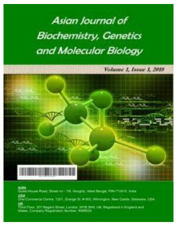

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Heritability and Correlations for Agronomic and Physiologic Traits of Maize under Deficit Irrigation at Two Growth Stages

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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

Strong associations between agronomic and physiologic traits and drought tolerance, high heritability and high genetic advance for such traits would allow plant breeder to use such traits as selection criteria for selecting drought tolerant genotypes. The objectives of the present investigation were: (i) to explain the relationships between the drought tolerance index (DTI) and 14 agronomic and physiologic traits of 22 maize genotypes and (ii) to estimate the broad-sense heritability (h^2_b) and genetic advance (GA) from selection for such traits, in order to determine the selection criteria for DTI. A two-year experiment was carried out using a split plot experiment with three replications. The main plots were devoted to irrigation regimes, *i.e.* well watering (WW), water stress at flowering (WSF) and at grain filling (WSG), and sub plots to maize genotypes. It is evident from results that the best selection criteria for drought tolerance in our study were: 100-kernel weight (100KW) and chlorophyll concentration index (CCI) under WSF and WSG, anthesis-silking interval (ASI), upper stem diameter (SDU) and lower stem diameter (SDL) under WSF and kernels/row (KPR) and ear leaf area (ELA) under WSG, since they show high correlation (r) values with grain yield/plant (GYPP), high h^2_b and high GA estimates under the respective environments. Under well watering

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conditions, KPR, 100KW, CCI, and SDL traits showed high (r) values, high h^2_b and high GA estimates and therefore could be considered selection criteria for GYPP under non-stressed environment. The results concluded that predicted selection gain would be higher if selection was practiced under WW for lower values of days to silking and higher values of ears/plant, rows/ear, KPR, 100KW, SDU and SDL, under WSF for lower values of ASI and higher values of GYPP and under WSG for lower values of plant height, ear height, and barren stalks, and higher values of CCI and ELA.

Keywords: Selection criteria; chlorophyll content; genetic advance; flowering stage; grain filling.

1. INTRODUCTION

Maize (*Zea mays* L.) in Egypt is grown as a summer season crop and depends on flood irrigation from Nile River and its branches and canals. However, the amount of water available for irrigation is reducing, especially at the ends of canals and due to expanding maize cultivation into the deserts and competition with other crops; especially rice. In order to stabilize maize production in Egypt, there is a need to develop drought tolerant maize hybrids. Edmeades *et al.* [1] demonstrated that germplasm developed from drought tolerant source populations performed significantly better under drought stress compared to conventional populations.

Maize is very sensitive to water stress during the flowering and grain-filling periods [2]. However, Witt et al*.* [3] reported that the most critical period for yield production goes approximately from 2 weeks before flowering time until 2 weeks after flowering time. Susceptibility of maize yield to stresses at flowering has been documented in maize germplasm [4-5].

Genetic correlation in particular determines the degree of association between traits and how they may enhance selection. It is useful if indirect selection gives greater response to selection for traits than direct selection for the same trait. It is suggested that indirect selection would be effective if heritability of the secondary trait is greater than that of the primary trait and genetic correlation between them is substantial [6]. Similarly, Rosielle and Hamblin [7] also indicated that magnitudes of selection responses and correlated responses will depend on heritabilities and phenotypic standard deviations as well as genetic correlations. Other studies reported that computed phenotypic correlation found positive correlations between grain yield and yield components, ear height and plant height [8]. The main criteria for drought tolerant trait selection is the association of each trait with grain yield under stress conditions [9,10]. A strong phenotypic association between grain yield and grain number/m2 in both water- stressed and well- watered environments (r = 0.96; r = 0.87) was reported by Chapman and Edmeades [11]. Bolaños and Edmeades [12] also indicated that variation in grain number has a more pronounced effect on yield rather than grain weight. Guei and Wassom, [13] who found high associations between grain yield and days to 50% silking, ASI, and EPP reported similar results under drought stress. Chapman and Edmeades [11] reported a strong phenotypic association between grain yield and grain number m^{-2} in both water-stressed and well- watered environments (r=0 .96; r=0.87). Under drought stress conditions, yield increases were strongly associated with reduced ASI, reduced barrenness and increased harvest index [10,14].

The estimation of the heritability is a very useful parameter for breeders because it allows one to predict the possibility of success with the selection, as it reflects the proportion of phenotypic variation that can be inherited; in other words, the heritability coefficient measures the reliability of the phenotypic value as an indicator of genotypic value [15].

Heritability estimates facilitate the choice of methods and characters used in the initial and advanced phases of improvement programs, thereby allowing the study of mechanisms, genetic values and variability for one character [16]. The estimations of high coefficients of heritability are associated with a greater genetic variability, greater selective accuracy [17] and greater possibilities for success in selecting genotypes with higher productivity of grain.

The objectives of the present investigation were: (i) to interpret the relationships between the drought tolerance index (DTI) or grain yield/plant (GYPP) and studied agronomic and physiologic traits of available maize germplasm and (ii) to estimate the heritability and genetic advance from selection of these traits, in order to determine the selection criteria for DTI or GYPP under drought stress and non-stress conditions at flowering and grain filling stages.

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 fertilization 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 Fertilizer (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, 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. [18] 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. **100-kernel weight (100KW) (g):** Adjusted at 155g water kg^{-1} grain.
14. **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.

2.8 Drought Tolerance Index (DTI)

Drought tolerance index is the factor used to differentiate between the genotypes from tolerance point of view and it is calculated by the equation of Fageria [19] as follows: DTI = (Y1/AY1) X (Y2/AY2), Where, Y1 = trait mean of a genotype at well watering. AY1 = average trait of all genotypes at well watering. Y2 = trait mean of a genotype at water stress. AY2 = average trait of all genotypes at water stress. When DTI is ≥ 1, it indicates that genotype is tolerant (T) to drought. If DTI is <1, it indicates that genotype is sensitive (S) to drought.

