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HETEROTIC PERFORMANCE OF F_1 HYBRIDS FOR PHENOLOGICAL, YIELD, OIL AND PROTEIN TRAITS OF SUNFLOWER

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ABSTRACT

The present study was conducted at Oil Seeds Section, Agriculture Research Institute, Tandojam, Pakistan. The crosses were attempted in line x tester mating design during 2008. Six cytoplasmic male sterile female lines i.e. ARG-0306, 64-A-93, PSF-025, SF-187, ARG-0405 and ARG-0505 and three testers, viz. RHP-46, RHP-64 and ARG-0106 were crossed in a line x tester mating design. Thus 18 F_1 hybrids were developed for evaluation of heterotic effects for days to 50% flowering, stem girth, head diameter, 1000-achene weight, seed yield kg ha^{-1} and oil and protein contents during 2009. The experiment was conducted in a Randomized Complete Block Design (RCBD) with four replications. The analysis of variance revealed significant differences among genotypes, parents, F_1s and parents vs. hybrids for all these traits. The F_1 hybrids like ARG-0405 x RHP-46 expressed maximum desirable negative heterobeltiosis of -24.11% for days to 50% flowering; 64-A-93 x ARG-0106 explicated a maximum desirable better parent heterosis of 32.55% for stem girth; ARG-0505 x RHP-46 demonstrated a highest heterobeltiotic effects of 43.80% for head diameter; 64-A-93 x RHP-46 exhibited a maximum high-parent heterosis of 28.80% for 1000-seed weight, 32.87% for seed yield and 11.85% for oil content, and F_1 hybrid SF-187 x ARG-0105 manifested 42.86% heterobeltiosis for protein content. These hybrids therefore are suitable for hybrid crop development. Results further revealed that if two parents with good performance involved in crosses expressed high heterosis, that heterosis was due to additive genes, while if one good and one poor performing parent manifested high heterotic effects, that heterosis was due to complementary genes, and if both poor performing parents manifested high heterosis, such heterotic effects were due to dominant genes.

Keywords: F_1 hybrids, heterosis, seed yield and oil traits, sunflower

INTRODUCTION

Expression of high heterotic effects in sunflower made it to emerge as one of the important oilseed crops in the world (Ahmad *et al.*, 2005). Sunflower hybrids are

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generally high yielding, possessing more oil and protein contents, resistant to lodging, abiotic and biotic stresses (Khan *et al.*, 2008a). The F_1 hybrids at preset are being grown all over the world (Sher *et al.,* 2010) yet Pakistan is way behind in developing potential hybrids. In hybrid breeding program, grain and oil yields have been increased tremendously by exploiting hybrid vigour in sunflower and many other crop species (Kaya, 2005). The higher heterosis in hybrids depends on the combining ability of male and female inbreds (Tan, 2010). High heterotic effects for yield and other important traits remained major concern by many earlier researchers (Bajaj *et al.*, 2003; Hladni *et al*., 2003; Gowtham, 2006; Kamati, 2009; Abdullah *et al*., 2010; Karasu *et al.*, 2010). Heterosis is explained as the advantage of F_1 hybrids over their inbred parents involved in the crosses. The main requirement of model hybrid is to identify parental lines those combine their desirable genes and produce better F_1 hybrids. Hybrid vigour remained a dynamic strength to accept F_1 sunflower hybrids as oilseed crop. Reduced maturity period, stability in performance, uniformity in stand, dwarf plant height, more leaves plant^{-1}, bigger head size, more seeds head^{-1}, higher 1000-achene weight, more seed yield and oil contents, resistance to lodging, insect-pests and diseases, all theses contribute an important role in building-up optimum plant structure of sunflower hybrids (Memon *et al*., 2015). Ideotype 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 important consideration to evolve thriving F_1 hybrids (Mena *et al*., 2013). For hybrid sunflower development, several earlier researchers such as Khan *et al*. (2008b); Aslam *et al*. (2010); Abdullah *et al*. (2010) observed heterotic effects for seed yield and oil quality. In general, they observed higher heterosis for plant height, head diameter and seeds per head. Considerably higher heterotic effects like up to 26% for plant height, 58% for head diameter, 134% for achene per head, 173% for 1000-seed weight and 218% for seed yield were noted. It was also observed that all the hybrids exhibited above 100% heterotic effects for 1000-seed weight and seed yield. The present study therefore was carried-out to estimate heterotic effects of eighteen newly evolved F_1 sunflower hybrids.

