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GENETIC ANALYSIS OF YIELD AND YIELD RELATED TRAITS IN SUNFLOWER (*Helianthus annuus* L.) UNDER WELL-WATERED AND WATER-STRESSED CONDITIONS

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Drought stress is one of the factors which influence sunflower (*Helianthus annuus* L.) production. Breeding for tolerance to drought stress has become a major focus. In the present investigation, combining ability, gene action and genetic analysis of several characteristics were studied in six pure lines of sunflower and their 15 hybrids. The materials were evaluated in two separate experiments using a randomized complete block design (RCBD) with three replications in two states (well-watered and water-stressed) under controlled conditions. Comparison of mean values exhibited that under water-stressed condition the average performance of sunflower genotypes were decreased for all studied traits. In well-watered condition the highest value for seed yield per plant (SY) was observed in the cross 'LR4×LR25', whereas in water-stressed condition the highest value for this trait was observed in the hybrid 'C104×LR25'. Combining ability analysis revealed that most of agronomical traits such as head diameter, number of achene per head, head weight and seed yield inherited differently in stressed and non-stressed conditions. In water-stressed conditions, the non-additive effects played a more important role for controlling the number of achene per head (NA), seed yield per plant (SY), head diameter (HD), and days from flowering to physiological maturity (DFM) than additive. Based on results yield improvement for water-

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stressed conditions requires selection under drought conditions. In well-watered condition, the cross 'LR4×C10' showed the best SCA value for seed yield per plant (SY). In water-stressed conditions, 'RHA266×C100' had the highest SCA for seed yield per plant (SY) and number of achene (NA) per head.

Key words: additive effects, combined analysis of experiments, drought stress, diallel analysis, relative water content, recombinant inbred lines.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the most important oil crops and due to its high content of unsaturated fatty acids and a lack of cholesterol, the oil benefits from a desirable quality (RAZI and ASSAD, 1999). It is a diploid plant with an estimated haploid genome size of about 3,000 Mb and 2n =2x = 34 chromosomes (ARUMUGANATHAN and EARLE, 1991).

Drought is the main environmental constraint, which occurs in many parts of the world every year, often having devastating effects on crop productivity. Sunflower is potentially drought tolerant plant because of well developed root system. However, its cultivation area and production is greatly affected by drought stress. According to FLAGELLA *et al.* (2002) flower bud formation and appearance stage (R_1) and other flowering stages are critical in drought stress of sunflower. Drought stress at flowering stage was also observed to be a limiting factor for seed filling, in which significant reduction of filled seeds occurs as a result of drought.

NEZAMI *et al.* (2008) showed that plant height, biological yield, stem and head diameter, seed number per head and 1000-achene weight are declined under dried and semi-dried conditions. RAZI and ASSAD (1999) reported that irrigation of sunflower plants leads to increase days to physiological maturity, head diameter, number of leaves per plant, plant height, 1000-achene weight, seed yield and harvest index. ANDRIA *et al.* (1995) showed that yield components of sunflower were affected by irrigation treatments. In their experiment, two or three times irrigations during growing season produced higher seed yield compared to non-irrigation conditions. ANDERSON and BEHBOUDIAN (2004) indicated that drought stress will decrease the head diameter of sunflower. According to DANESHIAN *et al.* (2005), the 1000-achene weight decreased due to drought stress.

Relative water content (RWC) is a trait most commonly used to assess plant water status (TEZARA *et al.,* 2002). Decreased RWC inhibits photosynthesis capacity of sunflower (TEZARA *et al.,* 2002). Different levels of water stress treatments decrease RWC, resulting in progressive and significant decline in stomatal conductance and net photosynthesis rate (TEZARA *et al.,* 2002).

Breeding for drought tolerance is becoming a more and more important challenge in crop plants, notably in sunflower (RAUF, 2008; GRIEU *et al.,* 2008; VINCOURT, 2010). The drought tolerant cultivars can be successfully grown in many dry regions. The breeding process normally encompasses the characterization of the basic breeding materials for performance under well-watered and water-stressed conditions. Drought tolerance is not a simple character but is mostly conditioned by many interacting components which may different among crops, especially in relation to intensity and duration and even type of water deficit. Moreover, most agronomical traits inherit differently in normal and stressed conditions (HITTALMANI *et al.,* 2003). The plant breeders are continuously trying to improve sunflower yield through changing the various plant traits. Understanding of traits inheritance under well-watered and water-stressed conditions will help to design the effective breeding programs. The diallel cross analysis is an efficient instrument in the genetic analysis of complex traits. This study aimed to determine combining abilities for seed yield and related traits as well as sunflower's water status under well-watered and water-stressed conditions.

MATERIALS AND METHODS

Plant materials

Five sunflower recombinant inbred lines (RILs) including 'C104', 'LR25', 'LR4', 'C100', 'LR55' and their paternal line 'RHA266' were selected on the basis of their contrasting responses to water stress and different agronomical characteristics revealed in previous experiments (POORMOHAMMAD KIANI *et al.,* 2007a; 2007b; 2008; 2009). The characteristics of selected sunflower lines were summarized in Table 1. These RILs are F_9 pure lines which were developed through single seed descent (SSD) from F_2 plants derived from a cross 'PAC2 × RHA266'. 'RHA266' was obtained from a cross between *Helianthus annuus* and *peredovik* by USDA and 'PAC2' (developed by INRA-France) is an inbred line from a cross between *H. petiolaris* and 'HA61' (POORMOHAMMAD KIANI *et al.,* 2007a). This public RILs population has been widely used for genetic analysis of complex traits in sunflower (RACHID AL-CHAARANI *et al.,* 2004, 2005; POORMOHAMMAD KIANI *et al.,* 2007a, 2007b, 2008, 2009; DARVISHZADEH *et al.,* 2007; ABOU AL FADIL *et al.,* 2007; DAVAR *et al.,* 2010; 2011). The six selected genotypes ('C104', 'LR25', 'LR4', 'C100', 'LR55' and 'RHA266') were grown and crossed in a diallel mating system without reciprocals to produce 15 F_1 hybrid combinations. The parental genotypes and their F_1 hybrids (21 genotypes) were grown in the greenhouse under controlled conditions.

