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Combining ability analysis in sunflower hybrids under water stress conditions

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Abstract

This study was conducted to evaluate combining ability for yield, agronomic and physiological traits through line × tester analysis with 30 hybrids, developed from five testers and six lines, at three water regimes. The experiment was conducted as split plot design based on randomized complete blocks for two years. Data analysis showed that GCA of lines were significant for seed yield, number of seeds per head, head diameter, plant height, and relative water content (RWC), respectively. GCA for testers was only significant for RWC. SCA of all traits, except leaf temperature, were significant. GCA and SCA estimates were obtained on the average of water regimes and years. Highest positive GCA for testers belonged to R50 for yield, number of seeds per head, 100 seed weight, head diameter, and plant height which were 4.28, 62.31, 0.18, 0.45, and 6.47, respectively. Line A329 had the highest positive GCA for yield and number of seeds per head (3.95 and 63.78, respectively), but the highest negative GCA (-2.79) for RWC. Cross R50 × A329 had the highest positive SCA for yield, number of seeds per head, and RWC which were 9.25, 138.66 and 3.71, respectively. The results showed high narrow sense heritability and incomplete dominance for all characters except leaf temperature. These results showed the potential for producing improved cultivars in sunflower under normal and water deficit conditions

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Introduction

Water stress is regarded as one of the major limiting factors to crop yield in the world and possible climate change will increase the risk of drought in the future (Nagarathna *et al.* 2012). This implies the necessity of improving more drought tolerant varieties in crop plants. Sunflower has a low to medium sensitivity to drought (Rauf, 2008). Drought stress affects various stages of sunflower growth. Flower bud formation/appearance (R1) and flowering (R4) are regarded as the critical growth stages of sunflower with regard to water stress (Flagella *et al.*, 2002). According to Iqbal *et al.* (2005) drought stress caused about 5.6 and 5.8 percent reduction in oil content at vegetative and reproductive stages, respectively. But based on some reports drought does not have a significant impact on the oil quality of sunflower (Petcu *et al.*, 2001). Tahir *et al.* (2002) evaluated 25 sunflower inbred lines under drought stress. Among the agronomic traits, the maximum decrease was observed *in yield* per plant and 100-achene *weight*.

During drought stress some physiological characters such as leaf water potential, relative water content (RWC), and plant evaporation are reduced and others such as canopy temperature are increased (Farooq *et al.*, 2009). Based on Baldini *et al.* (1997), selection of sunflower genotypes for the physiological characters under drought stress, showed higher water consumption, enhanced vegetative growth, and increased root-to-shoot ratio. These genotypes avoided drought stress via continued water uptake from the deeper soil layers.

Drought tolerance and yield are possibly controlled by separate gene loci. Thus, an objective in a breeding program for drought tolerance could be the identification and transfer of physiological traits associated with drought tolerance to agronomically plausible cultivars (Chiementi *et al.*, 2002). Drought tolerance is a complex character and may be associated with some traits such as root depth, osmotic adjustment, and antioxidant production (Bray, 1997; Chiementi *et al.*, 2002). RWC has been regarded as a useful measure to evaluate the plant water condition. RWC is related to the cell volume, therefore, it may represent the balance between water supply and the leaf transpiration rate (Sinclair and Ludlow, 1985). It has been reported that RWC is higher in drought resistant plants as compared with the sensitive plants and has also shown relatively high heritability (Hassanzadeh *et al.,* 2009). Rauf *et al.* (2009) crossed six drought tolerant cytoplasmic male sterile (CMS) lines as female parents and six tolerant genotypes with restorer genes as the male parents in a line × tester scheme. The results showed a heritability of 0.62 for RWC. Furthermore, a significant relationship was observed between drought tolerance and RWC. Leaf temperature is also regarded as an important criterion in the drought condition, especially at the seed filling period (Alza and Fernandez-Martinez, 1997).

Heterosis is defined as the difference between mean of parents and their hybrids for a measured trait. It is caused by the allelic differences of the parents and some levels of dominance or epistasis (Fehr, 1987; Škorić *et al.*, 2007). Nowadays, sunflower hybrids are usually cultivated as commercial varieties. Therefore, producing superior hybrids with higher yield and oil content, and also uniformity is the most important objective in sunflower breeding programs. Superior hybrids are obtained by crossing male sterile inbred lines with restorer testers and selecting for high general combining ability (GCA) and specific combining ability (SCA). Thus, estimation of genetic parameters such as GCA and SCA are essential in a sunflower breeding program (Škorić, 1992). Among various biometrical techniques used for genetic analysis of quantitative traits, line × tester analysis is widely used, which provides information on the genetic potential of parents and hybrids and nature of the gene action (Kumar *et al.*, 2013). Ortis *et al.* (2005) estimated GCA and SCA variances for plant height, 1000 seed weight, and seed yield in sunflower hybrids from several testers and lines. GCA variances were higher for plant height, oil content, and 1000 seed weight while SCA variance was higher for seed yield.

