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Research paper

Combining ability of sunflower (*Helianthus annuus* L.) inbred lines for grain yield and physiological traits under optimum and water-stress conditions

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Abstract

To investigate the combining ability of sunflower (*Helianthus* annuus L.) inbred lines and also the inheritance of several physiological traits of this plant in normal irrigation and water-deficit-stress conditions, eight inbred lines with different drought tolerance were crossed with three cytoplasmic male sterile lines. The resulting 24 hybrids, 11 parents, and a commercial hybrid (Barzghar) as the control were evaluated in a split-plot design based on the randomized complete block design with three replications. Irrigation was applied in the main plots at two levels, normal (irrigation based on 100% water requirement) and stress (irrigation withhold after the appearance of the inflorescence), and 36 sunflower genotypes in subplots. During the growing season, chlorophyll content (Chl), relative water content (RWC), leaf water loss (LWL), early growth rate (EGR), leaf temperature (LT), and grain yield (GY) were measured. The analysis of variance showed the significant effect of water-deficit stress on Chl, RWC, LT, and GY. According to the results of the line × tester analysis, the effect of lines was significant for Chl, LWL, EGR, and GY in normal conditions, and on Chl and EGR in the water-deficit-stress conditions. In the case of the testers, there was a significant difference in Chl, EGR, and GY under normal conditions, and in LWL, EGR, and GY under stress conditions. The significant effect of lines and testers on these traits indicated a difference between their general combining ability (GCA) and the existence of additive gene effects. The interaction of line × tester was significant only for GY in normal conditions. Chl and EGR had a relatively high broad-sense and narrow-sense heritability at both conditions. The GY had also relatively high broad-sense heritability in both conditions but its narrow-sense heritability was only relatively high at the water-deficit-stress conditions. The C122 and C123 lines and the A19 tester had the highest positive GCA for GY in both conditions. The hybrid A196 × C41 in the normal conditions and A112 × C111 in the stress conditions had a positive SCA. Among the physiological traits, only LWL showed a significant correlation with GY in normal conditions. Under water-deficit-stress conditions, LWL and EGR had a positive correlation with GY, while LT showed a negative correlation with GY. In conclusion, it seems that LWL, EGR, and LT can be used to indirectly improve GY of sunflower under water-deficit stress conditions.

Keywords: gene action; heritability; hybrid; line × tester

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Introduction

Although water is the most abundant compound of the earth and is critical to all chemical reactions, its shortage is the most important limiting factor for agricultural production worldwide. Among biotic and abiotic stresses, drought alone accounts for 45 percent of the decline in crop yields in the world (Passioura 1996). Iran is among the dry and semi-arid countries due to its low level of precipitation and the inappropriate distribution of its time and place (Kafi *et al.* 2009). The application of crop improvement methods and the use of drought tolerant varieties allow the optimum use of arid areas and increase the yield and productivity of these areas (Mozaffari *et al.* 1996).

Sunflower is one of the most important oilseed crops in the world, which, produces abundant and high quality oil (Nezami *et al*, 2008). Although it has a high adaptability to various environmental conditions such as drought, this stress reduces its vegetative growth, yield components (number and weight of grain), and ultimately economic yield (Vannozzi *et al.* 1998).

Hybrid cultivars in sunflower are highly popular due to uniformity in agronomic traits such as plant maturity and height, high yields due to adequate heterosis, and resistance to lodging, pests and diseases (Kaya and Atakisi 2004; Rezaeizad and Zaree Siahbidi 2015). It is important to find suitable parents for hybrid cultivars under drought stress conditions. To identify the suitable parents, a set of inbred lines with high general combining ability (GCA) should be improved, and then, attempt to identify the inbred lines with high specific combining ability (SCA) for important traits (Volotovich *et al.* 2008).

Ortis *et al.* (2005) crossed 20 cytoplasmic male sterile inbred lines of sunflower with four testers. Analysis of the results showed that the oil percentage, plant height, and 1000-seeds weight had the highest GCA, indicating the superiority of the additive components of genetic variance for these traits. While in the analysis of line × tester by Göksoy and Turan (2005) the variance of SCA for GY, number of seeds per head, and plant height was highly significant, indicating the importance of dominance gene effects in these traits.

