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Genetic Analysis of Transpiration Efficiency and its Relation to Grain Yield under Drought Stress Conditions in Bread Wheat

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ABSTRACT

Higher transpiration efficiency has been proposed as a mechanism to increase crop yields in dry environments. Therefore, gene action, general (GCA) and specific (SCA) combining ability of transpiration efficiency and morphophysiological traits were studied in a half diallel cross of bread wheat. Eight bread wheat genotypes and their 28 F_1 hybrids were evaluated under favorable and drought-stressed field conditions. Highly significant differences were observed among studied genotypes for all traits under favorable and drought stress conditions. Highly significant mean squares due to GCA and SCA effects were observed for all the traits under favorable and drought stress conditions, with GCA mean squares being much larger than that of SCA, except stomata frequency under drought stress. Both additive and non-additive gene actions were involved in the inheritance of the studied traits, with a predominance of the additive gene action. Compared to their parents, F_1 hybrids showed higher transpiration efficiency under drought stress. The regression analysis of transpiration efficiency indicated full adequacy of an additive-dominance model under favorable ($b= 0.94\pm0.08$) and drought stress ($b= 0.96\pm0.27$) conditions. A highly significant positive correlation ($r= 0.44$, $P<0.01$) was observed between transpiration efficiency and grain yield per plant under drought stress, indicating the usefulness of transpiration efficiency as an effective selection criterion for drought tolerance. The parents P_5 (Sids-14) followed by P_8 (Misr-2) and P_7 (L.1x15) were identified as the best general combiners, and five crosses ($P_1\times P_5$, $P_3\times P_4$, $P_4\times P_7$, $P_6\times P_7$ and $P_6\times P_8$) were the best promising combinations for transpiration efficiency under drought stress. Thus, inclusion of these superior genotypes into breeding programs could be useful for improvement of drought tolerance in wheat

INTRODUCTION

Drought is one of the most important abiotic stress factors affecting wheat in different growing regions of the world including Egypt (**El-Rawy and Hassan, 2021**). Drought stress occurs in different patterns and intensities at different crop growth stages **(Chenu et al., 2013; Daryanto et al., 2016; Sarto et al., 2017).** Effects of drought stress differ according to several factors including genotype, environmental conditions and genotype by environment interaction **(Hoffman et al., 2009)**. Therefore, understanding the response of crop plants to drought stress conditions is of great importance for plant breeding **(Bapela et al., 2022).**

Drought tolerance is a complex quantitative trait controlled by multiple genes with a high level of genotype by environment interaction (**Cooper et al., 2006; Mwadzingeni et al., 2017**). In addition, several types of stresses can simultaneously affect wheat plants **(Fleury et al., 2010).** Breeding for drought tolerance is also complicated due to the presence of several types of abiotic stress factors that can affect wheat plants simultaneously (**Fleury et al., 2010**). Therefore, selection of wheat genotypes tolerant to drought stress is one of the main tasks of plant breeders (**Clarke et al., 1992**). However, development of wheat genotypes tolerant to drought stress is restricted by several factors including the lack of effective selection criteria that can be effectively used to identify high yielding wheat genotypes under drought stress conditions (**El-Rawy and Hassan, 2014 a,b**).

Grain yield is the principal selection index commonly used under drought stress conditions. However, selection indices are more effective than direct selection for grain yield, and the relative effectiveness could be much better when two or more traits are used together than using single traits independently (**Muhe, 2011**). Furthermore, the strong correlation between grain yield and drought tolerance indices could be a good criterion to identify the best promising genotypes (**Farshadfar et al., 2012**). In this regard, a range of drought tolerance indices, including different morphological and physiological traits have been widely used for screening tolerant genotypes under drought stress (**Guttieri et al., 2001; Mitra, 2001; Sio-Se Mardeh et al., 2006; Ahsan et al., 2008; Drikvand et al., 2012; Edmeades, 2013**).

Wheat has gained special attention in respect to morphological and physiological traits affecting drought tolerance including transpiration rate and efficiency, stomata and leaf related-traits, water-use efficiency, relative water content and chlorophyll content (**Dencic et al., 2000**). In this regard, the use of morphological and physiological traits as indirect selection criteria would be important to increase yield-based selection procedures in wheat breeding programs **(Lonbani and Arzani, 2011)**. Ideally, secondary traits should be highly heritable, stable in expression, have low cost, fast, can be easily assessed, strongly correlated with grain yield under stress conditions, and not associated with yield loss under non-stressed conditions (**Barker et al., 2005; Campos et al., 2004; Lonbani and Arzani, 2011**). Transpiration efficiency, the amount of biomass produced per unit of water transpired, has been suggested as a trait of interest to improve yield in drought-prone environments **(Fletcher et al., 2018).** Thus, higher transpiration efficiency has been proposed as a mechanism to increase crop yields in dry environments where water availability usually limits biomass and yield **(Condon et al., 2002; Solomon and Labuschagne, 2004; Sinclair et al., 2004; Christy et al., 2018).**

The information on the genetic system controlling drought tolerance related traits is of great importance to increase the efficiency of wheat breeding programs. Therefore, objectives of the present study were 1) to analyze the genetic system controlling transpiration efficiency and several morphophysiological traits in a half diallel cross of bread wheat evaluated under favorable and drought-stressed field conditions, 2) to estimate general and specific combining ability for the studied traits as measures of additive and non-additive gene effects, respectively, 3) to clarify effectiveness of transpiration efficiency as an indirect selection criterion for drought tolerance in wheat and 4) to identify high yielding wheat genotypes tolerant to drought stress to be used as parents in wheat breeding programs.

MATERIALS AND METHODS

Plant materials

The initial plant materials utilized in the present study consisted of eight bread wheat genotypes (*Triticum aestivum* L.), quite variable in their performance under drought stress conditions **(Table 1).** Out of the eight genotypes used, four advanced inbred lines were developed at the Department of Genetics of Faculty of Agriculture, Assiut University, Egypt. The field trials of the study were carried out at the experimental Farm of Faculty of Agriculture, Assiut University, Egypt. In 2020/2021 winter season, the eight parental genotypes were sown in the fields at three sowing dates (16th November, 23rd November and 6th December), in order to synchronize the flowering stage, and crossed in a diallel pattern without reciprocals to produce 28 F_1 hybrids.

The eight parents and their 28 F_1 hybrids (36 genotypes) were used to study the gene action, general (GCA) and specific (SCA) combining ability of transpiration efficiency and several morphophysiological traits under favorable and drought stress conditions.

Field evaluation of the diallel cross

In 2021/2022 winter season, seeds of all genotypes were planted at an optimal sowing date (the 16th November). Two irrigation regimes were used as follow: 100% (favorable environment), and 50% (drought stress environment) field water capacity in clay fertile soil at the Experimental Farm of Faculty of Agriculture, Assiut University. For the favorable environment, the irrigation was applied every 2 weeks with a total number of eight irrigations throughout the growing season, excluding the establishment irrigation. For the drought stress environment, the irrigation was applied every 4 weeks with a total number of four irrigations throughout the growing season, excluding the establishment irrigation. For each environment, all genotypes were planted in a randomized complete block design (RCBD) with three replications. Each genotype was represented in each block by a one-row plot of 10 plants with rows spaced 50cm apart while plants within rows were spaced 30 cm from each other.

Field observations and measurements were recorded for individual plants grown under favorable and drought stress conditions. Leaf area (cm^2) was calculated using the formula described by **Dodig et al. (2010)**. Water transpired (ml/3leaves/h) was calculated as the amount of water lost by the last three leaves (including flag leaf) during 2 hours.

Transpiration rate [mg/(cm^2/h)] was measured as the amount of water transpired (in microliter or milligram) by the last three leaves (including flag leaf) during 2 hours divided by the total leaf area of the last three leaves (cm^2) as follow:

$$\text{Transpiration rate } [\text{mg}/(\text{cm2}/\text{h})] = \frac{\text{Water transpired} * 1000}{\text{Total leaf area of the last three leaves}}$$

Stomata frequency (number of stomata/mm^2) was measured following **El-Rawy and Hassan (2014b)**. The chlorophyll content (nm) of the flag leaf was measured using a Soil Plant Analysis and Development (SPAD) meter, which is widely used to rapidly measure SPAD values as a proxy for chlorophyll content (**Khadka et al., 2020**). At maturity, grain yield per plant (g), 1000-kernel weight (g) number of grains per spike, number of tillers, spike length (cm) and plant height (cm) were also recorded for the two environments.

Transpiration efficiency, which is defined as the amount of biomass produced per unit of water transpired **(Fletcher et al., 2018)**, was measured in the present study as the grain yield per plant (g) produced per unit of water transpired as follow:

$$\text{Transpiration efficiency (g seed/mg water)} = \frac{\text{Grain yield per plant (g)}}{\text{Water transpired (mg)}}$$

Statistical and biometrical analyses

To test for the significance of differences due to genotypes, GCA and SCA combining ability, an analysis of variance was performed for each environment separately. The diallel analysis was performed by the method developed by **Hayman (1954a,b)** and **Mather and Jinks (1971)** using computer “DIAL98” software developed by **Ukai (2006)**. **Jones (1965)** modifications for the half diallel cross (diallel without reciprocal) were also applied. GCA and SCA effects as measures of additive and non-additive gene effects, respectively, were estimated for each trait evaluated under drought stress conditions. Pearson’s correlation coefficients were also estimated among different traits evaluated under drought stress conditions.

RESULTS

1- Performance of wheat genotypes

The present study was carried out to investigate the gene action and assess GCA and SCA of several morphophysiological traits in a half-diallel cross of bread wheat evaluated under favorable and drought stress conditions.

The means of the eight parents and their 28 F_1 hybrids of all the traits studied under favorable and drought stress conditions are presented in **Supplementary Table 1.** The result showed that the parental genotypes as well as their F_1's responded differentially under both favorable and drought stress conditions. The results showed that under drought stress conditions, the parental genotypes P_5 showed higher TRE (25.54) followed by P_8 (16.25) and P_7 (14.38). Moreover, the lower TRR (18.64) was obtained by

P_5. Meantime, the higher GYP (36.83g) was obtained by P_5 followed by P_8 (33.04g), and the larger TKW (58.43g) was also obtained by P_5 followed by P_7 (48.70). As for F_1 hybrids, the larger values of TRE were obtained by P4×P5 (25.38), P7×P8 (23.90), P6×P7 (21.35), P1×P5 (20.85) and P5×P8 (20.26). Moreover, the lower TRR (16.87) was obtained by the F1 hybrid P4×P5, while the lower STF (50.73) was obtained by the F1 hybrid P5×P8. The higher TKW (58.90, 56.67, 55.43 and 55.40) were obtained by P1×P5, P1×P7, P7×P8 and P5×P8, respectively.