2.9 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. [20]. Expected mean squares at separate and across seasons under each irrigation regime were estimated from ANOVA table according to Hallauer et al. [21]. Genotypic (σ^2_g), genotype x season (σ^2_{gs}), error (σ^2_e) and phenotypic (σ^2_{ph}) variances were computed as follows: $\sigma^2_g = (M_3 – M_2)/sr$, $\sigma^2_{gs} = (M_2-M_1)/r$, $\sigma^2_{ph} = \sigma^2_g + \sigma^2_{gs}/ r + (\sigma^2_e /rs)$. Where r = number of replications, g = number of genotypes and s= number of seasons.

2.10 Heritability in the Broad Sense

Heritability in the broad sense (h^2_b %) for a trait in a separate environment was estimated according to Singh and Narayanan [22] using the following formula: h^2_b % = 100 × (σ^2_g / σ^2_{ph}) Where: σ^2_g = genetic variance, and σ^2_{ph} = phenotypic variance.

2.11 Expected Genetic Advance from Selection

Expected genetic advance from selection for all studied traits as a percent of the mean was calculated according to Singh and Narayanan [22] as follows: GA (%) = $(100\ K\ h^2_b\ \sigma_{ph})/\overline{x}$, Where: $\overline{x}$ = General mean, σ_{ph} = Square root of the denominator of the appropriate heritability, h^2_b = The applied heritability, K = Selection differential (K = 1.76, for 10% selection intensity, used in this study).

2.12 Rank Correlation Coefficients

Spearman's rank correlation coefficients calculated among studied traits and DTI under studied environments. It was computed by using SPSS 17 computer software and the significance of the rank correlation coefficient was tested according to Steel et al. [20].

3. RESULTS

3.1 Analysis of Variance

Combined analysis of variance across seasons (S) of the split-plot design for 14 agronomic, physiologic 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, 100-KW and GYPP 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 CCI, SDU, SDL and ELA traits) is presented in Table 2.

Mean squares due to seasons were significant ($P \leq 0.05$ or 0.01) for 10 out of studied 14 traits, namely days to silking (DTS), anthesis-silking interval (ASI), barren stalks (BS), ears/plant (EPP), 100-kernels weight (100KW), grain yield/plant (GYPP), chlorophyll concentration index (CCI), lower stem diameter (SDL), upper stem diameter (SDU) and ear leaf area (LEA).

Mean squares due to irrigation regime and genotype were significant ($P \leq 0.05$ or 0.01) for all studied traits, except rows/ear (RPE) and ear leaf area (LEA) for irrigation regimes.

Table 2. Mean squares from combined analysis of variance of split-plot design for studied traits of 22 maize genotypes under four irrigation regimes (T) across 2016 and 2017 years

SV	df	Mean squares				
		DTS	**ASI**	**PH**	**EH**	**BS**
Season (S)	1	644**	18.3**	49.9	939.3	1882.9**
R(S)	4	3.5	0.1	53.9	54.2	88.5
Treatment (T)	2	48.1*	13.8**	22341.4**	5318.6**	1520.2**
T x S	2	7.3	4.5**	18508.9**	9057**	1026.6*
Error (a)	8	7.7	0.3	785.8	425.3	149.6
Genotype (G)	21	165.6**	12.1**	5990.6**	2385.6**	269.5**
G x S	21	23.6**	1.7**	713**	265.5**	136.9**
G x T	42	6.8**	2.5**	307.9**	132.7**	102.3**
G x S x T	42	6.1**	2.5**	263.2**	134.6**	87.7**
Error (b)	252	1.6	0.7	148	51.6	50.8
		EPP	**RPE**	**KPR**	**100KW**	**GYPP**
Season (S)	1	0.8**	0.1	150.1	302.3**	26041.5*
R(S)	4	0.1	1.9	2	1.6	5318.3
Treatment (T)	2	0.7**	2.7	1284.5**	590.5**	47158.4**
T x S	2	0.01	0.1	321.2*	182.1**	3864.3
Error (a)	8	0.1	1.5	54.9	5.6	4686.9
Genotype (G)	21	0.1**	24.2**	245.6**	274.3**	12428.3**
G x S	21	0.1**	1.*	48.4**	24.9**	3439.6**
G x T	42	0.04**	1.1**	26.5**	18.1**	1335.8**
G x S x T	42	0.1**	0.7	28.6**	17.7**	1383.5**
Error (b)	252	0.02	0.6	7.8	4.9	219.5
		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 = 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 per plant, GYPF = grain yield per feddan, 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*

Mean squares due to the 1st order interaction, *i.e.* T × S, G × S and G × T were significant ($P \leq 0.05$ or 0.01) for all studied traits, except for 7 traits for T × S, namely, DTS, EEP, RPE, GYPP, CCI, SDU, and SDL, one trait (ELA) for G x S, and two traits (SDL and ELA) for G x T (Table 2). Mean squares due to the 2nd order interaction, *i.e.*, G×S×T, were significant ($P \leq 0.01$) for all studied traits, except for RPE, SDU and ELA (Table 2).

3.2 Drought Tolerance Index

Drought tolerance index (DTI) values of studied genotypes under the stressed environments WSF and WSG are presented in Table 3. According to our scale, when DTI is ≥1.0, it indicates that genotype is tolerant (T), if DTI is 1.0, it indicates that genotype is moderately tolerant (MT) and if DTI is <1.0, it indicates that genotype is sensitive (S).

