARC), TWC-324 (developed by ARC) and SC-166 (developed by ARC) in a descending order. The single cross P-3444 was among the four highest genotypes in GYPH, GYPP, EPP, KPP, 100-KW, CCI, i.e. most important grain yield and physiological traits. It should be noted that this hybrid was characterised by its ability to stay green even under water stress, which might help it to tolerate water stress at grain filling stage in a way much better than other tested hybrids and populations. The single cross SC-128 was among the four highest genotypes in GYPH, GYPP, KPR, SDU and ELA. The three-way cross TWC-324 was among the four highest genotypes in GYPH, KPR, PH and EH and the four lowest genotypes for BS (barren stalks %). The single cross SC-166 was among the four highest genotypes in GYPH and RPE and the four lowest genotypes

Table 7. The four highest and the four lowest genotypes for studied traits under water stress at flowering (WSF) and grain filling (WSG) across seasons

WSF	WSG	WSF	WSG	WSF	WSG	WSF	WSG
Days to silking		**Anthesis silking interval**		**Plant height**		**Ear height**	
Highest							
30K09	30K09	Sweep	HT-2031	SC-10	SC-10	SC-10	SC-10
HT-2031	HT-2031	Midland	SC-128	TWC-324	TWC-324	TWC-324	HT-2031
Eg-77	Eg-77	30K09	Fine 1005	Fine 1005	Fine 1005	Giza	TWC-324
Fine 1005	Fine 1005	Nebraska	Sweep	Watania 11	30K09	HT-2031	Fine 1005
Lowest							
SC-166	HT-2066	SC-128	Pop-45	TWC-352	Sweep	Nubaria	Golden
Nubaria	Nubaria	Golden	Nubaria	Sweep	Midland	HT- 2066	HT- 2066
SC-128	SC-166	SC-10	Nebraska	32D99	Nubaria	Golden	Nubaria
Golden	Golden	TWC-352	Midland	Golden	Golden	SC-166	SC-166
Barren stalks %		**Ears/plant**		**Rows/ear**		**Kernels/row**	
Highest							
Sweep	Sweep	SC-128	Midland	SC-166	Nubaria	SC-10	SC-10
Pop-45	Nebraska	P-3444	P-3444	TWC-360	Pop-45	TWC-324	HT-2066
Nebraska	TWC-352	SC-166	Giza	Nubaria	TWC-360	Wat- 11	TWC-324
Midland	Midland	32D99	SC-10	Pop-45	SC-166	HT-2066	SC-128
Lowest							
Fine 1005	SC-166	Pop-45	HT-1100	Sweep	TWC-324	Sweep	30K09
Eg-77	32D99	Midland	HT-2031	SC-10	SC-10	Pop-45	TWC-352
HT-2066	Hi-Tec 1100	Fine 1005	Sweep	HT-2031	HT-1100	Midland	Sweep
Wat- 11	TWC-324	Giza	Eg-77	HT-1100	HT-2031	Giza	TWC-360
Kernels/plant		**100-Kernel weight**		**Grain yield/plant**		**Grain yield/ha**	
Highest							
SC-128	P-3444	30K09	HT-2031	SC-128	P-3444	Eg-77	P-3444
P-3444	Midland	SC-128	SC-10	Eg-77	SC-128	P-3444	SC-128
SC-166	HT-2066	Fine 1005	P-3444	P-3444	Eg-77	SC-128	TWC-324
HT-2066	SC-10	TWC-324	30K09	HT-2066	SC-10	HT-2066	SC-166

WSF	**WSG**	**WSF**	**WSG**	**WSF**	**WSG**	**WSF**	**WSG**
			Lowest				
Midland	TWC-352	Sweep	Nebraska	Golden	Pop-45	Pop-45	Nebraska
Sweep	Eg-77	Nebraska	Golden	Nebraska	Golden	Golden	TWC-352
Fine 1005	HT-2031	Golden	Giza	Giza	TWC-352	Nebraska	Golden
Giza	Sweep	Nubaria	TWC-360	Sweep	Sweep	Sweep	Sweep
Chlorophyll concentration index		**Lower stem diameter**		**Upper stem diameter**		**Ear leaf area**	
			Highest				
HT-2066	HT-2066	30K09	30K09	Eg-77	SC-10	HT-2031	SC-10
Eg-77	Wat- 11	Fine 1005	TWC-324	SC-128	HT-1100	TWC-324	SC-128
SC-166	P-3444	TWC-324	Fine 1005	Fine 1005	SC-128	SC-10	HT-2066
Wat- 11	30K09	Eg-77	SC-10	30K09	32D99	TWC-352	TWC-324
			Lowest				
32D99	Sweep	SC-128	Sweep	TWC-360	HT-2031	Midland	Sweep
HT-1100	SC-166	Nubaria	P-3444	P-3444	P-3444	SC-166	Golden
HT-2031	Nubaria	Sweep	SC-166	TWC-352	SC-166	Golden	Nubaria
Sweep	Nebraska	Golden	Golden	SC-166	TWC-352	Sweep	SC-166