Table 1. Sunflower lines and their characteristics.

Sunflower line	Type	Origin	Characteristics (POORMOHAMMAD KIANI *et al.,* 2007a, 2007b, 2008, 2009)
C104	RIL	France	Good water status and osmotic adjustment as well as biomass and yield under water-stressed conditions
LR25	RIL	France	Good water status and osmotic adjustment as well as biomass under water stress conditions but it lost grain weight under water-stressed conditions
LR4	RIL	France	Average water status and osmotic adjustment as well as biomass and yield under water-stressed conditions
C100	RIL	France	Good water status and osmotic adjustment but very low in yield under both well-watered and water-stressed conditions
LR55	RIL	France	The lowest water status traits and osmotic adjustment as well as biomass and yield under water-stressed conditions
RHA266	BL	USA	Low water status traits and osmotic adjustment and average biomass and yield under water-stressed conditions

BL is breeder’s line; RIL is recombinant inbred line.

Experimental design

Plants were individually grown in plastic pots containing a mixture of 40% soil, 40% compost and 20% sand as described by POORMOHAMMAD KIANI *et al.* (2007a, b). Temperature was maintained at 25/18 ± 2 ºC (day/night) and relative humidity at about 65/85 ± 5%. The supplementary light was provided to obtain 16h light period. Twenty-one genotypes including 15 F_1 hybrids plus 6 parental lines were evaluated in well-watered and water-stressed conditions, separately. In each condition, the genotypes were evaluated using a randomized complete block design with three replications. In order to simulate natural water deficit conditions (similar to field) a progressive water stress from mild to severe stress was imposed on 45-day-old plants at stage near flower bud formation (R_1) for a period of 12 days (POORMOHAMMAD KIANI *et al.,* 2007a, b). Both well-watered and water-stressed plants were weighted and water loss replaced carefully. Well-watered plants (control) received sufficient water to maintain soil water content close to field capacity. Water-stressed plants were subjected to a progressive water stress and irrigated with a water volume of 60%, 50% and 40% of field capacity (each for 4 days) during 12 first days and then, they were irrigated with a water volume of 40% of field capacity up to harvest.

Trait measurements

Data were collected in each replication under both well-watered and water-stressed conditions. The measured traits were sowing to flowering (DSF), days from flowering to physiological maturity (DFM), plant height (PH), head diameter (HD) and leaf number (LN). Plants were harvested at maturity stage, and then the 100-achene weight (100 AW), seed yield per plant (SY), aerial part dry weight (APDW) and head weight (HW) was recorded according to ABDI *et al.* (2012). Relative water content (RWC) was determined on upper most fully expanded leaves as RWC=(FW-DW)/(TW-DW), where: FW is fresh weight and TW is turgid weight after 24h of rehydration at 4°C in dark room by placing the leaf samples in a container of distilled water. DW is dry weight after oven drying for 24h at 80°C. The greenness of the upper most fully expanded leaves was determined as an indicator of total chlorophyll content using a portable chlorophyll meter (SPAD-502; Soil-Plant Analysis Development Section, Minolta Camera, Osaka, Japan) as SPAD values.

Statistical analysis

Analysis of variance was performed using the general linear model (GLM) procedure in the SAS version 9.1 software (SAS Institute Inc, NC, USA). Diallel analyses were conducted according to Griffing's method 2 and model 1 (GRIFFING, 1956) using the SAS program for Griffing's diallel analysis (ZHANG *et al.,* 2005). The statistical model is as following:

$$Y_{ij} = \mu + \square_i + \square_j + S_{ij} + e_{ij}$$

where: μ = general mean effect; $\square_i$ ($\square_j$) = general combining ability (GCA) of the i^{th} (j^{th}) parent; S_{ij} = specific combining ability (SCA) of the cross between the i^{th} and j^{th} parent; and e_{ij} = residual. The hypothesis that GCA estimates of the parents equaled zero was tested by a two-tailed t-test.

RESULTS AND DISCUSSION

Combined analysis of variance

Combined analysis of variance revealed significant difference among genotypes for all studied traits (Table 2).

Table 2. Mean squares of agro-morphological traits in six lines and 15 F1 hybrids under two water treatment conditions.

Source of variation	df	MS			df	MS		df	MS	df	MS
		HD	HW	APDW		SY	NA		LN		PH
Environment	1	138.34*	1.66**	1691.63**	1	2.39**	71.60^{ns}	1	49.33^{ns}	1	30220.42^{ns}
Replication (Environment)	4	8.64	0.01	3.58	4	0.09	15.27	4	22.02	4	308.56
Genotype	20	2.08**	0.03**	25.84**	20	0.12**	18.24**	20	21.97**	20	563.65**
Genotype × Environment	20	1.01^{ns}	0.01^{ns}	10.56^{ns}	20	0.04^{ns}	5.63^{ns}	20	11.15*	20	235.88^{ns}
Residual	71	0.93	0.01	7.34	70	0.04	5.95	68	5.19	69	240.70
GE effect sliced by E for G											
Well-watered	20	-	-	-		-	-		15.48**		-
Water-stressed	20	-	-	-		-	-		17.18**		-
CV		16.56	10.21	23.31		16.82	23.63		1.90		12.04

HD: head diameter; HW: head weight; APDW: aerial part dry weight; SY: seed yield per plant; NA: number of achene per head; LN: leaf number; PH: plant height. *df* = degrees of freedom; MS= mean of squares. * and **: significant at 0.05 and 0.01 probability level, respectively; ns: not significant at 0.05 probability level.

