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HETEROSIS AND COMBINING ABILITY THROUGH LINE × TESTER ANALYSIS FOR YIELD, OIL AND MID OR HIGH OLEIC ACID CHARACTERS IN SUNFLOWER (*Helianthus annuus* L.)

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ABSTRACT

This research was conducted in the southern Marmara region of Turkey during 2017-2018 growing season in order to determine general combining abilities (GCA) of parental lines, specific combining abilities (SCA) of hybrids, and estimate performance and the genetical structure of hybrid population obtained from three cytoplasmic male sterile (CMS) and four restorer lines with mid or high oleic acid content. The field experiments were designed in a Randomized Complete Block with three replications. According to the results, male parents AGR2 and AGR4 considered as good general combiners for developing increased seed and oil yields in sunflower hybrids, although there were not good general combiners in female parents for the same traits. CMS3 x AGR4 test hybrid, which has high oleic acid content, has been determined to be a promising hybrid variety candidate with its high seed and oil yields, high oil content and oleic acid content. However, although the SCA effects of CMS1 x AGR2 and CMS3 x AGR2 test hybrids were not significant for seed and oil yields, it was concluded that they were promising hybrids with high yield, oil content and mid oleic acid content. It was determined that both additive and non-additive gene effects were effective for yield and some important yield components in the hybrid population studied. The values of heterosis and heterobeltiosis values ranged from 10.8 to 728.9 % and -20.1 to 608.8 % for seed yield, respectively. Similarly, positively high and significant heterosis and heterobeltiosis values were obtained in the oil yield.

Keywords: combining ability, *Helianthus annuus* L., heterosis, line x tester, oleic acid content, yield components.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crops in Turkey as well as in the rest of the world. The sunflower is grown mainly in dry conditions in Turkey where it is grown on around 0.7 M ha per year with approximately production of 1.6-1.9 M ton and average seed yields of 2.3-2.5 t ha^{-1} (FAO, 2020). Thrace region which is the European part of Turkey forms the majority (75%) sunflower areas while it grows also in South-Marmara Region, Black Sea, Central-Anatolia, Aegean and Mediterranean Region. Sunflower uses for oil production is common in Turkey. Based on latest data sunflower only supplies with 69% of vegetable oil production, nearly %84 of total oil consumption and 32% of total oil usage in our country (BSYD, 2017). Seeds of sunflower contains nearly 35–42% oil and also naturally rich in linoleic acid (55–70%) but poor in oleic acid (20–25%) (Premnath A. et al., 2016). However, there are genotypes with mid and high oleic acid content in sunflower germplasm. Škorić et al. (2007) suggested that female lines with oleic acid content greater than 90% in oil and male restorers with oleic acid content in the range of 89-93% were developed and using these lines, hybrids with oleic acid content in oil exceeding 90% could be developed. Other breeding studies using female (CMS) and male (restorer) lines and varieties with oleic acid content of more than 80% in sunflower were also reported (Fick, 1984; Jocic et al., 2000; Kaya et al., 2017). Frying oils and margarines produced from sunflower oils with mid (60-70%) or high levels (over 80%) of oleic acid are healthier since their trans fatty acid content is low. Moreover, this type of oil is more difficult to deteriorate and has longer shelf life (Kaya et al., 2017). So mid or higher oleic type sunflower oil increase its importance year by year in the world and also in Turkey (Kaya et al., 2008). Beside having high oleic acid content of sunflower cultivars, it is also important for consumers to have high yield, high oil content, and resistance to both orobanche (*Orobanche cumana* Wallr.) and mildew in our country. Therefore, most of the sunflower breeding program is designed to develop inbred lines and hybrids that are resistant to both orobanche (*Orobanche cumana* Wallr.)

and downy mildew together as well as having high yielding, high oil and oleic acid content.

In the last years hybrid cultivar use has reached to 99% in Turkey so seed production of sunflower has greatly increased. In general, hybrid varieties provide highly heterosis in terms of yield performance, some agronomic traits such as plant height, earliness and product quality. Hybrid sunflowers are more stable, highly self-fertile and more uniform at maturity (Dedio and Enns, 1976; Seetharam, 1979; Kaya and Atakisi, 2004). Resistance to diseases and orobanche (*Orobanche cumana* Wallr.) has also increased the importance of hybrid varieties.

The selection of parent lines with high combining ability in hybrid breeding is very important for the success of breeding. Heterotic performance of a hybrid combination depends upon combining abilities of it's parents (Allard, 1960; Kadkol et al., 1984). Good combining ability is the ability of the inbred line to give superior progeny in combination with another line (Jocic et al., 2015). The term "general combining ability (GCA)" is an average value of the inbred line based on its behavior in crosses with other lines (Jocic et al., 2015). The term "specific combining ability (SCA)" is the value of the line in crossing in a specific cross (Jocic et al., 2015). The differences in GCA are mainly due to the additive genetic effects and higher order additive interactions, while the differences in SCA are attributed to the non-additive dominance and other types of epitasis (Falconer, 1989). Information of general and specific combining abilities influencing yield and its components has become increasingly important to plant breeders to select appropriate parents for developing hybrid cultivars especially in cross pollinated crops (Istipliler et al., 2015).

