

INHERITANCE OF SOME PHYSIOLOGICAL TRAITS IMPORTANT FOR DROUGHT TOLERANCE OF GRAIN SORGHUM

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ABSTRACT

Five restorers were crossed in 1999 to each of five cms lines of grain sorghum to obtain 25 F₁ crosses. Restorer and cms lines varied in their drought tolerance. In 2000 season parents and F₁ crosses were grown under 3 watering regimes, i.e. full-irrigation (control), withholding irrigation at pre-flowering (GS2) and withholding irrigation at post-flowering (GS3) stage. The objectives were to study performance of drought tolerant (T) and susceptible (S) genotypes, heterosis, combining ability, type of gene action, heritability and predicted selection gain for three physiological traits important for drought tolerance, i.e. carbon exchange rate (CER) stomatal conductance (SC) and leaf temperature (LT) as well as grain yield / plant under water stress and non-stress conditions. Under stress at GS2 and GS3, T genotypes were significantly higher than S genotypes for CER (by 26.3 and 25 % for parents, 43.7 and 83.2 % for F₁'s) and SC (by 50 and 128.5 % for parents, 64.3 and 100 % for F₁'s), respectively. On the other hand T genotypes were significantly lower than S genotypes for LT by 1.1 and 1.5° C for parents and 2.1 and 2.4° C for crosses at GS2 and GS3, respectively. Heterobeltiosis results indicated that some hybrids had greater SC and CER and lower LT values than their respective parental lines under drought stress conditions. The best general combiner for CER, SC and LT was B-88005 under stress at both GS2 and GS3, R-89022 under stress at GS2 and V-112 under stress at GS3 stage. The best general combiners for grain yield were B-88005, B-102 and R-90011 under all soil-moisture regimes, R-89016 under control and under stress at GS2, and RTX under stress at GS3. Magnitude of additive (δ^2_A) was greater than dominance variance for all studied physiological traits under all irrigation regimes, except for SC and CER under stress at GS2. However, for grain yield, additive was much lower than dominance variance under all stress and non-stress environments. Overdominance ($a > 1$) was exhibited for CER and grain yield under all irrigation regimes and for SC and LT under control. Complete dominance to the higher parent ($a = 1$) was shown for SC and LT under stress at GS3, partial dominance ($a < 1$) was manifested by leaf temperature under stress at GS2. No dominance ($a = 0$) was shown for SC under stress at GS2. The best environment for maximizing the heritability of stomatal conductance, carbon exchange rate and grain yield would be stress at GS3, and for maximizing heritability for leaf temperature would be stress at GS2. Predicted direct selection gain reached its maximum under stress at GS3 for SC, CER and yield and at GS2 for LT. In all studied cases, selection for a physiological trait was predicted to be effective in improving grain yield than direct selection for grain yield itself. Under water stress at both GS2 and GS3, response of grain yield to selection for lower temperature was predicted to be larger than response of grain yield to selection for high SC and CER.

Key words: *Grain sorghum, Drought tolerance, Physiological traits, Carbon exchange rate, Stomatal conductance, Leaf temperature, Heterosis, Combining ability, Inheritance, Heritability, Selection gain*

INTRODUCTION

Grain sorghum is one of the crops suitable for growing in the Egyptian new reclaimed lands, where the soil is characterized by its low water-holding capacity and atmospheric temperature is high, because of its drought and heat tolerance characteristics. The ability of grain sorghum to withstand moisture deficit is associated with numerous plant traits that contribute to drought tolerance. However, to date only limited efforts have been made to combine such traits in breeding programmes. Drought tolerance has seldom been a primary breeding objective, and is usually addressed indirectly via major objectives such as improved yield and adaptation. The delay of plant breeders to incorporate drought tolerance into breeding programmes is related to the difficult task of identifying genetic and physiological control of drought tolerance.

Many investigators studied several of the physiological mechanisms causing drought tolerance in grain sorghum. Tolerant genotypes of grain sorghum were characterized by having lower canopy temperature (Chaudhuri *et al* 1986 and Blum *et al* 1989) higher stomatal conductance (Vegherughe 1987), higher water potential (Blum 1979 and Sullivan and Ross 1979), less under stress reduction of the photosynthetic rate (Garrity *et al* 1984a) and higher osmotic adjustment (Blum 1979 and Keith *et al* 1984).

Information on the genetic behaviour of the physiological traits associated with drought tolerance in grain sorghum are generally scarce (Al-Naggar *et al* 1999). Therefore, the objectives of the present investigation were: 1) to study effects of drought stress on some physiological traits related to drought tolerance, 2) to describe differences between drought tolerant and susceptible genotypes in such traits following the imposition of water deficit and 3) to estimate heterosis, combining ability, type of gene action, heritability and predicted selection gain for such traits under water-stress and non-stress conditions.

MATERIALS AND METHODS

Three drought tolerant restorer lines (R-89016, R-90011 and V-112) and two susceptible restorer lines (R-89022 and RTX-82BDM-499) were crossed to five cytoplasmic male sterile (cms) lines (the drought tolerant A-102 and the susceptible lines A-1, A-37, A-88005 and A-88006 and 25 fertile F_1 crosses were obtained in 1999 season at Exper. Res. Station of the ARC at Giza. In the 2000 season, one field experiment was carried out at the Agric. Res. Station of Assiut University (Assiut Governorate) to evaluate the parental lines and their F_1 's under 3 watering regimes, i.e. full

irrigation (control), withholding irrigation at pre-flowering (GS2) stage and withholding irrigation at post-flowering (GS3) stage.

A split-plot design in randomized complete blocks with 3 replications was used, where main plots were irrigation regimes and sub plots were devoted to genotypes. Each sub-plot consisted of one ridge 5 meters long and 70 cm wide. Sowing was done in hills 20 cm apart along the ridge. Hills were thinned to two plants per hill before the 1st irrigation. Other agricultural practices were done as recommended.

Three physiological measurements were taken at the end of each stress period on the first expanded leaf. Three plants from each subplot were selected as subsample for physiological measurements. Measurements were made between 9 and 11 am using a portable photosynthesis system Licor-6200 (LI-6200, Li - COR, Lincoln, NE, USA) of carbon exchange rate ($\text{mol m}^{-2} \text{s}^{-1}$) (CER), stomatal conductance (SC) ($\text{mol m}^{-2} \text{s}^{-1}$) and leaf temperature ($^{\circ}\text{C}$): air temperature ($^{\circ}\text{C}$) ratio (LT). The net exchange rate of CO_2 between the leaf and atmosphere was determined over a 20-35 second period. Stomatal conductance to water vapour was calculated based on measured temperature, vapour pressure deficit and boundary layer conductance. Air temperature, leaf temperature and relative humidity were measured directly by the sensor. The infrared gas analyzer of the LI - 2600 was calibrated before each use, and a 4-L chamber was used in this study.

