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Heterosis for seed, oil yield and quality of some different hybrids sunflower☆

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Abstract – Twenty-one hybrids of sunflower were produced by crossing 7 introduced cytoplasmic male sterile lines (CMS-lines) with 3 restorer lines (RF-lines) using line × tester mating design. The twenty-one hybrids, three restorers, seven maintainer lines (B-lines) were evaluated. The experiment was conducted in a randomized complete block design of three replications. Mean squares due to genotypes, parents (P), crosses (C), lines (L), testers (T), P *vs.* C, for stearic acid and line × tester for palmitic acid. The inbred lines and their F_1 hybrids differed significantly in their mean values of the traits under study. The variances due to specific combining ability (SCA) were higher than general combining ability (GCA) variances for all the studied traits, showing non-additive type of gene action controlling the traits. Non-additive type of gene action can be utilized for varietal improvement through heterosis breeding. Heterosis values for seed yield plant^{-1} were positive and highly significant relative to both the parental mean (17.68–72.38%) and the better parent (−2.86–56.842%). Significantly and negative heterosis was recorded in the case of linoleic acid relative to the parental mean (−81.24 to −38.02%) and better parent (−66.24–22.87%). With oleic acid, the heterotic effect ranged from −14.18 to 39.59% (parental mean) and from −15.06 to 38.72% (better parent). Therefore, these results are valuable for the improvement of quantitative as well as qualitative traits in sunflower breeding material to fulfill the edible oil requirements.

Keywords: Sunflower / oil yield / Heterobeltosis / line × tester / fatty acids / oil yield

Résumé – Hétérosis pour les graines, le rendement en huile et la qualité de différents hybrides de tournesol. Vingt et un hybrides de tournesol ont été produits par croisement de 7 lignées mâles stériles cytoplasmiques (lignées CMS) avec 3 lignées restauratrices (lignées RF) en utilisant un modèle de croisement lignée × testeur. Les 21 hybrides, 3 lignées restauratrices et 7 lignées mainteneuses (lignées B) ont été évalués. L'expérience a été menée selon un plan en blocs complets randomisés avec trois répétitions. Les effets des génotypes, parents (P), croisements (C), lignées (L), testeurs (T), P *vs.* C et lignée × testeur (L × T) étaient significatifs pour tous les caractères étudiés, à l'exception des parents pour l'acide palmitique, des testeurs pour l'acide stéarique et de l'interaction lignée × testeur pour l'acide palmitique. Les valeurs moyennes des caractères étudiés différaient significativement entre les lignées et leurs hybrides F_1. L'aptitude spécifique à la combinaison (ASC) était plus importante que l'aptitude générale à la combinaison (AGC) pour tous les traits étudiés, ce qui dénote un contrôle génétique non additif. Le contrôle génétique non additif peut être utilisé pour l'amélioration variétale *via* la sélection pour l'hétérosis. Les valeurs d'hétérosis pour le rendement en grain par plante étaient positives et très significatives par rapport à la moyenne des parents (17,68–72,38 %) et au meilleur parent (−2,86–56,842 %). Une hétérosis significative et négative a été enregistrée dans le cas de l'acide linoléique par rapport à la moyenne parentale (−81,24 à −38,02 %) et au meilleur parent (−66,24 à 22,87 %). Dans le cas de l'acide oléique, l'effet hétérotique variait de −14,18 à 39,59 % (moyenne parentale) et de −15,06 à 38,72 % (meilleur parent). Ces résultats sont donc précieux pour améliorer les caractéristiques quantitatives et qualitatives du matériel de sélection du tournesol afin de répondre aux exigences en matière d'huile alimentaire.

Mots clés : Tournesol / rendement en huile / Hétérosis / lignée × testeur / acides gras

☆ Contribution to the Topical Issue "Sunflower / Tournesol".

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1 Introduction

Sunflower (*Helianthus annuus* L.) is an important edible oilseed crop and ranks fourth in terms of its global edible oil production after palm, soybean and rapeseed. Sunflower seeds contain a high level of oil content (40–50%) (Naeem *et al.*, 2019). In conventional sunflower oil, 90% of the total fatty acids content is comprised of linoleic acid (C-18:2), oleic acids (C-18:1), and 8–10% of mainly palmitic acid (C-16:0) and stearic acid (C-18:0). According to Friedt *et al.* (1994), in addition to conventional fatty acids, sunflower oil also contains several other fatty acids, but is present only in traces (C14:0, C16:1, C14:1, C20:0, C22:0). Sunflower oil with high oleic acid content is nutritionally similar to olive oil which is considered superior to other types of seed oil (Doty, 1978; Hamed *et al.*, 2020). Grundy (1986) and Soliman *et al.* (2019) also suggested that a diet rich in monounsaturated fatty acids *i.e.* oleic acid reduces cholesterol in blood plasma (reducing the risk of coronary heart diseases), has a greater shelf life and a high degree of oxidative stability (Zahran *et al.*, 2020; Zahran and Najafi, 2020; Farrag *et al.*, 2020). The main breeding objective of sunflower is to develop high-yielding, disease-resistant hybrids with high oil quality (Dudhe *et al.*, 2009).