Various researchers have studied general and specific combining ability variances for several traits in sunflower. In a study which conducted in Bursa, Goksoy et al. (1999) determined that dominant gene effects on plant height, 1000 seed weight, single-table yield and seed yield were higher than additive gene effects. Some of the researchers found that GCA had more importance in certain yield traits such as plant height (Mruthunjaya et al., 1995; Mihaljcevic, 1988; Joksimovic et al., 2000), 1000-seed weight (Tyagi, 1988; Mruthunjaya et al., 1995; Mihaljcevic, 1988; Khan, 2001), flowering time (Mihaljcevic, 1988), physiological maturity date (Mihaljcevic, 1988; Tyagi, 1988) and oleic acid content in oil (Joksimović et al., 2006), etc. Others observed that sca affects dominantly some yield components such as head diameter (Mruthunjaya et al., 1995; Mihaljcevic, 1988), physiological maturity date (Mihaljcevic, 1988) and oleic acid content in oil (Shaktivel, 2003; Tan, 1993; Nasreen et al., 2014). However, significant positive GCA and SCA effects were obtained for oil content, seed yield, 1,000-seed weight, plant height, head diameter and other yield associated traits (Dagustu and Goksoy, 2002; Karasu et al., 2010; Tan, 1993; Hladni et al., 2011; Saleem et al., 2014). Oleic acid content is determined by Ol genes exhibiting dominant mode of inheritance with the non-additive gene action and in addition to genetic factors it is also influenced highly by environmental factors (mainly night temperatures during grain filling period) (Fick, 1984; Škorić et al., 2007; Kaya et al., 2010; Hlisnikovský et al., 2017).

The objectives of this study were to determine general combining abilities of parental lines, specific combining abilities of hybrids, and estimate performance and the genetical structure of hybrid population obtained from three CMS and four restorer lines with mid or high oleic acid content. Furthermore, the main purpose of present study was to identify the hybrid cultivar candidates with high oil content, oleic acid content and high seed yield.

MATERIALS AND METHODS

Plant materials

The population used in the study was established by LinexTester crossing method. Three cytoplasmic polen sterile genotypes, CMS1, CMS2 and CMS3 were used as female parents (lines) and four restorer genotypes, AGR1, AGR2, AGR3 and AGR4 as male parents (testers). Parental lines are known to be mid or high oleic type and they were developed by Agromar Marmara Agricultural Products A.S. company. Three male sterile lines were crossed with each of four restorer lines in 2017.

Experiment location; climate and soil properties

Seven parents and 12 F$_1$ hybrids were tested in a field trial arranged in the RCBD with three replication under Bandırma conditions (latitude 39°3´ N, longitude 27°5´ E, altitude 139 m) in 2018. Bandırma is located in the southern Marmara region, with average annual rainfall of 683 mm and 14.0 ^{0} C mean monthly temperature. In this region, total rainfall at growing period of sunflower (March to August) correspond to 32 % of the annual precipitation. Soil is slightly alkali (pH: 7.58), medium limy (7.21%), clayey, salt free and have high levels of phosphorus, sufficient potassium. Hovewer organic matter is low (1.6 %).

Cultural practices and measurements

Parental lines, experimental hybrids and check varieties were planted by hand on May 2, 2018 in a well prepared soil. Each plot consisted of two rows, 7.5 m long with 0.70 m between rows, resulting in a total plot area of 9.66 m^2. All rows were thinned to 0.30 m between hill. 50 kg composite fertilizer NPK 15-15-15 (Nitrogen 15%, Phosphorous 15%, Potassium 15%) was applied prior to sowing. Hand hoeing was done when necessary. Five plants were selected randomly from each of the hybrids and parents in each plot for observations such as plant height (cm), head diameter (cm), number of seeds per head. Additionally, days to 50 % flowering, days to physiological maturity, yield components such as seed yield, 1000 seed weight were also observed and recorded to field book. The seed yield and 1000 seed weight were calculated considering 10% seed moisture. Beside these parameters also oil and oleic acid content was measured by Spinlock SLK-200 NMR at Agromar Marmara

Agricultural Products A.S. Laboratory. Oil yield was calculated based on oil percentage and seed yield results.

Statistical analysis

The field experiment was designed in a randomized complete block with three replications. Variance analysis were performed for all data obtained from the field experiment by using JUMP-7 software. The data were subjected to ANOVA according to Steel and Torrie (1980). Furthermore, analysis of variance for combining ability was done according to LinexTester method in which estimates of GCA variances and SCA variances were obtained as suggested by Singh and Chaudhary (1977). Analysis of combining ability was made using TARPOPGEN (Ege University, Izmir, Turkey) software as outlined by Ozcan and Acıkgoz (1999). As percent increase or decrease in mean of the hybrid over it's better parent and mid-parents, heterosis was calculated. Least significant differences (LSD) test at 0.05 and 0.01 levels was used for means and heterotic effects test. The t-test was used in order to determine the significance of GCA and SCA effects at 0.05 and 0.01 level.