Based on DTI values, the 22 studied maize genotypes were grouped into three categories under water stress at flowering, namely tolerant (10 genotypes), moderately tolerant (2 genotypes) and sensitive (10 genotypes) (Table 3). Under water stress conditions at grain filling, number of tolerant (T), and sensitive (S) genotypes were 11, and 11, respectively.

Table 3. Drought tolerance index (DTI) of each genotype under WSF and WSG environments

Genotype no.	Designation	WSF	WSG	Genotype no.	Designation	WSF	WSG
1	Hi-Tec-2031	1.3	1.6	**12**	Watania -11	1.2	1.2
2	P-30K09	1.0	1.2	**13**	TWC-324	1.7	1.7
3	Fine 1005	1.0	1.3	**14**	TWC-360	0.7	0.6
4	Egaseed-77	2.4	1.6	**15**	TWC-352	0.6	0.4
5	SC-10	1.8	1.8	**16**	Giza Baladi	0.4	0.5
6	SC-128	2.5	2.2	**17**	Population-45	0.4	0.5
7	Hi-Tec-2066	1.4	0.9	**18**	Nubaria	0.5	0.6
8	P-3444	3.0	3.4	**19**	Nebraska Midland	0.3	0.3
9	SC-166	1.4	1.4	**20**	Midland Cunningham	0.4	0.4
10	P-32D99	1.3	1.4	**21**	Golden Republic	0.3	0.3
11	Hi-Tec-1100	0.9	0.9	**22**	Sweepstakes 5303	0.1	0.2

3.3 Superiority of Drought Tolerant (T) to Sensitive (S) Genotypes

Based on grain yield/plant and drought tolerance index (DTI), the best three genotypes were the single cross hybrids P-3444, SC-128 and Egaseed-77 under WSF and P-3444, SC-128 and SC-10 under WSG, while the drought sensitive and lowest yielding genotypes were the populations Sweepstakes, Golden Republic and Nebraska Midland under both water stress environments (WSF and WSG). Data averaged for each of the two groups (T and S) under WSF and under WSG indicated that GYPP of drought tolerant (T) was greater than that of the sensitive (S) genotypes by 189.0 and 131.3 % under drought at flowering (WSF) and grain filling (WSG), respectively (Table 4).

Significant superiority of drought tolerant (T) over sensitive (S) genotypes in GYPP under drought at flowering and grain filling was associated with significant superiority in higher EPP (13.0 and 15.0 %), higher 100-KW (36.2 and 28.7 %), higher KPR (15.5 and 18.4 %), lower BS (- 97.6 and – 82.8%), shorter ASI (– 47.4 % under WSF), higher CCI (49.6 and 219.1 %), higher SDL (9.3 and 9%), higher SDU (17.9 and 15.7%), higher ELA (31.7 under WSG), respectively. However, tolerant genotypes had taller plants (8.1 and 17.2%) and higher ear placement than sensitive genotypes (2.4 and 13.9%) under drought at flowering (WSF) and grain filling (WSG), respectively.

3.4 Correlations between DTI and Studied Traits

Drought tolerance index had a strong significant ($p\leq 0.01$) and positive correlation with grain yield/plant (r= 0.912** and 0.941**) under WSF and WSG conditions, respectively (Table 5).

Table 4. Superiority (Sup%) of the three most tolerant (T) over the three most sensitive (S) genotypes for selected characters under the stressed environments WSF and WSG, combined across 2016 and 2017 seasons

Trait	WSF			WSG		
	T	S	Sup%	T	S	Sup %
ASI	2.2	4.2	-47.4**	2.7	2.0	37.9
PH	247.0	228.4	8.1*	287.9	245.6	17.2**
EH	117.2	114.5	2.4	133.9	117.6	13.9**
BS	0.5	19.4	-97.6**	0.9	5.0	-82.8**
EPP	0.9	0.8	13.0*	1.1	0.9	15.0*
KPR	35.1	30.4	15.5**	42.3	35.7	18.4**
100-KW	35.2	25.8	36.2**	34.0	26.4	28.7**
GYPP	147.3	51.0	189.0**	158.1	68.3	131.3**
CCI	29.4	19.6	49.6**	12.0	3.8	219.1**
SDL	23.9	21.8	9.3*	22.5	20.6	9.0*
SDU	11.3	9.6	17.9*	8.8	7.6	15.7
ELA	667.5	598.1	11.6	749.7	569.2	31.7**

** and ** indicate significance at 0.05 and 0.01 probability levels, respectively*

Table 5. Correlation coefficients between drought tolerance index (DTI) and means of studied traits of all genotypes under water stress at flowering (WSF) and at grain filling (WSG) across seasons

Trait	WSF	WSG	Trait	WSF	WSG
DTS	0.114	0.361	**KPR**	0.594**	0.536*
ASI	-0.541**	0.379	**100-KW**	0.649**	0.720**
PH	0.436*	0.504*	**GYPP**	0.912**	0.941**
EH	0.030	0.193	**CCI**	0.443*	0.449*
BS	-0.704**	-0.584**	**SDL**	0.313	0.205
EPP	0.569**	0.174	**SDU**	0.363	0.075
RPE	-0.017	-0.196	**ELA**	0.283	0.540**

** and ** indicate significance at 0.05 and 0.01 probability levels, respectively*

Drought tolerance had a significant and positive correlation coefficient, with number of kernels/row (r = 0.594** and 0.536**), 100-kernels weight (r = 0.649** and 0.720**), plant height (r= 0.436* and 0.504*), chlorophyll concentration index (r = 0.443* and 0.449*) and a significant and negative correlation coefficient with percent of barren stalks (r = -0.704** and -0.584**) under WSF and WSG conditions, respectively. Moreover, drought tolerance index had a significant and negative correlation coefficient with anthesis-silking interval; ASI (r= 0.541**) and a significant and positive correlation coefficient with ears/plant; EEP (0.569**) under WSF and a significant and positive correlation coefficient with ear leaf area; ELA (0.540**), under WSG.