for BS (barren stalks %), DTS and EH. In a previous study [25] the single cross SC-128 (developed by ARC) proved the highest grain yielder under water stress at flowering among another set of maize genotypes. In contrast, the open-pollinated populations Pop-45, Golden, Nebraska, and Sweep under WSF and Nebraska, TWC-352, Golden and Sweep under WSG were the lowest for GYPH and GYPP. These genotypes were therefore considered as most sensitive to drought at respective growth stages. Several investigators [25,27,31,35] reported the presence of significant interaction between maize genotype and irrigation regime.

4. CONCLUSIONS

The present results concluded that the reduction in grain yield and its components due to water stress was more pronounced at flowering (WSF) than under grain filling (WSG). WSF affected number of kernels more than WSG, while WSG affected kernel weight (100-KW) more than WSF. In general, the best performing genotypes in this study under WSF or WSG were the single crosses, while the worst performing genotypes were the open pollinated populations. The highest yielding genotypes were Eg-77, P-3444, SC-128 and HT-2066 under WSF and P-3444, SC-128, TWC-324 and SC-166 under WSG, in a descending order. Each of these genotypes was characterised by one or more desirable grain yield components, physiological and agronomic traits. These genotypes could be offered to future breeding programs as useful germplasm for developing drought tolerant inbred lines and single cross hybrids.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAOSTAT. Food and Agriculture Organization of the United Nations. Statistics Division; 2016 (Accessed on 02/08/2016) http://faostat3.fao.org/
2. Monneveux P, Sanchez C, Beck D, Edmeades GO. Drought tolerance improvement in tropical maize source populations: Evidence of progress. Crop Sci. 2006;46(1):180-191.
3. Bolaños J, Edmeades GO. Eight cycles of selection for drought tolerance in lowland tropical maize. I. Responses in grain yield, biomass and radiation utilization. Field Crops Res. 1993;31:233–252.
4. Shaw RH. Water use and requirements of maize - a review. In: Agrometeorology of the Maize (corn) Crop. World Met. Organization Publication. 1977;480;119-134.
5. Chapman SC, Crossa J, Edmeades GO. Genotype by environment effects and selection for drought tolerance in tropical maize. I. Two mode pattern analysis at yield. Euphytica. 1997;95(1):1-9.
6. Grant RF, Jakson BS, Kiniry JR, Arkin GF. Water deficit timing effects on yield components in maize. Agron. J. 1989; 81(1):61-65.
7. NeSmith DS, Ritchie JT. Short- and long-term responses of corn to a preanthesis soil water deficit. Agron. J. 1992;84:107-113.
8. O'Neill PM, Shanahan JF, Schepers JS, Caldwell B. Agronomic responses of corn hybrids from different eras to deficit and adequate levels of water and nitrogen. Agron. J. 2004;96(6):1660-1667.
9. Bruce WB, Edmeades GO, Barker TC. Molecular and physiological approaches to maize improvement for drought tolerance. J. Exp. Bot. 2002;53:13-25.
10. Edmeades GO, Bolanos J, Hernandez M, Ballo S. Causes for silk delay in a low land tropical maize population. Crop Sci. 1993; 33:1029-1035.
11. Edmeades G, Lafitte HR. Defoliation and plant density effects on maize selected for reduced plant height. Agron. J. 1993;85: 850-857.
12. Ribaut JM, Jiang C, Gonzatez-de-Leon GD, Edmeades GO, Hoisington DA. Identification of quantitative trait loci under drought conditions in tropical maize. II Yield components and marker-assisted selection strategies. Theor. Appl. Genet. 1997;94:887-896.
13. Hall AJ, Viella F, Trapani N, Chimenti C. The effects of water stress and genotype on the dynamics of pollen shedding and silking in maize. Field Crop Res. 1982;5: 349-363.
14. Dass S, Dang YP, Dhawan AK, Singh NN, Kumar S. Morho- physiological basis for breeding drought and low -N tolerant maize genotypes in India. In Edmeades, G.O., Bänziger, M., Mickelson, H.R. and Pena-Valdiva, C.B. (Eds.), Developing Drought and Low N-Tolerant Maize.

Proceedings of a Symposium, March 25-29, 1996, CIMMYT, El Batan, Mexico. Mexico, D.F.: CIMMYT. 1997;106-111.