RESULTS AND DISCUSSION

Analysis of variance

Variance analysis for combining ability revealed that the lines were significant at the 5% probability level in terms of table diameter, days to physiological maturity and oil content, while the testers were significant at the 5% probability level in terms of number of seeds per head, days to flowering (50 %) and days to physiological maturity, and at the 1% probability level in terms of head diameter, 1000 seed weight, seed yield and oil yield. In addition, interactions between lines and testers were significant at the 1% probability level for number of seeds per head, 1000 seed weight, seed yield, oleic acid content and oil yield. Variance analysis for combining abilities revealed that there were no significant differences in terms of GCA effects of lines and testers, and interactions (SCA effects) between lines and testers for plant height (Table 1). These results revealed that additive gene effects were effective for table diameter, oil content, days to 50% flowerin and days to physiological maturity but non-additive gene effects for oleic acid content and both additive and non-additive gene effects for number of seed per head, 1000 seed weight, seed and oil yields.

Table 1. Analysis of variance (mean squares) for combining ability.

Source	**df**	**#Days of physiological maturity**	**#Days of flowering (50%)**	**Plant height**	**Head diameter**	**Number of seeds/head**	**1000 seed weight**	**Seed yield**	**Oil Content (%)**	**Oleic Acid Content (%)**	**Oil Yield (kg/ha)**
Lines	2	11.1*	3.25	568.7	24.1*	65.9	130.2	5.14	40.67*	121.1	1.83
Testers	3	9.58*	3.88*	757.2	48.3**	732.6*	931.6**	85.1**	6.30	39.1	22.2**
LinesxTesters	6	2.00	0.69	248.1	3.74	92.1**	73.6**	7.14**	4.08	25.7**	1.84**
Error	36	3.22	1.10	272.6	6.51	16.5	20.0	1.85	2.01	2.28	441.2
C.V. (%)		2.23	1.72	14.6	15.5	16.5	10.7	21.6	2.94	2.05	21.3

* : Significant at p=0.05, **: Significant at p=0.01, df : Degrees of freedom.

General combining ability

Mean values and general combining ability (GCA) effects of the parental lines are given in Table 2a and 2b. In general, the differences between the mean values of genotypes were statistically significant for all traits observed except to seed yield and oil yield. AGR4 had minimum days to 50 % flowering and days to physiological maturity (68 and 74 days, respectively) and the highest number of seeds per head (609 seeds head^{-1}) while AGR3 and CMS1 formed higher oil content (49.0 % and 48.4 %, respectively) and CMS3 produced the highest oleic acid content (84.5 %). In the study, male parent AGR1 showed negative and significant GCA effect in terms of days to flowering (50 %) and days to physiological maturity. Although the GCA effects of female parents were insignificant in terms of the days to 50 % flowering, only the CMS2 line had a positive and significant GCA effect in terms of the days to physiological maturity. It was concluded that AGR1, which has a negative GCA effect on the days to 50 % flowering and days to physiological maturity, was shortened the maturity period on the hybrid combinations which it is entered, and formed earlier hybrids. Although the GCA effects of lines and testers on the plant height were insignificant, these values varied between -12.38 and +9.50.

Table 2a. Estimates of GCA effects and mean values (M) of lines and testers for yield components observed

Parents	Days of physiological maturity		Days of flowering (50%)		Plant height (cm)		Head diameter (cm)		Seeds head^{-1}	
	M	GCA	M	GCA	M	GCA	M	GCA	M	GCA
Lines										
CMS 1	83.0 ab	-0.55	63.3 a	-0.41	71.0 e	-4.58	14.3 d-f	-0.05	489.3 de	59.69
CMS 2	83.6 a	1.11*	63.3 a	0.58	52.0 e	-3.33	13.0 e-g	1.44*	501.6 de	-82.97
CMS 3	82.0 a-c	-0.55	62.3 a-c	-0.16	61.6 e	7.91	9.66 g	-1.38	230.0 f	23.27
Mean of lines	82.8		62.9		61.5		12.3		406.9	
Testers										
AGR 1	80.3 b-e	-1.41*	61.3 b-e	-0.94*	105.3 cd	-0.05	13.0 e-g	-2.91**	341.6 ef	-418,6**
AGR 2	80.6 b-e	0.58	62.0 a-d	0.50	106.6 cd	9.50	10.3 fg	-0.02	331.6 ef	222.9**
AGR 3	78.0 e	0.91	60.0 e	0.38	114.6 b-d	-12.38	12.3 e-g	0.19	338.6 ef	103.1*
AGR 4	74.0 f	-0.08	57.6 f	0.05	67.3 e	2.94	13.3 e-g	2.75**	609.0 d	92.52*
Mean of testers	78.2		60.2		98.5		12.2		405.2	
LSD ($P \leq 0.05$)	2.9		1.7		27.2		4.2		212.2	
Standard errors										
S.E. (Lines)		0.51		0.30		4.76		0.73		37.10
S.E. (Testers)		0.59		0.35		5.50		0.85		42.84

* : Significant at p=0.05, **:Significant at p=0.01

Table 2b. Estimates of GCA effects and mean values (M) of lines and testers for yield and quality characters observed.