Due to drought stress, overall means of TRR, GYP, TKW, FLA, CHL, GPS, NOT, SPL, PLH and WTR were reduced by 8.6, 22.5, 3.4, 26.7, 19.8, 28.2, 32.4, 16.6, 12.6 and 38.5% for parental genotypes, and by 21.8, 40.9, 7.9, 44.2, 20.7, 23.5, 38.8, 17.3, 15.5 and 56.8% for F_1 hybrids, respectively. In contrast, stomata frequency was increased by 34.8 and 21.9% for parental genotypes and F_1 hybrids, respectively. Interestingly, drought stress reduced TRE by 17.6% overall parental genotypes, while an increment of 15.6% was observed in F_1 hybrids (**Figure 1**).

On average and compared with their parents, the F_1 hybrids produced higher GYP, TKW, FLA, SPL and PLH under both favorable and drought stress conditions. In contrast, F_1 hybrids produced lower TRR, CHL, GPS and NOT under both favorable and drought stress conditions. F_1 hybrids produced higher mean STF than their parents under favorable conditions, while a lower STF was found overall F_1 hybrids under drought stress conditions. Meantime, F_1 hybrids produced lower TRE than their parents under favorable conditions, while a higher TRE was found under drought stress (**Table 2**).

2- The diallel analysis of variance

Highly significant differences ($P<0.01$) were observed among parental genotypes and their F_1's for all the traits studied under favorable and drought stress conditions. Highly significant mean squares ($P<0.01$) due to GCA and SCA effects were also observed for all the traits studied under favorable and drought stress conditions, except WTR under drought stress. Obviously, GCA mean squares were much higher than that of SCA, except STF under drought stress, indicating a predominance of GCA than SCA effects **(Table 3)**.

3- The Wr/Vr relationship

The joint regression analysis of the covariance (Wr) on the variance (Vr) for the traits studied under favorable conditions is presented in **Table 4.** The slope of the regression line was significantly deviating from zero but not from unity for TRR (b = 0.87±0.16), STF (b = 0.79±0.24), TKW (b = 0.87±0.34), FLA (b = 0.81±0.13), NOT (b = 1.04±0.20), PLH (b = 0.99±0.06) and TRE (b = 0.94±0.08), indicating full adequacy of an additive-dominance model. However, partial adequacy was found for GYP (b = 0.44±0.14), CHL (b = 0.77±0.09), GPS (b = 0.53±0.13), SPL (b = 0.56±0.08) and WTR (b = 0.72±0.10) (**Table 4**).

The joint regression analysis of the covariance (Wr) on the variance (Vr) for the traits studied under drought stress conditions (**Table 5)** indicated full adequacy of an additive-dominance model for TRR (b = 0.81±0.18), STF (b = 0.81±0.22), TKW (b = 0.77±0.30), CHL (b = 1.04±0.16), PLH (b = 0.71±0.14) and TRE (b = 0.96±0.27).

Meantime, partial adequacy was observed for FLA (b = 0.58±0.12), GPS (b = 0.66±0.08) and SPL (b = 0.77±0.08), and non-adequate additive-dominance model was observed for GYP (b = -0.12±0.22), NOT (b = 0.56±0.20) and WTR (b = 0.52±0.15) under drought stress conditions. A significant dominance variance was also found for all the traits, except NOT and WTR (**Table 5**).

The graphical analysis of Wr/Vr relationships under favorable conditions (**Figure 2 and Figure 3)** indicated overdominance for STF, GYP, TKW and FLA, whereas a partial dominance was obtained for CHL, GPS, NOT, SPL, PLH, WTR and TRE, and a complete dominance was found for TRR.

The graphical analysis of Wr/Vr relationships under drought stress conditions (**Figure 4 and Figure 5)** indicated overdominance for TRR, STF, TKW and TRE, whereas a partial dominance was found for GYP, FLA, CHL, GPS, SPL, PLH and WTR, and a complete dominance was obtained for NOT.

4- The GCA and SCA effects

Estimates of GCA effects of parental genotypes for the traits studied under drought stress conditions are presented in **Table 6.** The highest positive GCA effect for TRE was found in P_5 (3.63) followed by P_8 (3.09) and P_7 (2.13). Moreover, the parent P_5 showed the highest positive GCA effects for STF (1.67) and TKW (1.97). In addition, P_8 possessed the highest positive GCA effect for GYP (4.37).

Estimates of SCA effects of the F_1 hybrids for the traits studied under drought stress conditions (**Table 7**) showed that greater positive SCA effects were found for TRE in the crosses $P_1 \times P_5$ (9.26), $P_3 \times P_4$ (6.23), $P_6 \times P_8$ (5.31), $P_4 \times P_7$ (4.14) and $P_6 \times P_7$ (3.54). In addition, the cross $P_1 \times P_5$ showed the highest SCA (7.89) for TKW. Meantime, the highest positive SCA effects for GYP were found in the crosses $P_4 \times P_7$ (19.46) followed by $P_1 \times P_5$ (9.51) and $P_6 \times P_8$ (7.72). It was also observed that the cross $P_4 \times P_7$ showed high SCA effects for GPS (28.90), SPL (1.70) and PLH (10.50).

5- Correlation coefficients analysis

Correlation coefficients among different traits under drought stress conditions **(Table 8)** indicated that TRE was significantly and positively correlated with GYP (r= 0.44; P<0.01) and TKW (r= 0.48; P<0.01). While, a negative correlation (r= -0.69; P<0.01) was obtained between TRE and TRR. Moreover, GYP was positively correlated with CHL (r= 0.34; P<0.05), GPS (r= 0.59; P<0.01), NOT (r= 0.43; P<0.01) and PLH (r= 0.41; P<0.05), while negatively correlated with STF (r= -0.37; P<0.05). In addition, TKW was negatively correlated with TRR (r= -0.52; P<0.01) and WTR (r= -0.41; P<0.05). GPS was also positively correlated with FLA (r= 0.63; P<0.01), CHL (r= 0.80; P<0.01), SPL (r= 0.80; P<0.01), PHL (r= 0.75; P<0.01) and WTR (r= 0.60; P<0.01).

DISCUSSION

The present study was carried out to investigate the type of gene action and assess GCA and SCA of transpiration efficiency and several morphophysiological traits in a half diallel cross of bread wheat evaluated under favorable and drought stress conditions. The studied traits were transpiration rate (TRR), stomata frequency (STF), grain yield per plant (GYP), 1000-kernel weight (TKW), flag leaf area (FLA), chlorophyll content (CHL), no. of grains per spike (GPS), no. of tillers (NOT), spike length (SPL), plant height (PLH), water transpired (WTR) and transpiration efficiency (TRE).

The findings of the current study provide an evidence for the existence of abundant genetic variation among the studied genotypes for all the traits, and thus wheat genotypes that differ in drought tolerance could be serve as important sources to study the adaptive responses of plants to drought stress conditions **(Bhargava and Sawant 2013).** The presence of genetic variability for transpiration efficiency has also been reported in different crop species, including wheat **(Condon and Richards, 1993; Hammer et al., 1997; Henderson et al., 1998; Kondo et al., 2004; Jackson et al., 2016).** Significant variation in TRE was also reported among wheat genotypes by **Condon et al. (1990)** and **Fischer et al. (1998).** The different levels of TRE in many wheat genotypes are associated mainly with differences in the leaf stomatal conductance **(Rebetzke et al., 2003; Condon et al., 2004).** Genotypic differences in TRE can be determined by variation in diverse synthetic, catabolic and regulatory pathways, as well as the morphological characteristics of genotypes **(Xue et al., 2006).** Moreover, TRE of plant genotypes is affected significantly and variably by canopy characteristics and leaf anatomy (i.e., leaf thickness, mesophyll cell size and position, stomatal density) and activity such as stomatal conductance **(Zheng et al., 2015).** The range of variation in TRE observed in the present study was substantial enough for further selection and use in breeding programs for improvement of drought tolerance in wheat.

The results showed that drought stress resulted in considerable reductions for TRR, GYP, TKW, FLA, CHL, GPS, NOT, SPL, PLH and WTR for parental genotypes and F_1 hybrids. In contrast, stomata frequency was increased under drought stress. Interestingly, drought stress reduced TRE overall parental genotypes, while an increment was observed in the F_1 hybrids. In accordance, several investigations reported that drought stress reduced flag leaf area **(Boussakouran et al., 2019)**, chlorophyll content **(Fotovat et al., 2007; Sayar et al., 2008)**, photosynthesis **(Tyagi et al., 2020)**, grain filling duration **(Ahmad et al. 2018)**, thousand kernel weight **(Shokat et al., 2020)** and consequently a reduction in grain yield **(Jamali et al., 2020)**. In addition, several investigations reported that stomata frequency was increased under drought stress conditions **(Yang and Wang, 2001; Zhang et al., 2006).** An increase in stomata frequency was observed also under moderate drought, but a reduction was observed with drought severity **(Xu and Zhou, 2008).** Stomatal frequency is also strongly associated with water use efficiency through its influence on stomatal conductance **(Zhang et al., 2006).** Moreover, drought affects photosynthesis negatively by changing the inner structure of mitochondria, chloroplasts and chlorophyll content **(Arjenaki et al., 2012).**

Highly significant GCA and SCA effects were observed for all the traits studied under favorable and drought stress conditions, except WTR under drought stress, with GCA mean squares being much higher than SCA mean squares, indicating the importance of GCA than SCA effects. These findings suggested that additive gene effects play a major role in the observed variation of these traits, and thus selection in early segregating generations may lead to successful identification of desirable wheat genotypes. Similar results were found for TRE in wheat by **Solomon et al. (2004),** as they demonstrated that TRE was under additive and dominant gene control, and GCA effects were the major components of the genetic variance. Additive and dominant type of gene actions have been also reported to control the inheritance of water use efficiency by **Ismail and Hall (1993), Johnson and Rumbaugh (1995)** and **Malik and Wright (1995).**

Under drought stress conditions, full adequacy of an additive-dominance model was found for TRR, STF, TKW, CHL, PLH and TRE. Meantime, partial adequacy was obtained for FLA, GPS and SPL, and non-adequate additive-dominance model was observed for GYP, NOT and WTR. Similar results were found by **Solomon et al. (2004)** for water use and transpiration efficiencies, as they were largely under the control of additive-dominance type of gene action. The high proportion of additive genetic variance observed in this study also suggests that selection may be effective in predicting the properties of recombinant lines that can be derived from these crosses.

