Pak. j. sci. ind. res. Ser. B: biol. sci. 2015 **58** (1) 1-10

Heterotic Effects in F_1s and Inbreeding Depression in F_2 Hybrids of Sunflower

Shahnaz Memon[a], Muhammad Jurial Baloch[b]*, Gul Muhammad Baloch[b] and Muhammad Ibrahim Keerio[c]

[a]Cotton Section, Agriculture Research Institute, Tandojam, Sindh, Pakistan

[b]Department of Plant Breeding and Genetics, Sindh Agriculture University, Tandojam, Sindh, Pakistan

[c]Department of Crop Physiology, Sindh Agriculture University, Tandojam, Sindh, Pakistan

(received June 12, 2014; revised February 25, 2015; accepted March 19, 2015)

Abstract. Genetically diverse female lines of sunflower were crossed with male testers to get heterotic hybrids. Studies were carried-out during 2008-2010 at Experiment filed of Agriculture Research Institute, Tandojam, Sindh, Pakistan. Six female lines like T-4-0319, PAC-0505, HO-I, Hysun-33, Peshawar-93 and CMS-03 and three testers i.e., PAC-0306, PAC-64-A and SF-187 were crossed in a line × tester mating design, thus 18 F_1 and F_2 hybrids were developed for evaluation of heterosis and inbreeding depression for days to initial flowering, days to maturity, leaves/plant, plant height (cm), head diameter (cm), 1000-achene weight (g), seed yield kg/ha and oil yield kg/ha. The experiment was conducted in a randomised complete block design with four replications. The analysis of variance revealed significant differences among parents, F_1s and F_2 hybrids for all the traits studied. The existence of significant genetic variability among the plant traits is particularly useful because variations in these traits would allow further improvement in sunflower seed yield and oil traits. The F_1 hybrids HO-I × PAC-0306 and HO-I PA × C-64-A exhibited desirable negative mid and better parent heterosis for days to initial flowering, days to maturity and plant height. These hybrids also manifested desirable positive heterotic effects for leaves/plant, head diameter, 1000-achene's weight, seed yield and oil yield. Inbreeding depression for phenological, seed yield and oil traits showed that desirable high inbreeding depression was observed in hybrids HO-I × P×AC-64-A, HO-I × PAC-0306 and HO-I × SF-187 for days to initial flowering, similarly T-4-0319 × PAC-0306, PAC-0505 × SF-187 and HO-I × PAC-64-A explicated maximum but rewarding inbreeding depression for days to maturity. The F_2 hybrids Hysun-33 × SF-187 and Peshawer-93 × PAC-64-A may be the most desirable ones in the sense that they recorded comparatively moderate inbreeding depression with enough number of leaves to be productive if F_2 hybrids are to be exploited for hybrid vigour. Low inbreeding depression for various traits indicated that such hybrids some how favour the usefulness of F_2 hybrids in sunflower.

Keywords: heterosis, inbreeding depression, oil traits, sunflower yield

Introduction

Breeding for yield components and the creation of new sunflower ideotype require an increased use of wild species of *Helianthus* and potential inbreds in breeding programmes, yet hybrid superiority over male and female inbreds is the key to successful development of sunflower hybrids.

Plant breeders have experienced that selection for yield components only may not necessarily be the most efficient way to produce sunflower varieties with improved performance. High heterotic effects for yield and its components in sunflower being cross-pollinated crop have been reported by many researchers (Abdullah *et al*., 2010; Karasu *et al*., 2010; Kamati, 2009; Gowtham, 2006; Bajaj *et al*., 2003; Hladni *et al*., 2003). Most of scientists believe that formation of heteriosis is controlled by both nuclear and cytoplasmic determinants and their complementary interactions of genes (Aubaidan *et al*., 2014; Saeedi *et al*., 2014). Heterosis is defined as the superiority of F_1 hybrids over their respective mid and better parents. The main precondition to design a model hybrid is to identify parental lines possessing desirable genes and recombine those genes in a way that such genes pair-up and produce superior F_1 hybrids. Hybrid vigour remained a main driving force for the acceptance of sunflower as oilseed crop. Reduced maturity period, stability in performance, uniformity in stand, dwarf plant height, more leaves/plant, bigger head size, more seeds/head, higher 1000-achene weight, more seed yield and oil contents, resistance to lodging, insect-pests and diseases, all these contribute an important role in defining optimum plant architecture of sunflower hybrids.