Sunflower hybrid breeding was started economically in discovering cytoplasmic male sterility CMS by Leclercq (1969) and restorer genes by Kinman (1970). Line × tester analysis is an extension of this method in which several testers are used (Kempthorne, 1957). Commercial exploitation of heterosis for a particular location (environment) requires isolation of suitable inbred lines and the development of hybrids. To accomplish this task, one has to know the genetic diversity of the available germplasm and the combining ability of the parents. For improving the yield potential of varieties and hybrids, the decision should be made on the choice of the right parent for hybridization. The higher heterosis in hybrids depends on the combining ability of male and female inbreds (Tan, 2010). Duotype sunflower hybrids for higher seed yield and oil traits can be developed with the use of prospective inbred lines, however hybrid superiority over male and female inbreds is an important consideration to evolve thriving F_1 hybrids (Meena *et al.*, 2013). A wide range of heterosis has been reported both for seed yield and oil quality in sunflower by various authors (Joksimovic *et al.*, 2006; Aslam *et al.*, 2010; Chahal *et al.*, 2019).

The predominant role of SCA has been determined for yield and other yield contributing components in sunflower Aleem *et al.* (2015) while others explained the superior effect of GCA effects over SCA for various traits contributing towards yield (Machikowa *et al.*, 2011). Higher SCA variances as compared to GCA variances were also reported for achene yield per plant, seed and oil yield per hectare (Memon *et al.*, 2014), palmitic, stearic, oleic acid and linoleic acid (Shamshad *et al.*, 2016; Rizwan *et al.*, 2020). Higher GCA variances as compared to SCA variances were also reported for achene yield per plant (Kholghi *et al.*, 2014), palmitic acid, stearic acid and oleic acid (Joksimovic *et al.*, 2006).

The main purpose of this study is to identify superior cross combination for seed and oil yield, as well as for oil quality, which identified as promising crosses and these crosses maybe need further evaluation for commercial exploitation.

2 Materials and methods

2.1 Field trial

Seven cytoplasmic male sterile (CMS) lines (A-lines) and three fertility restorer lines (Rf-lines) of sunflower. The A-lines were A_1, A_5, A_7, A_9, A_{11}, A_{13}, and A_{33}. The tester, Rf-lines, Rf_1, Rf_9, and Rf_{18} are male restorer lines. The female lines used in the experiment were cytoplasmic male sterile lines (CMS) as a line with their maintainer lines (B lines) and males were restorers (R lines). Parental lines (*cms* and *Rf*) in the study are given in Table 1.

Hybrid combinations were created by crossing A-sterile lines with Rf-restorer Research Institute, Agricultural Research Center (ARC), Egypt (22°, 32° N latitude to 24°, 37° E testers during year 2016 at Giza Agricultural Research station, Field Crops longitude). The crossing was undertaken into line × tester fashion and seeds were harvested separately to study heterosis. The three restorer inbred lines (testers) were crossed with the seven CMS lines during the flowering period. The twenty-one single crosses were obtained by bagging the sterile heads before flowering and the pollen grains were collected from each of the three restorer lines. The stigmas of the seven male sterile lines were pollinated with the collected pollen. The twenty-one obtained sunflower crosses, the three testers, the seven fertile lines (B-lines) were planted at Giza Research Station, Giza Governorate on 30th July, 2017. A randomized complete block design (RCBD) with three replications was used.

The plot size was 5 rows, 4-meter-long, and 60 cm apart. Planting was done in hills spaced 20 cm apart. Seedlings were thinned to one plant per hill before the first irrigation (two weeks after planting). Per hectare 240 kg superphosphate (15.5% P_2O_5) was added during seedbed preparation, while 120 kg/ha potassium sulfate (48% K_2O) was added after 15 days from planting. 350 kg/ha ammonium sulfate (20.5% N) was split into two equal doses 15 and 30 days after planting, irrigation was applied every 20 days. Physical and chemical soil analyses of the field experiments (Tab. 2) were performed at laboratories of the Soil and Water Research Institute of ARC, Egypt. The required weather data for the experimental site through the growing season were obtained from Central Lab for Agricultural Climate, Agricultural Research Center at Giza, Governorate, Egypt (Tab. 3).

Data of ten randomly selected plants were recorded from each replication for the characters like seed yield/plant (g), seed yield per hectare (kg), oil yield per hectare (Kg). The heterosis for these traits was estimated according to Wynne *et al.* (1970) using equations (1) and (2):

$$(\text{Mid parent heterosis})H_1 = \frac{F_1 - MP}{MP} \times 100(\%), \quad (1)$$

$$(\text{Better parent heterosis})H_2 = \frac{F_1 - BP}{BP} \times 100(\%), \quad (2)$$

Where:
- F_1 = single cross hybrid;
- MP = related mid-parent;
- BP = related better parents.

Table 1. Parental lines (*cms* and *Rf*) in the study.

CMS/Rf	Habitus	Origin	Type
A_1	Non-branched, Single headed	Romania	Oilseed
A_5	Non-branched, Single headed	USA	Oilseed
A_7	Non-branched, Single headed	Romania	Oilseed
A_9	Non-branched, Single headed	Russia	Oilseed
A_{11}	Non-branched, Single headed	Russia	Oilseed
A_{13}	Non-branched, Single headed	USA	Oilseed
A_{33}	Non-branched, Single headed	Romania	Oilseed
Rf_1	Branched, multi headed	Egypt	Oilseed
Rf_9	Branched, multi headed	Egypt	Oilseed
Rf_{18}	Branched, multi headed	Egypt	Oilseed

Table 2. Soil analysis at 0–30 cm depth in the experimental fields at Giza in 2019 growing season.