Under drought stress conditions, the results of the study showed that GYP was positively correlated with CHL, GPS, NOT, PLH and TRE, while negatively correlated with STF. In addition, TKW was positively correlated with TRE, while negatively correlated with TRR and WTR. GPS was also positively correlated with FLA, CHL, SPL, PHL and WTR. A highly significant and negative correlation was obtained between TRE and TRR. In accordance, GYP was negatively correlated with STF by **Gaskell and Pearce (1983)**, **Ahsan et al. (2008)** and **EL-Rawy and Hassan (2014b).** Thereby, stomata and flag leaf characteristics have been widely used as efficient tools to evaluate drought tolerance **(Gaskell and Pearce, 1983; Venora and Calcagno, 1991; Bkagwat and Bhatia, 1993; Wang and Clarke, 1993a,b; Singh and Sethi, 1995; Yang and Wang, 2001; Zhang et al., 2006; Blake et al., 2007; Ahsan et al., 2008; Xu and Zhou, 2008).** Stomata play a valuable role in controlling water evaporation and gas exchange in plant leaves **(Liao et al., 2005; Pirasteh-Anosheh et al., 2016).** Therefore, stomata characteristics as drought tolerance indices have been long used for selecting high-yielding wheat genotypes under drought stress conditions due to their being cheaper, fast, and can be easily assessed **(EL-Rawy and Hassan, 2014b).** Moreover, flag-leaf area has indirect effects on wheat grain yield. The greater flag leaf area can capture more energy from the sunlight, leading to higher photosynthetic rates and consequently higher grain yield. In addition, drought-tolerant and high-yielding wheat genotypes exhibited the highest chlorophyll content **(Arjenaki et al., 2012).** Therefore, chlorophyll content can be also used as an indicator for drought tolerance **(EL-Rawy and Hassan, 2021).**

The results showed that under drought stress conditions, the parental genotypes P_5 showed a higher TRE followed by P_8 and P_7. In addition, the highest positive GCA effect for TRE was found in P_5 followed by P_8 and P_7. These findings indicated that these genotypes could be considered as the best general combiners for TRE under drought stress conditions. As for F_1 hybrids, greater positive SCA effects were found for TRE in the crosses $P_1 \times P_5$, $P_3 \times P_4$, $P_4 \times P_7$, $P_6 \times P_7$ and $P_6 \times P_8$. These results indicated that these genotypes could be considered as the best promising combinations for TRE under drought stress conditions. Therefore, using of these promsing genotypes could be useful for improvement of drought tolerance in wheat breeding programs. Furthermore, higher TRE has been proposed as a mechanism to increase crop yields in dry environments where water availability usually limits biomass and yield **(Condon et al., 2002; Solomon and Labuschagne, 2004; Sinclair et al., 2004; Christy et al., 2018).** Therefore, high

TRE could be considered as a desirable physiological trait for increasing grain yield in wheat under water-limited environments **(Xue et al., 2006).** High TRE in some genotypes is attributed to a high biomass production capacity **(Morgan and LeCain, 1991; Ashok et al., 1999; Condon et al., 2004).** Greater TRE is also critical for yield protection in the agroecological regions with limited soil moisture availability **(Condon et al., 2004).** Wheat genotypes with higher TRE generally produce higher grain yield under water-limited conditions **(Condon et al., 2002; Xue et al., 2006).**

CONCLUSION

In the present study, drought stress showed significant effects on grain yield of wheat genotypes, and abundant genetic diversity was found among genotypes for the studied traits. Transpiration efficiency (TRE) was positively correlated with grain yield under drought stress; thus, TRE could be effectively used as indicator to identify drought-tolerant genotypes, and higher transpiration efficiency can be used as an effective mechanism to increase grain yield of wheat in dry environments. Meoreover, additive gene effects played the major role in the observed variation of TRE, and thus selection in early segregating generations may lead to effective identification of desirable genotypes. Three parental genotypes and five crosses were identified as the most drought-tolerant genotypes, suggesting their usefulness as valuable genetic resources for improvement of drought tolerance in wheat.

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Table 1. Names, pedigree and origin of eight bread wheat genotypes used in the study.

Code	**Name**	**Pedigree**	**Origin**
P_1	Line-1	Advanced inbred line developed at Assiut University	Egypt
P_2	Line-2	Advanced inbred line developed at Assiut University	Egypt
P_3	Line-3	Advanced inbred line developed at Assiut University	Egypt
P_4	Gemmiza-9	ALD'S'/HUAC'S'//CMH74.630/5X	Egypt
P_5	Sids-14	BOW "S"/VEE"S"//BOW"S"/TSI/3/BANI SEWEF 1	Egypt
P_6	CHAM-8	Kauz (CM67458)	Syria
P_7	L.1x15	Advanced inbred line developed at Assiut University	Egypt
P_8	Misr-2	SKAUZ/BAV 92	Egypt

Table 2. Means of parental genotypes and their F_1 hybrids under favorable and drought stress environments.

Traits	**Environment**	**Parental genotypes**			**F_1 hybrids**			**LSD (0.05)**	**LSD (0.01)**
		Mean	**Min**	**Max**	**Mean**	**Min**	**Max**		
TRR	Favorable	35.91	18.89	55.62	34.46	14.41	49.90	7.46	9.90
	Drought	32.83	18.64	42.05	26.96	16.87	36.93	4.06	5.39
STF	Favorable	46.27	39.45	49.69	49.66	41.88	56.76	4.34	5.76
	Drought	62.35	52.10	73.33	60.55	50.73	69.88	6.42	8.53
GYP	Favorable	37.62	28.53	61.59	52.39	28.40	85.62	6.23	8.27
	Drought	29.16	19.60	36.83	30.97	21.24	51.16	2.22	2.95
TKW	Favorable	49.97	40.53	56.23	56.01	50.53	62.87	4.42	5.87
	Drought	48.28	41.33	58.43	51.57	45.43	58.90	4.76	6.31
FLA	Favorable	36.30	26.81	50.67	48.50	24.10	65.95	7.00	9.30
	Drought	26.62	21.22	33.81	27.04	18.05	37.36	5.93	7.87
CHL	Favorable	51.93	46.03	56.48	50.52	43.06	55.76	2.16	2.87
	Drought	41.67	31.64	49.60	40.06	32.66	49.72	3.38	4.49
GPS	Favorable	102.68	84.56	130.78	96.26	66.67	133.13	5.79	7.69
	Drought	73.71	46.11	118.11	73.65	46.56	137.33	5.19	6.89
NOT	Favorable	13.06	6.87	21.27	12.67	7.27	19.73	2.96	3.93
	Drought	8.83	6.67	11.13	7.76	6.13	10.40	1.68	2.24
SPL	Favorable	15.65	9.65	22.03	16.10	10.93	23.57	1.14	1.51
	Drought	13.05	8.97	17.80	13.31	9.89	18.27	1.76	2.34
PLH	Favorable	117.35	98.30	151.00	128.58	103.68	152.27	5.37	7.13
	Drought	102.54	85.26	124.70	108.63	81.73	138.86	7.05	9.36
WTR	Favorable	4.21	1.49	7.47	5.07	1.77	9.67	1.32	1.76
	Drought	2.59	1.53	3.48	2.19	0.93	3.81	0.63	0.84
TRE	Favorable	15.53	5.07	41.57	13.29	4.11	30.50	5.71	7.58
	Drought	12.79	7.00	25.54	15.36	7.67	25.38	4.58	6.08

TRR: Transpiration rate, STF: Stomata frequency, GYP: Grain yield per plant, TKW: 1000-kernel weight, FLA: Flag Leaf area, CHL: Chlorophyll content, GPS: No. of grains per spike, NOT: No. of tillers, SPL: Spike length, PLH: Plant height, WTR: Water transpired and TRE: Transpiration efficiency.

Table 3. Mean square due to genotypes as well as general (GCA) and specific (SCA) combining ability for studied traits under favorable and drought stress conditions.

Traits		**TRR**	**STF**	**GYP**	**TKW**	**FLA**	**CHL**	**GPS**	**NOT**	**SPL**	**PLH**	**WTR**	**TRE**
S.O.V.	**d.f**	**Favorable**											
Replicates	**2**	12.40**	18.86**	22.74**	4.49*	1.46	2.17	11.24**	1.95	1.10	6.09**	0.25	11.40**
Genotypes	**35**	422.16**	37.79**	575.50**	67.73**	407.75**	34.10**	1042.03**	41.68**	34.47**	878.18**	18.39**	223.91**
GCA	**7**	955.48**	117.77**	1130.59**	103.52**	1171.84**	87.61**	2853.26**	128.41**	106.93**	2688.70**	59.05**	599.55**
SCA	**28**	288.83**	17.80**	436.72**	58.78**	216.73**	20.73**	589.22**	20.00**	16.36**	425.55**	8.23**	130.00**
Error	**70**	21.63	7.11	14.65	7.36	18.48	1.76	12.65	3.30	0.49	10.87	0.66	12.28
S.O.V.	**d.f**	**Drought**											
Replicates	**2**	40.93**	36.64**	1.97	3.37*	74.12**	0.62	3.07	0.81	2.53	8.23**	0.25	6.45**
Genotypes	**35**	116.27**	87.02**	166.19**	41.56**	78.53**	68.84**	1562.97**	4.11**	17.03**	556.66**	1.95**	78.50**
GCA	**7**	244.23**	71.87**	291.57**	65.93**	173.47**	167.79**	4018.71**	8.69**	54.53**	1919.22**	3.46**	203.05**
SCA	**28**	84.28**	90.81**	134.85**	35.47**	54.80**	44.10**	949.03**	2.97**	7.66**	216.02**	0.95	47.36**
Error	**70**	6.22	15.56	1.86	8.53	13.25	4.31	10.15	1.07	1.17	18.76	0.15	7.92

TRR: Transpiration rate, STF: Stomata frequency, GYP: Grain yield per plant, TKW: 1000-kernel weight, FLA: Flag Leaf area, CHL: Chlorophyll content, GPS: No. of grains per spike, NOT: No. of tillers, SPL: Spike length, PLH: Plant height, WTR: Water transpired and TRE: Transpiration efficiency. * and ** stand for significant differences at 0.05 and 0.01 probability, respectively.

Table 4. Joint regression analysis and mean squares of (Wr+Vr) and (Wr–Vr) for the traits studied under favorable conditions.