Few studies on combining ability and heritability of physiological traits in sunflower have been carried. Rauf *et al.* (2009) experimented in field and potting conditions and reported non-additive action for genes controlling the relative water content (RWC) under stress condition and estimated the broad-sense heritability of this trait in normal conditions and drought stress as 0.91 and 0.65, respectively. In a two-year study, Mohyaji *et al.* (2014) reported the broad-sense and narrow-sense heritabilities as 0.54 and 0.31, respectively, for the leaf temperature (LT), and as 0.83 and 0.61, respectively, for the RWC. On a genetic analysis of the physiological traits of sunflower in normal and drought stress condition, Pourmohammad *et al.* (2014) reported that under normal irrigation and mild drought stress conditions, LT, RWC, chlorophyll content (Chl), and proline content are controlled by additive genes. In the severe drought-stress conditions, LT and proline content were controlled by additive effects and Chl and RWC were controlled by both additive and dominance effects. In studying different physiological traits under normal and stress conditions in a pot experiment, Ghaffari *et al.* (2012) reported that leaf area, LT, Chl, and chlorophyll fluorescence can be used as efficient physiological traits for selecting sunflower drought tolerant lines.

The present study was carried out to investigate the combining ability and heritability of several physiological traits and GY of sunflower under both normal and water stress conditions.

Materials and Methods

This research was carried out in Bastam Agricultural Research Station located 3 km from Shahrood, Iran, latitude 36°28'N, longitude 54°58'E, and altitude 1360 m. According to the long-term meteorological data, the minimum, average, and maximum annual temperatures were 8.7, 14.7, and 20.6 degrees Celsius, respectively, and the average annual precipitation in this region was 152 mm. This station is classified as a dry and semi-arid climate in the climate zone. The soil of this area is loamy with a pH of 7.9 and EC of 1.4 ds/m.

In 2013, 20 sunflower lines were evaluated under drought stress and normal conditions. Based on yield and yield components, as well as some physiological traits, eight lines that showed different drought stress tolerance were selected for further hybridization (Abedini Esfahlani 2018). In 2014, 24 hybrids from crossing eight inbred lines with three cytoplasmic male sterile lines, along with 11 parents and Barzghar hybrid as the control were evaluated in a split-plot design based on a randomized complete block design with three replications. The main plots were allocated to the irrigation factor and 36 sunflower genotypes were located in subplots. The irrigation factor had two levels: irrigation based on 100% water requirement (normal) and irrigation withhold after appearance of the inflorescence (stress). Each genotype was sown in four rows of five-meter long with plant to plant distance of 25 cm and row distance of 60 cm. Estimation of water requirement was performed according to different parameters using the OPTIWAT software (Alizadeh and Kamali 2008) based on FAO Penman-Monteith method and the amount of water was measured using volumetric flow meter. In this study, the surface drip (tape) irrigation method was used, with drip emitters spaced at 20 cm and a discharge of 1.6 Lha^{-1}. During the experiment, five physiological traits, Chl, RWC, LT, leaf water loss (LWL), and early growth rate (EGR) were measured. Also, GY was determined at harvest as kilograms per hectare. Samplings were made from two middle lines in each plot with the removal of two plants from the beginning and the end of each line.

Chl was measured using chlorophyll meter (SPAD-502, Minolta, Japan) on five upper leaves at the end of flowering stage.

RWC was calculated by the following formula (Morant-Manceau *et al.* 2004):

$$RWC= [(FW-DW)/ (TW-DW)] \times 100$$

Where, FW is the fresh weight of the leaves, DW is the dry weight of the leaves that were dried for 24 hours at 75° C, and TW is the leaf turgidity weight after 24 hours of immersion in distilled water in dark at room temperature. For this purpose, leaf samples were taken from the upper leaves at the end of flowering stage at 8-9 am and placed inside the plastic bags, then, transferred to the laboratory inside the ice. At first, three leaf discs from each leaf, each with an area of one centimeter square, were prepared and weighed immediately as FW. The leaf disks were placed in the distilled water for 24 hours at room temperature in the dark. The following day, their surface water was dried slowly, and their turgidity weight was measured. Then, the leaf disks were placed in the oven at 75° C for 24 hours and their weigh was measured. At last, RWC was calculated based on the above relationship.