Soil characteristics			
Physical analysis		Chemical analysis	
Silt%	36.8	pH	7.73
Clay%	34.5	Ec(dsm^{-1})	1.40
Fine sand%	22.9	Sp	44.60
Coarse sand%	5.8	$CaCO_3$%	3.80
Soil type	Clay loam	Soil bulk density%	1.2
Soluble anions (mEqu/l)		Soluble cations (mEqu/l)	
HCO_3^-	0.6	Ca^{++}	4.8
Cl^-	8.3	Mg^{++}	2.7
SO_4^-	5.1	Na^{+1}	5.3
		K^{+1}	1.2

Source: Central Lab for Soil Analysis, Agricultural Research Center, Cairo, Egypt.

2.2 Oil content (%)

The oil extraction from sunflower seeds was performed in the Fats and Oils Department, National Research Centre, Cairo, Egypt according to the *Soxhlet* extraction method. The *n*-hexane was used as extraction solvent at a ratio of 1:10, a sample to solvent. Oil content (%) of seeds was determined according to AOAC (1990).

2.3 Fatty acids composition

The fatty acid composition was determined by the conversion of oil to fatty acid methyl esters (FAMEs) according to the modified method by Zahran and Tawfeuk (2019). The FAMEs were separated with an HP 6890 plus gas chromatography (Hewlett Packard, USA), using a capillary column Supelco™ SP-2380 (60 m × 0.25 mm × 0.20 μm), (Sigma-Aldrich, USA), Detector (FID) and the injector and detector temperature was 250 °C. The column temperature was 140 °C (hold for 5 min) and rises to 240 °C, at a rate of 4 °C/min, and holds at 240 °C for 10 min. The carrier gas was helium at a flow rate of 1.2 mL min^{-1}. FAMEs were identified by comparing their relative and absolute retention times to those authentic standards of FAMEs (Supelco™ 37 component FAME mix). The fatty acid composition was reported as a relative percentage of the total peak area.

2.4 Statistical analysis

The line × tester analysis was calculated according to Kempthorne (1957). The sum of squares for the F_1 single crosses was partitioned into components due to testers (males), lines (females), and line × tester interaction. The analyses reported in this study were performed with MS-EXCEL (2007) with spreadsheet formula commands.

3 Results and discussion

3.1 Analysis of variance

Plant breeders always perform breeding programs aiming to improve and increase the productivity of their plants. In this respect, breeders would try to obtain superior F_1 hybrids or develop new cultivars. Mean squares for line × tester analysis of lines, testers, and their interactions for all studied traits are presented in Table 4. Results revealed that genotypes and parents exhibited highly significant differences for all studied traits, except parents for palmitic acid indicating that variability existed among all inbred lines. Data revealed that crosses were highly significantly different for all studied traits. Mean squares due to parents *vs.* crosses were significant for all studied traits. Significant differences in parent's *vs.* crosses indicated the presence of heterosis in the crosses that may be manifested for the development of high yielding sunflower

Table 3. Meteorological data during the growing season of the experiment.

Month	Temperature		RH%	Wind speed 2 m (m/sec)	Sunshine duration (h)
	Max. (°C)	Min. (°C)			
June	36.7	16.0	23.3	2.0	13.9
July	38.2	24.5	33.5	1.6	13.8
August	37.1	24.6	32.5	2.0	13.1
September	33.5	23.6	32.5	2.2	13.0

Max. = Maximum, Min. = Minimum, RH % = Relative humidity.
Source: Central Lab for Agricultural Climate, Agricultural Research Center, Giza Governorate, Egypt.

Table 4. Mean squares of yield and oil quality components in sunflower.

Genotypes	Df	Seed yield plant^{-1} g	Seed yield t/ha^{-1}	Oil yield t/ha^{-1}	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid
Rep.	2	104.84	0.052	0.019	0.02	0.06	12.73	0.08
Genotypes	30	482.84**	1.580**	0.329**	0.87**	1.96**	217.87**	215.51**
Parents "P"	10	273.37**	0.358**	0.075**	0.55**	2.79**	99.69**	92.50**
Crosses "C"	20	259.89**	0.504**	0.137**	0.98**	1.65**	256.91**	261.12**
P *vs.* C	1	6827.12**	34.082**	6.451**	1.59**	0.68**	500.79**	410.45**
Lines	6	373.41**	0.689**	0.199**	1.70**	3.57**	485.03**	494.66**
Testers	2	592.34**	1.008**	0.296**	1.61**	0.07	53.80**	59.12**
L × T	12	147.72**	0.328**	0.079**	0.51**	0.95**	176.70**	178.01**
Error	60	53.03	0.022	0.007	0.28	0.04	5.97	3.52

hybrids. Meanwhile, the lines revealed significant differences for all studied traits. Testers revealed significant differences for all studied traits except stearic acids. Line × tester interaction exhibited significant differences for all studied traits except palmitic acid.

These results showed also great diversity for both lines and testers in seed yield, which contributed to the performance of their respective crosses. The results were following the findings of Manzoor *et al.* (2016) for seed yield per plant and fatty acids, Harun (2019) for fatty acids, Lakshman *et al.* (2020) for seed and oil yield per hectare, Haddadan *et al.* (2020) for seed yield per plant and seed and oil yield per hectare Rizwan *et al.* (2020) for seed yield per plant and fatty acids.