Parents	1000 seed weight (g)		Seed yield (kg ha^{-1})		Oil Content (%)		Oleic Acid Content (%)		Oil Yield (kg ha^{-1})	
	M	GCA	M	GCA	M	GCA	M	GCA	M	GCA
Lines										
CMS 1	35.7 de	-1.56	823.3 ef	21.68	48.4 c-e	0.19	64.5 ı	-0.73	400.6 fg	10.77
CMS 2	36.0 de	-3.78	879.4 ef	-19.56	38.1 h	-1.93**	68.2 gh	-2.74	334.6 fg	-13.51
CMS 3	27.9 f	-2.21	293.0 f	-2.12	43.9 g	1.73**	84.5 a	3.48	128.3 g	2.74
Mean of lines	33.2		665.2		43.4		72.4		287.8	
Testers										
AGR 1	24.0 f	-15.21**	363.6 f	-139.5**	44.3 g	-1.16	80.5 b	-2.33	160.5 g	-71.22**
AGR 2	27.8 f	5.27**	412.6 f	84.20**	47.9 de	0.75	79.6 b	-0.57	197.6 g	43.41**
AGR 3	27.9 f	4.00*	424.3 f	15.18	49.0 c-e	0.41	78.8 b	0.22	207.3 g	7.73
AGR 4	26.6 f	5.93**	739.3 ef	40.13**	47.8 de	0.0	67.5 h	2.68	354.3 fg	20.07**
Mean of testers	26.5		484.9		47.2		76.6		229.9	
LSD ($P \leq 0.05$)	7.4		709.1		2.3		2.48		345.9	
Standard errors										
S.E. (Lines)		1.29		12.43		0.40		0.43		6.06
S.E. (Testers)		1.49		14.36		0.47		0.50		7.00

* : Significant at p=0.05, **:Significant at p=0.01

Two male parents, AGR1 and AGR4 showed negative and positive highly significant GCA effect for head diameter, respectively, while this effect was positive and significant for only line CMS2. For the number of seeds per head and 1000 seed weight, positive and significant GCA effects were recorded in testers, AGR2, AGR3 and AGR4, whereas the GCA effects of the female parents was detected insignificantly for the both traits. Significant and negative GCA effects were recorded for male parent AGR1 in terms of seed yield and oil yield, while male parents AGR2 and AGR4 had positive and significant GCA effects for the same traits. Female parent, CMS3 had the highest, positive and significant GCA effect for oil content (%) while CMS2 showed the highest, negative and significant GCA effect. On the other hand, GCA effects of male parents were not significant in terms of oil content. In terms of oleic acid content, which is an important quality trait in sunflower, the GCA effects of parents varied between -2.74 and +3.48 and were statistically insignificant (Table 2b). According to the results, male parents AGR2 and AGR4 considered as good general combiners for developing increased seed and oil yields in sunflower hybrids, although there were not good general combiners in female parents for the same traits. Memon et al. (2015) reported that the mean squares of lines and testers from crosses both determine the GCA were also significant which revealed the prevalence of additive variances and additive gene action for days to maturity, leaves plant^{-1}, plant height, head diameter, seeds plant^{-1}, 1,000-achene weight, seed yield kg ha^{-1} and oil content. In many of previous studies, desirable negative GCA effects were found for plant height and life-cycle duration (Ghaffari et al., 2011; Memon et al., 2015) while significant positive GCA effects were obtained for oil content, seed yield, 1,000-seed weight, plant height, head diameter and other yield associated traits (Ambati, 2010; Karasu et al., 2010; Tan, 1993; Hladni et al., 2011; Saleem et al., 2014; Memon et al., 2015). The estimates of combining ability effect for all characters in this study were generally in agreement with the results reported by Laureti and Del Gatto (2001), Kaya and Atakisi (2004), Farrokhi et al. (2008), Tavade et al. (2009), Ambati (2010), Karasu et al. (2010), Tan (1993), Dudhe et al. (2011), Hladni et al. (2011), Saleem et al. (2014), Memon et al. (2015). On the other hand, in contrast to our results regarding the oleic acid content in oil, Joksimović et al. (2006) suggested that GCA effects were positively significant, but SCA effects and thus non-additive gene actions were insignificant.