At harvest time, grain yield per plant was recorded from 5 guarded plants/plot. Data were subjected to a regular analysis of variance according to Steel and Torrie (1980). Line x tester analysis according to Kempthorne (1957) was made for each irrigation treatment to estimate general (GCA) and specific (SCA) combining ability variances and effects, additive (δ^2_A), dominance (δ^2_D) and error (δ^2_e) variances. Average degree of dominance "a" was calculated from the equation " a " = $(2 \delta^2_D / \delta^2_A)^{1/2}$ where, $a = 0$ indicates no dominance, $a < \pm 1$ indicates positive or negative partial dominance, $a = \pm 1$ indicates positive or negative complete dominance and " a " $> \pm 1$ indicates positive or negative overdominance. Narrow - sense heritability (h^2_n) was calculated according to Hallaur and Miranda (1981). Genetic advance (GA) from direct selection was calculated according to Becker (1984). Correlated response (CR) in grain yield (j) to selection for a secondary trait (k) was estimated according to Falconer (1989).

RESULTS AND DISCUSSION

Analysis of variance (Table 1) showed significant differences ($P < 0.01$) among genotypes (parents, F_1 's) and soil moisture regimes for the 3 studied physiological traits as well as grain yield. Genotypes X soil moisture

Table 1. Analysis of variance for physiological traits of grain sorghum evaluated at Assiut, 2000.

Source of variance	d.f.	Carbon exchange rate ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$)	Stomatal conductance ($\text{mol m}^{-2} \text{ s}^{-1}$)	Leaf temp/air temp	Grain yield
Irrigations (I)	2	512.0**	0.1519**	0.1639	5252.5**
Reps (Irrigations)	6	0.058	0.00004	0.00004**	11.6
Genotypes (G)	34	142.2**	0.0114**	0.0075**	2681.6**
Parents (P)	9	32.89**	0.0117**	0.0057**	1704.7**
P vs F_1 's	1	1813.3**	0.0324**	0.0538**	15848.5**
Crosses (F_1)	24	113.6**	0.0104**	0.006**	2499.4**
G \times I	68	15.3**	0.0013**	0.0007**	231.0**
P \times I	18	2.5*	0.00104**	0.00047**	135.2**
I \times P vs F_1 's	2	88.6**	0.0033**	0.0024**	52.9**
$F_1 \times I$	48	17.1**	0.0013**	0.0007**	274.4**
Error	204	0.857	0.00005	0.000026	13.0
C.V. %		4.3	4.5	0.5	5.5

regimes interactions were also significant ($P < 0.01$) for all these traits. Thus genotypes differed in their response to variation in moisture regime confirming our previous results (Al-Naggar *et al* 1999).

Mean performance

a. Effect of drought stress

A comparative summary of means and ranges of all studied traits for parental lines and hybrids under the three soil moisture regimes is presented in Table (2). Mean grain yield was significantly reduced by soil moisture stress at both GS2 and GS3 stages to 81.8 and 91.4 % for parents and 80.8 and 91.6 %, respectively for F_1 hybrids from the control. This indicates that the grain yield was more sensitive to moisture stress at the developmental stage of (GS2) than (GS3) stage. These results confirm the results reported by Legg *et al* (1979), Bakheit (1990) and Craufurad and Peacock (1993) who reported that soil water stress at pre-flowering stage reduced yield more than at-post-flowering stage.

Yield under control ranged from 32.8 to 90.8 g/plant for parental lines and from 41.0 to 127.9 g/plant for F_1 's (Table 2), whereas yield under stress at GS2 ranged from 34.4 to 72.1 g/plant for parents and 41.0 to 88.5 g/plant for hybrids. Moreover, when water stress was developed at GS3 stage, yield range was 34.5-81.7 and 37.6-113.5 g/plant for parents and hybrids, respectively, indicating higher reduction of both maximum and minimum yield range limits for parents and higher reduction of maximum yield range limit for hybrids at GS2 than at GS3. This might be attributed to the effect of the severity of soil moisture stress at GS2 stage.

Table 2. Means and ranges of traits measured under 3 soil moisture regimes (control, stress at GS2 and stress at GS3) at Assiut, 2000.

Trait	Parents				Hybrids			
			Un-Stressed (control)	Stressed at		Un-Stressed (control)	Stressed at	
				GS2	GS3		GS2	GS3
Stomatal conductance	Ranges	Mol m ⁻² s ⁻¹	0.14-0.25	0.12-0.21	0.06-0.18	0.14-0.28	0.12-0.30	0.09-0.21
		%	-	63.6-85.7	35.3-72.0	-	69.2-100	45.0-75.0
	Mean	Mol m ⁻² s ⁻¹	0.187	0.147	0.103	0.204	0.181	0.129
		%	100	78.6	55.1	100	88.6	63.3
	LSD _{0.05} among stress levels				0.006			0.009
Carbon exchange rate	Ranges	μ mol m ⁻² s ⁻¹	16.6-24.0	14.3-21.3	12.6-18.0	18.0-33.8	18.0-28.0	14.0-30.0
		%	-	75.5-96.4	63.0-83.3	-	66.3-100	65.3-102
	Mean	μ mol m ⁻² s ⁻¹	20.2	17.6	14.7	25.4	20.9	22.2
		%	100	86.9	72.8	100	82.4	87.4
	LSD _{0.05} among stress levels				0.6			1.2
Leaf temp. to air temp.	Ranges	Ratio	0.928-1.015	0.985-1.059	1.008-1.095	0.915-1.013	0.953-1.045	0.972-1.091
		%	-	100.8-108.4	103.2-112.1	-	99.4-109.1	101.4-113.8
	Mean	Ratio	0.978	1.040	1.063	0.959	1.001	1.035
		%	100	106.1	108.5	100	104.4	108.0
	LSD _{0.05} among stress levels				0.003			0.009
Grain yield/plant	Ranges	g	32.8-90.8	34.4-72.1	34.5-81.7	41.0-127.9	41.0-88.5	37.6-113.5
		%	-	57.8-139.9	73.2-105.2	-	61.0-112.5	63.3-101.4
	Mean	g	60.9	48.6	53.5	78.6	62.9	70.2
		%	100	79.8	87.8	100	80.0	89.3
	LSD _{0.05} among stress levels				3.2			3.8

Both parents and hybrids differed markedly in drought tolerance measured in terms of relative yield under stress at both GS2 and GS3 stages. Relative yields ranged from 57.8 to 139.9 % at GS2 and from 73.2 to 105.2 % at GS3 among parents and 61.0 to 112.5 % among hybrids at GS2, and from 63.3 to 101.4 % at GS3 (Table 2).

The physiological traits: carbon exchange rate (CER) and stomatal conductance (SC) were significantly reduced as a result of water stress at both GS2 and GS3 stages, with a greater decline at GS3 than at GS2 for parental lines and at GS2 than at GS3 for hybrids. CER was significantly decreased to 86.9 and 82.4 % from control when water stress occurred at GS2 and to 72.8 and 87.4 % when stress was imposed at GS3 for parents and hybrids, respectively. It is clear that reduction in CER at GS3 was less pronounced in hybrids (12.6 %) than in parents (27.2 %). The greater vigour of the hybrids might accord higher tolerance to water stress than their parents.