3.5 Correlations between Grain Yield and Other Studied Traits

Estimates of correlation coefficients among grain yield/plant and other studied agronomic and physiologic traits across the two seasons under well watering, water stress at flowering (WSF) and grain filling (WSG) were calculated across all genotypes and presented in Table 6. Under well watering, grain yield/plant had a significant ($p \le 0.01$) and positive association with CCI (0.191), EPP (0.562), KPR (0.296), and 100-KW (0.0.287), but had a significant ($p \le 0.01$) and negative association with ASI (-0.277) and BS (-0.212).

Data in Table 6 showed that under WSF, grain yield/plant was significantly ($P \le 0.01$) and positively correlated with each of PH (0.292), CCI (0.473), KPR (0.521) and 100KW (0.494), but had a significant ($p \le 0.01$) and negative association with ASI (-0.262) and BS (-0.281). Under water stress at grain filling (WSG), grain yield/plant had a significant and positive correlation ($p \le 0.01$ or $p \le 0.05$) with DTS (0.191), PH (0.312), CCI (0.332), ELA (0.258) and EPP (0.251), KPR (0.410) and 100KW (0.420), but had a significant ($p \le 0.01$) and negative association with BS (-0.275).

Table 6. Correlation coefficients between grain yield/plant and each of studied agronomic and physiologic traits of maize under well watering (WW), water stress at flowering (WSF) and water stress at grain filling (WSG) across two years

Trait	WW	WSF	WSG
Days to 50% silking (DTS)	0.153	-0.020	0.191*
Anthesis-silking interval (ASI)	-0.277**	-0.262**	-0.007
Plant height (PH)	0.103	0.292**	0.312**
Barren stalks (BS)	-0.212*	0-.281**	-.275**
Chlorophyll concentration index (CCI)	0.191*	0.473**	0.332**
Ear leaf area (ELA)	0.035	0.154	0.258**
Ears per plant (EPP)	0.562**	-0.118	0.251**
Rows per ear (RPE)	-0.097	0.170	-0.051
Kernel per row (KPR)	0.296**	0.521**	0.410**
Kernels per plant (KPP)	0.560**	0.656**	0.376**
100-kernel weight (100KW)	0.287**	0.494**	0.420**

** and ** indicate significance at 0.05 and 0.01 probability levels, respectively*

3.6 Heritability and Genetic Advance

Estimates of heritability in the broad sense (h^2_b) and genetic advance (GA) from selection based on 10 % selection intensity for agronomic and yield traits under well-watered (WW), water stress at flowering (WSF) and water stress at grain filling (WSG) are presented in Table 7 and Figs. (1 and 2) and for physiologic and stem traits under well-watered at flowering (WWF), well-watered at grain filling (WWG), water stress at flowering (WSF) and water stress at grain filling (WSG) are presented in Table 8 and Figs. 3 and 4.

3.7 Agronomic and Yield Traits

For agronomic and yield traits, broad sense heritability (h^2_b) ranged from 0.00 % for ASI under WSG and EPP under WSF to 92.16 % for RPE under WW (Table 7 and Fig. 1). The largest h^2_b estimates (ca 90.0 %) were shown by PH, RPE and 100KW traits under the WW environment, RPE under WSF and PH and RPE under WSG. The estimates of h^2_b for agronomic and yield traits were of low magnitude in ASI (0.0%) and EPP (20.00%) under WSG and EPP (0.0%) under WSF, GYPP (3.20%), BS (31.19 %) and EPP (33.33%) under WW.

The magnitude of expected genetic advance (GA) from direct selection (Table 7 and Fig. 2) was the lowest under water stressed environment for 7 agronomic and yield traits (DTS, PH, EH, BS, EPP, RPE, and KPR) under WSF and two traits (ASI and 100-KW) under WSG. The magnitude of GA from direct selection was highest under well watering environment for five traits (DTS, EPP, RPE, KPR and 100KW), under water stress at flowering for two traits (ASI and GYPP), and under water stress at grain filling for four traits (PH, EH and BS).

3.8 Physiologic and Stem Traits

For physiologic and stem traits (Table 8 and Figs. 3 and 4), broad-sense heritability (h^2_b) ranged from 0.00 % for SDU under WWF to 89.2% for CCI under WWG. In general, the estimates of h^2_b for stem traits ranged from low to medium in magnitude. The lowest h^2_b estimates (< 20 % and > 0.0%) were expressed by SDU under WWF, SDU, SDL and ELA under WWG.

The largest h^2_b estimates (> 70.0 %) were shown by SDL under the three environments WWF, WWG and WSF, CCI under WWG and WSG, SDU under WWG and WSF, ELA under WWG and WSG.

Table 7. Heritability in the broad sense (h^2_b) and genetic advance (GA) from selection for agronomic and yield traits of maize evaluated under well-watered (WW), water stress at flowering (WSF) and at grain filling (WSG)

Trait	WW		WSF		WSG	
	h^2_b%	GA%	h^2_b%	GA%	h^2_b%	GA%
Day to 50 % silking	88.8	7.12	88.20	7.04	79.3	7.09
Anthesis-silking interval	70.6	38.85	80.70	51.06	0	0
Plant height	90.4	11.98	58.70	5.76	89.9	14.33
Ear height	81.89	12.67	82.71	11.69	85.55	17.98
Barren stalks	31.19	127.36	37.30	70.62	59.21	127.48
Ears per plant	33.33	4.37	0	0	20.00	3.31
Rows per ear	92.16	15.08	89.61	13.0	90.7	13.80
Kernels per row	81.6	15.86	55.77	11.38	73.83	12.38
100-kernel weight	91.49	20.88	83.68	18.88	75.78	15.95
Grain yield per plant	3.2	0.82	76.77	45.11	81.55	42.77