Specific combiming ability

Mean and SCA effect datas of twelve test hybrids in all traits are given in Table 3a and 3b. Large variation in hybrid performance were observed for days to 50 % flowering ranged from 59.6 to 62.6; days to maturity from 78.0 to 83.0; plant height from 101.6 to 147.3; head diameter from 15.0 to 23.6; number of seeds per head from 648.3 to 1,231.6; 1,000 seed weight from 29.0 to 63.2; seed yield from 564.0 to 3,470 kg ha^{-1}; oil content from 45.0 to 52.2 % and oil yield from 333.0 to 1,729 kg ha^{-1}. Two hybrids producing the highest grain yield and oil yield; CMS1 x AGR2 and CMS3 x AGR4 formed relatively taller plant height, produced more number of seeds per head (1,209.3 and 1,231.6 seeds $head^{-1}$, respectively), formed larger heads (19.6 and 20.3 cm, respectively), recorded relatively more oil content (49.9 and 51.8 %, respectively) with medium or higher oleic acid content (71.2 and 78.9 %, respectively). The mean values regarding the observed characteristics of the test hybrids obtained in our study were in agreement with the results obtained in many previous studies (Kaya et al., 2003; Kaya et al., 2009; Karasu et al., 2010; Dudhe et al., 2011; Hladni et al., 2011; Makanda et al., 2012; Memon et al., 2015).

Table 3a. Mean values (M) and SCA effects of test hybrids for yield components observed.

Crosses	Days of physiological maturity		Days of flowering (50%)		Plant height (cm)		Head diameter(cm)		Seeds $head^{-1}$	
	M	SCA	M	SCA	M	SCA	M	SCA	M	SCA
CMS1X AGR1	78.0 e	0.0	59.6 e	0.19	135.6 ab	10.13	15.0 c-e	-0.83	501.6 de	-65.13
CMS1X AGR2	79.6 c-e	-0.33	60.6 c-e	-0.25	135.6 ab	0.58	19.6 ab	0.94	1209.3 ab	4.19
CMS1X AGR3	80.6 b-e	0.33	61.0 b-e	0.19	101.6 d	-11.52	19.6 ab	0.72	1095.6 a-c	10.30
CMS1X AGR4	79.3 c-e	0.0	60.3 de	-0.13	129.3 a-c	0.80	20.6 ab	-0.83	1125.3 a-c	50.63
CMS2X AGR1	79.3 c-e	-0.33	60.3 de	-0.13	122.0 a-d	-4.77	18.6 bc	1.33	648.3 d	227.5**
CMS2X AGR2	83.0 ab	1.33	62.6 ab	0.75	137.6 ab	1.33	19.0 ab	-1.22	1052.3 a-c	-10.13
CMS2X AGR3	81.3 a-d	-0.66	61.3 b-e	-0.47	125.0 a-d	10.55	19.6 a	-0.77	969.3 c	26.63
CMS2X AGR4	80.6 b-e	-0.33	61.3 b-e	-0.13	122.6 a-d	7.11	23.6 d-f	0.66	688.0 d	-244.0**
CMS3X AGR1	78.3 e	0.33	59.6 e	-0.05	132.6 a-c	5.36	14.0 b-d	-0.50	364.6 ef	-162.38*
CMS3X AGR2	79.0 de	-1.0	60.6 c-e	-0.50	145.6 a	1.91	17.6 b-d	0.27	1174.6 a-c	5.94
CMS3X AGR3	80.6 b-e	0.33	61.3 b-e	0.27	126.6 a-d	0.97	17.6 ab	0.05	1012.0 bc	-36.94
CMS3X AGR4	79.6 c-e	0.33	61.0 b-e	0.27	147.3 a	6.30	20.3	0.16	1231.6 a	193.3*
Mean of crosses	79.9		60.8		130.1		18.8		922.7	
LSD (P ≤ 0.05)	2.9		1.7		27.2		4.2		212.2	
S.E.		1.03		0.60		9.53		1.47		74.21

* : Significant at p=0.05, **:Significant at p=0.01

Table 3b. Mean values (M) and SCA effects of test hybrids for yield and quality characters observed.