Table 2. Continued

Source of variation	df	MS		df	MS	df	MS
		DFS	CC		RWC		DFM
Environment	1	0.0003^{ns}	0.07**	1	16206.88**	1	181.71^{ns}
Replication (Environment)	4	0.001**	0.04	4	64.30	4	31.08
Genotype	20	0.0006**	0.01**	20	62.40*	20	51.72**
Genotype × Environment	20	0.0002^{ns}	0.002^{ns}	20	101.32**	20	14.31^{ns}
Residual	76	0.0002	0.002	75	33.75	73	15.69
GE effect sliced by E for G							
Well-watered	20	-	-	20	34.95^{ns}		-
Water-stressed	20	-	-	20	129.30**		-
CV		0.78	4.40		8.44		2.93

DFS: days from sowing to flowering; CC: chlorophyll content; RWC: relative water content; DFM: days from flowering to physiological maturity

Effect of different water treatments was observed on some studied traits such as head diameter (HD), head weight (HW), aerial part dry weight (APDW), seed yield per plant (SY), chlorophyll content (CC) and relative water content (RWC). Effect of water treatment × genotype interaction was observed only for number of leaf (LN) and relative water content

(RWC) traits, in which the response to water status by a given genotype varies among water treatments. Dissection of water treatment × genotype interaction effects revealed that there are significant differences among studied genotypes in leaf number (LN) in both well-watered and water-stressed conditions. In contrast, there are significant differences among genotypes in relative water content (RWC) only in water-stressed conditions. Maintenance of relative water content (RWC) is known to contribute the drought tolerance in sunflower (CHIMENTI *et al.,* 2002; POORMOHAMMAD KIANI *et al.,* 2007a).

The experimental coefficient of variation (CV) varied from 0.78 to 23.63. In general, CV value lower than 20% is considered to be reliable, indicating the accuracy of conducted experiments. The CV value higher than 20% is considered to be high; however, it can be possible to ignore from approximately high CV value when F test is significant and this item has been considered in several published research works (XU *et al.,* 2000; ALIYU and AWOPETU, 2005; ZAREI *et al.,* 2007; OKWUAGWU *et al.,* 2008; KANDIC *et al.,* 2009; SABU *et al.,* 2009).

A vast range of variation was observed among genotypes for the studied traits in both well-watered and water-stressed conditions. The mean comparisons for 11 traits of six lines and 15 F_1 hybrids under well-watered and water-stressed conditions are indicated in supplementary data 1. Comparison of mean values exhibited that under water-stressed condition the average performance of sunflower genotypes was decreased for all the studied traits. In both well-watered and water-stressed conditions the cross 'LR4×LR25' had the highest value for the number of achene per head (NA). This cross also showed the highest value for head diameter in both of water treatment conditions. In well-watered condition the highest value for seed yield per plant (SY) was observed in the cross 'LR4×LR25', whereas in water-stressed condition the highest value for this trait was observed in the cross 'C104×LR25'. For leaf number the cross 'LR4×C104' had the highest value in well-watered condition, whereas in water-stressed condition 'C104×LR25' had the highest value for this trait. These results indicate that yield improvement for stressed conditions requires selection under these conditions (CECCARELLI, 1987).

Sum of square of general (GCA) and specific combining abilities (SCA)

In well-watered condition, neither GCA nor SCA variances of achene per head (NA), seed yield per plant (SY), head diameter (HD), head weight, chlorophyll content (CC), and days from flowering to physiological maturity (DFM) were significant (Table 3). Regarding the aerial part dry weight (APDW), plant height (PH), and relative water content (RWC) the SCA variance was significant (Table 3). Concerning to leaf number (LN), both variances (GCA and SCA variances) were significant (Table 3).

In water-stressed condition, neither GCA nor SCA variances of plant height (PH) were significant (Table 3). About relative water content (RWC), achene per head (NA), seed yield per plant (SY), head diameter (HD), and days from flowering to physiological maturity (DFM) and leaf number (LN), the SCA variance was significant (Table 3). Regarding the chlorophyll content (CC) the GCA variance was significant (Table 3). Concerning to head weight, and aerial part dry weight (APDW), both variances (GCA and SCA variances) were significant (Table 3).

Combining ability analysis estimates the average of additive and dominance effects of all the genes involved in expression of a trait based on progeny performance (DARVISHZADEH *et al.,* 2009). The significant effect of general combining ability indicates the importance of additive genetic components in controlling of traits. The additive variance is the main determinant of the observable genetic properties of the population and selection response

(FALCONER and MACKAY, 1996). The genetic advances could be reached by selection for traits with higher additive genetic variance. The significant effects of specific combining ability indicated the importance of non-additive genetic components in control of traits. The general and specific combining abilities also emphasize the importance of both additive and non-additive genetic components (dominance and/or epistasis) (DARVISHZADEH *et al.,* 2009). However, the relative importance of general and specific combining ability in determining progeny performance is assessed according to the ratio presented by BAKER (1978). The ratios close to 1:1, for a given trait, show that additive gene effects are important than non-additives.