Table 8. Heritability in the broad sense (h^2_b) and genetic advance (GA) from selection for physiologic and stem traits of maize genotypes evaluated under well-watered at flowering (WWF), well water at grain filling (WWG), water stress at flowering (WSF) and water stress at grain filling (WSG) conditions

Trait	WWF		WWG		WSF		WSG	
	h^2_b %	GA%	h^2_b %	GA%	h^2_b %	GA%	h^2_b %	GA%
Chlorophyll con. index (CCI)	68.8	16.6	89.2	50.8	67.8	36.2	70.2	79.6
Upper stem diameter (SDU)	0	0	74.4	15.8	76.0	15.7	51.8	13.2
Lower stem diameter (SDL)	83.5	12	77.1	10.7	79.4	10.5	74.0	10.8
Ear leaf area (ELA)	67.1	11	76.6	15.0	63.6	10.6	81.7	17.4

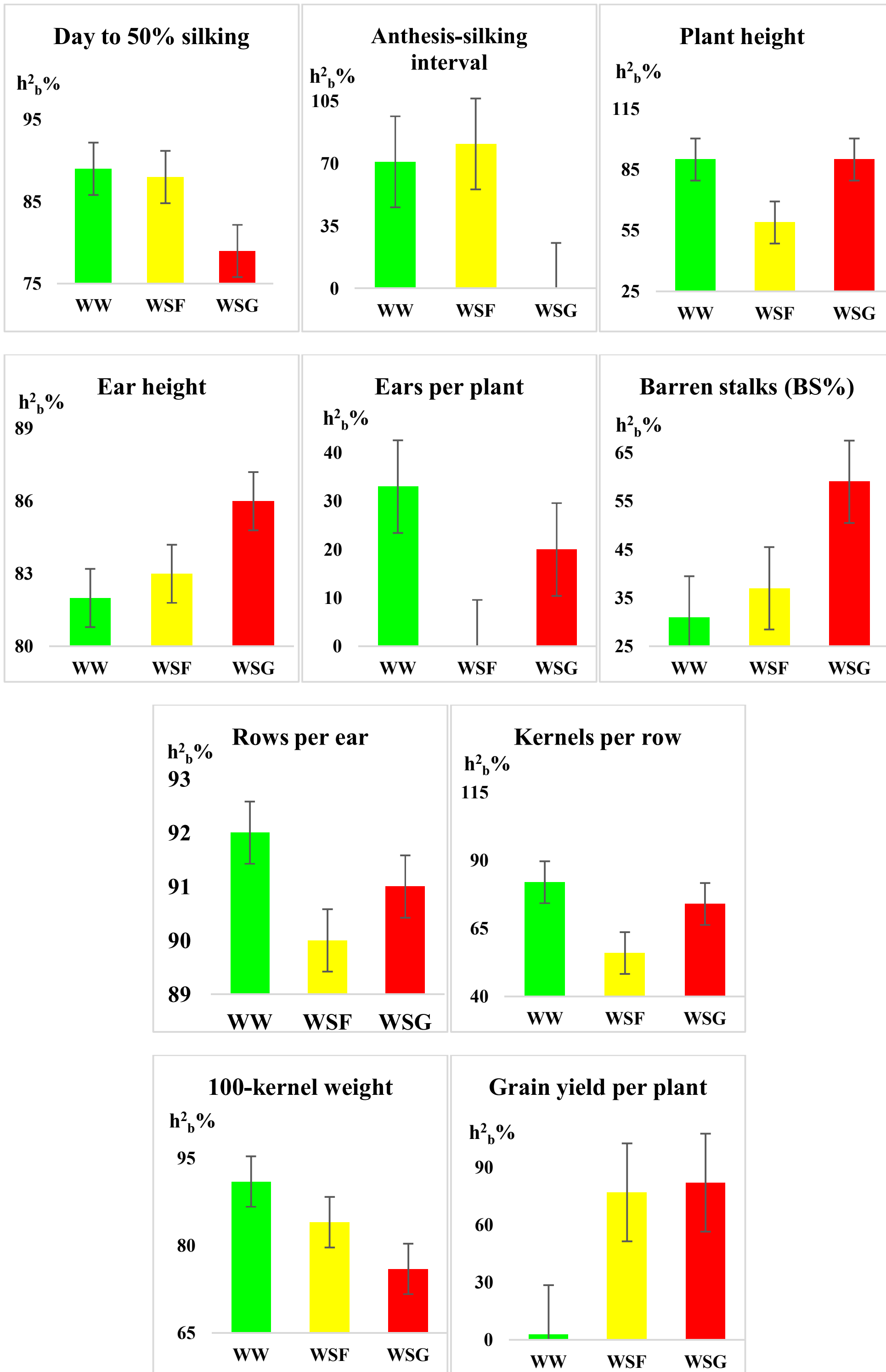

Fig. 1. Heritability in broad sense (h^2_b%) for studied agronomic and yield traits under well watering (WW), water stress at flowering (WSF) and water stress at grain filling (WSG) across two years