Crosses	1000 seed weight (g)		Seed yield (Kg ha^{-1})		Oil Content (%)		Oleic Acid Content (%)		Oil Yield (kg ha^{-1})	
	M	SCA	M	SCA	M	SCA	M	SCA	M	SCA
CMS1X AGR1	29.0 ef	-2.79	657.6 ef	-39.38	49.8 b-d	1.18	73.0 c-e	3.14*	333.3 fg	-17.23
CMS1X AGR2	57.4 ab	5.08	3470.0 a	18.12	49.9 b-d	-0.63	71.2 ef	0.38	1729.0 a	7.68
CMS1X AGR3	51.9 bc	0.80	2791.0 ab	19.23	49.7 b-d	-0.46	71.1 ef	1.35	1387.6 a-c	9.22
CMS1X AGR4	49.9 c	-3.09	2868.3 ab	2.02	49.7 b-d	-0.08	73.5 c-e	-1.40	1422.0 a-c	0.32
CMS2X AGR1	40.0 d	2.82	1282.3 de	64.33*	45.0 fg	-1.49	63.7 ı	-4.17**	576.0 ef	31.31*
CMS2X AGR2	55.6 bc	-2.02	2821.0 ab	-5.52	48.8 c-e	0.45	72.4 d-f	2.82	1375.3 bc	-3.39
CMS2X AGR3	50.8 bc	-5.65*	2187.6 bc	0.15	49.5 b-e	1.46	70.2 fg	-0.24	1082.3 cd	2.98
CMS2X AGR4	63.2 a	4.84	1846.0 cd	-58.95*	47.2 ef	-0.42	74.5 cd	1.60	866.7 de	-30.91*
CMS3X AGR1	31.1 ef	-0.03	564.0 f	-24.94	50.4 a-c	0.30	75.1 c	1.03	284.6 fg	-14.08
CMS3X AGR2	48.6 c	-3.05	2924.6 a	-12.60	52.2 a	0.18	73.4 c-e	-2.43**	1529.0 ab	-4.29
CMS3X AGR3	55.3 bc	4.85	2166.6 bc	-19.38	50.7 a-c	-1.00	78.2 b	1.59	1093.0 cd	-12.21
CMS3X AGR4	50.6 bc	-1.75	3179.3 a	56.93**	51.8 ab	0.50	78.9 b	-0.19	1644.3 ab	30.58*
Mean of crosses	48.6		2229.8		49.6		72.9		1110.2	
LSD (P ≤ 0.05)	7.4		709.1		2.3		2.48		345.9	
S.E.		2.58		24.87		0.81		0.87		12.12

* : Significant at p=0.05, **:Significant at p=0.01

The SCA effects of test hybrids were significant in terms of number of seeds per head, 1000 seed weight, seed yield, oil yield and oleic acid content, but not significant for days to 50 % flowering and days to physiological maturity, plant height, head diameter, oil content. Two (CMS2 x AGR1 and CMS3 x AGR4), out of 12 test hybrids exhibited significantly positive SCA effects for number of seeds per head, seed yield and oil yield and 1 test hybrid (CMS1 x AGR1) for oleic acid content. However, 2 test hybrids in terms of seed number of seeds per head (CMS2 x AGR4 and CMS3 x AGR1) and oleic acid content (CMS2 x AGR1 and CMS3 x

AGR2) and 1 test hybrid for 1000 seed weight (CMS2 x AGR3), seed yield and oil yield (CMS2 x AGR4) showed significantly negative SCA effects. Two test hybrids with the lowest and highest seed and oil yields; CMS2 x AGR1 and CMS3 x AGR4, respectively, exhibited the highest positive and significant SCA effects in terms of these traits. Especially, CMS3 x AGR4 test hybrid, which has high oleic acid content, has been determined to be a promising hybrid variety candidate with its high seed and oil yields, high oil content and oleic acid content. However, although the SCA effects of CMS1 x AGR2 and CMS3 x AGR2 test hybrids were not significant for seed and oil yields, it was concluded that they were promising hybrids with high yield, oil content and mid oleic acid content (Table 3a and 3b).

Test hybrids having the highest positively significant SCA effects for number of seeds per head, seed yield and oil yield could be considered exhibiting more effective dominant gene actions for the same characters. Previous studies have reported that crosses having highly positive SCA effects were obtained from cross populations of sunflower for some yield components and seed yield (Sawargaonkar et al., 2008; Farrokhi et al., 2008; Tavade et al., 2009; Dudhe et al., 2011; Memon et al., 2015). Non-additive type of gene action and therefore significant SCA action in oleic acid has also been reported by Shankara (1981), Baldini et al. (1991), Shaktivel (2003), Tan (1993), Nasreen et al. (2014). The present findings are compatible with the results of the investigations cited above. On the other hand, in contrast to our findings, Karasu et al. (2010), Hladni et al. (2011) and Memon et al. (2015) reported higher positive SCA effects for head diameter; Andarkhor et al. (2013) and Saleem et al. (2014) for 1,000 seed weight; and Kang et al. (2013) and Memon et al. (2015) for oil content. It is considered that the opposite findings are due to the genotypic differences of the parents used in these researches.