Reduction in photosynthetic rate due to water stress reported in our study is in agreement with the majority of previous reports on sorghum (Wong *et al* 1979, McCrue 1936, Al-Hamadani *et al* 1991, Massacci *et al* 1995 and Al-Naggar *et al* 1999). In contrast, Kaigama (1982) mentioned that water stress increased the rate of leaf photosynthesis in sorghum plants.

While Garrity *et al* (1984) did not find any reduction of the average photosynthesis rate per unit leaf area when drought stress was developed naturally. Diversity of the results might be attributed to the differences in stress intensity and/or to the genotypes used.

The second physiological trait, stomatal conductance (SC) was significantly declined by water deficit at GS2 to 78.6 and 88.6% from control and 55.1 and 63.3 % at GS3 for parental lines and hybrids, respectively (Table 2). Reduction in stomatal conductance due to water stress was more pronounced in parents than in hybrids and in GS3 than in GS2. Decline in stomatal conductance due to water deficit reported in our results agrees with Wong *et al* (1979), Al-Hamadani *et al* (1991), Massacci *et al* (1995) and Al-Naggar *et al* (1999).

On the other hand, the ratio of leaf temperature relative to air temperature significantly increased to 106.1 and 104.4 % at GS2 and 108.5 and 108.0 % at GS3 for parents and hybrids, respectively (Table 2). It increased up to 109.1 and 113.8 % in the poorest genotypes and was 99.4 and 101.4 % for the best ones when water stress was imposed at GS2 and GS3, respectively. Increase in leaf temperature is related to decreased transpiration cooling (Gates, 1964, Van Bavel and Ehrlér 1968 and Sumayao *et al* 1979) which is a result of stomatal closure.

b. Performance of drought tolerant vs. susceptible genotypes

To describe the differences between drought tolerant (T) and susceptible (S) genotypes, physiological data were averaged for two groups of genotypes differing in drought tolerance by definition, namely in both absolute and relative grain yield under drought stress (Table 3). The drought tolerant genotypes were the parental lines R-89016, R-90011 and V-112 at GS2 and B-102, R-89016, R-90011 and V-112 at GS3 and the hybrids A-1 X V-112, A-37 X R-90011, A-37 X V-112 and A-102 X R-89016 at GS2 and A-1 X V-112, A-37 X R-90011, A-37 X V-112, A-102 X R-89016, A-102 X R-90011, A-102 X V-112, A-88005 X R-90011, A-88006 X R-89022 and A-88006 X V-112 at GS3. The drought susceptible genotypes were the lines B-1, B-37, B-102, B-88005, B-88006, R-89022 and RTX82BDM499 at both GS2 and GS3 except B-102 at GS3 and the hybrids A-1 X R-89016, A-1 X R-89022, A-1 X R-90011, A-88005 X RTX-82 BDM-499, A-88006 X R-89016 and A-88006 X RTX82BDM499 at GS2 and A-1 X RTX82BDM499, A-37 X R-89016, A-37 X R-89022, A-102 X R-89022, A-102 X RTX82BDM499 and A-88005 X RTX82BDM499 at GS3 growth stage.

Table 3 Physiological characters and grain yield /plant over the best and the poorest performing genotypes under stress at GS2 and GS3.

Characteristic	Parental lines		Crosses	
	Tolerant	Susceptible	Tolerant	Susceptible
Stress at GS2				
No. of genotypes	3	3	4	7
Grain yield/plant	60.8	39.7	80.2	48.5
CER ($\mu \text{ mol m}^2 \text{ s}^{-1}$)	19.7	15.6	26.3	18.3
SC ($\text{mol m}^2 \text{ s}^{-1}$)	0.18	0.12	0.23	0.14
Leaf temp. / Air temp.	1.016	1.055	0.962	1.033
Stress at GS3				
No. of genotypes	4	5	6	6
Grain yield/plant	71.1	40.5	96.5	44.6
CER ($\mu \text{ mol m}^2 \text{ s}^{-1}$)	16.5	13.2	48.4	15.5
SC ($\text{mol m}^2 \text{ s}^{-1}$)	0.16	0.07	0.18	0.09
Leaf temp. / Air temp.	1.032	1.085	0.993	1.079

Grain yield of the drought tolerant (T) genotypes was greater than that of the susceptible (S) genotypes by 53.1 and 75.5 % for parents and 70.0 and 116.3% for crosses at GS2 and GS3 stages, respectively.

Stomatal conductance was also appreciably greater in the drought tolerant (T) than in susceptible (S) genotypes by 50 and 128.5 % for parental lines and 64.3 and 100.0 % for crosses at GS2 and GS3, respectively, which is very much in accordance with respective differences between T and S genotypes in plant water status. Mean leaf temperature relative to air temperature was significantly lower in T than in S by 1.1 and 1.5 °C for parental lines and by 2.1 and 2.4 °C for crosses at GS2 and GS3, respectively.

The advantage of T over S genotypes in stomatal conductance would allow greater expected CER in T than S genotypes. Consistent with expectation, CER was significantly higher in T than in S by about 26.3 and 25.0 % for parental lines and 43.7 and 83.2 % for crosses under stress at GS2 and GS3, respectively.

On the average, genotypes classified as the most drought tolerant in terms of absolute and relative yield had higher stomatal conductance, lower leaf temperature and higher carbon exchange rate, all of which indicated a better plant water status, as compared with the most susceptible genotypes.

Under water stress in this experiment, the absolute carbon exchange rate (CER) has significant and positive correlation with each of SC, and

grain yield/plant ($r = 0.89^{**}$ and 0.93^{**} at pre-flowering and 0.80^{**} and 0.91^{**} at post flowering stage, respectively). Under normal growing conditions, results of other studies indicated that the correlation between CER and yield was inconsistent, with the consensus being that the two variables are not well correlated (Heichel and Masgrave 1969, Irvine 1975, and Mauney *et al* 1978) . Under stress growing conditions, however, the ability to maintain photosynthetic rates may have an influence on yield (Sullivan and Ross 1979, Al-Hamadani *et al* 1991 and Al-Naggar *et al* 1999).

Significant and positive correlations are found in this study between absolute stomatal conductance (SC) under stress and absolute values of grain yield/plant ($r = 0.96^{**}$ at GS2 stage and 0.94^{**} at GS3, respectively). Henzell *et al.* (1976) suggested that stomatal sensitivity might be used as an important element in screening for drought tolerance among a number of genotypes.

Al-Hamadani *et al* (1991) also concluded that stomatal conductance appears to be a useful tool for screening sorghum genotypes at vegetative stage (pre-anthesis) of growth for drought tolerance.

Leaf to air temperature in absolute values under stress exhibited significant negative correlation coefficients with CER, SC and grain yield/plant ($r = -0.90^{**}$, -0.90^{**} and -0.95^{**} at GS2 and -0.90^{**} , -0.90^{**} and -0.97^{**} at GS3).