Traits	Joint regression (b ± se)	Test for b = 0	Test for b = 1	Mean squares of (Wr + Vr)	Mean squares of (Wr – Vr)	Fitness of the model
TRR	0.87±0.16	5.61**	-0.83	35100.43**	1274.39	Fully Adequate
STF	0.79±0.24	3.30**	-0.90	180.75*	31.77	Fully Adequate
GYP	0.44±0.14	3.06*	-3.94**	62022.48**	10760.66**	Partially adequate
TKW	0.87±0.34	2.58*	-0.40	781.94*	183.31	Fully Adequate
FLA	0.81±0.13	6.24**	-1.45	7544.79*	576.98	Fully Adequate
CHL	0.77±0.09	9.03**	-2.73*	170.14**	1.45	Partially adequate
GPS	0.53±0.13	4.17**	-3.73**	132598.48**	17592.38**	Partially adequate
NOT	1.04±0.20	5.19**	0.21	169.33*	9.92	Fully Adequate
SPL	0.56±0.08	6.87**	-5.34**	67.62**	6.66**	Partially adequate
PLH	0.99±0.06	16.25**	-0.22	133736.68**	779.93	Fully Adequate
WTR	0.72±0.10	7.18**	-2.75*	21.90**	1.17	Partially adequate
TRE	0.94±0.08	12.34**	-0.77	25786.74**	261.66	Fully Adequate

TRR: Transpiration rate, STF: Stomata frequency, GYP: Grain yield per plant, TKW: 1000-kernel weight, FLA: FLag Leaf area, CHL: Chlorophyll content, GPS: No. of grains per spike, NOT: No. of tillers, SPL: Spike length, PLH: Plant height, WTR: Water transpired and TRE: Transpiration efficiency. * and ** stand for significant differences at 0.05 and 0.01 probability, respectively.

Table 5. Joint regression analysis and mean squares of (Wr+Vr) and (Wr–Vr) for the traits studied under drought stress conditions.

Traits	Joint regression (b ± se)	Test for b = 0	Test for b = 1	Mean squares of (Wr + Vr)	Mean squares of (Wr – Vr)	Fitness of the model
TRR	0.81±0.18	4.51**	-1.07	4420.92**	325.08	Fully adequate
STF	0.81±0.22	3.67**	-0.86	2005.73**	259.74	Fully adequate
GYP	-0.12±0.22	-0.55	-5.19**	2536.17**	3579.51**	Non adequate
TKW	0.77±0.30	2.52*	-0.77	915.98**	61.3	Fully adequate
FLA	0.58±0.12	4.85**	-3.57**	676.14*	115.23	Partially adequate
CHL	1.04±0.16	6.72**	0.28	736.79**	25.88	Fully adequate
GPS	0.66±0.08	7.97**	-4.04**	850922.54**	47150.39**	Partially adequate
NOT	0.56±0.20	2.85*	-2.24	8.35	1.12	Non adequate
SPL	0.77±0.08	9.79**	-2.98*	24.92*	1.44	Partially adequate
PLH	0.71±0.14	5.07**	-2.1	16364.80**	1162.95	Fully adequate
WTR	0.52±0.15	3.53**	-3.20*	0.10	0.04	Non adequate
TRE	0.96±0.27	3.57**	-0.14	987.42*	56.84	Fully adequate

TRR: Transpiration rate, STF: Stomata frequency, GYP: Grain yield per plant, TKW: 1000-kernel weight, FLA: Flag Leaf area, CHL: Chlorophyll content, GPS: No. of grains per spike, NOT: No. of tillers, SPL: Spike length, PLH: Plant height, WTR: Water transpired and TRE: Transpiration efficiency. * and ** stand for significant differences at 0.05 and 0.01 probability, respectively.

Table (6): Estimates of GCA effects of parental genotypes for the traits studied under drought stress conditions.

Genotypes	**Traits**											
	TRR	**STF**	**GYP**	**TKW**	**FLA**	**CHL**	**GPS**	**NOT**	**SPL**	**PLH**	**WTR**	**TRE**
P1	4.51**	0.24	-0.90**	-2.28**	0.25	1.92**	2.83**	0.86**	0.30**	-4.17**	0.37**	-2.13**
P2	-1.79**	1.39**	2.76**	1.05**	3.78**	3.00**	14.74**	-0.12**	2.13**	8.55**	0.11**	-0.18
P3	1.55**	0.19	0.79**	-2.13**	2.98**	2.79**	17.54**	-0.55**	1.70**	14.65**	0.43**	-2.29**
P4	1.35**	-0.80	0.71**	0.57*	0.62	0.26*	2.19**	-0.43**	0.27**	2.71**	0.15**	-1.31**
P5	-4.80**	1.67**	-2.35**	1.97**	-2.31**	-1.70**	-10.85**	-0.45**	-1.45**	-7.62**	-0.52**	3.63**
P6	1.43**	1.54**	-5.80**	0.02	-0.70	-2.31**	-13.57**	-0.25**	-0.76**	-7.08**	0.01*	-2.94**
P7	-2.00**	-2.07**	0.43**	0.39	-2.71**	-3.11**	-9.20**	0.25**	-1.26**	-2.42**	-0.40**	2.13**
P8	-0.25	-2.16**	4.37**	0.40	-1.91**	-0.86**	-3.68**	0.68**	-0.93**	-4.62**	-0.15**	3.09**
SD $_{(Gi)}$	**0.18**	**0.45**	**0.05**	**0.25**	**0.39**	**0.13**	**0.30**	**0.03**	**0.03**	**0.55**	**0.004**	**0.23**

GCA: General combining ability, TRR: Transpiration rate, STF: Stomata frequency, GYP: Grain yield per plant, TKW: 1000-kernel weight, FLA: Flag Leaf area, CHL: Chlorophyll content, GPS: No. of grains per spike, NOT: No. of tillers, SPL: Spike length, PLH: Plant height, WTR: Water transpired and TRE: Transpiration efficiency.

Table (7): Estimates of SCA effects of the F_1 hybrids for the traits studied under drought stress conditions.

Genotypes	Traits											
	TRR	**STF**	**GYP**	**TKW**	**FLA**	**CHL**	**GPS**	**NOT**	**SPL**	**PLH**	**WTR**	**TRE**
P1×P2	-2.73	-2.38	-0.06	-2.36	2.84	1.54	-1.12	-0.14	-1.65**	12.63*	0.12**	-0.99
P1×P3	1.68	2.34	-3.43**	1.16	-1.06	3.84**	24.08**	-0.58*	1.52**	6.94	0.06	-1.71
P1×P4	7.92**	2.64	-2.60**	-2.57	-4.55	-4.45**	-12.24**	-0.30	-2.46**	-20.57**	0.14**	-1.86
P1×P5	-9.34**	2.66	9.51**	7.89**	0.23	-4.28**	-15.53**	1.19**	-3.13**	-8.06	-0.59**	9.26**
P1×P6	3.01	10.61*	-4.26**	-0.83	-1.10	-4.15**	-16.81**	-1.95**	0.26	0.13	0.15**	-2.73
P1×P7	-0.94	2.75	-6.35**	-0.27	-1.42	-7.59**	-16.85**	-0.25	-1.37**	2.45	-0.48**	-0.41
P1×P8	1.32	0.04	-1.00*	-7.64**	-4.07	4.40**	-6.03*	1.59**	-1.09**	-2.64	-0.32**	0.51
P2×P3	3.00	-5.81	-4.92**	-4.35	0.85	3.33**	2.51	-0.41	1.19**	-7.21	0.38**	-2.97
P2×P4	0.38	6.41	-12.01**	-0.81	-7.50*	-2.01	-27.93**	-0.19	-1.39**	-16.84**	-0.53**	-2.33
P2×P5	-0.44	0.78	5.93**	5.02*	0.01	1.61	5.67*	1.03**	0.38	9.14	-0.08**	2.60
P2×P6	-9.06**	-4.11	-2.91**	1.10	3.50	-1.37	-15.94**	0.56	1.01**	-0.99	-0.52**	1.35
P2×P7	2.20	5.44	-4.22**	4.36	-2.64	-3.89**	-21.98**	-0.07	-0.71*	-1.17	0.02	-2.03
P2×P8	7.88**	0.60	1.10*	-0.98	2.62	0.10	-9.61**	-1.37**	0.14	-1.70	0.91**	-5.39*
P3×P4	-6.63**	6.45	1.98**	1.01	-3.53	-4.26**	-12.51**	0.63*	-1.27**	-2.08	-0.85**	6.23**
P3×P5	-2.03	4.05	-0.73	-0.17	-1.79	0.21	-4.91	0.00	-0.18	1.71	-0.53**	1.09
P3×P6	-4.67**	7.21	-4.31**	2.75	1.09	-3.01*	-23.41**	-1.08**	-0.16	4.45	-0.29**	-0.54
P3×P7	3.95*	-6.97	-3.69**	1.55	-5.39	-4.04**	-20.45**	-0.48	-1.82**	-4.17	-0.23**	-1.01
P3×P8	-1.91	3.32	2.59**	-2.63	2.98	-3.51**	-6.07*	-1.34**	-1.72**	-4.21	0.12**	-1.07
P4×P5	6.83**	0.57	3.27**	1.51	1.79	-0.04	14.77**	-0.14	1.14**	10.97*	0.68**	-4.31
P4×P6	0.44	-9.78*	0.65	1.72	10.50	5.47**	13.05**	0.27	2.47**	13.99**	0.82**	-2.46
P4×P7	6.00**	-1.13	19.46**	-0.75	1.15	2.91*	28.90**	1.04**	1.70**	10.50*	0.60**	4.14
P4×P8	0.08	-4.93	6.35**	2.67	6.23	1.29	9.61**	0.01	0.39	10.94*	0.59**	-0.61
P5×P6	12.03**	-0.89	-0.23	-5.65*	2.93	0.88	11.54**	-0.34	0.32	-10.84*	1.20**	-7.81**
P5×P7	-2.10	-0.03	-6.74**	-0.75	4.26	2.28	-7.06*	-0.53	0.78*	-0.64	0.15**	-5.86**
P5×P8	-1.37	4.14	-5.49**	-3.80	-0.01	1.40	-1.24	-1.03**	0.13	-4.81	-0.22**	-1.63
P6×P7	-5.07**	3.20	-1.38**	-2.61	-3.46	3.39**	-3.23	1.46**	-1.35**	-6.47	-0.53**	3.54
P6×P8	-4.31*	-9.60*	7.72**	4.12	-1.15	5.06**	14.48**	1.96**	0.05	-0.94	-0.29**	5.31*
P7×P8	-1.14	-1.54	-2.67**	0.71	3.54	0.80	-3.45	-0.03	1.26**	-4.70	0.20**	-2.99
SD $_{(Sij)}$	**1.70**	**4.27**	**0.51**	**2.34**	**3.63**	**1.18**	**2.78**	**0.29**	**0.32**	**5.14**	**0.04**	**2.17**

SCA: Specific combining ability, TRR: Transpiration rate, STF: Stomata frequency, GYP: Grain yield per plant, TKW: 1000-kernel weight, FLA: Flag Leaf area, CHL: Chlorophyll content, GPS: No. of grains per spike, NOT: No. of tillers, SPL: Spike length, PLH: Plant height, WTR: Water transpired and TRE: Transpiration efficiency.