Heterotic performance

Heterosis (H_t) and heterobeltiosis (H_b) values of test hybrids are given in Table 4a and 4b. Significant heterosis was estimated for different number of test hybrids in all the traits. The heterosis and heterobeltiosis values ranged from -4.28% to 1.68% and -5.80 % to – 1.06% for the days to 50 % flowering; -4.49% to 2.32 and -6.02% to -0.79% for the days to physiological maturity; 9.52% to 128.4% and -11.3% to 118.8% for plant height; 9.77% to 79.7% and 4.68% to 77.4% for head diameter; 19.9% to 318.2% and 1.84% to 254.1% for number of seeds per head; -2.84% to 101.9% and -18.7% to 97.9% for 1000 seed weight; 10.8% to 728.9% and -20.1% to 608.8% for seed yield; 2.11% to 14.3% and -1.32% to 8.97% for oil content; -14.3% to 11.2% and -20.9% to 9.24% for oleic acid content; and 18.8% to 838.3% and -16.8% to 673.7% for oil yield, respectively. Except for CMS1xAGR3, all test hybrids exhibited significant heterosis for plant height, whereas heterobeltiosis values were significant for seven test hybrids. CMS3 x AGR2, CMS3 x AGR3, CMS3 x AGR4, CMS1 x AGR2 and CMS1 x AGR3 had the highest positively and significant heterosis values in terms of seed yield, oil yield, and 1000 seed weight. In addition, test hybrids CMS3xAGR2 and CMS3xAGR3 showed significant and positive heterosis for number of seeds per head. Except for CMS1 x AGR3, all test hybrids showed significant heterosis for oil content. CMS3xAGR1 (118.8%), CMS1xAGR4 (82.1%) and CMS2xAGR4 (82.1%) showed more than 80% heterosis over better parent in the cross for plant height. All crosses were found to be superior for head diameter. The highest and significant heterosis (79.7%) and heterobeltiosis (77.4%) belong to CMS2 x AGR4 for head diameter. CMS3xAGR2 showed the highest (254.1%) and significant heterobeltiosis among the crosses for number of seeds per head. For 1000 seed weight except CMS1xAGR1 all test hybrids showed significantly positive heterosis and heterobeltiosis. CMS3xAGR1 showed highest significant heterosis 14.3% and heterobeltiosis 13.9% for oil content. For oleic acid content eight hybrids showed negative heterosis and five of them were significant. Ten hybrids showed negative and significant heterosis over better parent for oleic acid content. CMS1xAGR1 showed highest but negative heterosis and all test hybrids showed negative heterobeltiosis for days to physiological maturity. For the days to 50 % flowering negative heterobeltiosis obtained from all test hybrids. CMS1xAGR1 had the highest but negative heterosis for days to 50 % flowering. Except CMS1xAGR1 all test hybrids showed significant heterosis for oil yield and CMS3xAGR5 (838.3%), CM3xAGR7 (581.4%), CMS3xAGR6 (551.3%) showed more heterosis 500% than over mid-parent. All crosses except for CMS1xAGR1 showed positive significant heterobeltiosis for oil yield. CMS3xAGR5 was exhibited more than 600% heterosis over higher parent for oil yield. In other previous studies, it was determined that heterosis and heterobeltiosis values ranged between 98.4 % to 274.1 % and 54.8 % to 171.5 % for seed yield per head (Hladni et al. 2007), 13.9 % to 152.7 % and 22.4 % to 116.1% for 1000 seed weight (Gejli et al., 2011), 18.4 % to 64.5 % and -7.6 % to 39.7% for head diameter (Kaya et al., 2003), 11.2 % to 77.9 % and 9.0 % to 63.6 % for plant height (Habib et al., 2007), respectively. Sapkale et al. (2016), examined 50 hybrids in terms of some characteristics and determined heterosis values for plant height between-1.9 to 44.9%, for head diameter-22.5 to 114.7%, for 1000 seed weight-42.1 to 92.8% and oil content between -18.2 to 21.1%. However they determined heterobeltiosis values for plant height between-8.1 to 43.8%, for head diameter between -22.5 to 113.1%, for 1000 seed weight between -42.7 to 78.1% and for oil contenet between -26.2 to 11%. Kaya (2005), determined the highest heterosis (288%) and heterobeltiosis (98%) values of hybrid combinations for oil yield. The estimates of heterosis and heterobeltiosis for yield, yield components and quality characters observed in our study were in agreement with those reported by previous studies.

Table 4a. The heterosis (H_t) and heterobeltiosis (H_b)values of test hybrids for yield components observed.