Our results suggest that leaf temperature is of high value at GS2 and GS3 in predicting variations in plant water stress among sorghum genotypes. This does not agree with the previous results for sorghum reported by Chaudhuri *et al* (1986) and Blum *et al* (1989 and 1992) who concluded that canopy temperature is of no value in predicting genotypic variation under water stress. Blum *et al* (1982) mentioned that plant water stress must be severe enough to constitute a major effect on temperature differences among genotypes.

Our correlation studies indicate that under water stress at either GS2 or GS3 stages, the strongest association ($r > 0.91$) with absolute grain yield was with each of absolute SC and CER values (physiological traits). This suggests that selection for one or more of these characters under drought stress could be considered useful index for screening for grain yield under drought stress if these phenotypic correlations reflect significant relationships at the genetic level.

Useful Heterosis

The contrast between parents and crosses (Table 1) was significant for all traits suggesting significant non-additive gene effect (heterosis). The

heterosis X irrigation treatment interaction was significant for all traits, suggesting that the expression of heterosis was not stable under irrigation treatments.

The expression of useful heterosis (heterobeltiosis), the degree of superiority of the F_1 over the better parent, averaged over locations differed for the different studied traits (Table 4). Average heterobeltiosis across all crosses ranged from -4.7 % for stomatal conductance to 19.1 % for carbon exchange rate under control, from -2.4 % for leaf temperature to 20.4 % for grain yield under stress at GS2 and from -1.1 % for leaf temperature to 39.9 % for carbon exchange rate under stress at GS3 stage. Maximum average heterobeltiosis was shown by CER under control and under stress at GS3 and by grain yield under stress at GS2.

Significant positive heterobeltiosis (favourable) for stomatal conductance (SC) was shown in 7, 18 and 12 crosses under control, stress at GS2 and stress at GS3, respectively. Estimates of heterobeltiosis for SC ranged from -36.3 % (A-102 X R-89022) to 85.7 % (A-88006 X R-89022) under control, from -20.0 % (A-88005 X RTX) to 50 % (A-1 X RTX) under stress at GS2 and from -40.0 % (A 102 X R-89022) to 183.3 % (A-88006 X R-89022) under stress at GS3.

Concerning carbon exchange rate (CER) significant positive (favourable) heterobeltiosis estimates were obtained from 20, 16 and 20 crosses under control, stress at GS2 and stress at GS3, respectively. Heterobeltiosis estimates for CER ranged from -14.0 % (A-102 X R-89022) to 63.3 % (A-88006 X R-89022) under control, from -15.9 (A-1 X R-89016) to 38.2 % (A-37 X R-90011) under stress at GS2 and from -13.5 % (A-102 X R-89022) to 123.8 % (A-88006 X R-89022) under stress at GS3.

Heterobeltiosis values for leaf temperature (LT) were significant and negative (favourable) in 6, 15 and 8 crosses under control, stress at GS2 and stress at GS3, respectively. Ranges of heterobeltiosis were from -7.7 % (A-88006 X R-89022) to 5.8 % (A-102 X R-89022) under control, from -6.8 % (A-37 X R-90011) to 2.4 % (A-88005 X V-112) under stress at GS2 and from -8.0 % (A-88006 X R-89022) to 4.8 % (A-102 X R-89022) under stress at GS3.

With respect to grain yield 13, 14 and 3 crosses exhibited significant positive heterobeltiosis values under control, stress at GS2 and at GS3, respectively.

The range of heterobeltiosis for grain yield was from -41.2 % (A-102 X R-89022) to 113.8 % (A-88006 X R-89022) under control, from -16.7 % (A-88005 X V-112) to 56.8 % (A-1 X RTX) under stress at GS2 and from -45.4 % (A-102 X R-89022) to 126.6 % (A-88006 X R-89022) under stress at GS3.

Table 4. Heterobeltiosis of F₁ crosses, tested under three irrigation regimes over two locations in 2000 season.

Crosses	Cont.	GS2	GS3	Cont.	GS2	GS3	Cont.	GS2	GS3	Cont.	GS2	GS3
	Stomatal conductance			Carbon exchange rate			Leaf temp./ Air temp.			Grain yield		
A-1 X R-89016	-8.3*	0.0	-28.5**	17.7**	-15.9**	11.8**	1.1	0.9	2.8*	15.0**	-2.9	-18.8**
A-1 X R-89022	17.6**	14.3**	150.0**	31.5**	10.0**	114.3**	-4.8**	-2.5*	-6.8**	48.0**	23.5**	101.9**
A-1 X R-90011	10.0*	-5.9	16.6**	29.5**	-2.1	62.8**	2.6*	0.7	-3.0*	31.7**	-1.3	24.2**
A-1 X V-112	12.0**	14.3**	5.5	41.2**	3.5	61.7**	-1.4	-3.2*	-2.5*	40.8**	22.7**	27.7**
A-1 X RTX	5.9	50.0**	28.6**	24.0**	33.5**	21.8**	3.7**	-6.3**	-0.7	36.6**	56.8**	16.7**
A-37 X R-89016	-33.3**	18.7**	-21.4**	0.43	11.7**	24.2**	4.2	-4.1**	-1.1	-14.1**	1.0	5.8
A-37 X R-89022	-12.5**	0.0	-10.0**	11.1**	5.8	7.3*	0.1	0.9	0.2	1.8	3.5	-1.0
A-37 X R-90011	10.0*	35.3**	8.3*	31.3**	38.2**	53.8**	-2.8*	-6.8**	-2.3*	33.6**	43.2**	17.4**
A-37 X V-112	0.0	9.5*	-27.8**	22.1**	22.1**	38.9**	0.4	-2.3*	1.3	2.5	9.1*	-6.5
A-37 X RTX	-12.5**	7.7*	-10.0**	-1.0	4.1	0.0	0.7	-1.1	0.4	-9.0*	4.2	-8.2*
A-102 X R-89016	-16.6**	37.5**	20.0**	12.1**	32.5**	4.1	1.8	-6.0**	0.5	-3.6	35.5**	1.9
A-102 X R-89022	-36.3**	7.1*	-40.0**	-14.0**	7.8*	-13.5**	5.8**	0.4	4.8**	-41.2**	2.1	45.4**
A-102 X R-90011	22.7**	17.6**	20.0**	35.3**	20.4**	77.3**	-3.0*	-4.5**	-4.4**	46.7**	0.43	40.0**
A-102 X V-112	12.0**	4.7	16.6**	30.8**	17.4**	67.2**	0.8	-1.2	-3.6**	30.3**	3.1	38.9**
A-102 X RTX	-31.8**	28.6**	-33.3**	-0.4	12.7**	4.9	0.3	-4.4**	3.2**	-11.2*	0.90	-25.0**
A-88005 X R-89016	-33.3**	18.7**	-21.4**	3.0	7.9*	26.7**	4.2**	-3.7**	0.7	-13.2**	17.8**	-3.8
A-88005 X R-89022	-10.5*	26.6**	33.3**	18.2**	11.1**	50.0**	0.8	-4.0**	-4.1**	20.4**	23.6**	51.4**
A-88005 X R-90011	-25.0**	17.6**	-8.3*	7.1*	12.0**	35.3**	0.9	-3.7**	-1.0	7.3*	18.2**	9.3*
A-88005 X V-112	-16.0**	-14.3**	-22.2*	12.5**	-10.3**	45.0**	1.8	2.4*	-0.8	-8.1*	-16.7**	-4.7
A-88005 X RTX	-26.3**	-20.0**	0.0	11.3**	0.0	-6.7*	3.6**	0.5	1.2	-32.3**	18.4**	-20.3**
A-88006 X R-89016	-25.0**	6.2*	14.3**	8.2*	1.1	36.7**	2.6*	-1.9	-0.1	-8.9*	4.2	1.7
A-88006 X R-89022	85.7**	28.5**	183.3**	63.3**	17.5**	123.8**	-7.7**	-3.9**	-8.0**	113.8**	36.1**	126.6**
A-88006 X R-90011	15.0**	11.7**	16.6**	53.2**	6.3*	60.3**	-3.1*	-3.3**	-2.7*	34.7**	16.9**	23.4**
A-88006 X V-112	-8.0*	-4.7	-11.1**	18.8**	3.3	51.8**	1.2	0.6	-0.5	-3.5	7.9*	8.7*
A-88006 X RTX	-12.5**	38.5**	42.8**	9.9*	9.8*	38.4**	0.9	-3.8**	-1.7	16.9**	38.7**	41.8**
Average	-4.7	13.9	12.9	19.1	10.4	39.9	0.3	-2.4	-1.1	13.4	14.7	16.1