Table 8. Correlation coefficients among different traits under drought stress conditions.

	STF	GYP	TKW	FLA	CHL	GPS	NOT	SPL	PLH	WTR	TRE
TRR	-0.06	0.02	-0.52**	0.14	0.21	0.28	0.01	0.25	0.06	0.77**	-0.69**
STF		-0.37*	-0.01	-0.21	-0.31	-0.28	-0.39*	-0.16	-0.13	-0.21	-0.1
GYP			0.19	0.29	0.34*	0.59**	0.43**	0.26	0.41*	0.23	0.44**
TKW				-0.08	-0.32	-0.21	0.03	-0.15	-0.02	-0.41*	0.48**
FLA					0.67**	0.63**	-0.16	0.79**	0.67**	0.71**	-0.45**
CHL						0.80**	0.19	0.79**	0.57**	0.60**	-0.26
GPS							0.08	0.80**	0.75**	0.60**	-0.13
NOT								-0.11	-0.18	-0.08	0.38*
SPL									0.76**	0.66**	-0.44**
PLH										0.45**	-0.18
WTR											-0.72**

TRR: Transpiration rate, STF: Stomata frequency, GYP: Grain yield per plant, TKW: 1000-kernel weight, FLA: Flag Leaf area, CHL: Chlorophyll content, GPS: No. of grains per spike, NOT: No. of tillers, SPL: Spike length, PLH: Plant height, WTR: Water transpired and TRE: Transpiration efficiency. * and ** stand for significant differences at 0.05 and 0.01 probability, respectively.

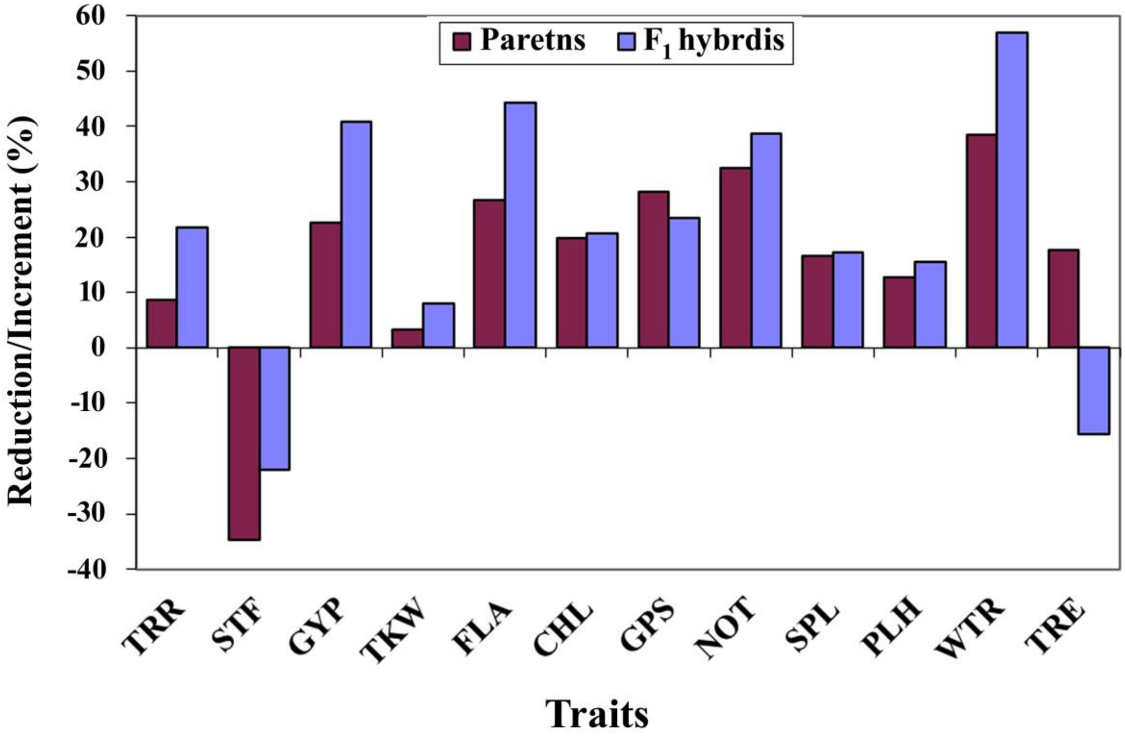
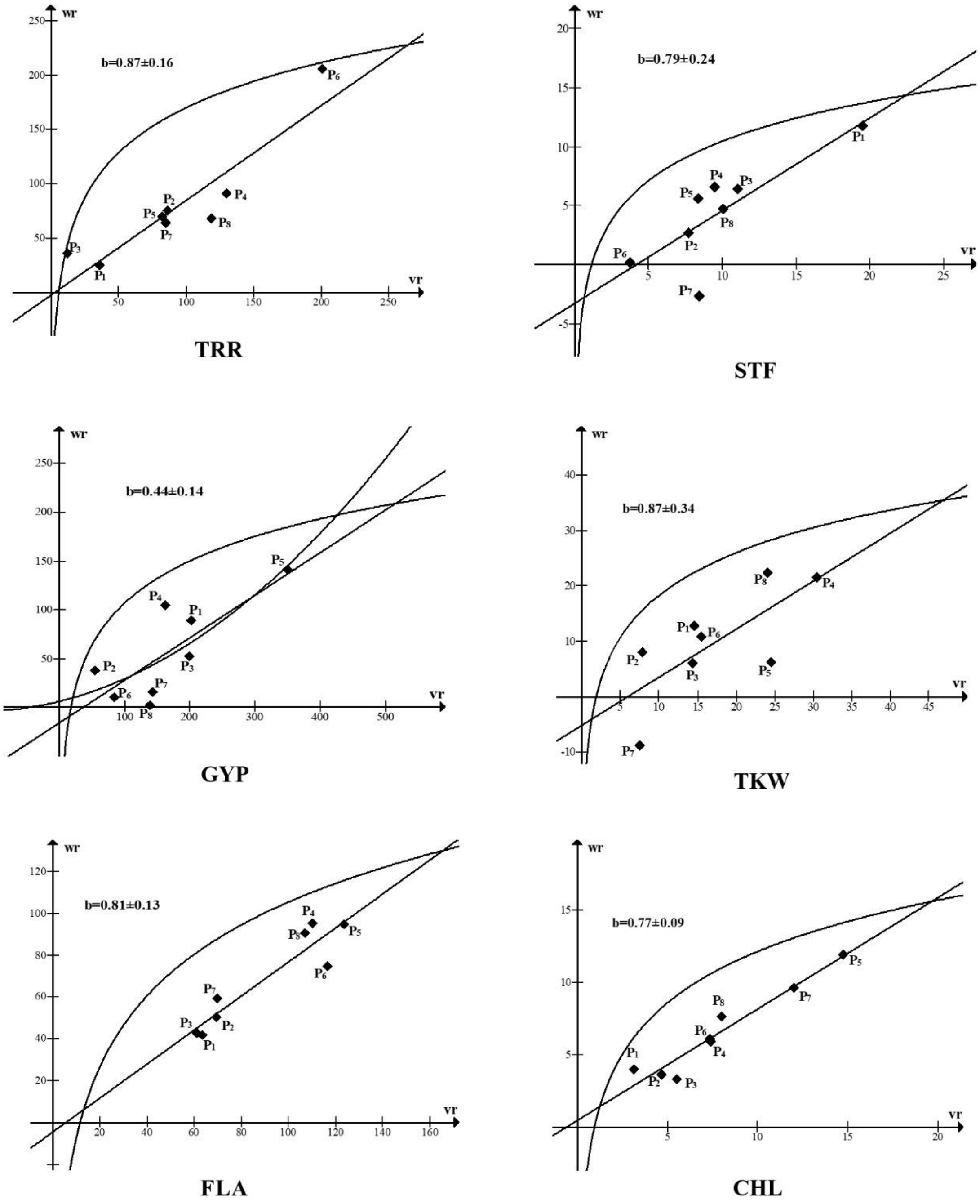


Figure 1. Percentage of reduction and increment resulted in the studied traits due drought stress conditions for parental genoptypes and F_1 hybrids. TRR: Transpiration rate, STF: Stomata frequency, GYP: Grain yield per plant, TKW: 1000-kernel weight, FLA: Flag Leaf area, CHL: Chlorophyll content, GPS: No. of grains per spike, NOT: No. of tillers, SPL: Spike length, PLH: Plant height, WTR: Water transpired and TRE: Transpiration efficiency.



TRR

STF

GYP

TKW

FLA

CHL

Figure 2. The Wr/Vr graphs of TRR: Transpiration rate, STF: Stomata frequency, GYP: Grain yield per plant, TKW: 1000-kernel weight, FLA: Flag leaf area and CHL: Chlorophyll content under favorable conditions.