MATERIALS AND METHODS

Present research was conducted at Oil Seeds Section, Agriculture Research Institute, Tandojam during 2009. Six female lines viz. ARG-0306, 64-A-93, PSF-025, SF-187, ARG-0405 and ARG-0505 and three testers RHP-46, RHP-64 and ARG-0106 were crossed in a line x tester mating design during 2008. Thus 18 F_1 hybrids were evaluated in 2009 for their heterotic effects. At maturity, the crossed heads were collected, dried and threshed separately. The well-filled seeds from each cross were separated for F_1 hybrid evaluation. The F_1 seeds alongwith parents were grown in a randomized complete block design with four replications in a plot size of 12 x 25 feet. To calculate the heterotic effects, the data from F_1 plants and their parents were recorded for days to 50% flowering, stem girth (cm), head diameter (cm), 1000-achene weight (g), seed yield (kg ha^{-1}), oil and protein content in percentage. For taking the observations, ten plants were randomly tagged from each replication and in each genotype. For determining significant differences among the parents, F_1 hybrids and parents vs. F_1 hybrids for above traits, the ANOVA was applied. The mean differences were determined by using LSD at 1 and 5% probability levels. All the inputs were applied as recommended for sunflower. The data were analyzed according to Gomez and Gomez (1984), while heterotic effects were calculated according to formulae developed by Fehr (1987).

RESULTS AND DISCUSSION

Analysis of variance and mean performance of inbred lines

The mean squares are presented in Table 1 which showed that variation among genotypes including parents, F_1s and parents vs. hybrids were significant which allowed determining the heterotic performance of F_1 hybrids. In genetic terms, the best inbred lines are expected to have a masking effect due to its desirable dominant alleles; therefore it should not be preferred to use potential tester. Hence, in order to obtain the real potential of lines, poor performing testers are to be used. In present study, the cytoplasmic male sterile lines (CMS) and tester (restorer lines) used provided a wide range of expressions for all different traits studied. Mean values of seven traits of six lines and testers are given in the Table 2. The mean performance of cytoplasmic male sterile (CMS) female lines indicated that SF-187 performed better for almost all traits like it took minimum (52.50) days to 50% flowering and very closely followed by line 64-A-93 (53.25 days), yet both the lines produced equally bigger (14.70 cm) heads, followed by ARG-0405 (14.18cm). Maximum 1000-seed weight (42.99 g) was also produced by SF-187, followed by 64-A-93 (41.08 g), whereas maximum seed yield ha^{-1} (2288.00 kg) was also produced by SF-187, closely followed by ARG-0405 (2254.30 kg). Line SF-187 ranked top with maximum oil content of 41.32 % followed by ARG-0405 (41.17%). It was observed that PSF-025 produced Chubby stems with maximum girth of 4.317 cm. Line PSF-025 possessed higher protein content (22.96%) and next in rank was ARG-0306 (22.17%). From above results, it may be inferred that from females SF-187 and PSF-025 performed very well for 50% flowering, seed yield, oil and protein percentage, thus these lines may be utilized for further sunflower breeding programs so as to develop new sunflower hybrids or composites with improved yield, oil and protein contents.