In general, significant favourable heterosis above the better parent in this study was manifested in some hybrids for all studied traits such as A-88006 X R-89022, A-102 X R-90011 and A-102 X V-112 under control and stress at GS3, A-37 X R-90011, A-88006 X R-90011 and A-1 X R-89022 under all soil-moisture regimes, A-1 X RTX, A-102 X R-89016 under stress at GS2, A-88005 X R-89022 under stress at GS2 and GS3. The existence of heterosis for different characters in grain sorghum crosses developed under either control or water stress conditions had been demonstrated by several authors. Sinha and Khanna (1975) noted evidence of heterosis in photosynthesis in hybrids over their parents. Hoffmann *et al* (1984) found heterosis for apparent photosynthesis in leaves of field-grown sorghum, but the results for certain hybrids were not consistent over 2 years. Blum (1979) suggested that sorghum hybrids fixed more carbon dioxide per unit leaf area over a wider temperature range than their parental lines. He found that heterosis in the temperature response of leaf gas exchange was associated with greater stomatal conductance and transpiration. He concluded that heterosis in biomass production of sorghum may be ascribed to stability in carbon exchange rate (CER) over a wide range of environmental conditions. Blum *et al.* (1990) reported that significant heterosis was found for grain yield per plant. They found that CER and stomatal conductance for some hybrids, in the controls, were greater than respective parents at leaf temperature above 38 °C, but when extreme stress conditions developed, the hybrid's performance depended on its genetic background more than on heterosis.

Results in this study indicated that some grain sorghum hybrids had higher stomatal conductance, CER and lower leaf temperature than their parental lines under no stress as well as under drought stress conditions.

Analysis of variance

Partitioning mean squares of the 25 hybrids tested under each soil moisture regime into males, females and male X female components (data not presented) showed that highly significant differences existed for mean squares due to males and females in their respective crosses for all traits evaluated, indicating that estimates of GCA effects were significant ($P \leq 0.01$) for both parental males and females for all traits.

Contribution of females to the total variation was greater than the contribution of males for all traits except leaf temperature under control. This indicates that most of the total GCA variance was due to the females GCA variance. Variation due to male X female interaction was also highly

significant for all studied traits. This suggests that SCA effects were significant at the 0.01 level under all soil moisture conditions.

General combining ability effects

Estimates of GCA effects of males and females evaluated under each soil moisture regime are presented in (Table 5).

Concerning carbon exchange rate, the highest positive significant GCA effects (favourable) were exhibited by the male R-89016 (under all moisture regimes), R-89022 (under stress at GS2) and R-90011 (under stress at GS2 and GS3) and the female B-88005 followed by B-102 under all irrigation treatments. These lines can be considered the best combiners for high CER under the respective soil moisture regimes

For stomatal conductance, the highest positive and significant GCA effects (favourable) were shown by the male R-90011 and the females B-88005 and B-102 under all soil moisture regimes, and by the males R-89016 and RTX82BDM499 under control and stress at GS3, indicating that these lines seem to be good combiners for high stomatal conductance under the respective environments.

The most favorable lines regarding GCA effects for leaf temperature are those having the lowest negative effects. Thus, the best general combiners for leaf temperature were R-90011, B-102 and B-88005 under all irrigation treatments, R-89016 and RTX-82 BDM-499 under control and stress at GS3 and B-1 under control and stress at GS2. For grain yield/plant, the male R-89016 under control and stress at GS2, RTX under stress at GS3 followed by R-90011 under all soil-moisture regimes and the females B-88005 and B-102 under all treatments had positive and significant (favourable) GCA effects, indicating that they are good general combiners for yield. The superiority of these lines in GCA effects for grain yield is associated with their superiority in GCA effects for all the 3 studied physiological traits, i.e carbon exchange rate, stomatal conductance and leaf air temperature.

Specific combining ability effects

Estimates of SCA effects for the F_1 hybrids tested under the three soil moisture regimes are presented in Table (6). For CER, 7, 10 and 13 crosses showed significant and positive SCA effects under control, stress at GS2 and at GS3, respectively. The most favorable (positive) SCA effects for CER were shown in the cross A-37 X RTX82BDM499 and A-88005 X R-89016 under all irrigation treatments, A-102 X R- 90011 under control and stress at GS3, A-88005 X R-89016 under control and stress at GS2 and A-1 X R-90011, A-102 X R-89022 and A-88006 X R-89016 under stress at GS2. Regarding stomatal conductance, 13, 13 and 9 crosses had significant

Table 5. General combining ability effects for studied traits of 5 male and 5 female sorghum lines evaluated at Assiut in 2000 season.