Table 3. Mean squares for general combining ability (GCA) and specific combining ability (SCA) and the baker's ratio (2Sgca/2Sgca+Ssca) of different sunflower (Helianthus annuus L.) traits under well-watered (WW) and water-stressed (WS) conditions.

Source of variation	df	MS											
		NA		SY		HW		HD		APDW		CC	
		WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW
GCA	5	3.52^{ns}	11.67^{ns}	0.01^{ns}	0.01^{ns}	0.01*	0.02^{ns}	0.57^{ns}	0.91^{ns}	6.79*	23.31^{ns}	0.009**	0.005^{ns}
SCA	15	10.86**	16.22^{ns}	0.10**	0.08^{ns}	0.02**	0.02^{ns}	1.32*	2.22^{ns}	7.86**	30.00*	0.003^{ns}	0.004^{ns}
$2S_{gca}/2S_{gca}+S_{sca}$		0.39	0.59	0.17	0.2	0.5	0.67	0.46	0.45	0.63	0.61	0.86	0.71

SY: seed yield per plant; NA: number of achene per head; HW: head weight; HD: head diameter; APDW: aerial part dry weight; CC: chlorophyll content. *df* = degrees of freedom; MS= Mean of squares. * and **: significant at 0.05 and 0.01 probability level, respectively; ns, not significant at 0.05 probability level.

Table 3. Continued

Source of variation	df	MS									
		LN		RWC		DSF		DFM		PH	
		WS	WW	WS	WW	WS	WW	WS	WW	WS	WW
GCA	5	6.06^{ns}	29.47**	44.41^{ns}	7.94^{ns}	0.0005^{ns}	0.0001^{ns}	15.03^{ns}	33.01^{ns}	255.44^{ns}	415.37^{ns}
SCA	15	21.05**	10.44*	146.87**	39.97*	0.0005^{ns}	0.0003^{ns}	25.22*	33.57^{ns}	398.52^{ns}	404.73*
$2S_{gca}/2S_{gca}+S_{sca}$		0.37	0.85	0.38	0.28	0.67	0.4	0.54	0.66	0.56	0.67

LN: leaf number; RWC: relative water content; DFS: days from sowing to flowering; DFM: days from flowering to physiological maturity; PH: plant height

The Baker's ratio was close to 0.5 in head weight, in which both variances due to general and specific combining abilities were significant in water-stressed condition. This result supports the influence of both additive and non-additive genetic effects in controlling the trait. For aerial part dry weight (APDW), and leaf number (LN) in water-stressed condition, the Baker's ratio was near to 1, supporting the influence of additive genes. In total, our results showed that most of agronomical traits inherited differently in stressed and non-stressed conditions (HITTALMANI *et al.,* 2003).

General and specific combing ability values

Assessment of the contribution of individual lines to hybrid performance was accomplished by comparing the GCA effect among the parents (Table 4).

Table 4. Estimates of general combining effects of parents for yield and related traits in sunflower (Helianthus annuus L.) under well-watered (WW) and water-stressed (WS) conditions.

Parents	GCA effects									
	HD		HW		DSF		PH		DFM	
	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW
RHA266	0.21	0.20	0.01	0.03	-0.0050	0.0003	0.74	1.31	-0.15	-0.17
LR55	0.05	-0.39	-0.01	-0.04	-0.0056	-0.0029	-6.59	-9.14**	-0.56	1.66
LR4	0.17	0.02	-0.04**	-0.04	0.0018	0.0029	-1.37	-0.72	-0.03	-0.29
C104	-0.19	0.12	0.01	0.03	0.0062	0.0004	1.94	3.24	1.51*	1.27
LR25	-0.08	-0.11	0.03*	-0.01	-0.0023	-0.0032	2.93	2.80	-0.94	-1.73
C100	-0.15	0.15	-0.01	0.03	0.0050	0.0026	2.36	2.51	0.17	-0.73
LSD 0.05 {V(g)}	0.29	0.44	0.02	0.05	0.0067	0.0061	6.59	4.90	1.30	1.89
LSD 0.05 {V(gi-gj)}	0.45	0.68	0.04	0.07	0.0103	0.0095	10.21	7.58	2.02	2.93

HD: head diameter; HW: head weight; DFS: days from sowing to flowering; PH: plant height, DFM: days from flowering to physiological maturity.

Table 4. Continued

Parents	GCA effects											
	LN		RWC		APDW		NA		CC		SY	
	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW
RHA266	0.79	1.38*	-1.23	-0.11	0.18	1.06	0.02	-0.40	-0.009	-0.018	-0.03	0.01
LR55	-0.29	-1.93**	2.47	0.75	0.12	-1.14	0.30	-0.86	-0.035*	-0.019	0.01	0.01
LR4	-0.48	0.49	-0.30	0.76	-0.88*	-1.52	0.57	1.14	0.003	0.006	0.02	0.03
C104	0.38	-0.72	-1.55	-0.10	-0.07	1.12	-0.14	-0.76	0.002	0.014	0.02	-0.02
LR25	0.21	1.08*	0.79	-0.82	0.87*	-0.43	-0.15	0.50	0.022**	0.008	0.01	-0.01
C100	-0.61	-0.30	-0.19	-0.48	-0.21	0.91	-0.61	0.37	0.018	0.010	-0.03	-0.01
LSD 0.05 {V(g)}	0.91	0.81	2.62	1.64	0.62	1.35	0.54	1.22	0.015	0.021	0.05	0.10
LSD 0.05 {V(gi-gj)}	1.41	1.25	4.06	2.54	0.96	2.09	0.83	1.89	0.024	0.033	0.08	0.15