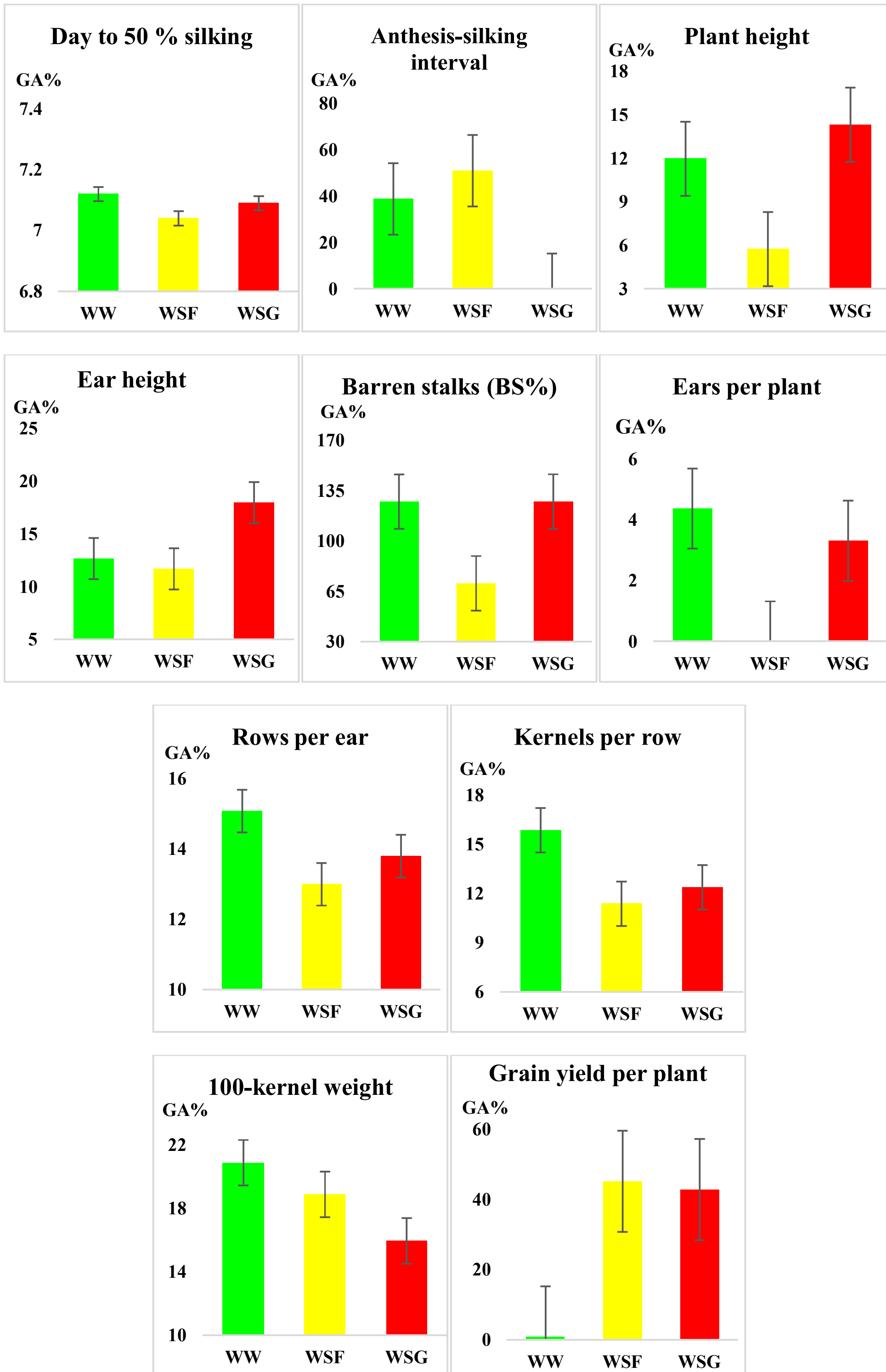

Fig. 2. Genetic advance (GA %) from selection for studied agronomic and yield traits under well watering (WW), water stress at flowering (WSF) and at grain filling (WSG) across two years

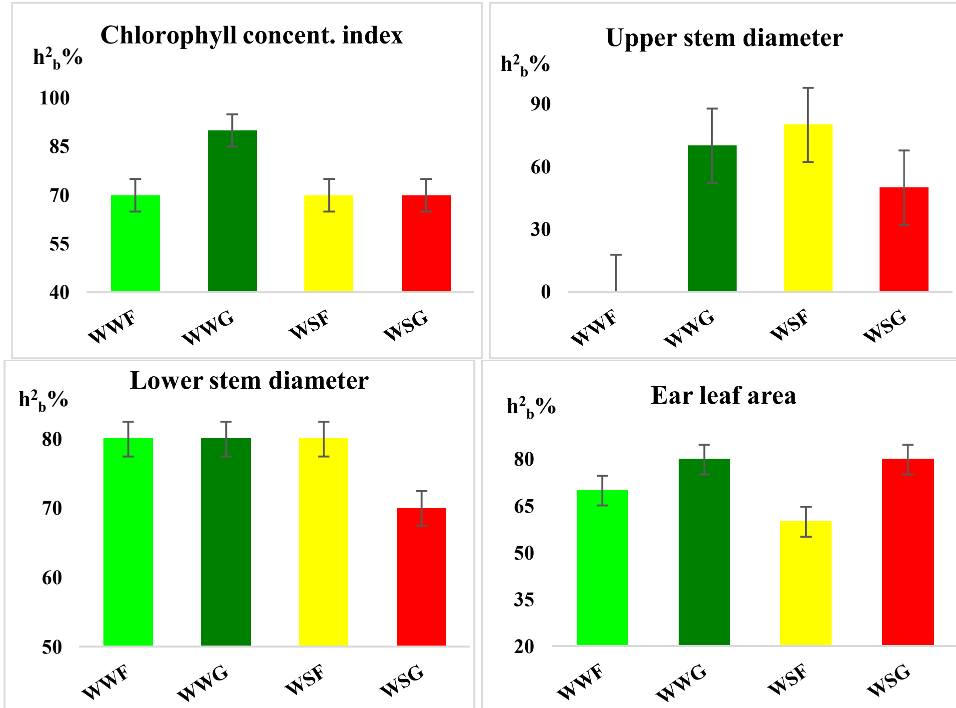

Fig. 3. Heritability in broad sense (h^2_b %) for studied stem traits under well watering at flowering (WWF), WW at grain filling (WWG), water stress at flowering (WSF) and WS at grain filling (WSG) across two years