To measure LWL, five leaves were randomly cut from each plot and immediately transferred to the laboratory in a plastic bag inside ice and then weighed as FW. The samples were kept at the laboratory temperature for three hours to reach the wilted weight (WW). LWL was calculated using the following formula (Xing *et al.* 2004):

$$LWL= (FW-WW)/FW \times 100$$

To determine EGR, the height of five plants per plot was measured two and four weeks after planting. The difference in height at this period was a reflection of EGR. This trait was measured using the following formula (Veisi-Mal-Amiri *et al.* 2009):

$$EGR = (H_2-H_1)/(t_2-t_1)$$

In this formula, H_1 and H_2 refer to plant height at two and four weeks after planting, respectively, and t_1 and t_2 are the plant height measurement time.

LT was measured using an infrared thermometer on 10 random leaves per plot at the end of flowering stage at noon (between 12 and 14).

Analysis of line × tester was carried out using the method used by Kempthorne (1957). Statistical analysis was performed using EXCEL and SPSS software.

Results and Discussion

Analysis of variance of measured traits for 36 sunflower genotypes showed the significant effect of water-deficit stress for Chl, RWC, LT, and GY (Table 1). Also, significant differences were observed among genotypes for all traits. The genotype × stress interaction was only significant for Chl, LWL, LT, and GY. The significance of the interaction for a trait means that the differences among genotypes were not similar in normal and water-deficit stress conditions. Alavi *et al.* (2014) and Arefi *et al.* (2015) also reported significant genotype × stress interaction for several traits in sunflower.

The broad sense heritability of Chl and GY under normal conditions was higher than water-deficit stress conditions (Table 2), which was due to larger genotypic differences under normal growth conditions (Alza and Fernandez-Martinez 1997).

For Chl, both line and tester effects were significant under normal irrigation conditions, but only line effect was significant under stress conditions, and the effect of line × tester was not significant in any of the conditions (Table 2). Therefore, it can be stated that the additive effects play an important role in controlling this trait. The narrow sense heritability for Chl was calculated to be 0.65 and 0.60 in normal and stress conditions, respectively. Pourmohammad *et al.* (2014) also reported the role of additive effects of genes in controlling of this trait under normal and water-stress conditions.

Under normal irrigation conditions, line effects and under stress conditions, tester effects were significant for LWL (Table 2). So, the role of additive effects of genes is important in this trait. Dhannda and Sethi (1998) by examining diallel crosses in wheat showed that the additive effect of genes played a major role in the inheritance of LWL. Narrow-sense heritability of this trait was estimated 0.39 and 0.37 in normal and stress conditions, respectively.

The general combining ability of lines and testers was significant for EGR, indicating the role of the additive effects in controlling this trait. The lack of significance of the line × tester interaction implies that non-additive effects do not play a vital role in controlling EGR. Narrow-sense heritability for this trait was estimated to be 69.8 and 76.0 in normal and stress conditions, respectively.

The mean squares of lines, testers, and line × tester interaction were not significant for RWC and LT. Therefore, it can be stated that the general and specific combining ability of lines and testers were

Table 1. Analysis of variance in sunflower for chlorophyll content (Chl), relative water content (RWC), leaf water loss (LWL), early growth rate (EGR), leaf temperature (LT), and grain yield (GY) under normal and water-deficit stress conditions

Source of variation	df	Mean squares					
		Chl	RWC	LWL	EGR	LT	GY
Replication	2	9.53	192.62	55.67	15.50	4.54	6833074
Stress (A)	1	941.67*	7361.67*	1631.85	11.34	13881.66**	330328999**
Error a	2	11.28	101.55	129.04	1.71	99.58	1797351
Genotype (B)	35	51.42**	89.58**	20.59**	2.39**	37.02**	2123427**
A × B	35	4.45**	23.18	8.18*	0.06	15.44**	630046**
Error b	140	2.43	20.70	5.25	0.07	9.16	179770
CV (%)		3.99	7.14	15.41	10.58	14.11	17.10