The present study was performed to study the combining ability and gene action for several agronomic and physiological traits through line × tester analysis at normal and water stress conditions.

Materials and methods

Plant material

Seeds of 30 F1 hybrids were developed by crossing five male restorer lines (R19, R26, R46, R50, R55) as testers to six male sterile female lines (A110, A221, A326, A329, A344, A356). Hybrids were evaluated in a split plot design based on randomized complete blocks with three replications at three water regimes for two years. The water stress imposed by withholding irrigation from flowering stage (R4). For the mild water stress treatment, plants were irrigated after 15 days from beginning of the stress and for the severe stress treatment plants were not irrigated until harvest. Well-watered plants (control) received sufficient water to maintain soil water content close to field capacity. Seed yield per plant, number of seeds per head, 100 seed weight, head diameter, plant height, leaf temperature, and relative water content (RWC) were measured at different stages. RWC was determined as bellow:

RWC= (FW-DW) / (TW-DW).

where, FW is fresh weight, TW is turgid weight after 24 hours of rehydration at 4°C in a dark room by placing the petioles in a container with distilled water, and DW is dry weight after oven drying for 24 hours at 80°C (Smart and Bingham, 1974). Leaf temperature was measured by a laser thermometer with four sampling units in each experimental plot. Physiological traits were measured at R7 stage and traits related to seed were recorded after harvest.

Statistical methods

Line × tester analysis was performed based on the data combined over years. The hybrid source of variation was partitioned into variations due to lines, testers and line × testers. GCA and SCA effects were determined, based on the average of two years and three water regimes, as follows:

GCA for lines (L) = $X....j/y{\times}r{\times}s{\times}t - X...../\ y{\times}r{\times}s{\times}t{\times}l$

GCA for testers (T) = $X\ ...i.\ /y{\times}r{\times}s{\times}l\ - X...../\ y{\times}r{\times}s{\times}t{\times}l$

SCA (L x T) = $X\ ...ij/y{\times}r{\times}s - X\ ....j/y{\times}r{\times}s{\times}t - X...i./y{\times}r{\times}s{\times}l + X...../\ y{\times}r{\times}s{\times}t{\times}l$

where, $X...j$ is the summation for jth line, $X...i.$ is the summation for ith tester, $X\ ...ij$is the summation for the combination of the jth line with ith tester, $X.....$ is the summation overall hybrids, y is the number of years, r is the number of replications, s is the number of water levels, l is the number of lines, and t is the number of testers.

Furthermore, variance estimates for GCA and SCA were obtained assuming years, lines, and testers as random factors. Using GCA and SCA variances, narrow sense and broad sense heritabilities were also estimated.

Results

GCA and SCA variances

Line mean squares were significant for seed yield, number of seeds per head, head diameter, plant height, and RWC. Variation among testers was only significant for RWC (Table 1). This result showed that testers were discriminative only for RWC. Alza and Fernandez-Martinez (1997) reported the existence of genetic diversity among lines and testers in sunflower. However, they observed that lines were more diverse than testers for seed yield and yield components. SCA was significant for all traits except leaf temperature. Significant GCA of lines and SCA for almost all traits indicated the existence of both additive and non-additive gene effects for the genetic materials under investigation. None of the interactions involving water regime were significant, except for the water regime × line interaction in plant height. Most of the interactions involving year were also non-significant. However, as shown in Table 1, mean squares of year × tester and year × line were large and significant for 100 seed weight and leaf temperature. These effects were used for calculating F statistics of testers and lines in the ANOVA table and because of their magnitude, no significant F statistic was obtained for testers and lines regarding these traits. In spite of non-significance of lines and testers mean squares for leaf temperature and 100 seed weight, average of two years was used for further genetic variance estimation for these traits.

Table 2 showed that the contribution of lines was greater than testers for yield, number of seeds per head, plant height, and head diameter. For both physiological characters the contribution of testers was greater than lines. Contribution of line × tester interaction was greater than both lines and testers for RWC and 100 seed weight.