3.2 Mean performance

The mean performance of parents and 21 hybrids for studied traits are presented in (Tab. 5). There were significant differences in seed yield plant^{-1}, seed yield ha^{-1}, oil yield ha^{-1}, linoleic acid, oleic acid, palmitic acid and stearic acid between the A lines and Rf testers on one side and their F_1 hybrids on the other indicate the presence of genetic differences among the studied genotypes. A_5 and A_7 had the highest head diameter, 100-seed weight, and the number of seeds plant^{-1}, as well as the number of leaves. However, A_1 and A_{33} produced higher 100-seed weight and more unfilled seed %. The superiority of A_5 and A_7 in seed yield and most of its components might be attributed to the improved plant type characters; *i.e.*, dry matter production, leaf area index (LAI), and the number of filled seeds that compensated for its lower 100-seed weight.

3.3 Heterosis effects

The seed yield of sunflower is a complex character that depends on many traits and varies with the environment. The changeable magnitude of mid parent and better parent heterosis was observed in the hybrids for seed yield per plant. Results in Table 6 showed that seed yield had significant and positive heterosis for all hybrids over mid parent and 16 crosses over better parent respectively. The hybrid $A_{13} \times Rf_1$, $A_{13} \times Rf_{18}$, and $A_1 \times Rf_9$ had the highest significant positive values for heterosis for mid, better parents. The combinations $A_5 \times Rf_1$ which were best for oil content, 100-seed weight and head diameter, and the number of seeds plant^{-1} respectively, these combinations involving high × high parents, indicating that additive × additive effects which are fixable components. The combinations $A_{13} \times Rf_1$, $A_1 \times Rf_9$, and $A_{13} \times Rf_{18}$ have low × high and low × low combining parents, respectively, indicating good complementation between favorable alleles of the involved parents. Present results are in agreement with those of Hladni *et al.* (2007) who reported that heterotic values for seed yield were significantly positive relative to parental average as well as better parents. Higher heterosis for seed yield per plant was also reported by Lakshman *et al.* (2020). The statistical differences within and between parental lines and resulting cross combinations indicate real genetic differences and heterotic impact of high magnitude on the important agronomic traits was expected. A highly significant heterosis

Table 5. Mean performance of yield and oil quality components in sunflower.