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

Table 2. Line × tester analysis of variance in sunflower for chlorophyll content (Chl), relative water content (RWC), leaf water losses (LWL), early growth rate (EGR), leaf temperature (LT), and grain yield (GY) under non-stress (NS) and water-deficit stress (S) conditions, and the estimates of broad-sense (h^2b) and narrow-sense (h^2n) heritability

Source of variation	df	Mean squares					
		Chl		RWC		LWL	
		NS	S	NS	S	NS	S
Replication	2	9.64*	11.03*	175.32**	113.48*	179.15**	8.96*
Genotypes	34	32.81**	23.75**	47.57**	67.16**	19.24**	8.80**
Parents (P)	10	44.04**	37.48**	48.65**	23.52	29.30**	15.08**
P vs. C	1	398.06**	302.85**	598.84**	1537.00**	65.86**	40.58**
Crosses (C)	23	12.05**	5.65**	23.13	22.23	12.83	4.69*
Lines (L)	7	23.93**	15.23**	26.15	13.53	25.12**	4.12
Testers (T)	2	24.68**	0.61	50.00	36.86	9.83	19.17**
L × T	14	4.30	1.57	17.78	24.49	7.12	2.90
Error	68	2.57	2.34	18.87	23.36	7.92	2.72
h^2_b		0.79	0.60	-	-	0.39	0.42
h^2_n		0.65	0.60	-	-	0.39	0.37

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

Table 2 continued

Source of variation	df	Mean Squares					
		EGR		LT		GY	
		NS	S	NS	S	NS	S
Replication	2	13.57**	3.46**	59.76**	42.02*	7671669**	855269**
Genotypes	34	1.58**	0.92**	6.84	45.32**	2366543**	414244**
Parents (P)	10	0.35**	0.28**	2.81**	17.85	1169395**	631972**
P vs. C	1	42.14**	24.60**	84.00**	1183.79**	45818689**	2800489**
Crosses (C)	23	0.36**	0.17**	5.24	7.77	997818**	215830**
Lines (L)	7	0.41**	0.21**	3.90	8.23	1107066**	119997
Testers (T)	2	1.94**	0.90**	26.98	12.36	2672145**	1525610**
L × T	14	0.10	0.04	2.81	6.88	704004**	76634
Error	68	0.10	0.03	8.45	9.22	293440	74909
h^2_b		0.77	0.79	-	-	0.74	0.64
h^2_n		0.70	0.76	-	-	0.38	0.63

*, **: Significant at the 0.05 and 0.01 probability levels, respectively not significant for these traits.

In the normal irrigation conditions, the mean square of lines, testers, and line × tester interaction and in the stress conditions, the effect of tester on grain yield were significant (Table 2). Therefore, under normal irrigation conditions, there was a significant difference between the GCA of lines and testers and their SCA, while in the stress conditions, there was a significant difference only in GCA of the testers. The broad sense heritability of grain yield in normal and stress conditions were 0.74 and 0.64, respectively, and narrow sense heritability was estimated to be 0.38 in non-stress conditions. The decrease in heritability of grain yield under stress conditions compared to normal condition is consistent with the results of Saremi-Rad and Mostafavi (2020) and Gholinezhad and Darvishzadeh (2018). The existence of dominance effects in controlling this trait in normal conditions is consistent with the results of Göksoy *et al.* (2001), Jan *et al.* (2005), Karasu *et al.* (2010), Ghaffari *et al.* (2011), Rezaiezd and Zarei Siahbidi (2015), and Memon *et al.* (2015). Pourmohammad *et al.* (2014) reported that under normal conditions, the additive effects of genes played the most important role in explaining grain yield of sunflower, while in severe stress conditions, dominance effects played a greater role. Due to the greater share of dominance effects in controlling GY in normal conditions, producing hybrid cultivars is justifiable for sunflower.