Table 1. Analysis of variance for the line × tester design in sunflower at three water levels combined over two years.

S.O.V	df	SY	NS	SW	HD	PH	LT	RWC
Year(Y)	1	20632.1**	2434335**	71.33**	562.21*	4.7	734.45*	986.0
Rep(Y)	4	984.0	154613	3.40	35.98	2506.0	57.96	221.1
Stress(S)	2	12988.5**	1618688**	39.45**	475.44*	2365.6	1185.81**	2469.9*
Year*S	2	335.6	190569	5.60	160.06*	1736.0	92.10**	682.1
S*Rep(Yr)	8	487.3	108638	1.30	17.95	1278.6	10.60	157.9
Tester(T)	4	379.5	65416	0.72	9.65	1360.4	293.24	179.5*
Line(L)	5	1739.7**	537447**	0.62	40.79**	4306.1**	17.12	116.0*
T*L	20	369.4**	76628**	0.62*	5.15*	414.4**	4.22	45.3**
S*T	8	46.2	15397	0.35	2.08	101.3	1.89	30.5
S*L	10	128.0	23722	0.97	4.21	308.4**	6.09	35.3
S*T*L	40	112.8	28608	0.33	2.58	108.1	2.89	23.3
Y*T	4	252.4	45226	0.78*	5.47	179.8	305.17**	11.8
Y*L	5	217.7	49613	0.92*	5.06	113.1	11.11**	22.7
Y*S*L	10	84.9	16897	0.40	3.44	142.4	3.87	20.6
Y*S*L	8	197.3	62712	0.28	3.62	176.2	2.73	31.3
Y*T*L	20	148.4	36230	0.37	3.48	137.3	4.08	23.0
Y*S*T*L	40	154.6	36868	0.39	3.13	99.1	2.17	24.3
Error	348	124.1	31922	0.31	2.73	109.0	2.75	19.3

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

SY: Seed yield, NS: Number of seeds per head, SW: Seed weight, HD: Head diameter, PH: Plant height, LT: Leaf temperature, RWC: Relative water content.

The variance ratio of general to specific combining ability was higher than unity for all traits except leaf temperature. For plant height and head diameter GCA variance was three times higher than SCA. It seems that plant height and head diameter are governed more by additive gene action rather than non-additive gene action in the materials under study. Ortis *et al.* (2005) and Nooryazdan *et al.* (2011) also reported that additive component had considerable role in the inheritance of plant height in sunflower.

Table 2. Proportional contribution (%) of lines, testers, and their interaction for agronomic and physiological traits.

	SY	NS	SW	HD	PH	LT	RWC
Tester	8.62	5.84	15.70	11.17	15.43	87.34	32.59
Line	49.41	59.96	16.85	59.04	61.06	6.37	26.32
Tester*Line	41.96	34.20	67.44	29.79	23.50	6.28	41.09

SY: Seed yield, NS: Number of seeds per head, SW: Seed weight, HD: Head diameter, PH: Plant height, LT: Leaf temperature, RWC: Relative water content.

Heritability estimates for all traits are shown in Table 3. The results showed relatively high broad sense (h^2_b) and narrow sense heritability (h^2_n) for most characters. Amounts of h^2_n and h^2_b for yield, number of seed per head, 100 seed weight, head diameter, and RWC were 0.60 and 0.86, 0.71 and 0.88, 0.53 and 0.75, 0.76 and 0.87, 0.61 and 0.83, respectively. In a study of 36 sunflower hybrids under stress and well-watered condition by Alza and Fernandez-Martinez (1997) almost similar results were reported for h^2_n. The results demonstrated higher h^2_n for yield components, except for 100 seed weight, as compared with seed yield. Rauf *et al.* (2009), estimated h^2_b separately in the drought and control conditions. Amount of h^2_b for RWC which was reported as 0.91 in the control condition was reduced to 0.65 in the drought condition.

Table 3. Estimates of general combining ability, specific combining ability and additive and dominant variances, broad and narrow sense heritability, and degree of dominance for agronomic and physiological traits from the line × tester analysis in sunflower.