Crosses	Days of physiological maturity		Days of flowering (50%)		Plant height (cm)		Head diameter(cm)		Seeds head^{-1}	
	H_t	H_b	H_t	H_b	H_t	H_b	H_t	H_b	H_t	H_b
CMS1X AGR1	-4.49**	-6.02**	-4.28**	-5.80**	53.8**	28.7*	9.77**	4.68*	19.9	1.84
CMS1X AGR2	-2.65	-4.02**	-3.20**	-4.22**	52.7**	27.1*	59.4**	37.1**	194.6	147.1
CMS1X AGR3	0.20	-2.82	-1.08	-3.68**	9.52	-11.3	47.4**	37.1**	164.6	123.9
CMS1X AGR4	1.06	-4.42**	-0.27	-4.74**	86.9**	82.1**	49.3**	44.1**	104.9	84.7
CMS2X AGR1	-3.25*	-5.18**	-3.21**	-4.74**	55.0**	15.8	43.5**	43.5**	53.7	29.2
CMS2X AGR2	1.02	-0.79	-0.01	-1.06	73.5**	29.0*	62.8**	46.1**	152.5	109.7
CMS2X AGR3	0.62	-2.79	-0.54	-3.16**	50.0**	9.01	55.2**	59.4**	130.7	93.2
CMS2X AGR4	2.32	-3.59*	1.38	-3.16**	105.5**	82.1**	79.7**	77.4**	23.8	12.9
CMS3X AGR1	-3.49*	-4.48**	-3.51**	-4.28**	58.8**	25.9	23.5**	7.69*	27.5	6.73
CMS3X AGR2	-2.86	-3.66*	-2.42**	-2.68**	73.0**	36.5**	76.6**	70.9**	318.2**	254.1*
CMS3X AGR3	0.82	-1.63	0.27	-1.60	43.6**	10.4	60.6**	43.2**	255.9*	198.8
CMS3X AGR4	2.13	-2.85	1.68	-2.13*	128.4**	118.8**	76.8**	52.5**	193.6	102.2
Average	-0.71	-3.52	-1.26	-3.43	65.8	37.8	53.7	43.6	136.6	97.0

* : Significant at p=0.05, **:Significant at p=0.01

Table 4b. The heterosis (H_t) and heterobeltiosis (H_b)values of test hybrids for yield and quality characters observed.

Crosses	1000 seed weight (g)		Seed yield (Kg ha^{-1})		Oil Content (%)		Oleic Acid Content (%)		Oil Yield (kg ha^{-1})	
	H_t	H_b	H_t	H_b	H_t	H_b	H_t	H_b	H_t	H_b
CMS1X AGR1	-2.84	-18.7**	10.8	-20.1	7.44**	2.89*	0.67	-9.31**	18.8	-16.8**
CMS1X AGR2	80.5**	60.5**	461.5**	321.4**	3.57**	3.10**	-1.16	-10.5**	478.0**	331.6**
CMS1X AGR3	62.9**	45.0**	347.4**	239.0**	2.11	1.49	-0.83	-9.81**	356.5**	246.3**
CMS1X AGR4	60.0**	39.5**	267.1**	248.3**	3.26**	2.69*	11.2**	8.79**	276.7**	254.9**
CMS2X AGR1	33.3**	11.2**	106.3**	45.8	9.18**	1.58	-14.3**	-20.9**	132.6**	72.1**
CMS2X AGR2	74.4**	54.6**	336.6**	220.7**	13.5**	1.88	-1.97	-9.00**	416.8**	311.0**
CMS2X AGR3	58.9**	81.8**	235.6**	148.7**	13.6**	1.08	-4.51**	-10.9**	299.5**	223.4**
CMS2X AGR4	101.9**	75.6**	128.0**	109.9**	9.85**	-1.32	9.75**	9.24**	151.6**	144.6**
CMS3X AGR1	19.9**	11.7**	71.7*	55.1	14.3**	13.9**	-8.95**	-11.0**	97.0**	77.3**
CMS3X AGR2	74.4**	74.2**	728.9**	608.8**	13.7**	8.97**	-10.5**	-13.1**	838.3**	673.7**
CMS3X AGR3	98.0**	97.9**	504.1**	410.6**	9.14**	3.53**	-4.17**	-7.38**	551.3**	427.2**
CMS3X AGR4	85.6**	81.3**	515.9**	330.0**	12.8**	8.30**	3.81**	-6.59**	581.4**	364.1**
Average	62.2	51.2	309.4	226.5	9.37	4.00	-1.74	-7.53	349.8	259.1

* : Significant at p=0.05, **:Significant at p=0.01

CONCLUSION

In the present study, promising parent lines and hybrids were determined in terms of yield, some yield components, oil and oleic acid content. According to the results, male parents AGR2 and AGR4 considered as good general combiners for developing increased seed and oil yields in sunflower hybrids, although there were not good general combiners in female parents for the same traits.

Two test hybrids with the lowest and highest seed and oil yields; CMS2 x AGR1 and CMS3 x AGR4, respectively, exhibited the highest positive and significant SCA effects in terms of these traits. Especially, CMS3 x AGR4 test hybrid, which has high oleic acid content, has been determined to be a promising hybrid variety candidate with its high seed and oil yields, high oil content and oleic acid content. However, although the SCA effects of CMS1 x AGR2 and CMS3 x AGR2 test hybrids were not significant for seed and oil yields, it was concluded that they were promising hybrids with high yield, oil content and mid oleic acid content. In addition, these hybrids exhibited high heterotic performance in terms of yield and quality characteristics.

In fact, the results obtained from this research are based on field trials conducted in one year and at a single location. However, in order to reach more precise decisions about the hybrids developed in such studies, these hybrids should be tested in Region Yield Trials.

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