15. Vasal SK, Cordova H, Beck DL, Edmeades GO. Choices among breeding procedures and strategies for developing stress tolerant maize germplasm. In Edmeades, G.O., Bänziger, M., Mickelson, H.R. and PenaValdiva, C.B. (Eds.), Developing Drought and Low N Tolerant Maize. Proceedings of a Symposium, March 25-29, 1996, CIMMYT, El Batan, Mexico. Mexico, D.F.: CIMMYT. 1997; 336-347.
16. Duvick DN. Commercial strategies for exploitation of heterosis. In Coors J.G. and Pandey, S. (Eds.), The Genetics and Exploitation of Heterosis in Crops. ASA, CSS, and SSSA. Madison, Wisconsin, USA.1999;19-29.
17. Francis GA, Rutger JN, Palmer AFE. A rapid method for plant leaf area estimation in maize (*Zea mays* L.). Crop Sci. 1969;9: 537- 537.
18. Steel RG, Torrie DGHDickey DAPrinciples and Procedures of Statistics: A Biometrical Approach. 3rd ed. McGraw-Hill, New York, USA; 1997.
19. Denmead OT, Shaw RH. The effect of soil moisture stress at different stages of growth on the development and yield of corn. Agron. J. 1960;52:272-274.
20. Moss, GI, Downey LA. Influence of drought stress on female gametophyte development in corn (*Zea mays* L.) and subsequent grain yield. Crop Sci. 1971;11: 386-372.
21. Al-Naggar AMM, El-Ganayni AA, El-Sherbeiny HY, El-Sayed MY. Direct and indirect selection under some drought stress environments in corn (*Zea mays* L.). J. Agric. Sci. Mansoura Univ. 2000;25(1): 699–712 .
22. Al-Naggar AMM, Shabana R, Sadek SE, Shaboon SAM. S_1 recurrent selection for drought tolerance in maize. Egypt. J. Plant Breed. 2004;8:201-225.
23. Al-Naggar AMM, El-Murshedy WA, Atta MMM. Genotypic variation in drought tolerance among fourteen Egyptian maize cultivars. Egypt. J. Appl. Sci. 2008;23(2B): 527-542.
24. Al-Naggar AMM, Shabana R, Mahmoud AA, Abdel El-Azeem MEM, Shaboon SAM. Recurrent selection for drought tolerance improves maize productivity under low-N conditions. Egypt. J. Plant Breed. 2009;13: 53-70.
25. Al-Naggar AMM, Soliman SM, Hashimi MN. Tolerance to drought at flowering stage of 28 maize hybrids and populations. Egypt. J. Plant Breed. 2011a;15(1):69-87.
26. Al-Naggar AMM, Shabana R, Al-Khalil TH. Differential nitrogen use efficiency in maize genotypes of narrow- *vs* broad–base genetic background. Egypt. J. Plant Breed. 2011b;15(1):41-56.
27. Al-Naggar AMM, Atta MMM, Ahmed MA, Younis ASM. Influence of deficit irrigation at silking stage and genotype on maize (*Zea mays* L.) agronomic and yield characters. Journal of Agriculture and Ecology Research International. 2016a; 7(4):1-16.
28. Al-Naggar AMM, Atta MMM, Ahmed MA, Younis ASM. Direct vs indirect selection for maize (*Zea mays* L.) tolerance to high plant density combined with water stress at flowering. Journal of Applied Life Sciences International. 2016b;7(4):1-17.
29. Al-Naggar AMM, Atta MMM, Ahmed MA, Younis ASM. Secondary traits and selection environment for drought tolerance at flowering in maize (*Zea mays* L.) Inbreds and Their F1 Diallel Crosses. Asian Research Journal of Agriculture. 2016c;1(2):1-15.
30. Al-Naggar AMM, Abd El-Salam RM, Badran AEE, El-Moghazi Mai MA. Genotype and Drought Effects on Morphological, Physiological and Yield Traits of Quinoa (*Chenopodium quinoa* Willd.). Asian Journal of Advances in Agricultural Research. 2017; 3(1):1-15.
31. El-Ganayni AA, Al-Naggar AMM, El-Sherbeiny HY, El-Sayed MY. Genotypic differences among 18 maize populations in drought tolerance at different growth stages. J. Agric. Sci. Mansoura Univ. 2000;25(2):713–727.
32. Al- Naggar AMM, Shehab-El-Deen MT. Predicted and actual gain from selection for early maturing and high yielding wheat genotypes under water stress conditions. Egypt. J. Plant Breed. 2012; 16(3):73-92.
33. Dhliwayo T, Pixley K, Menkir A, Warburton M. Combining ability, genetic distances, and heterosis among elite CIMMYT and

IITA tropical maize inbred lines. Crop Sci. 2009;49:1201–1210.

34. Claassen MM, Shaw RH. Water deficit effect on corn. 1-Vegetative components. Agron. J. 1970;62: 649-652.

35. Parajuli S, Ojha BR, Ferrara GO. Quantification of secondary traits for drought and low nitrogen stress tolerance in inbreds and hybrids of maize (*Zea mays* L.). J. Plant Genet. Breed. 2018;2:106.

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