Variance	df	SY	NS	SW	HD	PH	LT	RWC
$\sigma^2_{Testre(T)}$	4	0.09	-	0.01	0.04	8.76	-	1.24
$\sigma^2_{Line(L)}$	5	15.23	5120.21	0.01	0.40	41.06	0.05	0.62
σ^2_{T*L}	20	13.41	2463.01	0.01	0.13	16.57	0.08	1.35
$\sigma^2_{Stress(S)*T}$	8	-	-	-	-	-	-	-
σ^2_{S*L}	10	-	-	-	-	6.55	-	-
σ^2_{S*L*T}	40	-	-	-	-	-	-	-
$\sigma^2_{Year(Y)*T}$	4	-	-	0.01	-	-	5.60	-
σ^2_{Y*L}	5	-	-	0.01	-	-	0.18	-
σ^2_{Y*S*L}	10	-	-	-	-	-	-	-
$\sigma_{Y}{}^{2}{}_{*S*T}$	8	-	-	-	-	-	-	-
σ^2_{Y*R*L}	20	-	-	-	-	-	-	-
$\sigma^2_{Y*S*T*L}$	40	-	-	-	-	-	-	-
Error	348	124.06	31922.23	0.31	2.73	109.00	2.75	19.30
GCA/SCA		1.14	2.08	1.24	3.48	3.01	0.63	1.38
$\sigma^2_{A\ tester}=2\ \sigma^2_{GCA}$		0.19	0.00	0.02	0.08	17.52	0.00	2.49
$\sigma^2_{A\ line}=2\ \sigma^2_{GCA}$		30.45	10240.43	0.02	0.79	82.12	0.10	1.24
$\sigma^2_D= \sigma^2_{SCA}$		13.41	2463.01	0.01	0.13	16.57	0.08	1.35
h^2_n		0.60	0.71	0.53	0.76	0.81	0.30	0.61
h^2_b		0.86	0.88	0.75	0.87	0.95	0.54	0.83
a		0.94	0.69	0.90	0.54	0.57	1.26	0.85

SY: Seed yield, NS: Number of seeds per head, SW: Seed weight, HD: Head diameter, PH: Plant height, LT: Leaf temperature, RWC: Relative water content, GCA/SCA: General combining ability/Specific combining ability, σ^2_A: Additive variance, σ^2_D: Dominant variance, h^2_n: Narrow sense heritability, h^2_b: Broad sense heritability, a: Degree of dominance.

Estimates of degree of dominance for all characters were in the range of incomplete dominance except for leaf temperature which showed an over-dominance type of gene action. However, degree of dominance for some characters such as yield, 100 seed weight, RWC, and leaf temperature were close to unity. This showed that dominance plays an important role in governing the physiological characters under study, in addition to yield and yield components.

General and specific combining ability

As it was indicated earlier, most of the interactions involving water regime and year were not significant. Therefore, GCA and SCA effects were calculated based on the average of years and water regimes. Tables 4 and 5 showed significant GCA effect of lines and testers for nearly all inbred lines. However, GCA effects were not significant for several testers in some characters, especially seed yield. Inbred R50 had the highest positive GCA values for seed yield, number of seed per head, 100 seed weight, head diameter, plant height, and leaf temperature (4.28, 62.31, 0.18, 0.45, 6.47, and 1.49, respectively). Thus R50 had a good genetic potential for yield and yield components and could be utilized in breeding programs. Inbred R26 had the highest GCA for RWC and high negative GCA for leaf temperature. Therefore, it might be used as a source of drought tolerance genes. Although the highest negative leaf temperature belonged to R19, however, R19 had low RWC. Among the lines, inbred A329 had the highest positive GCA values for seed yield and number of seeds per head, head diameter, and plant height but highest negative value for RWC (Table 5). Highest positive GCA values for physiological traits belonged to A344 and A356, but they had negative or non-significant GCA values for yield and yield components. Among the lines, A110 had the highest negative GCA for plant height and relatively high value for seed yield and yield components. This inbred line may be used to produce high yielding hybrids with shorter stature and more proper agronomic characters. According to Angadi and Entz (2002) shorter hybrids are also able to tolerate the drought condition better than the standard hybrids.

Table 4. General combining ability of testers for different traits of sunflower in the line × tester cross combined over three water stress levels and two years.

Testers	SY	NS	SW	HD	PH	LT	RWC
R19	-0.30	-18.17**	0.01	-0.39**	-0.40**	-2.16**	-0.67**
R26	-1.76	-13.60**	-0.21**	-0.20**	-1.51**	-1.07**	1.55**
R46	-1.23	-16.95**	0.00	0.07**	-5.41**	0.05	1.42**
R50	4.28**	62.31**	0.18**	0.45**	6.47**	1.49**	-0.49**
R56	-1.00	-13.60**	0.02	0.07**	0.85**	1.69**	-1.81**
SE	0.17	2.56	0.007	0.021	0.188	0.16	0.062

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

SY: Seed yield, NS: Number of seeds per head, SW: Seed weight, HD: Head diameter, PH: Plant height, LT: Leaf temperature, RWC: Relative water content.