The most desirable male tester is the one which provides maximum information on the performance of a line in cross combinations under different environmental conditions. Mean values of seven traits of three testers are given in Table 2. Results showed that male RHP-46 performed better for about all the traits against other two. According to the results, male ARG-0106 opened 50 % flowers earlier (50.75 days), followed by RHP-46 (51.25 days). For head diameter, male RHP-46 produced larger (9.45 cm) heads and recorded more stem girth (3.97 cm). Both males RHP-46 and ARG-0106 in same manner produced higher 1000-seed weight, seed yield kg per ha and oil content. In case of protein content, higher protein content (19.38%) was recorded by male ARG-0106 followed by RHP-64 which gave 18.17% protein content. Similar to our findings, Abdullah *et al*. (2010) and Attia *et al*. (2012) observed significant differences in the performance of inbred lines of sunflower for days to 50% flowering, head diameter, 1000-acene weight, achene yield kg per ha and protein and oil percentages. While Sher *et al*. (2009) and Memon *et al.* (2015) analyzed the mean squares of parents, hybrids and parents vs. hybrids from line x tester mating design. They reported significant differences for days to first 75% maturity, stem girth, head diameter, 1000-seed weight, seed yield kg per ha and oil and protein content in sunflower. Genetic variation among characters associated with plant growth and resultant morphological and physiological differences serve as the basis for development of lines and hybrids with improved agronomic traits. Siddiqi *et al*. (2012) obtained maximum oil content of 42.00% from parental line TR-120 and minimum of 35.00% from TR-6023.

Table 1. Mean squares from analysis of variance for phenological, seed yield, oil and protein contents in F_1 hybrids of sunflower

Source of Variation	**D.F**	**Days to 50% flowering**	**Stem girth**	**Head diameter**	**1000-achene weight**	**Seed yield (kg ha^{-1})**	**Oil content**	**Protein content**
Replication	03	34.69	0.02	0.06	2.97	2487.46	0.522	0.061
Genotypes	26	61.43**	1.05**	48.38**	109.24**	758120.49**	48.624**	68.189**
Parents (P)	08	15.49**	0.18**	28.61**	23.83**	574551.16**	52.313**	12.588**
F_1 hybrids (H)	17	11.60**	0.55**	4.23**	26.33**	65957.32**	15.313**	6.567**
P vs. H	01	1276.07**	16.49**	957.18**	1984.71**	13993467.54**	586.788**	1560.56**
Error	78	2.92	0.01	0.17	0.34	36.52	22.143**	9.337**

** = Significant at 1% probability level.

Table 2. Parental mean values for phenological, yield, oil and protein content of female and male inbred lines of sunflower

Female parents (Lines)	**Days to 50% flowering**	**Stem girth (cm)**	**Head diameter (cm)**	**1000- seed weight (g)**	**Seed yield (kg ha^{-1})**	**Oil content (%)**	**Protein content (%)**
ARG-0306	55.00	4.269	14.10	39.01	2152.0	39.70	22.17
64-A-93	53.25	4.313	14.70	41.08	2230.2	40.65	21.68
PSF-025	55.25	4.317	14.15	39.16	2143.8	38.47	22.96
SF-187	52.50	4.134	14.70	42.99	2288.0	41.32	20.53
ARG-0405	56.00	4.201	14.18	40.24	2254.3	41.17	20.73
ARG-0505	54.50	4.174	13.63	38.46	2220.0	40.22	21.99
Mean	54.42	4.235	14.24	40.15	2214.7	40.25	21.68
LSD (5%)	3.32	0.080	0.67	0.852	8.63	1.70	0.41
LSD (1%)	4.60	0.111	0.93	1.179	11.93	2.34	0.57
Male Parents (Lines)	**Days to 50% flowering**	**Stem girth (cm)**	**Head diameter (cm)**	**1000 seed weight (g)**	**Seed yield (kg ha^{-1})**	**Oil content (%)**	**Protein content (%)**
RHP-46	51.25	3.97	9.45	37.44	1468.80	35.00	17.63
RHP-64	51.25	3.84	8.75	36.13	1462.20	33.57	18.17
ARG-0106	50.75	3.72	8.65	35.12	1455.30	31.71	19.38
Mean	51.08	3.84	8.95	36.23	1462.10	33.43	18.39
LSD (5%)	2.77	0.15	0.12	0.58	10.07	1.07	0.65
LSD (1%)	4.19	0.23	0.17	0.88	15.26	1.62	0.99