The GCA values of lines and testers for different traits are given in Table 3. The C111, LR32, and LR59 lines under normal irrigation conditions, and R217 and LR59 under stress conditions, had a positive GCA for Chl, while among the testers, A196 had the highest positive GCA.

The reduction in RWC of the leaves, indicates decreased turgidity in the plant cells and reduced growth (Yousefi *et al.* 2016; Sarvari *et al.* 2017). Regarding the desirability of the positive values for RWC, the lines C123 and R217 had the highest positive GCA values under normal and stress conditions, respectively. In the case of testers, A196 and A19 had the highest values in normal and stress conditions, respectively.

In the case of LWL, the line R217 and the tester A19, had positive GCA in normal and stress conditions, respectively.

The R217 line had a positive GCA at both normal and stress conditions for EGR, and among the testers, A19 had the highest value.

Cultivars with less canopy temperatures will be more tolerant to drought stress (Alza and Fernandez-Martinez 1997). Therefore, the negative values of LT will be desirable. Although the mean squares of lines, testers, and line × tester interaction were not significant for LT (Table 2), estimation of GCA values of lines and testers (Table 3) showed that, the line C123 and the tester A196 in the normal conditions, and the line C122 and the tester A19 under stress condition had the highest GCA values.

In the case of the grain yield, the lines C122 and C123 and the tester A19 at both conditions had the highest positive GCA. The superiority of A19 as a good tester has also been reported by Khani *et al.* (2005) and Arefi *et al.* (2015).

As seen in the Table 2, the line × tester

Table 3. General combining ability of lines and testers in sunflower for chlorophyll content (Chl), relative water content (RWC), leaf water loss (LWL), early growth rate (EGR), leaf temperature (T), and grain yield (GY) under non-stress (NS) and water-deficit-stress (S) conditions

Lines/testers	Chl		RWC		LWL	
	NS	S	NS	S	NS	S
R217	0.36	1.84^{**}	1.57	2.01	2.14^{*}	0.62
C41	-0.80	-0.99	0.94	1.36	0.46	-0.06
C111	1.96^{**}	0.65	-0.62	-0.07	0.32	1.02
C122	-0.89	0.37	-2.53	-1.60	1.09	0.09
C123	-0.64	0.84	2.22	-0.37	0.88	-0.24
C148	-2.92^{**}	2.10^{**}	1.19	0.05	0.13	-0.56
LR32	1.52^{**}	0.62	-1.54	-1.38	-2.66^{**}	-1.14
LR59	1.40^{**}	1.19^{*}	-1.24	0.00	-2.37^{*}	0.27
SE(GCA)	0.53	0.51	1.45	1.61	0.94	0.55
SE(GCAi-GCAj)	0.76	0.72	2.05	2.28	1.33	0.78
A112	-1.16^{**}	0.13	-1.13	-0.69	-0.60	-0.63
A19	0.44	0.05	-0.023	1.43	0.67	1.02^{**}
A196	0.72^{*}	-0.18	1.55	-0.74	-0.07	-0.40
SE(GCA)	0.33	0.31	0.89	0.99	0.57	0.34
SE(GCAi-GCAj)	0.46	0.44	1.25	1.39	0.81	0.48

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

Table 3 continued

Lines/Testers	EGR		LT		GY	
	NS	S	NS	S	NS	S
R217	0.23^{*}	0.19^{**}	-0.32	0.37	-134.2	63.59
C41	-0.22^{*}	-0.05	-0.20	1.46	215.68	-14.61
C111	0.00	-0.02	-0.11	-1.05	-134.92	66.00
C122	0.20	0.15^{*}	0.05	-1.52	355.43	85.79
C123	-0.28^{*}	-0.22^{**}	-0.62	-0.21	345.43	81.48
C148	-0.19	-0.21^{**}	-0.75	-0.19	294.53	39.21
LR32	0.00	0.07	0.88	0.62	-437.34^{*}	-67.14
LR59	0.26^{*}	0.09	1.08	0.52	-504.62^{**}	-254.31^{**}
SE(GCA)	0.11	0.06	0.97	1.01	180.57	91.23
SE(GCAi-GCAj)	0.15	0.09	1.37	1.43	255.36	129.02
A112	-0.14^{*}	-0.10^{**}	0.98	0.36	21.49	-117.90^{*}
A19	0.33^{**}	0.022^{**}	0.15	-0.83	322.41^{**}	289.48^{**}
A196	-0.18^{**}	-0.12^{**}	-1.13	0.47	-343.90^{**}	-171.58^{**}
SE(GCA)	0.06	0.04	0.59	0.62	110.57	55.87
SE(GCAi-GCAj)	0.09	0.05	0.84	0.88	156.38	79.01