The cross R50 × A329 had highest positive SCA for seed yield, number of seeds per head, and RWC (Table 6). As shown in Tables 4 and 5, the highest GCA for yield and number of seeds per head belonged to R50 and A329. Highest seed yield also belonged to R50 × A329. Thus, this cross has a good potential to be released as a new variety after multi-location testing. Cross R26 × A344 had high SCA (3.55) for RWC. Also R26 and A344 had highest GCA for RWC which were 1.55 and 1.01, respectively.

Discussion

Water stress had significant effect on nearly all traits. But none of the interactions of stress × lines, stress × testers and stress × testers × lines were significant, except for plant height. These results were not in concordance with other studies in sunflower (Fereres *et al.*, 1986; Alza and Fernandez-Martinez, 1997; Rauf *et al.*, 2009). This may have been occurred primarily due to the nature of the genetic materials under investigation and environmental conditions. Genetic variances among lines were larger than those of testers for seed yield, yield components, plant height, and leaf temperature. This reveals lower genetic diversity among testers than lines for these characters and clearly demonstrates that the restorer population needs to be diversified for obtaining superior sunflower genotypes. Low diversity for yield and yield components also has been reported by other researchers (Alza and Fernandez-Martinez, 1997; Ortis *et al.*, 2005; Nooryazdan *et al.*, 2011).

SCAs for line × tester interaction of RWC and leaf temperature were higher than both lines and testers GCAs. Degree of dominance also was 1.24 for leaf temperature and 0.85 for RWC. This reveals that these physiological traits are governed by larger dominance effects. Rauf *et al.* (2009) reported similar results for RWC, leaf water potential, osmotic potential, and osmotic adjustment. This fact may describe some aspects of hybrid vigor in facing environmental stresses and an evidence of potential for producing drought tolerant hybrids in sunflower.

Table 4. General combining ability of lines for different traits of sunflower in the line × tester cross, combined over three water stress levels and two years.

Lines	SY	NS	SW	HD	PH	LT	RWC
A110	2.08**	44.26**	0.13**	0.78**	-10.22**	-0.36**	0.44**
A148	2.81**	27.44**	0.11**	-0.17**	0.37**	-0.50**	0.30**
A222	2.62**	63.47**	-0.17**	0.07**	2.13**	-0.12**	0.32**
A329	3.95**	63.78**	0.05*	0.97**	8.46**	-0.07*	-2.79**
A344	-6.05**	-96.80**	-0.14**	-1.24**	0.84**	0.53**	1.01**
A356	-5.40**	-102.15**	0.02	-0.41**	-1.59**	0.52**	0.72**
SE	0.21	3.07	0.008	0.025	0.22	0.03	0.074

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

SY: Seed yield, NS: Number of seeds per head, SW: Seed weight, HD: Head diameter, PH: Plant height, LT: Leaf temperature, RWC: Relative water content.

Table 5. Specific combining abilities for different traits of sunflower together with seed yield in the line × tester cross combined over three water stress levels and two years.