Parental line	Cont.	GS2	GS3	Cont.	GS2	GS3
	Carbon exchange rate			Stomatal conductance		
Males						
ICSR-89016	2.50 **	0.40**	0.90**	0.02**	-0.002	0.005**
ICSR-89022	-1.50 **	0.80**	-2.10**	-0.01**	0.002	-0.01 **
ICSR-90011	0.30	1.06**	0.40**	0.01**	0.007**	0.01 **
ICSV-112	-2.20 **	-1.20**	-1.30**	-0.03**	-0.007**	-0.01 **
RTX82BDM499	0.80 **	-1.10**	2.10**	0.01**	0.001	0.01 **
Females						
ICSB-1	0.06	-0.30**	-1.5**	-0.01**	0.003	-0.01 **
ICSB-37	-1.70**	-2.10**	-0.6**	-0.01**	-0.02 **	-0.003**
ICSB-102	2.10**	0.90**	2.7**	0.02**	0.013**	0.013**
ICSB-88005	3.40**	3.0 **	5.4**	0.05**	0.03 **	0.04 **
ICSB-88006	-3.80**	-1.5 **	-6.0**	-0.04**	-0.02	-0.03 **
S.E.gi	0.32	0.03	0.026	0.0005	0.002	0.001
S.E.gi-gj	0.45	0.04	0.036	0.0007	0.003	0.001
	Leaf temp. to air temp.			Grain yield/plant		
Males						
ICSR-89016	-0.02**	0.001	-0.004**	12.38**	2.03**	2.89**
ICSR-89022	0.01**	-0.002**	0.010**	-7.81**	0.44	-9.17**
ICSR-90011	-0.003**	-0.005**	-0.005**	5.65**	1.88**	5.56**
ICSV-112	0.020**	0.002**	0.006**	-9.50**	-3.77**	-5.84**
RTX82BDM499	-0.01**	0.004**	-0.010**	-0.74	-0.58	6.56**
Females						
ICSB-1	-0.001**	-0.002**	0.01 **	-2.08*	0.40	-4.17**
ICSB-37	0.010 **	0.02 **	0.006**	-7.61**	-8.31**	-4.30**
ICSB-102	-0.01 **	-0.01 **	-0.01 **	9.92**	3.94**	8.82**
ICSB-88005	-0.03 **	-0.02 **	-0.03 **	20.92**	11.02**	21.96**
ICSB-88006	0.03 **	0.01 **	0.04 **	-21.14**	-7.05**	-22.3**
S.E.gi	0.0	0.001	0.001	0.82	0.41	0.56
S.E.gi-gj	0.0	0.0014	0.0014	1.10	0.58	0.80

*,** Significant at 0.05 and 0.01 probability levels respectively.

positive (favourable) and 11, 10 and 11 crosses had significant negative (unfavourable) SCA effects under control, stress at GS2 and at GS3, respectively. The highest positive SCA effects were exhibited by the crosses A-37 X RTX82BDM499 under all soil moisture regimes, A-37 X V-112 under control and stress at GS3, A-102 X R-90011 and A-88005 X R-90011 under control and stress at GS3, A-88006 X V-112 under control and A-88005 X R-89016 under stress at GS2.

For grain yield, SCA effects were significant and positive for 9, 11 and 11 crosses under control, stress at GS2 and stress at GS3, respectively. The highest SCA effects for grain yield were obtained for the crosses A-37

Table 6. Specific combining ability effects of 25 sorghum crosses tested under 3 irrigation regimes .

Crosses	Cont.	GS2	GS3	Cont.	GS2	GS3	Cont.	GS2	GS3	Cont.	GS2	GS3
	Carbon exchange rate			Stomatal conductance			Leaf temp. to air temp.			Grain yield		
A-1 X R-89016	-0.60	-2.6**	-3.6**	0.01**	-0.02**	-0.02**	0.003**	0.03**	0.02**	3.4	-11.7**	-13.0**
A-1 X R-89022	-0.60	-0.6*	1.5**	-0.01**	0.004*	0.01**	0.003**	-0.003	-0.01**	2.1	1.8	8.0**
A-1 X R-90011	0.20	3.1**	1.8**	0.004**	0.02**	-0.004	-0.004**	-0.02**	-0.01**	-3.9	9.5**	1.3
A-1 X V-112	0.70	0.8*	1.1**	0.007**	0.01**	0.01**	-0.003**	-0.02**	-0.01**	4.5	5.5**	6.4**
A-1X RTX	0.30	-0.7*	-0.7*	-0.01**	-0.02**	-0.003	0.002**	0.01**	0.002	0.7	-5.2**	-2.7**
A-37 X R-89016	0.17	-0.5*	4.4**	-0.004**	0.004*	0.02**	-0.01**	-0.001	-0.02**	-1.2	0.4	12.1**
A-37 X R-89022	-2.1**	-1.7**	-3.3**	-0.03**	-0.02**	-0.01**	0.02**	0.01**	0.02**	-8.3**	-7.2**	-9.4**
A-37 X R-90011	-4.9**	-1.9**	-7.9**	-0.05**	-0.04**	-0.05**	0.04**	0.02**	0.05**	-34.4**	-14.4**	-32.5**
A-37 X V-112	2.1**	2.4**	2.3**	0.02**	0.03**	0.01**	-0.02**	-0.02**	-0.01**	16.0**	12.3**	11.5**
A-37XRTX	4.7**	1.7**	4.5**	0.06**	0.02**	0.03**	-0.03**	-0.02**	-0.03**	27.9**	8.8**	18.4**
A-102 X R-89016	-2.8**	-3.6**	-0.4*	-0.07**	-0.03**	-0.005	0.01**	0.03**	0.004*	-15.7**	-13.9**	-4.7**
A-102 X R-89022	1.7**	3.5**	1.3**	0.06**	0.03**	0.004	-0.01**	-0.02**	-0.01**	2.4	12.2**	3.0**
A-102 X R-90011	2.2**	-0.03	3.6**	0.06**	-0.0002	0.03**	-0.02**	0.001	-0.02**	19.7**	0.2	15.6**
A-102 X V-112	-1.3**	0.7*	-2.4**	-0.03**	0.01**	-0.01**	0.01**	-0.01**	0.01**	-9.2**	2.6*	-5.3**
A-102XRTX	0.20	-0.5*	-1.9**	-0.001	-0.007*	-0.01**	0.003**	0.004	0.01**	2.7	-1.2	-8.7**
A-88005 X R-89016	2.6**	3.6**	0.5*	0.01**	0.03**	0.007*	0.002**	-0.02**	-0.01**	13.9**	12.9**	9.2**
A-88005 X R-89022	1.9**	1.1**	-0.4*	0.01**	0.01**	-0.01**	-0.01**	-0.01**	0.006**	6.1**	4.7**	-6.4**
A-88005 X R-90011	1.6**	-0.1*	2.0**	0.02**	-0.001	0.03**	-0.007**	0.0002	-0.02**	14.3**	-1.2	15.5**
A-88005 X V-112	-2.5**	-3.7**	-0.1*	-0.01**	-0.02**	-0.01**	-0.002**	0.03**	0.01**	-3.2	-9.8**	-8.4**
A88005XRTX	-3.6**	-0.9*	-2.0**	-0.03**	-0.01**	-0.01**	0.01**	0.009**	0.01**	-31.2**	-6.6	-9.8**
A-88006 X R-89016	0.7	3.2**	-0.9*	0.004**	0.02**	-0.01**	-0.01**	-0.03**	0.006**	6.3**	12.3**	-3.5
A-88006 X R-89022	-0.9	-2.4**	1.0*	0.006**	-0.02**	0.01**	0.005**	0.02**	-0.006**	2.4	-11.5**	4.8**
A-88006 X R-90011	0.8	-1.1**	0.5*	-0.01**	0.013**	-0.01**	-0.006**	-0.01**	0.002	4.4**	5.8**	0.1
A-88006 X V-112	1.0*	-0.2*	-0.7*	0.02**	-0.03**	0.001	0.007**	0.02**	-0.004*	-8.1**	-10.7**	-4.2**
A-88006 X RTX	-1.6**	0.5*	0.2*	-0.02**	0.02**	-0.003	0.008**	-0.01**	0.002	-0.2	4.2**	2.8**
S.E. sq	0.5	0.05	0.05	0.001	0.004	0.003	0.0003	0.003	0.002	3.2	1.0	1.3
S.E. SW-3KL	0.7	0.07	0.07	0.0014	0.005	0.004	0.0004	0.004	0.003	4.5	1.5	1.8