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

interaction was not significant for five physiological traits. Therefore, the SCA for physiological traits were not estimated. Estimation of SCA for grain yield (Table 4) showed that the hybrid A196×C41 under normal conditions and A112×C111 under stress conditions, had a positive specific combining ability, and were identified as suitable hybrids.

In the crop improvement programs, selection for a trait regardless of other traits may not have favorable results. Therefore, the knowledge on correlations among traits are needed (Bhatt 1973).

Table 4. Specific combining ability of the line × tester crosses in sunflower for grain yield under non-stress (NS) and water-deficit-stress (S) conditions

Crosses	A112		A19		A196	
	NS	S	NS	S	NS	S
R217	-214.48	-106.52	-10.57	173.40	225.04	-66.88
C41	288.28	-185.99	-1038.25**	-38.40	749.97*	224.39
C111	228.38	316.50*	67.79	-24.88	-296.17	-291.63
C122	-372.21	3.94	402.10	17.80	-29.89	-21.75
C123	-46.61	5.02	258.17	-77.89	-211.56	72.86
C148	-208.21	-105.01	-91.00	55.05	299.21	49.96
LR32	64.47	12.71	-31.12	-30.50	-33.34	17.79
LR59	260.38	59.34	442.89	-74.60	-703.27*	15.25
SE(SCA)	312.752	158.018				
SE(SCA_{ij}-SCA_{kl})	442.298	223.471				

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

Among the physiological traits, only LWL showed significant correlation with the grain yield under normal conditions (Table 5). Under the stress conditions, LWL and EGR had a positive correlation with GY, while LT showed a negative correlation with GY. The negative correlation coefficient of LT with GY under stress conditions was also reported by Ghaffari *et al.* (2012) and Pourmohammad *et al.* (2014). Lack of significant relationship between grain yield and Chl content in both irrigation conditions is consistent with Gholinezhad *et al.* (2013). According to the results of our study, LWL, EGR, and LT may be used as efficient physiological traits for selecting drought tolerant genotypes.

Conclusions

Considering the results obtained about the general and specific combining ability and heritability of the studied traits, it can be concluded that it is possible to improve the physiological traits such as LWL, EGR, and LT, which showed a significant correlation with GY, to indirectly improve GY of sunflower under stress conditions.

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Table 5. Correlation coefficients among chlorophyll content (Chl), relative water content (RWC), leaf water losses (LWL), early growth rate (EGR), leaf temperature (LT), and grain yield (GY) under non-stress (above diagonal) and water-deficit stress (below diagonal) conditions in sunflower

Trait	Chl	RWC	LWL	EGR	LT	GY
Chl	1.00	0.03	-0.12	0.39	0.02	-0.25
RWC	0.14	1.00	0.41*	-0.14	-0.60*	-0.01
LWL	0.25	0.56**	1.00	0.20	-0.31	0.57**
EGR	0.47	0.28	0.41*	1.00	0.17	0.13
LT	-0.08	-0.11	-0.37	-0.18	1.00	0.10
GY	-0.12	0.37	0.53**	0.50*	-0.54**	1.00

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

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ترکیب پذیری عملکرد دانه و برخی صفات فیزیولوژیک لاین‌های اینبرد آفتابگردان (*Helianthus annuus* L.) در شرایط آبیاری معمول و تنش کم‌آبی