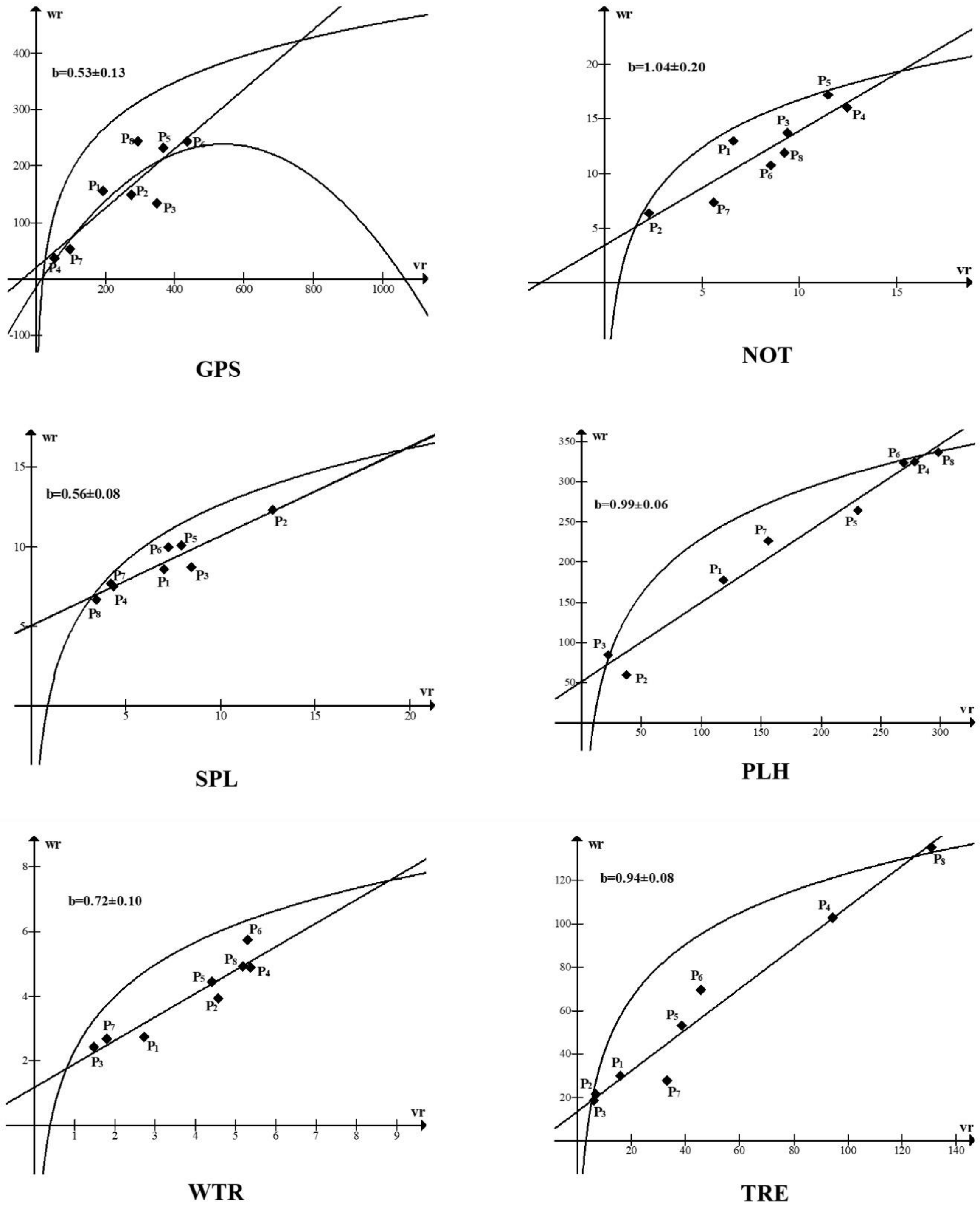


Figure 3. The Wr/Vr graphs of GPS: No. of grains per spike, NOT: No. of tillers, SPL: Spike length, PLH: Plant height, WTR: Water transpired and TRE: Transpiration efficiency under favorable conditions.

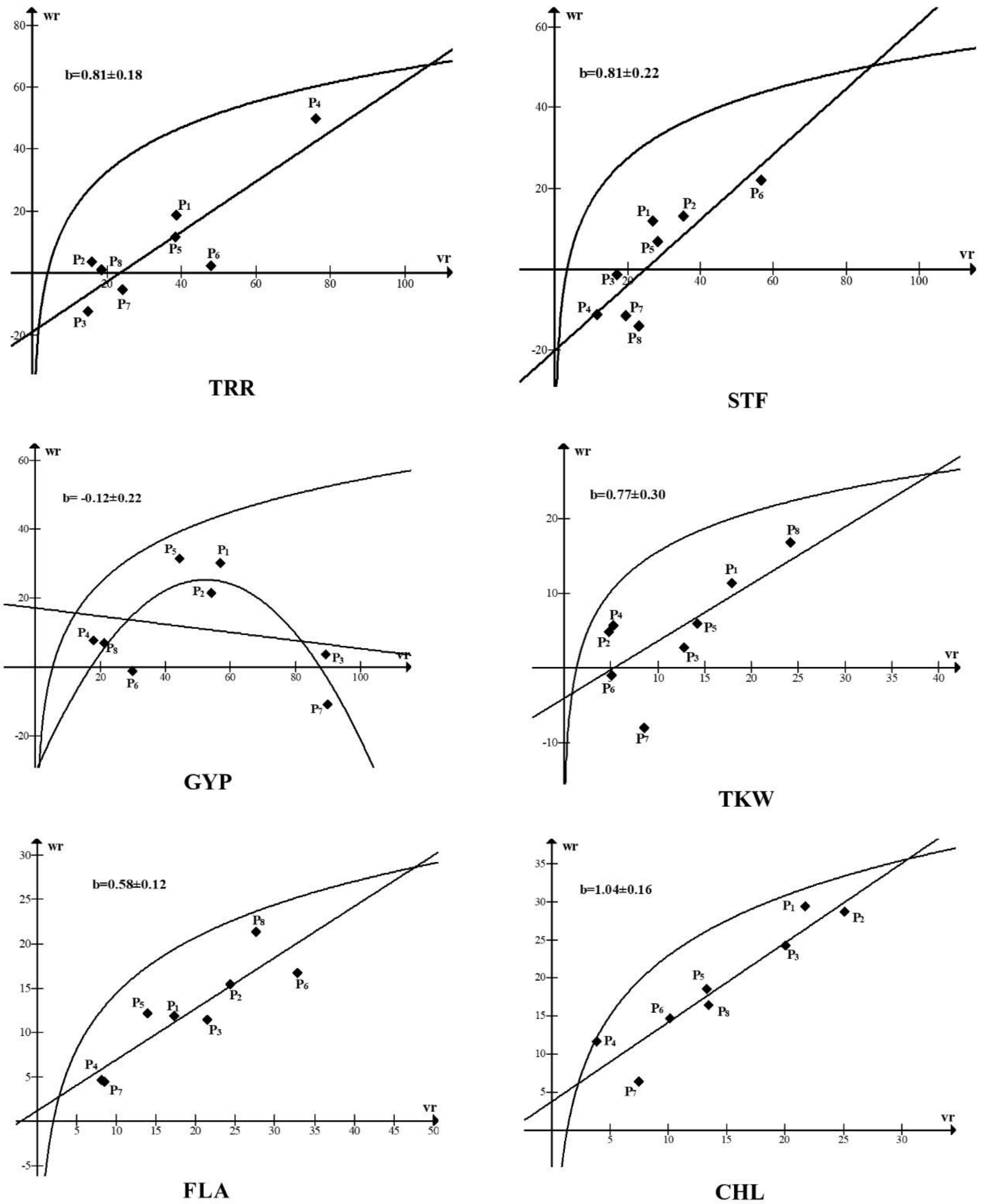
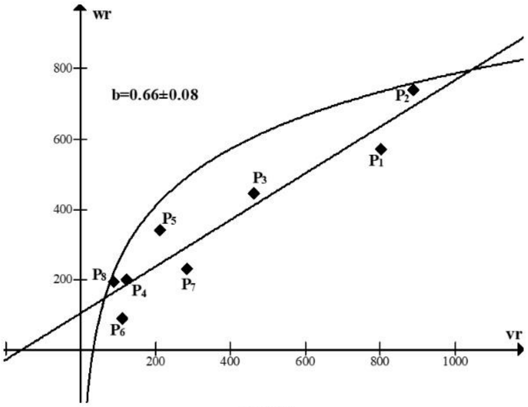
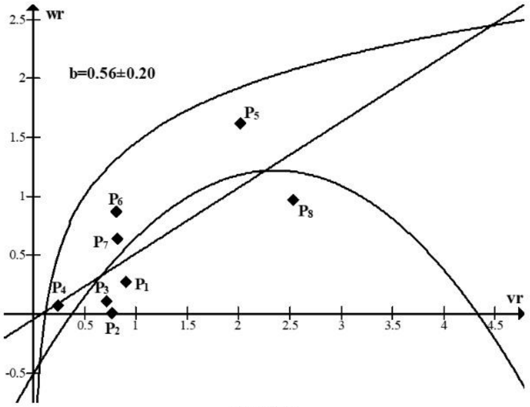


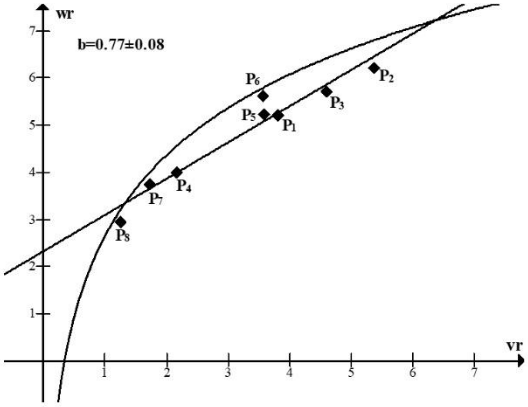
Figure 4. The Wr/Vr graphs of TRR: Transpiration rate, STF: Stomata frequency, GYP: Grain yield per plant, TKW: 1000-kernel weight, FLA: Flag leaf area and CHL: Chlorophyll content under drought stress conditions.



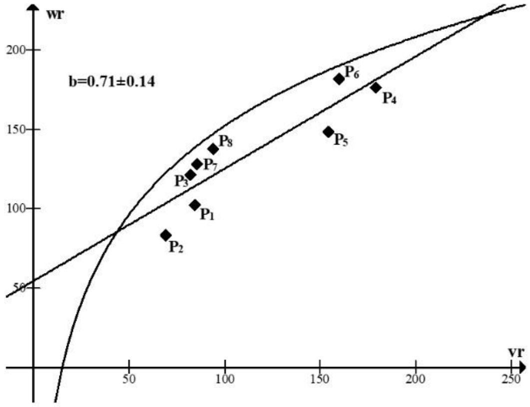
GPS



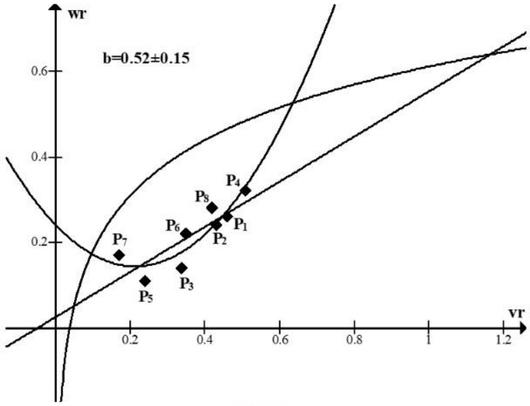
NOT



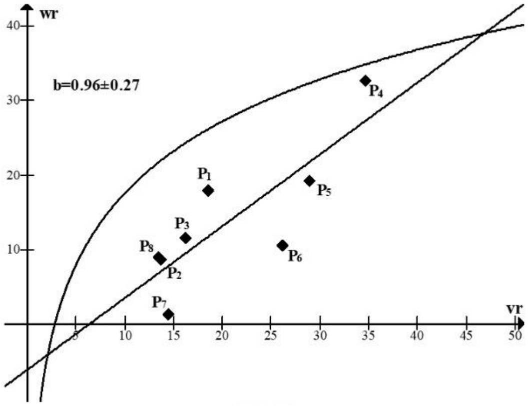
SPL



PLH



WTR



TRE

Figure 5. The Wr/Vr graphs of GPS: No. of grains per spike, NOT: No. of tillers, SPL: Spike length, PLH: Plant height, WTR: Water transpired and TRE: Transpiration efficiency under drought stress conditions.