X RTX82BDM499 and A-88005 X R-90011 under control and stress at GS3, and A-88005 X R-89016 under stress at GS2. It is interesting to mention that under any soil moisture regime the superiority of each hybrid regarding its SCA effect for grain yield was due to its superiority in SCA effects for one or more physiological characters.

Components of genetic variance

Variance components estimates (Table 7) were appreciably larger for additive (σ^2_A) than for dominance (σ^2_D) variance for all studied physiological traits under control, and under stress at GS3 and for leaf temperature under stress at GS2. On the other hand, the magnitude of dominance (σ^2_D) variance was greatly larger than that of additive (σ^2_A) variance in grain yield under all treatments and SC and CER under stress at GS2 (Table 7).

Concerning physiological traits, similar results were obtained by Kidambi (1987) and Al-Naggar *et al* (1999) who recognized the importance of additive genetic variance in the inheritance of gas exchange processes under water-stress environments. The present results concerning grain yield are in agreement with those obtained by Chhina and Phul (1988) and Patel and Desai (1990) in that non-additive gene action is of major importance in the inheritance of grain yield under irrigated and limited irrigation environments. On the other hand, Laosuwan and Atkins (1977) found that additive gene effects of the R-lines accounted for the largest portion of the variation expressed for grain yield.

Degree of dominance "a" (Table 7) was in the range of overdominance ($a > 1$) for CER and grain yield under all irrigation regimes and for SC and LT under control. Complete dominance to the higher parent ($a \approx 1$) was shown by SC and LT under stress at GS3. Partial dominance ($a < 1$) was manifested by leaf temperature under stress at GS2. No dominance ($a \approx 0$) was shown by SC under stress at GS2.

Heritability

Narrow-sense heritability estimates (Table 7) ranged from 14.6 % for grain yield to 54.5 % for SC under control, from 11.1 % for grain yield to 76.3 % for LT under stress at GS2 and from 16.7 % for grain yield to 69.3 % for SC under stress at GS3 stage. Narrow-sense heritability for grain yield was of low magnitude 14.6, 11.1 and 16.7 % under control and stress at GS2 and stress at GS3, respectively.

Table 7. Estimates of additive ($\delta^2 A$) and dominance ($\delta^2 D$) variance, degree of dominance "a" heritability $h^2(n)$ and selection gain (GA) for studied characters of sorghum under each soil moisture regime in 2000.

Genetic parameter	SC	CER	LT	Grain yield/ Plant
Non- stress (control)				
$\delta^2 A$	0.0012	9.2	0.0001	36.8
$\delta^2 D$	0.001	7.0	0.00009	279.4
$\delta^2 e$	0.000003	1.06	0.0001	10.4
"a"	1.29	1.29	1.34	3.9
$h^2(n)$	54.5	51.8	34.5	
GA:				
Direct	31.6	20.7	1.8	11.3
Indirect	22.1	22.2	16.8	
RE	(151.4)	(152.0)	(115.1)	
Water stress at GS2				
$\delta^2 A$	0.000293	2.78	0.002	4.7
$\delta^2 D$	0.0006	6.6	0.0006	118.3
$\delta^2 e$	0.00003	0.92	0.00002	1.2
"a"	0.02	2.18	0.77	7.1
$h^2(n)$	31.8	35.7	76.3	11.1
GA:				
Direct	17.7	14.7	7.8	11.1
Indirect	12.8	12.0	-17.8	
RE	(115.3)	(108.1)	(-160.4)	
Water stress at GS3				
$\delta^2 A$	0.0007	17.5	0.00064	39.5
$\delta^2 D$	0.0003	11.0	0.0003	187.4
$\delta^2 e$	0.00001	0.92	0.00001	1.8
"a"	0.93	1.12	0.97	3.1
$h^2(n)$	69.3	59.5	67.4	17.3
GA:				
Direct	37.8	36.9	4.3	16.7
Indirect	21.2	18.8	-22.9	
RE	(126.9)	(112.6)	(-137.1)	

RE = Relative efficiency = GA from indirect selection / GA from direct selection x 100

It is concluded that maximum heritability estimates in the narrow-sense were exhibited for SC (54.5 %) under control, LT (76.3 %) under stress at GS2 and SC (69.3 %) under stress at GS3. This indicates that the stress environment is the suitable environment for practicing selection programmes to improve traits for better expression under water-stress. Thus, the best environment for maximizing the heritability of stomatal conductance, carbon exchange rate and grain yield would be stress at GS3, and for maximizing heritability for leaf temperature would be stress at GS2.

Similar to our results, some researchers found that heritability was increased in stress environments (Stuber and Moll 1977, Troyer and

Rosenbrook 1983 and Al-Naggar *et al* 1999). However others reported decreased heritability under stressed environments (Frey 1964, Subandi and Compton 1974, and Asay and Johnson 1990).

Predicted selection gain

The expected genetic advance for physiological traits and grain yield under all soil moisture regimes (environments) were calculated for direct and indirect selection using a 10 % selection intensity (Table 7).

Genetic advance from direct selection under each moisture regime reached its maximum values under stressed environment at GS3 for stomatal conductance (37.8 %) carbon exchange rate (36.9 %) and yield (16.7) under stressed environment at GS2 for leaf temperature (7.8 %) due to the higher heritability estimates for these traits observed under the respective environments (Table 7).

Responses of grain yield to selection for physiological traits related to drought tolerance were calculated (Table 7). Selection was for either an increased value of SC and CER or a decrease in leaf temperature. In all cases selection for a physiological trait was predicted to be more effective in improving grain yield than direct selection for grain yield. This conclusion is based on comparisons between predicted responses in grain yield from indirect selection for a physiological trait and direct selection for grain yield trait itself by calculating the value of relative efficiency ($RE > +100\%$). These comparisons showed that indirect selection via any single physiological trait was significantly superior to direct selection for grain yield itself. When responses to selection for single physiological traits were compared under water stress at both GS2 and GS3 stages, response of grain yield to selection for low leaf temperature was predicted to be larger than response of grain yield to selection for high SC and CER.