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چکیده

به منظور بررسی ترکیب‌پذیری لاین‌های اینبرد آفتابگردان در شرایط آبیاری معمول و تنش کم‌آبی و نیز وراثت برخی از صفات فیزیولوژیکی در این گیاه، هشت لاین اینبرد با تحمل به تنش متفاوت با سه لاین نر عقیم تلاقی داده شدند. ۲۴ هیبرید حاصل به همراه ۱۱ والد و یک هیبرید تجاری به نام برزگر به عنوان شاهد در یک طرح کرت‌های خرد شده در قالب طرح بلوک‌های کامل تصادفی در سه تکرار مورد ارزیابی قرار گرفتند. فاکتور آبیاری در کرت‌های اصلی در دو سطح نرمال (آبیاری بر اساس ۱۰۰ درصد نیاز آبی) و تنش (قطع آبیاری از مرحله ظهور گل آذین) و ۳۶ ژنوتیپ آفتابگردان در کرت‌های فرعی قرار گرفتند. در فصل رشد صفات شاخص کلروفیل، محتوای آب نسبی، تلفات آب برگ، سرعت رشد اولیه، دمای برگ و عملکرد دانه اندازه‌گیری شدند. تجزیه واریانس صفات بیانگر اثر معنی‌دار تنش کم‌آبی روی شاخص کلروفیل، محتوای آب نسبی، دمای برگ و عملکرد دانه بود. با توجه به نتایج تجزیه لاین × تستر، اثر لاین‌ها در شرایط نرمال از نظر شاخص کلروفیل، تلفات آب برگ، سرعت رشد اولیه و عملکرد دانه و در شرایط تنش آبی از نظر شاخص کلروفیل و سرعت رشد اولیه معنی‌دار بود. در مورد تسترها نیز از لحاظ شاخص کلروفیل، سرعت رشد اولیه و عملکرد دانه در شرایط نرمال و از لحاظ تلفات آب برگ، سرعت رشد اولیه و عملکرد دانه در شرایط تنش کم‌آبی اختلاف معنی‌دار وجود داشت. معنی‌دار بودن اثر لاین‌ها و تسترها در مورد این صفات نشان دهنده تفاوت بین ترکیب‌پذیری عمومی آن‌ها و وجود اثر افزایشی ژن‌ها بود. اثر متقابل لاین × تستر فقط در شرایط نرمال در مورد صفت عملکرد دانه معنی‌دار بود. شاخص کلروفیل و سرعت رشد اولیه از وراثت پذیری عمومی نسبتاً بالایی در هر دو شرایط آبیاری برخوردار بودند. عملکرد دانه نیز دارای وراثت پذیری عمومی نسبتا بالا در هر دو شرایط بود ولی وراثت پذیری خصوصی آن تنها در شرایط تنش کم‌آبی نسبتا بالا بود. برآورد اثرات ترکیب پذیری عمومی نشان داد که لاین‌های C122 و C123 و تستر A19 در هر دو شرایط دارای بیشترین مقدار مثبت ترکیب‌پذیری عمومی از لحاظ عملکرد دانه بودند. هیبرید C41 × A196 در شرایط نرمال و هیبرید C111 × A112 در شرایط تنش کم‌آبی دارای ترکیب‌پذیری خصوصی مثبت معنی‌داری بودند. از بین صفات فیزیولوژیکی مورد بررسی در شرایط نرمال فقط صفت تلفات آب برگ با عملکرد همبستگی معنی‌داری را نشان داد. در شرایط تنش کم‌آبی، تلفات آب برگ و سرعت رشد اولیه همبستگی مثبت معنی‌داری با عملکرد دانه داشتند در حالی که دمای برگ با عملکرد دانه همبستگی منفی نشان داد. در نتیجه، به نظر می رسد که از تلفات آب برگ، سرعت رشد اولیه و دمای برگ می‌توان برای بهبود غیرمستقیم عملکرد دانه آفتابگردان تحت شرایط تنش کمبود آب استفاده کرد.

واژه‌های کلیدی: اثر ژن؛ لاین × تستر؛ وراثت پذیری؛ هیبرید