Cross number	Cross	Seed yield	Specific combining ability						
			SY	NS	SW	HD	PH	LT	RWC
1	R19×A110	48.24	6.41**	113.11**	0.10**	0.99**	10.12**	0.48**	1.29**
2	R19×A148	35.71	-6.85**	-129.70**	-0.80**	-1.94**	-14.25**	-1.28**	-0.75**
3	R19×A222	42.82	0.45	-13.82	0.49**	0.16	3.94**	0.25**	-2.57**
4	R19×A329	35.13	-8.57**	-128.58**	-0.48**	-1.18**	-9.99**	0.62**	-0.95**
5	R19×A344	37.17	3.47**	65.35**	0.34**	0.61**	5.59**	-0.03	-0.43**
6	R19×A356	39.44	5.10**	93.63**	0.35**	1.35**	4.58**	-0.04	3.42**
7	R26×A110	42.84	2.48**	43.01**	0.14**	-0.92**	1.49**	-0.14	-0.16
8	R26×A148	45.54	4.45**	70.73**	0.35**	0.46**	5.04**	0.40**	1.66**
9	R26×A222	35.47	-5.43**	-53.84**	-0.52**	0.21**	-2.57**	-0.24**	0.89**
10	R26×A329	38.71	-3.53**	-43.98**	0.12**	-0.07	-3.61**	0.24**	-4.71**
11	R26×A344	34.68	2.45**	18.85	-0.02	0.86**	-3.80**	-0.08	3.55**
12	R26×A356	32.47	-0.41	-34.77**	-0.07*	-0.56**	3.44**	-0.18	-1.24**
13	R46×A110	32.45	-8.45**	-124.05**	-0.27**	0.06	-8.95**	0.43**	0.52**
14	R46×A148	43.61	1.98**	53.98**	0.10**	0.61**	1.22*	0.07	0.92**
15	R46×A222	49.08	7.64**	101.65**	0.23**	0.41**	-0.12	0.35**	-0.60**
16	R46×A329	41.01	-1.75*	-33.60**	-0.12**	0.06	3.41**	-0.25**	0.68**
17	R46×A344	35.17	2.40**	52.56**	0.32**	-0.37**	5.80**	-0.33**	1.41**
18	R46×A356	31.59	-1.83**	-50.53**	-0.25**	-0.76**	-1.35**	-0.27**	-2.94**
19	R50×A110	44.67	-1.74**	-39.50**	-0.01	-0.26**	-2.94**	-0.19*	-2.83**
20	R50×A148	47.48	0.34**	-0.07	0.15**	0.47**	1.64**	0.44**	-1.71**
21	R50×A222	48.48	1.53**	6.51	0.06	-0.73**	0.25**	0.04	-0.42
22	R50×A329	57.53	9.25**	138.66**	0.25**	0.92**	6.97**	-0.54**	3.71**
23	R50×A344	32.71	-5.56**	-81.94**	-0.28**	-0.38**	-1.95**	0.23**	0.02
24	R50×A356	35.11	-3.81**	-23.66**	-0.18**	-0.01	-3.97**	0.02	1.23**
25	R56×A110	42.44	1.31*	7.44	0.05	0.13**	0.29	-0.59**	1.18**
26	R56×A148	41.93	0.08	5.06	0.20**	0.40**	6.34**	0.38**	-0.12
27	R56×A222	37.48	-4.19**	-40.50**	-0.27**	-0.05	-1.49**	-0.40**	2.70**
28	R56×A329	47.61	4.61**	67.50**	0.23**	0.28**	3.22**	-0.06	1.27**
29	R56×A344	30.23	-2.76**	-54.82**	-0.37**	-0.72**	-5.65**	0.20**	-4.55**
30	R56×A356	34.60	0.96	15.33	0.15**	-0.04	-2.70**	0.47**	-0.47*
	SE	124.06	0.62	9.93	0.03	0.09	0.58	0.09	0.24

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

SY: Seed yield, NS: Number of seeds per head, SW: Seed weight, HD: Head diameter, PH: Plant height, LT: Leaf temperature, RWC: Relative water content.

Estimates of GCA effect for lines and testers showed that R50 was the best general combiner among testers for seed yield, yield components, and plant height. However, the best combiner for physiological characters among testers was R26. Among lines A329 was the best combiner for seed yield and yield components except 100 seed weight. On the other hand A344 was the best combiner for RWC and A148 for leaf temperature. To obtain a superior hybrid in drought condition it would be necessary to produce inbred lines with high combining ability for both yield and physiological traits. Meseka *et al.* (2011) reported that maize inbred lines with high GCA effects for drought tolerance produced drought-tolerant hybrids. Because yield and drought resistance are possibly controlled by separate genetic loci, improved drought tolerance involves the identification and transfer of physiological traits responsible for drought tolerance to high-yielding and agronomically acceptable cultivars (Chiementi *et al.*, 2002). This indicates the possibility of combining better physiologic performance with high yield in inbred lines in order to produce hybrids with high yield and drought resistance ability However, some reports indicated the co-location of QTLs for water status traits and oil percentage as well as for agronomic traits (PoormohammadKiani *et al.*, 2007) and suggest a linkage between genes for plant water status and yield-related traits. In this case, positive combination of the related genes should be selected after crossing over, depending on the closeness of these genes on a chromosome.

Among the lines and testers studied for RWC and leaf temperature, none of the lines or testers was the best general combiner for both traits. However, among testers R26 was the highest general combiner for RWC and relatively high for leaf temperature. The results showed that despite of the existence of genetic variation among the genotypes under study for both RWC and leaf temperature, no line or tester was superior for both traits. It seems that different genotypes have different physiological measures to tolerate the water deficit condition. Thus, in order to produce more drought tolerant hybrids in sunflower,efforts should be made to generate better inbred lines by combining several physiological characters into common genotypes.

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