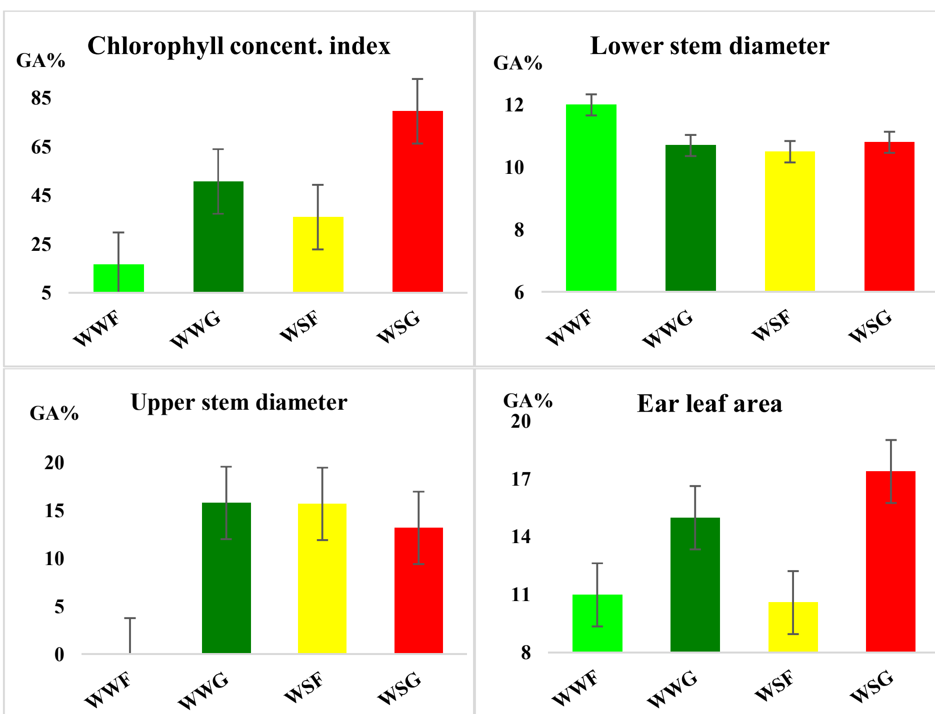

Fig. 4. Genetic advance (GA %) from selection for studied stem traits under well watering at flowering (WWF), WW at grain filling (WWG), water stress at flowering (WSF) and WS at grain filling (WSG) across two years

The magnitude of expected genetic advance (GA) from direct selection for physiologic and stem traits was the lowest under well-watered environment for CCI, SDU under WWF, but was the lowest under water stressed environments for SDL and ELA under WSF. The magnitude of GA from direct selection was highest under water stressed environments (CCI, ELA).

4. DISCUSSION

Combined analysis of variance across seasons (S) of the present investigation indicated significant effect of climatic conditions on nine out of studied 14 traits. Mean squares due to the two studied factors indicated that irrigation treatment (T) has a significant effect on 12 out of 14 traits and that genotype (G) has an obvious and significant effect on all studied agronomic, physiologic and yield traits. Significance of G×T mean squares in the present study indicated that means of studied traits of genotypes varied with water supply, confirming previous results [23,24]. Significance of G×S×T mean squares for 11 out of 14 traits indicated that genotype performance differ from one 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 almost all studied agronomic and yield traits as proposed by Al-Naggar et al. [5,25-28].

Drought tolerance index (DTI) for the studied 22 genotypes indicated that the highest DTI under both the two stressed environments (WSF and WSG) was exhibited by the genotype No. 8 (P-3444). The 2nd and 3rd highest genotypes in DTI were SC-128 and Egaseed-77 under WSF and SC-128 and SC-10 under WSG. For productivity (grain yield/plant) under WSF, the genotype Egaseed-77 ranked 1st, but P-3444 and SC-128 ranked 3rd. Under WSG, P-3444, SC-128 and SC-10 ranked 1st, 2nd and 3rd, for productivity as well as drought tolerance index. On the contrary, the most drought sensitive genotypes were the open-pollinated populations Sweepstakes 5303, Golden Republic and Nebraska Midland under both water stress environments (WSF and WSG); their grain yield were the lowest. Drought tolerant (T) was superior to sensitive (S) genotypes under drought at flowering (WSF) and grain filling (WSG) in higher GYPP, EPP, 100-KW and KPR, lower BS, shorter ASI, higher CCI, SDL, SDU), ELA, taller plants and higher ear placement.

CIMMYT breeders found that maize grain yield under drought was closely related to some secondary traits such as more ears per plant, *i.e.* less barrenness, short ASI and late leaf senescence, *i.e*. stay green [10,29,30]. These results are in consistency with those reported by Al-Naggar et al. [23-25]. Reduction in barren stalks and shortening in ASI of tolerant as compared to sensitive genotypes in the present study are desirable and may be considered as important contributors to drought tolerance. Edmeades et al. [30] and Al-Naggar et al. [5] reported similar conclusions.

The strong and significant correlation coefficient between DTI and GYPP indicates that grain yield was the best indicator of drought tolerance in this experiment. Correlation analysis indicated that drought tolerant genotypes under both WSF and WSG conditions are characterized by high GYPP, tall PH, less BS, high KPR, heavy 100-kernel weight and high CCI, Moreover, drought tolerance genotypes are characterized by short ASI, high number of ears/plant, under water stress at flowering (WSF) and characterized by large ear leaf area, under water stress at grain filling (WSG). These traits could be considered as selection criteria for drought tolerance in maize if they proved high heritability and high-predicted genetic advance from selection. This conclusion is in accordance with other investigators [5,10,26-28,31-34] for agronomic and yield traits.