Genotypes	SYP	SYF	OYF	PA	SA	OA	LA
B_1	61.28 ± 0.72	1.98 ± 1.330	0.86 ± 0.034	4.75 ± 0.08	2.54 ± 0.08	66.16 ± 0.12	25.74 ± 0.04
B_5	66.09 ± 0.87	2.02 ± 1.362	0.82 ± 0.030	4.41 ± 0.06	2.13 ± 0.02	63.34 ± 0.83	29.88 ± 0.85
B_7	65.14 ± 2.51	2.11 ± 1.421	0.91 ± 0.061	5.40 ± 0.08	2.42 ± 0.02	56.24 ± 0.18	35.25 ± 0.02
B_9	62.91 ± 1.32	1.83 ± 1.244	0.71 ± 0.033	4.95 ± 0.10	4.67 ± 0.13	65.73 ± 0.03	23.96 ± 0.24
B_{11}	61.57 ± 1.13	1.92 ± 1.274	0.80 ± 0.006	4.67 ± 0.24	4.97 ± 0.10	55.68 ± 1.18	34.28 ± 1.11
B_{13}	57.91 ± 0.77	1.68 ± 1.130	0.65 ± 0.032	4.81 ± 0.14	3.46 ± 0.09	60.44 ± 0.48	30.77 ± 0.25
B_{33}	53.86 ± 2.31	1.65 ± 1.095	0.69 ± 0.049	5.78 ± 0.13	3.47 ± 0.19	53.66 ± 0.99	36.31 ± 0.48
Rf_1	47.47 ± 3.32	1.58 ± 1.065	0.73 ± 0.053	4.80 ± 0.14	2.40 ± 0.08	56.38 ± 1.10	35.83 ± 1.15
Rf_9	39.79 ± 5.21	1.02.669	0.37 ± 0.057	5.52 ± 0.03	2.88 ± 0.07	47.75 ± 1.62	42.98 ± 0.12
Rf_{18}	42.41 ± 0.29	1.28 ± 0.844	0.55 ± 0.021	5.17 ± 0.12	3.12 ± 0.01	56.13 ± 1.09	34.76 ± 1.20
$A_1 \times Rf_1$	75.35 ± 6.63	2.97 ± 1.968	1.36 ± 0.047	4.66 ± 0.22	2.89 ± 0.06	58.75 ± 0.69	32.68 ± 0.95
$A_1 \times Rf_9$	84.23 ± 5.05	3.47 ± 2.348	1.50 ± 0.050	4.37 ± 0.25	2.33 ± 0.02	77.50 ± 1.07	14.51 ± 1.22
$A_1 \times Rf_{18}$	68.97 ± 8.91	2.91 ± 1.913	1.19 ± 0.050	4.70 ± 0.22	2.80 ± 0.12	57.87 ± 1.60	34.09 ± 0.96
$A_5 \times Rf_1$	91.37 ± 10.84	3.88 ± 2.569	1.73 ± 0.050	4.16 ± 0.14	3.74 ± 0.16	68.64 ± 1.10	22.83 ± 1.26
$A_5 \times Rf_9$	74.13 ± 1.56	2.93 ± 1.957	1.22 ± 0.065	5.46 ± 0.20	5.04 ± 0.09	71.91 ± 0.19	15.77 ± 0.92
$A_5 \times Rf_{18}$	79.58 ± 4.95	3.25 ± 2.137	1.40 ± 0.009	5.35 ± 0.22	4.42 ± 0.22	65.01 ± 0.74	24.56 ± 0.55
$A_7 \times Rf_1$	76.62 ± 6.08	3.11 ± 2.068	1.33 ± 0.064	5.11 ± 0.09	2.41 ± 0.17	51.58 ± 2.88	40.82 ± 0.13
$A_7 \times Rf_9$	63.28 ± 8.92	2.57 ± 1.674	1.11 ± 0.126	4.73 ± 0.04	2.81 ± 0.11	64.68 ± 0.74	26.98 ± 1.11
$A_7 \times Rf_{18}$	83.22 ± 9.69	3.45 ± 2.310	1.51 ± 0.037	5.66 ± 0.09	2.44 ± 0.27	48.22 ± 1.50	42.24 ± 0.21
$A_9 \times Rf_1$	74.93 ± 4.66	2.96 ± 1.951	1.28 ± 0.090	4.37 ± 0.08	2.63 ± 0.21	60.90 ± 2.57	31.97 ± 0.44
$A_9 \times Rf_9$	72.17 ± 5.36	2.75 ± 1.862	1.07 ± 0.059	4.52 ± 0.05	2.75 ± 0.17	67.33 ± 1.85	24.93 ± 0.19
$A_9 \times Rf_{18}$	66.34 ± 2.01	2.37 ± 1.561	0.89 ± 0.059	4.78 ± 0.10	2.92 ± 0.17	66.05 ± 2.41	25.71 ± 2.06
$A_{11} \times Rf_1$	78.50 ± 4.50	3.15 ± 2.085	1.33 ± 0.048	3.72 ± 0.20	3.15 ± 0.13	76.21 ± 1.87	14.39 ± 1.93
$A_{11} \times Rf_9$	70.40 ± 2.48	2.81 ± 1.874	1.18 ± 0.036	4.22 ± 0.47	3.55 ± 0.09	67.25 ± 0.62	24.39 ± 1.19
$A_{11} \times Rf_{18}$	72.58 ± 5.41	2.76 ± 1.828	1.11 ± 0.003	3.83 ± 0.13	2.56 ± 0.14	76.64 ± 1.48	15.66 ± 1.33
$A_{13} \times Rf_1$	90.83 ± 9.76	3.68 ± 2.455	1.56 ± 0.042	3.90 ± 0.02	3.86 ± 0.08	72.23 ± 1.43	19.45 ± 1.50
$A_{13} \times Rf_9$	67.72 ± 7.80	2.68 ± 1.779	1.14 ± 0.080	5.37 ± 0.25	1.95 ± 0.03	51.34 ± 1.99	40.55 ± 0.05
$A_{13} \times Rf_{18}$	81.14 ± 5.17	3.44 ± 2.285	1.54 ± 0.012	5.12 ± 0.10	2.89 ± 0.03	61.72 ± 1.48	29.84 ± 1.35
$A_{33} \times Rf_1$	72.31 ± 7.94	2.88 ± 1.913	1.21 ± 0.012	5.15 ± 0.13	2.34 ± 0.06	51.32 ± 2.31	40.72 ± 0.02
$A_{33} \times Rf_9$	55.10 ± 3.71	2.37 ± 1.564	0.95 ± 0.022	5.11 ± 0.03	3.17 ± 0.01	52.99 ± 1.74	38.05 ± 2.37
$A_{33} \times Rf_{18}$	58.83 ± 4.32	2.60 ± 1.736	1.11 ± 0.033	5.19 ± 0.14	2.83 ± 0.16	55.18 ± 1.12	35.88 ± 1.28
Mean	68.26	2.58	1.09	4.83	3.08	61.51	29.93
LSD (0.05)	11.89	0.24	0.14	0.72	0.27	3.33	2.56

SYP = Seed yield/plant (g); SYH = Seed yield (t/ha); OYH = Oil yield (t/ha); LA = linoelic acid; OA = oleic acid; PA = palmitic acid; SA = stearic acid; Values = means ± Standard division.

impact on seed yield plant^{-1}, seed and oil yield ha^{-1} and fatty acids (up to some extent) both relative to parental mean and better parent was noted.

3.4 Seed yield

Significant and desirable positive mid-parent heterosis was observed in all 21 F_1 hybrids, while twelve hybrids manifested heterobeltiosis revealing that hybrids could produce higher seed yield due to dominant or over-dominant genes. The superiority of hybrids over open-pollinated populations in terms of uniformity, productivity, yield stability, oil content, and tolerance to pests and diseases shifted the breeding emphasis from population improvement to heterosis breeding. The hybrids such as $A_{13} \times Rf_{18}$, $A_1 \times Rf_9$ and $A_{13} \times Rf_1$ expressed high relative heterosis of 133.01, 131.25 and 126.24%, and heterobeltiosis of 105.54, 75.07%, and 119.48%, respectively (Tab. 6). The superiority these hybrids might be due to seed yield plant^{-1} and yield attributes. Positive mid-parent heterosis has also been reported by Habib *et al.* (2007) in sunflower. Similarly, positive heterosis over the best parent has also been reported by Memon *et al.* (2015), Depar *et al.* (2017) and Khan *et al.* (2019) and Lakshman *et al.* (2020) for seed yield (kg/ha^{-1}.) in sunflower. It is, therefore, concluded that five hybrids viz., $A_1 \times Rf_9$, $A_{13} \times Rf_1$, $A_{13} \times Rf_{18}$, $A_5 \times Rf_1$, and $A_7 \times Rf_{18}$ can be exploited for hybrid seed development on a commercial basis.