Heterotic effects in F_1 hybrids of sunflower

The main objective of sunflower breeding is to develop productive F_1 hybrids with stability in performance and higher seed and oil yields. The basic breeding approach in sunflower breeding is the utilization of heterosis with increased vigor of F_1 hybrids relative to their parents (Kaya *et al*., 2012). Heterosis in sunflower is mostly utilized through single-cross hybrids developed by crossing potential female inbred lines (cytoplasmic male sterile) with male inbreds possessing strong fertility-restoring genes. The heterotic effects were calculated from the mean performance of male and female parents (Table 2) and compared with F_1 hybrid performance (Table 3). The characterwise heterotic effects of F_1 hybrids are discussed here under:

Days to 50% flowering

Good parents in crosses are supposed to develop better progenies which could be selected as desirable inbreds for hybrid crop development. The heterotic effects shown in Table 4 suggested that all eighteen hybrids gave notable negative relative heterosis ranging from -6.35 to -20.75% and heterobeltiosis from -9.15 to -24.11% for days to 50% flowering. Nonetheless, F_1 hybrid ARG-0405 x RHP-46 expressed maximum desirable negative relative heterosis (-20.75%) and heterobeltiosis (-24.11%), followed by ARG-0505 x ARG-0106 with relative heterosis and heterobeltiotic effects of -18.29 and -21.10%, respectively. The F_1 hybrid PSF-025 x RHP-64 ranked third with relative heterosis of -17.37% and heterobeltiosis of -20.36% (Table 4). It was also noted that for days to 50% flowering, the better F_1 hybrids expressing higher heterotic and heterobeltiosis involved parents with high x high, low x low and low x high performing parents. The F_1 cross combinations like ARG-0306 x RHP-46 and 64-A-93 x ARG-0106, however recorded minimum (-6.35 and -9.55%) and (-8.17 and -10.33%) relative and better parent heterosis, respectively. The high negative heterosis in F_1 hybrids indicated that above hybrids possess dominant genes with effects in negative directions. Similar to our results, Premalatha *et al*. (2006) and Khan *et al.* (2008b) also reported negative heterosis for early flowering and early maturity.

Stem girth

Positive heterosis for stem girth is considered attractive in sunflower breeding because such hybrids are predictable to provide resistance to lodging. All F_1 hybrids gave positive heterotic effects for stem girth (Table 4). A fair amount of relative heterosis was expressed by the hybrids that varied from 12.23 to 42.30% while heterobeltiosis ranged from 7.98 to 32.55%. Normally, the mid parent heterotic effects for stem girth were little bit better than the high parents as expected. Nonetheless, the hybrids, 64-A-93 x ARG-0106 explicated the maximum desirable relative heterosis (42.30%) and heterobeltiosis (32.55%), next scoring of ARG-0505 x ARG-0106 which gave 35.60 and 28.28% mid parent heterosis and heterobeltiosis correspondingly. The F_1 hybrid ARG-0306 x ARG-0106 stood at third position by expressing 34.93% relative and 26.28% better parent heterosis. Similar to present findings, Faridi *et al*. (2015) also noted that hybrid A6.4 x A12.2 recorded maximum better parent heterosis for stem diameter. It means for stem girth, highly good performing F_1 hybrids exhibited high heterosis and heterobeltiosis which involved the parents with high x low, low x low and low x low performing parents, respectively. High positive heterosis indicated that dominant genes with increasing effects were involved in manifesting higher stem girth and such traits can be utilized for sunflower so as to develop hybrids resistant to lodging.