Supplementary Table 1. The means of the eight parents and their 28 F_1 hybrids of all studied traits under favorable and drought stress conditions.

A: Favorable												
Traits	**TRR**	**STF**	**GYP**	**TKW**	**MLA**	**CHL**	**GPS**	**NOT**	**SPL**	**PLH**	**WTR**	**TRE**
P1	44.29±5.03	39.45±0.83	34.18±0.44	54.10±0.49	50.44±0.76	56.48±0.75	116.67±1.76	6.87±0.64	22.03±0.28	114.03±2.09	6.56±0.79	5.34±0.53
P2	51.27±3.91	46.38±0.33	41.27±1.70	51.53±1.13	50.67±2.00	53.08±0.44	103.11±1.18	9.93±0.58	16.50±0.21	151.00±2.30	7.47±0.68	5.58±0.30
P3	52.62±5.01	45.50±1.13	33.44±1.85	49.67±0.88	42.89±1.51	55.81±0.67	130.78±0.59	8.60±1.25	20.33±0.32	147.00±3.12	6.80±0.80	5.07±0.69
P4	22.64±2.92	44.53±1.14	30.09±1.20	40.53±0.77	26.85±1.02	46.03±0.09	87.67±1.58	11.80±0.95	14.70±0.55	98.30±1.46	1.80±0.40	18.98±5.07
P5	22.02±2.14	48.20±0.94	36.51±8.76	55.97±2.09	26.81±2.47	50.02±0.59	88.11±0.48	18.67±0.33	9.65±0.43	100.90±1.23	1.66±0.04	21.91±5.07
P6	55.62±4.81	47.84±0.72	35.38±0.33	48.13±1.73	36.63±3.48	51.00±0.76	84.56±1.56	10.00±0.31	15.35±0.58	111.50±2.20	6.34±0.65	5.69±0.52
P7	18.89±3.18	49.69±1.69	28.53±0.55	56.23±0.65	28.10±1.08	48.00±0.26	89.67±2.87	17.33±0.41	12.56±0.63	113.63±0.90	1.49±0.23	20.09±3.25
P8	19.92±0.44	48.57±1.52	61.59±1.99	43.60±1.57	28.04±2.66	55.01±0.35	120.89±2.90	21.27±0.37	14.09±0.26	102.43±0.62	1.53±0.20	41.57±5.65
Mean	35.91	46.27	37.62	49.97	36.3	51.93	102.68	13.06	15.65	117.35	4.21	15.53
P1×P2	46.98±3.23	45.70±0.85	47.91±0.80	58.60±0.67	65.56±2.68	55.76±0.94	122.00±4.03	8.20±1.06	23.57±0.38	138.31±1.63	9.13±0.32	5.26±0.27
P1×P3	43.28±0.99	43.72±0.28	34.31±2.38	53.50±1.84	62.29±2.80	55.34±0.46	129.67±1.68	7.27±0.85	22.09±0.49	145.77±1.63	8.34±0.11	4.11±0.25
P1×P4	42.86±1.66	48.06±1.25	35.12±3.79	51.30±0.81	52.51±2.62	51.61±0.59	91.78±1.90	9.93±0.81	17.63±0.22	114.37±2.22	6.70±0.66	5.41±0.98
P1×P5	39.22±2.91	45.28±0.74	65.04±2.17	62.87±1.44	51.71±1.01	53.75±0.22	120.22±1.28	11.13±2.03	16.53±0.41	129.20±2.35	6.02±0.42	10.88±0.59
P1×P6	32.34±1.06	49.50±0.75	42.48±0.64	57.10±0.45	62.64±4.03	54.99±0.79	111.00±1.20	9.27±1.05	18.67±0.44	127.40±1.50	5.83±0.20	7.31±0.36
P1×P7	29.80±2.23	54.21±1.12	57.33±0.77	59.57±3.14	41.52±1.47	53.49±0.41	91.11±0.48	12.80±1.30	17.57±0.30	127.20±1.51	3.67±0.29	15.80±1.22
P1×P8	41.18±0.96	49.24±1.77	69.55±2.10	58.47±1.88	56.27±0.89	52.00±1.28	114.89±1.64	14.00±1.17	17.83±0.44	122.93±2.06	6.93±1.06	10.38±1.16
P2×P3	49.90±5.30	41.88±0.50	57.30±2.02	53.03±0.67	65.95±4.03	53.73±0.33	133.13±1.58	9.87±0.98	22.89±0.48	152.27±2.38	9.67±0.40	5.93±0.12
P2×P4	34.09±1.47	51.00±3.70	49.71±1.19	53.07±1.19	55.21±3.20	51.42±0.33	100.78±0.97	11.73±0.29	16.60±0.40	144.33±0.43	5.59±0.28	8.93±0.43
P2×P5	47.53±2.01	48.39±1.40	57.40±1.49	59.23±0.48	46.06±2.13	50.66±0.34	93.33±1.39	11.87±0.87	16.27±0.24	141.87±2.94	6.41±0.12	8.97±0.40
P2×P6	33.44±1.44	48.18±2.74	46.02±1.02	58.27±1.98	51.74±4.47	52.72±0.72	114.78±2.42	9.20±1.15	17.77±0.66	148.30±2.23	5.13±0.28	9.03±0.62
P2×P7	26.10±2.09	47.67±0.87	40.80±1.61	57.70±1.76	42.68±2.57	50.86±1.34	86.44±0.29	10.00±0.53	14.22±0.36	136.87±2.23	3.18±0.10	12.87±0.73
P2×P8	36.95±1.79	49.61±0.79	59.84±2.32	55.63±1.54	53.80±0.50	48.71±0.51	89.33±1.15	12.67±1.39	14.34±0.18	151.57±3.30	5.95±0.27	10.12±0.81
P3×P4	42.79±1.42	48.87±1.17	39.26±1.20	54.97±1.40	54.67±1.33	50.55±0.40	89.67±0.58	12.33±1.34	15.51±0.36	139.10±2.78	6.99±0.86	5.83±0.89
P3×P5	43.38±3.39	50.99±2.00	69.99±1.51	62.17±0.60	52.21±2.66	53.36±0.56	108.11±0.91	11.27±0.35	16.23±0.27	137.95±1.66	6.69±0.60	10.60±0.75
P3×P6	46.23±2.55	46.85±0.82	62.33±0.61	58.57±1.95	59.21±4.22	51.75±0.84	124.89±1.79	11.93±0.37	19.69±0.62	143.33±1.33	8.11±0.41	7.72±0.39
P3×P7	45.55±1.75	51.01±2.26	58.18±0.56	56.47±2.15	45.98±2.26	53.29±0.95	91.11±1.37	14.13±1.14	16.32±0.45	141.00±1.97	5.77±0.64	10.37±1.29
P3×P8	45.38±1.44	48.6±1.11	60.99±1.72	54.33±1.45	53.44±1.11	48.87±0.62	96.78±1.87	16.87±0.87	16.57±0.41	142.27±1.69	7.28±0.82	8.67±1.28
P4×G5	26.52±2.12	52.73±2.05	46.36±0.91	50.53±2.53	32.32±1.08	45.75±0.28	74.89±1.56	14.13±1.94	10.93±0.50	113.27±1.36	2.55±0.12	18.20±0.56
P4×P6	14.41±1.71	52.22±1.49	33.62±1.21	50.63±1.13	43.76±2.58	50.09±0.28	86.89±1.79	8.00±0.12	13.73±0.55	103.68±1.40	1.84±0.21	18.65±1.62
P4×P7	15.89±1.12	54.22±2.27	51.45±1.04	60.13±0.84	38.47±2.34	46.64±0.93	93.89±0.97	14.80±1.73	13.38±0.50	111.23±1.56	1.77±0.08	29.11±1.22
P4×P8	19.28±2.39	49.50±1.54	69.33±0.78	52.07±0.88	44.36±2.54	45.37±2.00	88.56±2.25	19.73±0.82	13.77±0.13	105.30±0.67	2.29±0.15	30.50±2.04
P5×P6	25.31±2.28	51.21±2.61	47.52±4.11	51.73±0.88	30.44±1.17	45.50±0.76	69.33±2.36	11.33±0.59	11.90±0.36	110.23±2.89	2.23±0.53	22.83±3.45
P5×P7	33.40±2.80	51.07±0.77	28.40±0.43	51.21±2.08	24.10±0.56	43.06±0.39	66.67±0.38	14.87±1.79	11.13±0.26	105.47±1.13	2.32±0.50	13.78±3.65

P5×P8	**35.48±1.63**	**54.49±1.63**	**85.62±1.39**	**58.73±1.59**	**39.30±3.19**	**48.79±0.86**	**77.00±6.58**	**19.53±1.12**	**11.71±0.14**	**115.89±0.35**	**3.50±0.22**	**24.71±1.1.92**
P6×P7	**23.42±2.43**	**51.21±2.50**	**52.01±1.29**	**58.20±1.31**	**47.17±3.12**	**48.90±0.63**	**74.44±2.51**	**16.40±0.50**	**14.63±0.30**	**117.40±0.47**	**2.86±0.08**	**18.22±0.74**
P6×P8	**16.99±0.70**	**48.29±1.94**	**49.02±3.14**	**53.40±1.76**	**50.62±0.71**	**49.99±1.61**	**77.89±1.87**	**14.80±0.95**	**14.17±0.45**	**111.97±1.39**	**2.59±0.07**	**19.02±1.64**
P7×P8	**27.04±2.99**	**56.76±0.38**	**50.04±0.37**	**57.37±3.18**	**33.99±2.62**	**48.60±0.35**	**76.67±0.69**	**16.60±1.36**	**15.21±0.39**	**121.73±1.51**	**2.65±0.06**	**18.88±0.40**
Mean	**34.46**	**49.66**	**52.39**	**56.01**	**48.5**	**50.52**	**96.26**	**12.67**	**16.1**	**128.58**	**5.07**	**13.29**
LSD (0.05)	**7.457**	**4.341**	**6.232**	**4.417**	**7.0**	**2.158**	**5.791**	**2.959**	**1.139**	**5.37**	**1.324**	**5.707**
LSD (0.01)	**9.9**	**5.763**	**8.274**	**5.865**	**9.294**	**2.865**	**7.688**	**3.929**	**1.512**	**7.129**	**1.758**	**7.576**

Supplementary Table 1. continued.