LN: leaf number; RWC: relative water content; APDW: aerial part dry weight; NA: number of achene per head; CC: chlorophyll content; SY: seed yield per plant

A parent with a significant positive GCA value would contribute with a high level of performance. In contrast a parent with a negative value has a low level contribution. In well-watered condition, line 'LR25' and its paternal line 'RHA266' showed highly significant positive GCA values for leaf number (LN), whereas line 'LR55' exhibited highly significant negative GCA values for the same trait. For producing a population with high genetic variability in leaf number (LN) under non-stressed condition it will be relevant to cross the lines which exhibit contrasting GCA effects. In water-stressed condition 'LR25' showed highly significant positive GCA value for aerial part dry weight (APDW), whereas line 'LR4' exhibited highly significant negative GCA value. Moreover, in water-stressed condition 'LR25' showed highly significant positive GCA value for chlorophyll content (CC), whereas line 'LR55' exhibited a high significant negative GCA. Therefore, we suggest that 'LR25' is a good combiner for leaf number (LN), aerial part dry weight (APDW), and chlorophyll content (CC).

The SCA values for studied traits were summarized in Supplementary data 2. The SCA is controlled by non-additive gene action which is an important criterion for the evaluation of hybrids performance. F_1 hybrids derived from 'LR4×C104' had the best SCA values for seed yield per plant (SY) in well-watered condition. This cross also showed significant positive SCA values for head diameter in water-stressed condition. The cross 'RHA266×C100' had the highest positive and significant SCA value in water-stressed conditions for seed yield per plant (SY) and number of achene per head (NA). The highest SCA effect was observed in cross 'LR4×C100' for relative water content (RWC) in well-watered condition. This cross also showed significant positive SCA values for number of achene per head (NA).

CONCLUSION

In conclusion, mean values exhibited that under water-stressed condition the average performance of sunflower genotypes was decreased for all the studied traits. In well-watered condition the highest value for seed yield per plant (SY) was observed in cross 'LR4×LR25' whereas in water-stressed condition the highest value for this trait was observed in cross 'C104×LR25'. Analyses of combining ability revealed that most agronomical traits inherited differently at stressed and non-stressed conditions and these results indicated that yield improvement for stressed conditions requires selection under drought condition. For the number of achene per head (NA), seed yield per plant (SY), head diameter (HD), and days from flowering to physiological maturity (DFM) the non-additive effects played a more important role than additive effects in water-stressed condition. In well-watered condition, the cross 'LR4×C10' showed the best SCA value for seed yield per plant (SY), where as in water-stressed conditions the 'RHA266×C100' had the best SCA for seed yield per plant (SY) and number of achene per head (NA).

Abbreviations: NA: number of achene per had; LN: leaf number; HW: head weight; HD: head diameter; APDW: aerial part dry weight CC: chlorophyll content; PH: plant height; DFS: days from sowing to flowering; DFM: days from flowering to physiological maturity; RWC: relative water content; SY: seed yield per plant.

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GENETIČKA ANALIZA PRINOSA I OSOBINA VEZANIH ZA PRINOS KOD SUNCOKRETA (*Helianthus annuus* L.) U USLOVIMA DOBRE OBEZBEĐENOSTI VODOM I U USLOVIMA STRESA VODOM

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IZVOD

Stres sušom je jedan od faktora koji utiču na prinos (*Helianthus annuus* L.) iI oplemenjivanje na tolerantnost na sušu se nalazi u fokusu istraživanja. Vršena su istraživanja kombinacione sposobnosti, dejstvo gena i genetičke analize nekih karakteristika kod 6 samooplodnih linija suncokreta i 15 njihovih hibrida. Ocena materijala je vršena u dva posebna eksperimenta u slučajnom blok sistemu (RCBD) u tri ponavljanja u uslovima dobre snabdevenosti vodom, uslovima stresa vodom u kontrolisanim i nekontrolisanim uslovima. Poređenjem srednjih vrednosti utvrđeno je das u u uslovima stresa prosečne vrednosti genotipova bile smanjene za sve ispitivane osobine.Analiza kombinacione sposobnosti je pokazala da se većina agronomskih osobina nasleđuje različito u normalnim i uslovima stresa. U uslovima stresa neaditivni efekat gena ima značajniju ulogu u kontroli broja semenki po glavi, (NA). prinosa semena po biljci(SY) diameter glave (HD) i dana od cvetanja do fiziološke zrelosti (DFM). na osnovu rezultata za povećanje prinosa u uslovima stresa vodom neophodna je selekcija u uslovima suše. U povoljnim uslovima 'LR4×C10'je iimao najveću vrednos PKS za prinos zrna po boljci. dok je ulsovima stresa 'RHA266×C100' imala visoku vrednost PKS i broj semenki po glavi.

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Supplementary data 1

Mean comparisons for 11 characters of six lines and 15 F1 hybrids of sunflower (Helianthus annuus L.) under well-watered (WW) and water-stressed (WS) conditions.