Table 3. Mean values of F_1 sunflower hybrids for various traits derived from line x tester analysis

F_1 Hybrids (Line x Tester crosses)	Days to 50% flowering	Stem Girth (cm)	Head Diameter (cm)	1000-achene weight	Seed yield (Kg ha^{-1})	Oil Content (%)	Protein Content (%)
ARG-0306 x RHP-46	49.75	4.64	17.98	47.19	2640.2	43.34	28.20
ARG-0306 x RHP-64	47.00	4.97	17.40	43.72	2621.2	43.03	28.37
ARG-0306 x ARG-0106	47.50	5.39	15.30	45.98	2631.7	42.93	29.23
64-A-93 x RHP-46	46.50	4.73	20.50	52.91	2963.3	45.46	27.10
64-A-93 x RHP-64	46.75	5.43	18.55	47.98	2656.0	42.35	29.31
64-A-93 x ARG-0106	47.75	5.72	17.83	46.36	2610.2	39.80	30.92
PSF-025 x RHP-46	45.25	4.77	17.70	45.62	2609.8	39.57	30.99
PSF-025 x RHP-64	44.00	4.90	18.18	48.07	2645.8	42.78	29.23
PSF-025 x ARG-0106	45.75	5.24	17.98	46.60	2644.7	40.77	29.47
SF-187 x RHP-46	46.75	4.56	20.63	53.66	3019.8	45.90	26.79
SF-187 x RHP-64	46.75	4.47	19.95	50.66	2871.8	44.55	27.55
SF-187 x ARG-0106	45.75	4.46	18.73	47.68	2667.8	42.11	29.33
ARG-0405 x RHP-46	42.50	4.62	19.20	48.99	2824.8	45.00	27.47
ARG-0405 x RHP-64	46.00	4.90	19.38	49.69	2764.2	43.83	28.03
RG-0405 x ARG-0106	45.50	5.19	20.18	51.44	2834.8	45.18	27.10
A RG-0505 x RHP-46	46.50	4.65	19.60	49.48	2794.5	44.15	27.93
ARG-0505 x RHP-64	45.25	4.80	18.15	47.30	2663.3	41.48	29.47
ARG-0505 x ARG-0106	43.00	5.35	18.58	48.32	2629.8	40.37	30.16
Mean	46.01	4.93	18.79	48.42	2727.4	42.92	28.70
LSD (5%)	2.14	0.15	0.58	0.86	9.11	0.72	0.23
LSD (1%)	2.86	0.20	0.77	1.15	12.15	0.96	0.31

Head diameter

The larger heads are supposed to set higher number of seeds per head in sunflower. All the F_1 progenies showed a desirable capacity of hybrid vigour for above cited trait (Table 4). The F_1 progenies with positive relative heterosis varied from 50.00 to 76.78% while heterobeltiosis varied from 21.29 to 43.80%. The superior F_1 hybrid was ARG-0405 x ARG-0106 which exhibited a maximum positive mid parent heterosis of 76.78% and 42.31% a better parent heterosis. The F_1 hybrids those manifested higher positive relative heterosis were: SF-187 x RHP-46, SF-187 x RHP-64 and ARG-0505 x RHP-46 with 70.85%, 70.15%, 69.84% heterosis, respectively. However, high parent heterosis of 43.80% was exhibited by ARG-0505 x RHP-46, followed by SF-187 x RHP-46 (40.34%) and 64-A-93 x RHP-46 (39.46%). It was noted that for head diameter, F_1 hybrids exhibiting high heterosis and heterobeltiosis involved the parents with high x low, high x high, high x low and low x high performing parents, respectively. The high heterotic effects of above hybrids may be due to complementary effect of additive genes because such crosses involved parents as one good and one poor performing parent. Parameswari *et al.* (2004) and Abdullah *et al*. (2010) also recorded positive heterosis for yield and head diameter. Whereas Encheva *et al*. (2015) and Encheva and Penchev (2015) reported high magnitude of heterosis for seed yield per plant in comparison to parental mean, followed by head diameter in comparison to better parent. Some hybrids like, PSF-025 x RHP-46 and ARG-0306 x RHP-64 recorded minimum relative heterosis of 50.00 and 52.30% and heterobeltiotic effects of 25.09 and 23.40%, respectively