3.5 Oil yield

Oil yield is an important trait in sunflower which depends on the oil content of the genotype. The results on heterosis for oil yield kg/ha^{-1} depicted in Table 6 suggested that hybrids $A_{13} \times Rf_{18}$ (155.96%), $A_{13} \times Rf_1$ (126.44%), $A_1 \times Rf_9$ (143.79%),

Table 6. Heterosis over mid-parent (MP), better-parent (BP) for seed yield plant^{-1}, seed and oil yield ha^{-1} in sunflower genotypes.

Hybrid	Seed yield /plant (g)		Seed yield (t/ha)		Oil yield (t/ha)	
	MP	BP	MP	BP	MP	BP
$A_1 \times Rf_1$	38.58**	22.96**	67.20	50.06	71.05	57.92
$A_1 \times Rf_9$	66.66**	37.44**	131.25	75.07	143.79*	75.08
$A_1 \times Rf_{18}$	33.02**	12.54*	78.51	46.93	68.74	38.24
$A_5 \times Rf_1$	60.93**	38.26**	115.86	92.12	123.77*	111.08
$A_5 \times Rf_9$	40.03**	12.17*	92.91	45.11	104.79	49.18
$A_5 \times Rf_{18}$	46.70**	20.42**	97.28	61.18	105.08	71.11
$A_7 \times Rf_1$	36.08**	17.62**	68.74	47.31	62.62	46.14
$A_7 \times Rf_9$	20.61**	−2.86	64.13	21.66	72.30	21.55
$A_7 \times Rf_{18}$	54.75**	27.76**	103.45	63.41	106.33	65.21
$A_9 \times Rf_1$	35.76**	19.10**	74.06	62.10	78.83	81.23
$A_9 \times Rf_9$	40.55**	14.72*	93.67	50.85	97.51	51.03
$A_9 \times Rf_{18}$	25.98**	5.45	52.90	30.05	41.96	25.96
$A_{11} \times Rf_1$	43.99**	27.50**	80.33	64.07	74.46	66.13
$A_{11} \times Rf_9$	38.92**	14.35*	91.08	46.19	101.17	47.48
$A_{11} \times Rf_{18}$	39.60**	17.88**	72.25	43.51	63.81	37.78
$A_{13} \times Rf_1$	72.38**	56.84**	126.24	119.48	126.44*	115.14
$A_{13} \times Rf_9$	38.64**	16.95**	99.35	60.28	121.14	73.88
$A_{13} \times Rf_{18}$	61.76**	40.11**	133.01	105.54	155.96*	135.22
$A_{33} \times Rf_1$	42.72**	34.25**	78.95	75.09	71.86	76.95
$A_{33} \times Rf_9$	17.68**	2.31	78.06	44.12	79.09	38.44
$A_{33} \times Rf_{18}$	22.22**	9.23	77.91	58.13	77.99	61.90
LSD (0.05)	10.30	11.89	0.21	0.24	0.12	0.14

*, ** and ns indicates significant at the 0.05 and 0.01 level of probability and non-significant, respectively.

and $A_5 \times Rf_1$ (123.77%), gave high relative heterosis % and better parent heterosis of 135.22, 115.14, 75.08 and 111.08% for oil yield kg/ha^{-1}. The results showed that oil yield had significant and positive heterosis for all hybrids over a mid and better parent. The superiority of these hybrids in seed and oil yields ha^{-1} may be due to their genetic constitution and its capability of withstanding climatic fluctuation and soil conditions than ones and related to the increase in root length, a number of leaves plant^{-1}, leaf area index, head diameter, 100-seed weight, seed weight plant^{-1}, daily seed weight plant^{-1} and oil content. The extent of heterotic effects for oil yield kg ha^{-1} was greater than other yield and oil traits which indicated that oil yield may be improved in further generations through simple selection procedures. Present results are following those of Memon *et al.* (2015), who observed heterosis over mid parent and a better parent and noted a higher magnitude of average heterosis of (0.08–194.00%), and (−30.93–182.47%) for the better parent in oil yield kg/ha. Lakshman *et al.* (2020) also observed high positive heterosis over mid and better parents for oil yield.

3.6 Linoleic acid (C18:2)

Linoleic acid is an important ω-6 (omega-6) fatty acid out of major polyunsaturated fatty acids because it has health benefits of lowering blood cholesterol levels (Orsavova *et al.*, 2015). The heterosis over mid parent for linoleic acid content ranged from −81.24% ($A_1 \times Rf_9$) to −42.81–38.49% ($A_7 \times Rf_1$), (Tab. 7). Linoleic acid belongs to the unsaturated fatty acid group. Similar to oleic acid positive heterosis is considered to be desirable for this trait also. As many as twenty-eight hybrids recorded significant positive heterosis over mid-parent. The heterobeltosis ranged from −66.24% ($A_1 \times Rf_9$) to 22.87% ($A_7 \times Rf_{18}$). The fatty acid composition changes depending on genotypes and some other factors such as environmental conditions, planting and harvesting time (Roche *et al.*, 2006). The three hybrids recorded significant positive heterosis over the better parent. These results are in agreement with the results reported by Shamshad *et al.* (2016) and Harun (2019). Linoleic acid constitutes unsaturated fatty acids which are desirable from the health point of view. So significant positive heterosis is desirable for linoleic acid to improve the quality of sunflower oil.