*Author for correspondence; E-mail: j.rind58@gmail.com

In sunflower breeding, several researchers have observed mid and high parent heterotic effects for seed yield and oil quality (Aslam *et al*., 2010; Khan *et al*., 2008). Abdullah *et al*. (2010) also observed significant heterosis and heterobeltiosis values in some hybrids for 1000-achenes weight and seed yield. In general, heterosis values were high for plant height, head diameter and seeds/head. Contrary to superiority of F_1 hybrids over male and female inbreds parents, the loss of vigour is a common phenomenon seen in F_2 hybrids which is referred to as inbreeding depression and occurs due to homozygosity at many loci. Apart from F_1s, the F_2s which have larger heterogeneity and genetic variation may result in greater range of adaptation and good performance over their parental inbreds or even in some cases over F_1 hybrids. Theoretically, it is expected that F_2 populations may express only 50% of economic heterosis shown by F_1 hybrids and even less when heterosis is compared with high yielding parent. Nonetheless, F_2 hybrids with lower inbreeding depression in yield and express superior performance over adapted cultivars have been reported in many crop species (Kant and Srivastava, 2012; Abdullah *et al*., 2010). Bajaj *et al*. (2003) and Hladni *et al*. (2003) observed significantly high inbreeding depression of 49.81% for seed yield/plant, whereas, very low in magnitude for days to maturity. Kant and Srivastava (2012) also recorded the extent of heterosis over mid parent, better and standard parent as well as inbreeding depression in F_2 generation. Negative and significant standard heterosis, heterobeltiosis, mid-parent heterosis and inbreeding depression were recorded for days to 50% flowering and days to maturity. The objectives of present research were to determine the magnitude of heterosis in F_1 hybrids and the level of inbreeding depression in F_2 hybrids of sunflower.

Materials and Methods

Present research was carriedout during 2008-2010 at experimental field of Oil Seeds Section, Agriculture Research Institute, Tandojam, Pakistan. Six lines (T-4-0319, PAC-0505, HO-I, Hysun-33 and Peshawar-93) and three testers (CMS-03, PAC-0306 and SF-187) were crossed in line × tester fashion, and thus 18 F_1 hybrids were developed during 2008. At maturity, the crossed heads were collected, dried and threshed separately. The well-filled seeds from each cross were separated for hybrids' evaluation. The F_1 seeds alongwith parents were grown in a randomised complete block design with four replications. During 2009, some F_1 heads were also selfed by covering the heads with cloth bags to obtain F_2 seeds to grow during 2010 for determining inbreeding depression. The hybrids and parents were sown in six-meter long rows with plant to plant distance of 30.0 cm and row to row distance of 75.0 cm. A basal fertilizer dose of 120 kg nitrogen/ha and 60 kg phosphorus/ha were applied. Full dose of diammonium phosphate (DAP) and half dose of nitrogen were applied at the time of sowing, while the remaining half dose of nitrogen was applied just before head initiation. For recording the data, 10 plants were randomly tagged from each replication for seed germination%, days to initial flowering, days to 75% flowering, days to maturity, number of leaves/plant, plant height, head diameter, number of seeds/plant, 1000-achene weight, seed yield/plant, seed yield kg/ha, oil content % and oil yield kg/ha. The entire data set was subjected to statistical analysis according to Gomez and Gomez (1984) for determining significance differences among the genotypes, parents and F_1 hybrids by using Statistix-8.0 version, while heterotic effects and inbreeding depression were calculated according to formulae developed by Fehr (1987) with software Excel-2007.