Table 4. Heterosis in F_1 hybrids of sunflower for various traits in sunflower

F_1 hybrids	Days to 50% flowering		Stem girth		Head diameter		1000-achene weight	
	MPH%	BPH%	MPH%	BPH%	MPH%	BPH%	MPH%	BPH%
ARG-0306 x RHP-46	-6.35	-9.55	12.41	8.71	52.70	27.52	23.46	20.97
ARG-0306 x RHP-64	-11.53	-14.55	22.54	16.35	52.30	23.40	16.38	12.07
ARG-0306x ARG-0106	-10.17	-13.64	34.93	26.28	56.48	26.24	24.06	17.87
64-A-93 x RHP-46	-11.00	-12.68	13.82	9.53	69.77	39.46	34.78	28.80
64-A-93 x RHP-64	-10.53	-12.21	33.16	25.83	58.21	26.19	24.29	16.80
64-A-93 x ARG-0106	-8.17	-10.33	42.30	32.55	52.72	21.29	21.67	12.84
PSF-025 x RHP-46	-15.02	-18.10	14.84	10.47	50.00	25.09	19.11	16.50
PSF-025 x RHP-64	-17.37	-20.36	20.11	13.46	58.78	28.48	27.71	22.77
PSF-025 x ARG-0106	-13.68	-17.19	30.36	21.39	57.72	27.07	25.49	19.01
SF-187 x RHP-46	-9.88	-10.95	12.38	10.40	70.85	40.34	33.45	24.83
SF-187 x RHP-64	-9.88	-10.95	12.23	8.23	70.15	35.71	28.06	17.84
SF-187 x ARG-0106	-11.38	-12.86	13.63	7.98	60.43	27.41	22.09	10.91
ARG-0405 x RHP-46	-20.75	-24.11	12.87	10.02	62.51	35.40	26.15	21.76
ARG-0405 x RHP-64	-14.22	-17.86	21.95	16.69	69.04	36.67	30.13	23.47
ARG-0405 x ARG-0106	-14.75	-18.75	30.93	23.48	76.78	42.31	36.51	27.82
ARG-0505 x RHP-46	-12.06	-14.68	13.88	11.36	69.84	43.80	30.39	28.66
ARG-0505 x RHP-64	-14.42	-16.97	19.89	15.07	62.20	33.16	26.83	22.99
ARG-0505 x ARG-0106	-18.29	-21.10	35.60	28.28	66.79	36.32	31.34	25.64

MPH% = mid parent heterosis and BPH% = better parent heterosis.

1000-achene weight

Higher 1000-achene weight can be obtained from more number and bigger seeds set on the capitulum. Heterotic effects presented in Table 4 revealed that all eighteen F_l progenies showed positive relative heterosis in the range of 16.38 to 36.51% and better parent heterosis varying from 10.91 to 28.80%. The amount of positive relative heterosis and heterobeltiosis were low to moderate in F_1 crosses. From F_1 progenies, the top three good performing hybrids were: ARG-0405 x ARG-0106, 64-A-93 x RHP-46 and SF-187 x RHP-46 with relative heterosis of 36.51%, 34.78% and 33.45% and heterobeltiotic effects 27.82%, 28.80% and 24.83%, respectively. From these results, it may be inferred that for 1000-achene weight, at least three good F_1 hybrids exhibited high relative heterosis and heterobeltiosis which involved the parents with high x low, high x high and high x high *per se* performing parents, respectively. On the contrary, F_1 hybrid ARG-0306 x RHP-64 showed minimum relative heterosis (16.38%) while SF-187 x ARG-0106 recorded lowest better parent heterosis (10.91%). Hladni *et al.* (2003) and Abdullah *et al*. (2010) reported up to 173.1% high heterosis for 1000-seed weight.