B: Drought stress												
Traits	**TRR**	**STF**	**GYP**	**TKW**	**MLA**	**CHL**	**GPS**	**NOT**	**SPL**	**PLH**	**WTR**	**TRE**
P1	36.84±3.15	52.10±0.68	32.86±0.60	48.60±2.16	32.00±3.23	49.6±0.67	101.56±3.60	9.93±1.22	17.80±0.95	103.51±2.50	3.48±0.16	9.49±0.56
P2	28.25±0.80	60.20±3.09	32.37±0.35	47.27±0.73	33.81±2.73	46.87±1.31	90.11±1.28	8.60±0.42	14.03±0.89	124.29±3.44	2.87±0.29	11.49±1.17
P3	36.00±0.57	63.71±0.88	27.03±1.22	47.60±0.81	29.12±2.71	48.96±1.19	118.11±0.87	7.73±1.07	16.76±0.19	124.7±0.68	3.14±0.25	8.66±0.29
P4	42.05±0.56	63.03±2.88	27.78±0.06	46.57±1.00	23.26±0.95	38.14±0.71	66.44±2.16	8.13±0.24	11.36±0.46	85.26±2.33	2.93±0.08	9.49±0.25
P5	18.64±0.70	65.52±2.47	36.83±1.25	58.43±1.32	25.11±2.85	36.35±1.17	50.11±0.68	9.60±1.27	8.97±0.27	87.43±2.48	1.53±0.26	25.54±4.56
P6	37.22±3.13	73.33±0.88	19.60±0.55	47.77±1.18	25.39±1.56	35.88±1.41	46.11±2.12	6.67±0.55	13.05±0.23	96.17±2.63	2.81±0.09	7.00±0.27
P7	29.83±2.11	61.86±2.29	23.75±0.26	48.7±1.57	23.07±2.00	31.64±0.99	50.44±0.99	8.86±0.18	10.92±0.39	103.13±0.72	1.76±0.29	14.38±2.68
P8	33.85±1.22	59.07±0.90	33.04±0.84	41.33±2.17	21.22±3.57	45.88±2.77	66.78±1.57	11.13±1.34	11.53±0.24	95.85±2.05	2.17±0.44	16.25±2.69
Mean	**32.83**	**62.35**	**29.16**	**48.28**	**26.62**	**41.67**	**73.71**	**8.83**	**13.05**	**102.54**	**2.59**	**12.79**
P1×P2	24.07±0.67	63.26±2.76	44.63±1.13	51.97±0.81	34.67±1.29	46.76±2.42	137.33±1.35	8.07±0.18	18.03±1.08	127.43±3.73	2.36±0.25	19.31±1.90
P1×P3	31.02±1.09	56.71±0.84	29.20±1.15	45.43±1.38	34.56±4.31	49.53±1.17	108.44±2.04	6.93±0.48	18.27±1.13	123.27±3.07	3.20±0.33	9.36±1.14
P1×P4	28.19±1.24	67.95±2.36	22.03±0.54	51.67±0.84	23.85±1.41	41.67±1	62.67±2.33	7.27±0.71	14.27±0.62	101.70±2.59	2.01±0.04	10.97±0.05
P1×P5	21.23±1.68	64.78±1.06	36.91±0.57	58.90±2.69	28.42±2.71	43.32±0.72	83.22±2.74	8.47±0.71	14.31±0.70	117.34±1.32	1.80±0.15	20.85±1.80
P1×P6	18.84±0.42	59.77±2.64	24.61±0.66	53.03±1.02	33.52±1.38	39.74±0.89	58.89±1.56	8.20±0.31	15.63±0.96	107.75±1.11	1.89±0.04	13.03±0.47
P1×P7	26.66±1.66	65.71±1.64	29.53±0.15	56.67±0.57	25.38±2.05	36.41±2.58	57.22±2.70	8.07±0.55	13.42±0.76	112.23±4.04	2.01±0.04	14.71±0.34
P1×P8	34.10±3.29	60.77±1.30	38.80±1.64	51.33±2.86	31.44±3.33	42.66±0.68	75.11±1.64	7.20±0.53	14.60±0.58	109.50±4.95	3.15±0.06	12.31±0.50
P2×P3	34.67±0.88	56.03±4.84	38.40±1.15	46.93±1.63	36.33±2.25	49.72±0.36	129.11±2.94	8.53±0.27	17.87±0.58	138.86±4.52	3.81±0.26	10.21±0.95
P2×P4	24.53±1.74	66.79±0.31	34.04±0.82	50.30±2.37	27.02±1.44	39.20±1.19	80.89±1.06	7.65±0.18	13.95±0.19	122.57±2.34	2.00±0.25	17.42±1.70
P2×P5	22.98±0.44	66.85±0.40	28.27±0.95	50.52±0.35	25.82±1.34	41.71±0.95	75.44±2.12	7.00±0.20	13.31±0.71	116.02±2.57	1.66±0.16	17.22±1.16
P2×P6	26.58±1.23	69.88±2.79	21.24±0.38	51.50±0.45	30.32±2.69	37.89±0.41	54.22±2.08	6.13±0.48	14.03±0.69	119.30±3.32	2.43±0.32	9.04±1.18
P2×P7	31.76±0.66	52.10±2.25	28.10±0.38	50.67±2.00	21.83±1.13	36.06±0.59	61.56±1.75	7.22±0.62	11.87±0.34	115.33±1.51	2.08±0.14	13.63±1.04
P2×P8	27.66±0.47	62.30±0.77	38.32±1.87	46.50±3.76	31±0.58	38.84±1.09	81.44±2.08	6.80±0.12	12.30±1.07	113.10±0.59	2.68±0.31	14.53±0.97
P3×P4	23.45±0.30	59.24±3.30	23.44±0.22	50.60±1.00	26.13±0.68	41.48±0.43	71.22±1.25	6.48±0.24	13.50±0.60	109.25±2.67	1.84±0.03	12.77±0.31
P3×P5	31.63±1.57	62.40±2.60	32.19±0.54	54.91±0.34	27.04±2.09	38.93±0.47	79.78±1.64	6.98±0.49	13.21±0.45	113.33±2.29	2.58±0.32	12.79±1.35
P3×P6	31.48±2.11	51.92±0.87	26.12±0.69	53.17±0.35	37.36±2.63	43.83±2.29	75.33±0.58	7.60±0.40	15.23±0.81	116.90±1.72	3.26±0.22	8.09±0.58
P3×P7	33.60±0.31	56.95±2.54	51.16±0.85	51.06±0.59	26.00±2.12	40.48±0.61	95.56±0.78	8.87±0.47	13.97±0.46	118.07±0.20	2.62±0.23	19.75±1.41
P3×P8	29.44±3.73	53.07±3.58	42.00±0.90	54.50±1.76	31.88±2.25	41.11±1.54	81.78±1.31	8.27±0.82	12.99±0.98	116.31±1.35	2.87±0.53	15.96±3.54
P4×P5	16.87±2.17	58.65±3.66	23.10±0.48	52.77±1.41	18.61±1.15	35.98±0.16	50.33±0.77	7.00±0.00	10.63±0.43	93.30±0.86	0.93±0.09	25.38±3.07
P4×P6	36.93±0.06	63.26±1.80	22.19±0.14	47.20±0.84	26.86±3.36	37.29±0.96	60.78±1.87	6.97±0.23	11.36±0.09	81.73±0.82	2.98±0.37	7.67±0.86
P4×P7	19.36±0.95	60.52±2.70	21.91±0.54	52.47±1.36	26.18±2.89	37.88±0.57	46.56±0.80	7.27±0.24	11.32±0.65	96.59±1.31	1.50±0.09	14.69±1.02
P4×P8	21.85±1.09	64.60±2.21	27.10±0.26	49.43±2.95	22.72±1.15	39.26±0.88	57.89±2.04	7.20±0.31	11.00±0.30	90.23±4.48	1.39±0.16	19.88±1.84

P5×P6	34.95±0.97	65.70±1.78	21.32±0.13	50.60±2.20	19.39±1.25	32.66±2.06	56.67±0.69	7.07±0.44	10.43±0.43	93.46±3.48	2.03±0.12	10.58±0.66
P5×P7	22.62±0.07	63.62±0.84	23.81±0.44	48.67±1.26	20.07±0.92	38.39±1.05	47.67±0.19	9.47±0.37	9.89±0.55	91.30±0.10	1.36±0.07	17.53±0.53
P5×P8	25.14±1.70	50.73±0.36	36.86±0.80	55.40±1.13	23.18±1.56	42.31±0.61	70.89±1.06	10.40±0.50	11.61±0.47	94.63±1.56	1.85±0.17	20.26±1.75
P6×P7	22.81±0.43	55.94±0.59	34.20±0.41	50.52±0.29	23.51±0.92	37.27±0.65	77.33±2.65	7.93±0.52	11.49±0.27	104.53±1.16	1.61±0.09	21.35±1.06
P6×P8	24.87±0.44	55.17±2.45	32.70±0.71	52.37±1.56	25.87±0.93	37.25±0.65	57.33±2.33	8.91±0.97	12.32±0.70	95.53±1.71	1.93±0.08	17.02±1.04
P7×P8	27.50±0.84	60.61±4.63	35.00±0.47	55.43±2.94	18.05±1.94	33.93±0.87	67.44±1.97	9.47±0.29	11.82±0.27	102.07±0.82	1.48±0.11	23.90±1.66
Mean	29.96	60.55	30.97	51.57	27.04	40.06	73.65	7.76	13.31	108.63	2.19	15.36
LSD (0.05)	4.061	6.424	2.221	4.756	5.928	3.381	5.188	1.684	1.761	7.053	0.6307	4.583
LSD (0.01)	5.392	8.528	2.949	6.314	7.87	4.488	6.888	2.236	2.339	9.364	0.8373	6.084