The significant and negative genetic correlation between grain yield and both ASI and BS under water stress and non-stress, indicated the importance of these two traits in tolerance to drought stress. These results are in agreement with those reported by other investigators [10,32].

The results of this study indicate that drought tolerant genotypes under both WSF and WSG conditions are characterized by early DTS, short ASI and less BS%. This conclusion is in accordance with other investigators [5,10,26-28, 31,32,34]. These traits could be considered as selection criteria for drought tolerance in maize.

Significant correlations under drought stress were found between maize grain yield and each of number of barren plants [34]. ASI, ears per plant, stay green [23] grain filling period, leaf rolling, leaf senescence and number of kernels plant^{-1} [11,31,32,35].

Significant and positive r-values detected between GYPP of genotypes and plant height in WSG and WSF environments indicated that taller plants of genotypes are of high yielding, under drought conditions. This conclusion is in agreement with others [26-28]. In contrast, other investigators [36,37] reported that taller genotypes are higher yielding than shorter genotypes under both WW and WS conditions.

The largest h^2_b estimates (*ca* 90.0 %) were shown by PH, RPE and 100KW traits under the WW environment, RPE under WSF and PH and RPE under WSG. In general, the estimates of h^2_b for agronomic and yield traits ranged from low to high in magnitude. The lowest estimates of h^2_b were exhibited by ASI and EPP under WSG, EPP and KPP under WSF, GYPP, BS and EPP under WW, indicating that the genetic variance was the smallest component of phenotypic variances, and that environment was of great effect on the performance of these traits. Low heritability estimates for these traits, could be attributed to the very small magnitude of genotypic variance as reported by Al-Naggar et al. [24].

In general, the estimates of h^2_b for physiologic and stem traits ranged from low to medium in magnitude. The lowest h^2_b estimates were expressed by SDU under WWF, SDU, SDL and ELA under WWG, indicating that the genetic variance was the smallest component of phenotypic variances, and that environment was of great effect on the performance of these stem traits. The largest h^2_b estimates were shown by SDL under WWF, WWG and WSF, CCI under WWG and WSG, SDU under WWG and WSF, ELA under WWG and WSG.

It is obvious from results that h^2_b estimates for agronomic and grain yield traits were generally the highest under full irrigation as compared to those under drought stress at flowering and/or grain filling stages, except ASI under WSF and EH, BS and GYPP under WSG, which showed higher h^2_b under water stressed as compared to non-stressed environments. Moreover, under well watering, two traits showed the highest h^2_b estimates (CCI and SDL). Similar to these results, many researchers reported a decrease in heritability under stressed environments [10,38-40].

On the contrary, ASI under WSF and EH, BS and GYPP under WSG, showed higher h^2_b under water stressed as compared to non-stressed environments. Moreover, the results of physiologic and stem traits indicated that h^2_b estimates were the highest under water stress environments (ELA under WSG and SDU under WSF). Similar to these results, a group of researchers found that heritability was increased in stressful environments [24,25,41-43].

It is worthy to mention that direct selection under the water-stressed environments would ensure the preservation of alleles of drought tolerance [44,23], while direct selection under full irrigation regime would take advantage of the high heritability [41,45-47].

The results also concluded that predicted selection gain would be higher if selection was practiced under WW for lower values of DTS and higher values of EPP, RPE, KPR, 100KW, SDU and SDL, under WSF for lower values of ASI and higher values of GYPP and under WSG for lower values of PH, EH, and BS, and higher values of CCI and ELA.

It is worthy to note that ageing of maize plant; expressed in change from WWF to WWG caused an obvious increase in the magnitude of heritability in stem traits, namely CCI, SDU and ELA. Change from WSF to WSG caused an obvious increase in the magnitude of heritability in two root traits, namely CCI, ELA. Ageing of maize plant; expressed in change from WWF to WWG caused an obvious increase in the magnitude of genetic advance from selection in CCI, SDU, ELA. This suggests that selection for such traits would be more effective when practiced at later stages of plant growth than at earlier stages. Change from WSF to WSG caused an obvious increase in the magnitude of genetic advance from selection in CCI, SDL and ELA. This suggests that selection for such traits would be more effective when practiced at WSG than at WSF.

Based on the correlation (r) analysis between studied traits and DTI and GYPP under drought at flowering (WSF) and grain filling (WSG) and their corresponding estimates of broad-sense heritability (h^2_b) and genetic advance from selection (GA), it is evident that the best secondary traits (selection criteria) for drought tolerance in our study are: 100KW and CCI under the two stressed environments WSF and WSG, ASI, SDU and SDL under WSF and KPR and ELA under WSG, since they show high (r) values, high (h^2_b) estimates and high GA estimates under the respective environments.

Under well watering conditions, KPP, 100KW, CCI, and SDL traits showed high (r) values, high (h^2_b) estimates and high GA estimates and therefore could be considered selection criteria for GYPP under non-stressed environment.

5. CONCLUSIONS

Results concluded that the best selection criteria for drought tolerance in our study are: 100-kernel weight (100KW) and chlorophyll concentration index (CCI) under both WSF and WSG, anthesis-silking interval (ASI), upper stem diameter (SDU) and lower stem diameter (SDL) under WSF and kernels/row (KPR) and ear leaf area (ELA) under WSG, since they showed high (r) values, high h^2_b and high GA estimates under the respective environments. Under well watering conditions, KPP, 100KW, CCI, and SDL were the best selection criteria for GYPP. These selection criteria could be offered to plant breeders for developing drought tolerant hybrids of maize. The results also concluded that predicted selection gain would be higher if selection was practiced under WW for lower values of DTS and higher values of EPP, RPE, KPR, 100KW, SDU and SDL, under WSF for lower values of ASI and higher values of GYPP and under WSG for lower values of PH, EH, and BS, and higher values of CCI and ELA.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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