3.7 Oleic acid (C18:1)

The high oleic sunflower types are superior to regular sunflower, soybean and peanut oils due to suitability for cooking, and frying for better resistance against heat (Smith *et al.*, 2007). This is an important ω-9 (omega-9) fatty acid. The heterosis over mid parent ranged from −14.18% ($A_7 \times Rf_{18}$) to 39.59% ($A_{11} \times Rf_1$), (Tab. 7). Oleic acid is considered to be important from a health point of view, as it belongs to the unsaturated group of fatty acids and enhances the shelf-life of oil due to its oxidative stability. Thus, the emphasis was given to exploit positive heterosis for oleic acid

Table 7. Heterosis over mid-parent (MP), better-parent (BP) for fatty acids composition in sunflower.

Hybrid	Palmitic acid		Stearic acid		Oleic acid		Linoleic acid	
	MP	BP	MP	BP	MP	BP	MP	BP
$A_1 \times Rf_1$	8.27**	−2.92**	17.00	13.78**	−4.11*	−11.20**	−50.94**	−8.79**
$A_1 \times Rf_9$	−9.25**	−20.83**	−14.02	−19.10**	36.25**	17.29**	−81.24**	−66.24**
$A_1 \times Rf_{18}$	−11.90**	−9.09**	−1.06**	−10.25**	−5.36*	−12.53**	−47.56**	−1.93
$A_5 \times Rf_1$	−9.56**	−13.33**	65.12**	55.83**	14.67**	8.37**	−66.76**	−36.28**
$A_5 \times Rf_9$	9.97**	−24.64**	101.20**	75.00**	29.45**	13.52**	−78.88**	−60.98**
$A_5 \times Rf_{18}$	11.69**	−19.54**	68.38**	41.67**	8.83**	2.64	−63.39**	−29.34**
$A_7 \times Rf_1$	0.20	−5.37**	0.00	−0.41	−8.40**	−8.51**	−42.81**	13.93**
$A_7 \times Rf_9$	−13.37**	−14.31**	6.04**	−2.43**	24.40**	15.01**	−67.14**	−37.23**
$A_7 \times Rf_{18}$	7.10**	4.81**	−11.91**	−21.79**	−14.18**	−14.26**	−38.02**	22.87**
$A_9 \times Rf_1$	−10.36**	−11.72**	−25.60**	−43.68**	−0.25	−7.35**	−51.36**	−10.77**
$A_9 \times Rf_9$	−13.66**	−18.12**	−27.15**	−41.11**	18.66**	2.43	−67.39**	−42.00**
$A_9 \times Rf_{18}$	−5.53**	−7.54**	−25.03**	−37.47**	8.40**	0.49	−59.90**	−26.04**
$A_{11} \times Rf_1$	−21.44**	−22.50**	−14.52**	−36.62**	39.59**	38.72**	−79.70**	−59.84**
$A_{11} \times Rf_9$	−17.17**	−23.55**	−9.55**	−28.57**	30.04**	20.78**	−70.11**	−42.25**
$A_{11} \times Rf_{18}$	−22.15**	−25.92**	−36.71**	−48.49**	37.09**	37.64**	−77.40**	−54.95**
$A_{13} \times Rf_1$	−18.83**	−18.92**	31.74**	11.56**	23.66**	19.51**	−71.86**	−45.72**
$A_{13} \times Rf_9$	3.97**	−2.72**	−38.49**	−43.64**	−5.09**	−15.06**	−49.10**	−5.42**
$A_{13} \times Rf_{18}$	2.61**	−0.97*	−12.15**	−16.47**	5.89**	2.12	−55.81**	−14.15**
$A_{33} \times Rf_1$	−2.65**	−10.90**	−20.27**	−32.56**	−6.72**	−8.97**	−43.37**	12.15**
$A_{33} \times Rf_9$	−9.56**	−11.59**	−0.16	−8.65**	4.50*	−1.25	−53.95**	−11.47**
$A_{33} \times Rf_{18}$	−5.21**	−10.21**	−14.11**	−18.44**	0.52	−1.69	−48.96**	−1.18
L.S.D	0.75	0.86	0.28	0.33	3.46	3.99	2.65	2.35

*, ** and ns indicates significant at the 0.05 and 0.01 level of probability and non-significant, respectively.

content in sunflower hybrids. In the present investigation, thirteen of the twenty-one experimental hybrids recorded significant positive heterosis over a mid-parent, whereas, eight hybrids recorded significant positive heterosis over the better parent. Some environmental factors, such as temperature, sunlight and precipitation, affect the growth of sunflowers differently. Every 1 °C increase in temperature causes a 2% increase in oleic acidcontent (Demurin *et al.*, 2000). Grunvald *et al.* (2013) reported that the temperature, especially during the maturation of the seeds, the amount of oleic acid in the oil of conventional sunflower genotypes could exceed 70%. Higher temperatures led to average increases of up to 35% for this fatty acid. Oil and fatty acid composition in seeds are important targets in sunflower breeding.