It is worthy to note that relative efficiency (RE) of indirect selection for grain yield via leaf temperature was higher under water stress at both GS2 and GS3 than under control, while RE of indirect selection via SC and CER was lower under stress at GS2 and GS3 than under control.

According to Singh (2000) a good selection criterion for drought resistance should have high (or at least moderate) heritability, exhibit a significant association with drought, and show a positive association with yield under stress. All studied physiological traits exhibited very strong association with yield at the phenotypic and genotypic levels (data not presented). Narrow-sense heritability estimates for LT were relatively high under stress at both GS2 and GS3. Moreover, for SC and CER, h^2_n estimates were high under stress at GS3. It is therefore believed that LT under both stress environments and SC and CER under stress at GS3 meet the

qualifications proposed by Singh (2000) and could be recommended for grain sorghum breeders as selection criteria to achieve progress for improving yield in water limited environments.

We therefore conclude that the physiological traits LT, SC and CER are valuable aids in increasing the efficiency of selection for grain yield under stress conditions. These traits should be used in water-deficit breeding programmes. They are related to genotypic water –stress tolerance, with leaf temperature probably being the more important physiological trait. Other drought tolerance related traits not considered in this study may deserve attention regarding their value in a water deficit breeding programme.

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توارث صفات معدل التبادل الغازي و التوصيل الثغري و درجة حرارة الورقة

كميكانيكيات فسيولوجية لتحمل الجفاف في الذرة الرفيعة للحبوب

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هجتت خمسة سلالات معيدة للخصب الذكري مع كل من خمسة سلالات عقيمة الذكر سيتوبلازميا من الذرة الرفيعة للحبوب تختلف في درجة تحملها للجفاف للحصول على ٢٥ هجين F_1 في موسم ١٩٩٩. وفي موسم ٢٠٠٠ زرعت الآباء و هجتها في محطة تجارب جامعة أسيوط تحت ثلاثة أنظمة ري هي الري الكامل (كنترول)، و منع الري في مرحلة ما قبل التزهير (CS2) و منع الري في

مرحلة ما بعد التزهير (GS3). استهدف البحث دراسة أداء التراكيب الوراثية المحتملة و الحساسية و قوة الهجين و القدرة على الإمتلاف و نوع فعل الجين و درجة التوريت و التحسين المتوقع من تطبيق الإختاب لثلاثة صفات فسيولوجية هامة فى تحمل الجفاف هي معدل التبادل الغازي (CER) و التوصيل الثغري (SC) و درجة حرارة الورقة (LT) و كذلك محصول الحبوب للنبات تحت ظروف الإجهاد و عدم الإجهاد المائي. أعطت التراكيب الوراثية المقاومة تحت ظروف الإجهاد فى مرحلتى GS2 , GS3 قيمة أعلى عن التراكيب الحساسة لصفات معدل التبادل الغازي (٢٦,٣ ، ٢٥,٠% للآباء ، ٤٣,٧ ، ٨٣,٢% للهجن مقارنة بالكنترول) و التوصيل الثغري (٥٠,٠ ، ١٢٨,٥% للآباء ، ٦٤,٣ ، ١٠٠% للهجن) ، على التوالي. كما أظهرت التراكيب المقاومة قيمة أقل من التراكيب الحساسة لصفة درجة حرارة الورقة بمقدار ١,١ ، ١,٥ م للآباء ، و ٢,١ ، ٢,٤ م للهجن تحت الإجهاد فى مرحلة GS3,GS2 على التوالي.

أشارت نتائج قوة الهجين منسوبة للأب الأفضل إلى تميز بعض الهجن فى صفتي معدل التبادل الغازي و درجة حرارة الورقة عن الآباء تحت ظروف الإجهاد الرطوبي . وبالنسبة للقدرة العامة على الإمتلاف للآباء للصفات SC,LT,CER كان احسن الآباء هو B-88005 تحت ظروف الإجهاد فى الـ GS2,GS3 و R-89022 تحت ظروف الإجهاد فى الـ GS2 و V-112 تحت ظروف الإجهاد فى الـ GS3. و بالنسبة لمحصول الحبوب كانت أحسن الآباء هي B-88005,B-102 and R-90011 فى قدرتها الإمتلافية العامة تحت كل مستويات الإجهاد الرطوبي و R-89016 تحت ظروف الرى الكامل و الإجهاد فى مرحلة GS2 و RTX تحت ظروف الإجهاد فى مرحلة GS3. كان مقدار التباين التجميعي (σ^2_A) أكبر من تباين السيادة (σ^2_D) لكل الصفات الفسيولوجية المدروسة تحت كل أنظمة الرى ما عدا صفتي CER, SC تحت الإجهاد فى مرحلة GS2. أما بالنسبة لمحصول الحبوب فقد كان مقدار تباين السيادة أهم من التباين التجميعي تحت كل مستويات الإجهاد و الرى الكامل . ظهرت السيادة الفائقة لصفتي معدل التبادل الغازي و محصول الحبوب تحت كل أنظمة الرى و لصفتي التوصيل الثغري و درجة حرارة الورقة تحت الكنترول . و ظهرت السيادة الكاملة للأب الأعلى بواسطة صفتي التوصيل الثغري و حرارة الورقة تحت ظروف الإجهاد فى مرحلة GS3 . أما السيادة الجزئية فقد ظهرت بواسطة صفة حرارة الورقة تحت ظروف الإجهاد فى مرحلة GS2 . و لم تظهر أى سيادة فى صفة التوصيل الثغري تحت ظروف الإجهاد فى مرحلة GS2. و استنتج أن أحسن بيئة لتعظيم درجة التوريت بمعناها الخاص لصفات التوصيل الثغري و معدل التبادل الغازي و محصول الحبوب كانت هي بيئة الإجهاد فى مرحلة GS3 و لصفة درجة حرارة الورقة كانت بيئة الإجهاد فى مرحلة GS2 . كانت الإستجابة المتوقعة بالإختاب المباشر قد وصلت إلى أقصى درجة تحت ظروف الإجهاد فى مرحلة GS3 لصفات التوصيل الثغري و معدل التبادل الغازي و محصول الحبوب و تحت ظروف الإجهاد فى مرحلة GS2 لصفة حرارة الورقة . و فى الصفات المدروسة كان التحسين المتوقع بالإختاب للصفة

الفسبولوحية أكثر كفاءة في تحسين محصول الحبوب عن الإلتخاب المباشر لصفة محصول الحبوب نفسها . و كانت الإستجابة المتوقعة لتحسين صفة المحصول بالإلتخاب لقيم منخفضة من صفة درجة حرارة الورقة أكبر من الإستجابة المتوقعة لصفة المحصول بالإلتخاب لقيم عالية من التوصيل الثغري و معدل التبادل الغازي .

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