Seed yield

The desirable positive mid parent heterosis was noted in all eighteen F_1 progenies (41.65 to 60.77%) and the same hybrids also manifested heterobeltiosis varying from 16.60 to 32.87% (Table 5). This showed that progenies performed better for achene yield due to higher magnitude of fixable genes. The supremacy of F_1 progenies over open-pollinated populations, in terms of seed yield, oil content and resistance to biotic and abiotic stresses is well established in sunflower (Shakuntala *et al*., 2012). Nevertheless, the top three high heterotic hybrids were: SF-187 x RHP-46, 64-A-93 x RHP-46 and SF-187 x

RHP-64 expressed high relative heterosis of 60.77%, 60.22% and 53.16% and heterobeltiosis of 31.99%, 32.87% and 25.52%, respectively. These three hybrids expressed maximum relative heterosis and heterobeltiosis involving the parents with high x high, high x high and high x low performing parents. Looking at the performance of these three hybrids, it may be noted that dominant and complementary genes were involved in manifesting higher heterotic effects. Our results are in conformity with those of Gowtham (2006), who noted higher heterotic effects for seed yield (kg ha^{-1}). The values of heterosis and heterobeltiosis values ranged from 109.8 to 218.3% for seed yield (Abdullah *et al*., 2010). Other hybrids including ARG-0405 x ARG-0106, ARG-0405 x RHP-46 and ARG-0505 x RHP-46 displayed moderate relative heterosis of 52.84, 51.74 and 51.51% and heterobeltiosis of 25.75, 25.31 and 25.88% and involved parents with high x low, high x high and low x high general combiners, respectively for seed yield.

Oil content %

Sunflower produces good quality oil as it contains high proportion of linoleic acid (48-74%), which is a poly-unsaturated fatty acid, an important component of sunflower oil present in the form of triglyceride (Jockovic *et al*., 2014). Sunflower hybrids with higher percentage of oil are desirable for maximum oil yield production on the basis of per unit area land thus higher hybrid vigour is more important for oil content. All the F_1 progenies produced higher amount of heterosis in positive directions, yet the relative heterosis varied from 7.70 to 20.27% while seventeen hybrids demonstrated positive heterobeltiosis ranging from 1.91 to 11.85% (Table 5). The hybrid 64-A-93 x RHP-46 however divulged maximum (11.85%) better parent heterosis. The F_1 hybrid SF-187 x RHP-46 exhibited highest mid-parent heterosis (20.27%) and heterobeltiosis (11.08%), followed by ARG-0306 x ARG-0106 and 64-A-93 x RHP-46 which recorded 20.24 and 20.20% mid parent heterosis and 8.14 and 11.85% better parent heterobeltiosis, correspondingly. Therefore, for the enhancement of oil content, these crosses may be utilized for further field evaluation. It is noted that three F_1 hybrids which exhibited high mid and better parent heterosis involved the parents with high x high, high x high and high x high good performing parents. These parents possessed dominant genes which expressed high heterosis in the form of hybrids. Andarkhor *et al*. (2012) evaluated some hybrids developed from crossing eight lines with six testers of sunflower. Their results from analysis of variance showed significant differences among the hybrids for all the traits including grain yield, 1000-seed weight, oil content and oil yield.