3.8 Palmitic acid (C16:0)

The range of heterosis over mid parent was from −22.15% ($A_{11} \times Rf_{18}$) to 11.65% ($A_5 \times Rf_{18}$) and the number of hybrids with negative heterosis was 14, of which, all were significant, the range of heterobeltosis was from −25.92% ($A_{11} \times Rf_{18}$) to 4.81% ($A_7 \times Rf_{18}$), (Tab. 7). Twenty hybrids recorded significant negative heterosis over the better parent. Heterosis for palmitic acid has been recorded by Tan (2010). As palmitic acid belongs to the unsaturated group of fatty acids, a lot of health risks are involved with a higher concentration of this fatty acid. In the present study hybrids ($A_{11} \times Rf_{18}$) exhibited significantly low levels of palmitic acid and these might serve as potential hybrids, which can be used in the future breeding programs.

3.9 Stearic acid (C18:0)

The heterosis over mid parent for stearic acid content ranged from −38.49% ($A_{13} \times Rf_9$) to 101.2% ($A_5 \times Rf_9$), (Tab. 7). Similar to palmitic acid, negative heterosis for this fatty acid is considered to be desirable. Most of the experimental hybrids recorded highly significant negative heterosis over mid-parent, a better parent. Heterobeltosis ranged from 48.49% ($A_{11} \times Rf_{18}$) to 75.00% ($A_5 \times Rf_9$). Negative heterosis for stearic acid in sunflower has also been reported by Ferfuia *et al.* (2012), Shamshad *et al.* (2016) and Harun (2019).

3.10 Gene action and heritability

3.10.1 Genetic components for seed yield and quality traits in sunflower

Genotypes are presented in Table 8. Results indicated that the non-additive genetic variance including dominance (δ^2D) was larger than their corresponding additive genetic variance (δ^2A) for all studied traits. It was also indicated that non-additive genetic variances played a major role in the inheritance of these traits. This showed that the hybridization program could be effective in the improvement of those traits. The importance of non-additive variances was verified by the

Table 8. Genetic components for seed yield and quality traits in sunflower genotypes during summer 2017.

Genetic components	Seed yield/plant	Seed yield/ha^{-1}	Oil yield/ha^{-1}	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid
G.C.A	2.92	4592.84	1502.32	0.01	0.02	2.09	2.16
S.C.A	31.56	102 225.51	24 036.42	0.15	0.30	56.91	58.17
δ^2A	5.84	9185.68	3004.63	0.02	0.04	4.18	4.33
δ^2D	31.56	102 225.51	24 036.42	0.15	0.30	56.91	58.17
$(\delta^2D/\delta^2A)^{1/2}$	2.32	3.34	2.83	0.89	2.88	3.69	3.67
h^2_b	67.91	84.06	78.89	68.45	86.90	91.10	94.67
h^2_n	10.61	6.93	8.77	9.80	9.43	6.23	6.56
The proportional contribution of lines, testers, and their interactions							
L	43.10	40.99	43.66	52.09	65.08	56.64	56.83
T	22.79	20.00	21.60	16.45	0.39	2.09	2.26
L × T	34.10	39.01	34.74	31.46	34.53	41.27	40.90

dominance degree ratio, which was more than uniform for all studied traits Table 6. The preponderance of non-additive gene action for these traits was supported in the results of Chahal *et al.* (2019) and Lakshman *et al.* (2019).

Heritability values in broad and narrow senses were calculated and results are shown in Table 8. Results revealed that broad heritability ($H^2_{b.s}$) estimates were larger than their corresponding values of narrow-sense heritability ($H^2_{n.s}$) for all studied traits. Values of heritability in the broad sense ranged between 94.67 for linoleic acid and 67.91 for seed yield plant^{-1}, while the heritability in the narrow sense ranged from 6.23 for oleic acid to 10.61 for seed yield plant^{-1}. These results were in agreement with those obtained by many other authors Attia *et al.* (2012) and Memon *et al.* (2014).

3.10.2 Contribution of lines, testers and line × tester interactions

Lines, testers, and their interaction revealed different contributions in the expression of the studied traits Table 8. The contribution of lines in the expression of seed yield plant^{-1} (43.10%), seed yield per hectare (40.99%), oil yield per ha^{-1} (43.66%), palmitic acid (52.09%), stearic acid (65.08%), oleic acid (56.64%), and linoleic acid (56.83%) was the greatest. The contribution of testers in the expression of seed yield plant^{-1} and seed yield ha^{-1} and oil yield ha^{-1} was the greatest. Its contributions in the expression of stearic, oleic, and linoleic acids were almost neglected. Interaction between lines and testers expressed high contributions in many traits, being the highest in oleic acid and linoleic acid.

4 Conclusion

Significant differences existed among the genotypes (inbreds and hybrids) in their mean values of seed yield and fatty acids traits. The heterosis values for seed yield per plant and fatty acids were highly significant in almost all of the hybrids both mid-parent and a better parent. The results revealed that additive and non-additive gene action was involved in the inheritance of all traits. The dominance variances (σ^2D) were more for seed yield and oil quality as compared to additive variances (σ^2A) and high heritability was found in these traits. This study may prove useful in the future development of high-yielding sunflower hybrids.

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