Genotype	NA		SY		LN		HW		HD		APDW	
	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS
RHA266	116.40 A	34.21 E	6.66 A	1.01 BC	23.69 AB	18.33 BC	9.67 A	4.33 CD	5.88 A	4.28 AB	13.46 B	5.33 B
LR55	91.00 A	72.00 ABCDE	3.17 A	1.65 AB	15.00 C	17.00 C	6.00 A	4.67 BCD	5.40 A	5.33 AB	9.67 AB	6.67 B
LR4	79.05 A	96.00 ABCDE	2.61 A	2.31 AB	18.21 BC	21.67 ABC	10.63 A	5.00 ABCD	6.16 A	5.00 AB	12.59 AB	7.00 B
C104	80.05 A	54.67 BCDE	3.15 A	1.65 ABC	17.21 BC	22.00 ABC	12.63 A	5.67 ABCD	6.76 A	3.90 AB	14.09 AB	8.33 B
LR25	123.33 A	76.67 ABCDE	7.14 A	2.67 A	18.67 BC	19.65 BC	10.00 A	7.67 AB	6.57 A	5.08 AB	14.00 AB	8.33 B
C100	86.00 A	31.00 DE	4.07 A	0.34 C	19.67 ABC	20.00 BC	8.00 A	4.00 D	5.92 A	3.22 B	12.67 B	5.00 B
RHA266×LR55	130.67 A	116.67 ABC	9.64 A	2.92 A	22.33 AB	21.00 ABC	10.67 A	5.00 ABCD	7.20 A	5.67 A	16.33 AB	7.00 AB
RHA266×LR4	161.67 A	140.33 AB	7.21 A	2.99 A	23.00 AB	22.67 ABC	10.67 A	5.33 ABCD	7.97 A	5.28 AB	14.00 AB	8.67 B
RHA266×C104	96.05 A	104.33 ABC	5.79 A	2.32 AB	22.21 AB	25.67 AB	15.13 A	6.33 ABCD	7.63 A	4.07 AB	26.09 AB	9.67 A
RHA266×LR25	123.67 A	92.00 ABCDE	6.82 A	2.20 AB	19.33 ABC	20.33 BC	13.00 A	6.33 ABCD	7.83 A	5.40 AB	17.00 AB	8.00 AB
RHA266×C100	156.67 A	135.67 AB	7.42 A	3.55 A	20.67 ABC	28.33 A	12.33 A	8.67 A	7.47 A	5.42 AB	16.67 A	11.33 AB
LR55×LR4	112.67 A	129.67 ABC	5.10 A	2.72 A	17.67 BC	20.33 BC	10.33 A	4.67 BCD	6.80 A	4.70 AB	15.67 AB	6.67 AB
LR55×C104	88.67 A	84.05 ABCDE	8.11 A	2.37 AB	18.00 BC	22.15 ABC	14.33 A	5.34 ABCD	7.73 A	4.36 AB	19.00 AB	8.20 AB
LR55×LR25	145.67 A	112.67 ABC	7.97 A	2.63 A	19.67 ABC	21.13 ABC	10.67 A	7.00 ABCD	6.50 A	4.60 AB	17.33 AB	9.33 AB
LR55×C100	118.55 A	96.33 ABCDE	6.07 A	1.75 AB	21.21 ABC	20.67 ABC	7.63 A	4.67 BCD	6.51 A	4.57 AB	12.09 AB	7.33 B
LR4×C104	241.90 A	105.67 ABCD	6.35 A	2.85 A	19.19 BC	22.33 ABC	10.17 A	5.67 ABCD	6.88 A	4.66 AB	16.46 AB	8.00 AB
LR4×LR25	253.33 A	144.33 A	13.68 A	3.63 A	19.67 ABC	20.67 ABC	10.33 A	6.00 ABCD	8.23 A	5.75 A	15.00 AB	6.67 AB
LR4×C100	209.33 A	102.00 ABC	8.54 A	1.97 AB	26.11 A	22.33 ABC	10.33 A	4.33 CD	7.93 A	4.27 AB	15.67 AB	7.67 AB
C104×LR25	156.90 A	112.33 ABC	12.26 A	5.19 A	21.69 ABC	20.67 ABC	14.67 A	6.00 ABCD	8.16 A	5.17 AB	18.46 AB	7.67 AB
C104×C100	66.67 A	55.74 CDE	3.61 A	1.82 ABC	20.67 ABC	24.72 AB	11.33 A	7.29 ABC	5.93 A	4.50 AB	14.67 AB	9.79 AB
LR25×C100	194.67 A	110.67 ABC	6.94 A	3.39 A	22.00 AB	22.33 ABC	12.00 A	6.67 ABCD	7.23 A	5.00 AB	19.00 A	10.67 AB

SY: seed yield per plant; NA: number of achene per had; LN: leaf number; HW: head weight; HD: head diameter; APDW: aerial part dry weight

Continued (Supplementary data 1)