Protein content %

Sunflower seed contains a number of different organic compounds, however besides oil, sunflower seed is a significant and most important source of proteins (Redic *et al*., 2009). Present day sunflower cultivars contain 18 to 20% proteins (Aslam *et al*., 2010). Like all other yield and oil traits, all eighteen F_1 hybrids also manifested desirable positive relative heterosis as well as heterobeltiosis for protein content (Table 5). The mid parent heterosis ranged from 35.13 to 52.70% and heterobeltiosis varied from 25.00 to 42.86%, which revealed that hybrids could synthesized more proteins possibly due to favourable dominant genes. Nevertheless, the top three good performing hybrids with higher protein content were: PSF-025 x RHP-46, 64-A-93 x ARG-0106 and SF-187 x ARG-0106 expressed high relative heterosis of 52.70%, 50.61% and 46.98% and heterobeltiosis of 34.97%, 42.62% and 42.86%, respectively. Other hybrids such as ARG-0505 x ARG-0106, 64-A-93 x RHP-64 and ARG-0505 x RHP-64 displayed moderate relative heterosis of 45.81, 45.33 and 44.96% and heterobeltiosis of 37.15, 35.24 and 34.02% for protein content%, respectively. The top three good hybrids which expressed maximum heterosis involved parents with low x high, high x low and high x low as *per se* performing parents. These results indicated that heterotic effects in such hybrids were due to complementary gene action.

Table 5. Heterosis in F_1 hybrids of sunflower for seed yield, oil and protein content

F_1 hybrids	**Seed yield kg ha^{-1}**		**Oil content%**		**Protein content%**	
	MPH%	**BPH%**	**MPH%**	**BPH%**	**MPH%**	**BPH%**
ARG-0306 x RHP-46	45.88	22.72	16.01	9.15	41.71	27.20
ARG-0306 x RHP-64	45.05	21.80	17.46	8.39	38.93	27.97
ARG-0306 x ARG-0106	45.91	22.29	20.24	8.14	40.70	31.84
64-A-93 x RHP-46	60.22	32.87	20.20	11.85	37.88	25.00
64-A-93 x RHP-64	43.87	19.09	14.11	4.18	45.33	35.24
64-A-93 x ARG-0106	41.65	17.04	10.02	-2.08	50.61	42.62
PSF-025 x RHP-46	44.48	21.74	7.70	2.85	52.70	34.97
PSF-025 x RHP-64	46.75	23.42	18.75	11.18	40.43	27.31
PSF-025 x ARG-0106	46.96	23.36	16.19	5.98	39.21	28.35
SF-187 x RHP-46	60.77	31.99	20.27	11.08	40.41	30.49
SF-187 x RHP-64	53.16	25.52	18.98	7.82	40.56	34.19
SF-187 x ARG-0106	42.54	16.60	15.33	1.91	46.98	42.86
ARG-0405 x RHP-46	51.74	25.31	18.16	9.31	43.07	32.37
ARG-0405 x RHP-64	48.75	22.62	17.28	6.46	42.28	35.21
ARG-0405 x ARG-0106	52.84	25.75	18.51	4.89	35.13	30.73
ARG-0505 x RHP-46	51.51	25.88	17.40	9.79	40.99	27.01
ARG-0505 x RHP-64	44.66	19.97	12.43	3.14	44.96	34.02
ARG-0505 x ARG-0106	43.11	18.46	12.30	0.42	45.81	37.15

MPH%= mid parent heterosis percentage, BPH%=better parent heterosis percentage.

CONCLUSION

The F_1 hybrids like ARG-0405 x RHP-46 expressed maximum desirable negative heterobeltiosis (-24.11%) for days to 50% flowering; 64-A-93 x ARG-0106 explicated maximum desirable better parent heterosis of 32.55% for stem girth; SF-187 x RHP-46 demonstrated a highest of 70.85% heterobeltioitic effects for head diameter, 28.80% for 1000-seed weight and 60.77% for seed yield; ARG-0306 x ARG-0106 manifested 20.24% better parent heterosis for oil content and F_1 hybrid PSF-025 x RHP-46 exhibited 52.70% heterobeltiosis for protein content. These results demonstrated that considerable improvement in seed yield, oil and protein content can be made through exploiting sunflower hybrids.

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