Genotype	CC		PH		DSF		DFM		RWC	
	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS
RHA266	18.20 ^{AB}	12.38 ^{AB}	134.17 ^{AB}	90.67 ^{A}	91.33 ^{A}	87.00 ^{B}	133.67 ^{A}	133.09 ^{ABC}	82.33 $_{AB}$	65.88 ^{AB}
LR55	13.33 ^{B}	11.52 ^{B}	111.33 ^{B}	103.00 ^{A}	95.33 ^{A}	96.67 ^{AB}	132.00 ^{A}	131.67 ^{ABC}	81.84 $_{AB}$	71.66 ^{AB}
LR4	22.62 ^{AB}	17.80 ^{AB}	140.50 ^{AB}	111.33 ^{A}	97.67 ^{A}	97.67 ^{A}	137.30 ^{A}	135.33 ^{ABC}	78.23 $_{AB}$	61.00 ^{AB}
C104	18.22 ^{AB}	17.23 ^{AB}	135.50 ^{AB}	119.33 ^{A}	96.33 ^{A}	96.67 ^{AB}	142.80 ^{A}	136.67 ^{A}	76.75 $_{AB}$	56.38 ^{AB}
LR25	26.65 ^{AB}	19.60 ^{AB}	141.67 ^{AB}	105.00 ^{A}	95.33 ^{A}	96.67 ^{AB}	135.00 ^{A}	135.33 ^{ABC}	80.02 $_{AB}$	64.44 ^{AB}
C100	18.87 ^{AB}	16.20 ^{AB}	134.67 ^{AB}	101.67 ^{A}	97.67 ^{A}	97.00 ^{A}	127.67 ^{A}	126.67 ^{C}	72.18 $_{B}$	72.85 ^{A}
RHA266×LR55	18.73 ^{AB}	15.70 ^{AB}	142.00 ^{AB}	106.00 ^{A}	97.33 ^{A}	94.00 ^{AB}	137.67 ^{A}	131.33 ^{ABC}	84.15 $_{AB}$	53.67 ^{AB}
RHA266×LR4	19.02 ^{AB}	18.28 ^{AB}	158.00 ^{A}	120.00 ^{A}	93.67 ^{A}	92.67 ^{AB}	139.67 ^{A}	130.33 ^{ABC}	75.78 $_{AB}$	52.93 ^{AB}
RHA266×C104	19.27 ^{AB}	14.95 ^{AB}	173.00 ^{A}	116.00 ^{A}	94.00 ^{A}	98.56 ^{A}	136.67 ^{A}	137.67 ^{A}	82.00 $_{AB}$	50.24 ^{B}
RHA266×LR25	16.55 ^{AB}	19.65 ^{AB}	148.00 ^{AB}	141.33 ^{A}	97.67 ^{A}	100.00 ^{A}	141.00 ^{A}	136.33 ^{AB}	81.33 $_{AB}$	54.84 ^{AB}
RHA266×C100	20.70 ^{AB}	14.38 ^{AB}	144.33 ^{AB}	118.33 ^{A}	97.00 ^{A}	100.00 ^{A}	135.33 ^{A}	135.67 ^{AB}	79.82 $_{AB}$	50.73 ^{AB}
LR55×LR4	20.12 ^{AB}	15.17 ^{AB}	141.33 ^{AB}	104.00 ^{A}	98.00 ^{A}	96.00 ^{AB}	139.00 ^{A}	134.33 ^{ABC}	87.21 $_{A}$	57.45 ^{AB}
LR55×C104	18.00 ^{AB}	12.61 ^{AB}	152.00 ^{AB}	103.20 ^{A}	94.00	98.56 ^{A}	135.00 ^{A}	135.79 ^{AB}	78.85 $_{AB}$	52.29 ^{AB}
LR55×LR25	18.85 ^{AB}	18.05 ^{AB}	151.67 ^{AB}	108.14 ^{A}	94.67 ^{A}	97.67 ^{A}	139.33 ^{A}	134.00 ^{ABC}	81.24 $_{AB}$	60.81 ^{AB}
LR55×C100	21.57 ^{AB}	12.17 ^{AB}	134.50 ^{AB}	110.00 ^{A}	91.81 ^{A}	92.33 ^{AB}	128.80 ^{A}	127.67 ^{BC}	81.46 $_{AB}$	58.65 ^{AB}
LR4×C104	18.41 ^{AB}	24.20 ^{A}	157.67 ^{A}	118.67 ^{A}	97.33 ^{A}	98.00 ^{A}	140.36 ^{A}	135.33 ^{ABC}	87.95 $_{A}$	52.64 ^{AB}
LR4×LR25	21.77 ^{AB}	14.72 ^{AB}	154.67 ^{A}	114.33 ^{A}	94.67 ^{A}	95.33 ^{AB}	137.67 ^{A}	136.33 ^{AB}	77.27 $_{AB}$	54.54 ^{AB}
LR4×C100	21.85 ^{AB}	16.07 ^{AB}	156.32 ^{A}	119.33 ^{A}	96.00 ^{A}	96.00 ^{AB}	134.33 ^{A}	132.00 ^{ABC}	81.79 $_{AB}$	53.37 ^{AB}
C104×LR25	62.32 ^{A}	18.77 ^{AB}	161.67 ^{A}	115.00 ^{A}	95.33 ^{A}	94.33 ^{AB}	139.33 ^{A}	134.00 ^{ABC}	81.99 $_{AB}$	50.95 ^{AB}
C104×C100	19.15 ^{AB}	14.45 ^{AB}	144.00 ^{AB}	132.51 ^{A}	96.67 ^{A}	97.91 ^{A}	138.33 ^{A}	135.12 ^{ABC}	80.66 $_{AB}$	56.22 ^{AB}
LR25×C100	20.50 ^{AB}	18.93 ^{AB}	155.33 ^{A}	121.33 ^{A}	92.67 ^{A}	95.67 ^{AB}	133.00 ^{A}	136.67 ^{A}	81.67 $_{AB}$	52.08 ^{AB}

CC: chlorophyll content; PH: plant height; DFS: days from sowing to flowering; DFM: days from flowering to physiological maturity; RWC: relative water content.

Supplementary data 2

Estimates of specific combining effects for yield and related traits in 15 F1 hybrids of sunflower (Helianthus annuus L.) under well-watered (WW) and water-stressed (WS) conditions.

F1 hybrid	HD		HW		DSF		PH		DFM	
	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW
RHA266×LR55	0.35	0.53	0.15**	0.061	-0.034*	-0.016*	9.54	3.67	-3.84*	-2.75
RHA266×LR4	0.48	-0.15	-0.01	-0.001	0.013	0.006	-8.02	-7.08	0.30	1.84
RHA266×C104	-0.76	0.20	0.02	0.074	0.007	0.009	-1.33	20.91**	-1.23	1.95
RHA266×LR25	0.35	0.75	-0.06	-0.032	0.006	0.003	1.68	5.41	1.21	4.95*
RHA266×C100	1.47	2.03	0.16*	0.133	0.023	0.022	49.05*	14.30	5.97	5.25
LR55×LR4	-0.46	-0.23	-0.03	-0.057	0.007	0.010	3.32	-3.18	-1.67	-0.99
LR55×C104	0.03	-0.06	-0.08*	-0.036	0.006	-0.002	-5.99	-1.26	-0.17	-0.88
LR55×LR25	-0.18	-0.13	0.03	0.046	0.016	0.004	-2.02	9.52	4.95**	0.45
LR55×C100	-0.60	1.79	0.06	0.274*	-0.018	-0.019	-7.92	29.02**	-1.06	4.72
LR4×C104	0.96*	0.96	0.05	-0.013	0.001	0.001	-0.88	3.65	-1.03	-0.27
LR4×LR25	-0.64	0.89	-0.09*	0.028	-0.016	-0.006	3.12	6.48	-2.58	5.07*
LR4×C100	-0.02	0.54	0.01	-0.086	-0.002	0.008	3.61	11.32	-0.37	2.44
C104×LR25	-0.39	-1.21*	0.04	-0.056	0.001	-0.001	11.33	-10.53	2.88	-2.49
C104×C100	1.23	1.32	0.04	0.072	0.001	-0.019	-4.75	24.28	1.33	2.00
LR25*C100	-0.02	0.41	-0.02	0.035	-0.004	-0.003	16.91	13.95	-3.11	0.33
LSD 0.05 {V(sii-sjj)}	0.89	1.36	0.08	0.142	0.021	0.019	20.43	15.17	4.03	5.86
LSD 0.05 {V(sij-sik)}	1.18	1.79	0.10	0.188	0.027	0.025	27.03	20.07	5.34	7.76
LSD 0.05 { V(sij-skl)}	1.09	1.66	0.09	0.174	0.025	0.023	25.02	18.58	4.94	7.18

HD: head diameter; HW: head weight; DFS: days from sowing to flowering; PH: plant height, DFM: days from flowering to physiological maturity

Continued (Supplementary data 2)

F1 hybrid	LN		RWC		APDW		NA		CC		SY	
	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW
RHA266×LR55	5.90**	0.66	-6.45	-1.83	2.88**	0.55	1.46*	2.27	0.017	0.035	0.16*	0.07
RHA266×LR4	-1.24	-0.09	-0.75	2.49	-0.45	0.59	0.35	-0.83	-0.010	-0.004	0.09	0.12
RHA266×C104	2.57*	0.53	-2.93	1.20	1.41	7.68**	0.47	-1.52	-0.011	-0.023	0.01	-0.17
RHA266×LR25	-0.27	-0.01	-2.58	-4.30*	-0.54	-2.83	1.94**	0.55	0.007	0.001	0.08	-0.01
RHA266×C100	3.40	-3.49	-12.08*	-0.63	3.05*	3.65	4.75**	-0.96	0.070	-0.047	0.41**	-0.03
LR55×LR4	-0.49	1.63	0.54	-0.88	-0.07	-1.49	-0.91	-1.52	-0.024	0.010	-0.12	0.00
LR55×C104	-1.68	-0.24	0.58	5.54*	-1.54	-0.52	1.33	0.37	0.020	0.006	0.02	-0.05
LR55×LR25	-0.62	-0.03	1.60	0.30	0.18	2.69	0.44	0.95	0.034	-0.001	0.01	0.11
LR55×C100	5.58*	1.37	-17.83**	-1.77	2.01	7.29*	1.90	-1.54	-0.065	0.032	0.17	0.32
LR4×C104	-1.15	-0.66	0.44	-4.41*	-0.54	-0.81	1.75*	4.07*	-0.020	-0.004	0.11	0.27*
LR4×LR25	0.68	3.64*	-3.07	0.84	-0.48	1.41	-0.20	1.37	-0.017	0.004	-0.08	0.10
LR4×C100	0.79	3.04	-8.47	10.59*	0.33	1.51	1.34	8.51**	0.051	-0.030	0.08	0.31
C104×LR25	1.98	-0.24	1.62	0.56	0.55	-2.23	-2.77**	-3.08	-0.007	-0.030	-0.17*	-0.19
C104×C100	-0.35	5.34*	-6.80	5.25	-0.53	4.65	3.75**	2.08	0.010	0.148**	0.40**	0.38
LR25×C100	3.38	4.71*	-11.38	1.32	3.41*	3.67	2.21	3.21	-0.010	-0.052	0.13	-0.14
LSD 0.05 {V(sii-sjj)}	2.81	2.50	8.12	5.08	1.92	4.18	1.66	3.78	0.047	0.066	0.17	0.30
LSD 0.05 {V(sij-sik)}	3.72	3.31	10.74	6.72	2.54	5.53	2.20	5.00	0.062	0.087	0.22	0.39
LSD 0.05 { V(sij-skl)}	3.45	3.06	9.94	6.22	2.35	5.12	2.04	4.63	0.058	0.081	0.20	0.36

LN: leaf number; RWC: relative water content; APDW: aerial part dry weight; NA: number of achene per head; CC: chlorophyll content; SY: seed yield per plant