Results and Discussion

Mean performance of maintainer lines and testers. Significant mean squares existed for genotypes, parents, F_1s and F_2 hybrids, which revealed that parents, F_1 and F_2 hybrids performed variably for the characters studied (Table 1). This analysis allowed further evaluating the mean performance of lines and testers which is presented in Table 2. The results revealed that T-4-0319 took minimum days to initial flowering and gave higher oil yields kg/ha while Hysun-33 produced maximum number of leaves/plant and gave bigger heads, yet PAC-0505 took minimum days to maturity, recorded bolder seeds with higher index value and produced highest seed yield in kg/ha. By and large, the lines Hysun-33, PAC-0505 and T-4-0319 performed very well for phenological, yield and oil traits, thus these lines may be utilised for further breeding programmes so as to develop new potential sunflower hybrids or composites with improved maturity, yield production and oil yield. The tester parents may be pure lines/inbreds or broad based heterogeneous populations or existing hybrids (Hallauer and Miranda, 1986). Hallauer and Miranda (1986), however, defined that a good tester is the one which provides information that correctly classifies the relative merit of lines, maximises the

Table 1. Mean squares of F_1 and F_2 hybrids from analysis of variance for phenological, seed yield and oil traits in sunflower

Character	Genotypes D.F = 35	Parents D.F = 8	F_1s D.F = 17	F_2s D.F = 17	Error D.F = 105
Days to initial flowering	174.78**	105.2**	178.77**	118**	0.02
Days to maturity	110.55**	29.7**	114.1**	114**	0.03
Leaves/plant	39.85**	17.4**	41.32**	40.73**	0.03
Plant height	3838.22**	1748.4**	3950.6**	3952**	0.50
Head diameter	5065.22**	12.11**	52.56**	51.71**	0.03
1000-achene weight	115.84**	73.20**	119.8**	118**	0.02
Seed yield kg/ha	442190**	302753**	455222**	455159**	0.01
Oil yield kg/ha	267917.5**	58024**	275819**	275776**	0.01

**,* = significant at 1% probability levels; D.F = degrees of freedom.

Table 2. Mean performance of female lines and male testers for phenological, seed yield and oil traits in sunflower

Mean	Days to initial flowering	Days to maturity	Leaves/ plant	Plant height (cm)	Head diameter (cm)	1000-Achene weight (g)	Seed yield kg/ha	Oil yield kg/ha
Female lines								
T-4-0319	55.3	89.3	23.0	150.1	18.0	50.2	1518.3	577.0
PAC-0505	58.0	87.1	20.0	169.3	19.0	53.1	1577.7	520.7
HO-I	70.0	95.0	21.0	195.1	18.0	44.1	1246.0	436.1
Hysun-33	66.0	91.0	24.0	170.2	22.0	51.2	1084.7	444.8
Peshawar-93	59.0	94.0	21.0	168.4	19.0	48.6	1313.31	525.3
CMS-03	67.0	89.3	19.0	175.1	18.0	46.1	1563.1	641.2
Average	62.5	9.96	21.3	171.4	19.0	48.9	1383.8	524.2
LSD (5%)	1.89	4.10	0.69	1.64	0.46	0.46	2.43	11.4
Male testers								
PAC-0306	57.0	88. 8	19.0	125.3	17.0	45.1	1314.7	473.3
PAC-64-A	59.0	90.9	22.0	139.3	20.0	39.2	1497.5	584.0
SF-187	62.0	87.4	18.0	155.1	16.0	48.2	2050.0	820.9
Average	59.3	89.1	19.7	139.9	17.6	44.2	1620.7	626.1
LSD (5%)	2.68	5.79	0.97	2.32	0.64	0.64	3.43	16.2

genetic gains and is simple in use. In the present studies, it is important to note that the performance of all three testers/pollinators was more discriminating for the characters under study (Table 2). The tester parents PAC-64-A took minimum days to initial flowering produced more number of leaves/plant and recorded bigger head diameters. While SF-187 was earlier in maturity, gave increased 1000-achene weight, gave maximum seed yield kg/ha and higher oil yield production in kg/ha. However, PAC-0306 produced desirably reduced plant height was earlier in days to initial flowering. Similar to our findings, Attia *et al*. (2012) observed lowest number of days to first flowering, days to complete flowering and days to physiological maturity. Sher *et al*. (2009) analysed the mean squares due to hybrids, lines, testers and line × tester interaction reported significant for days to first flowering, days to maturity and plant height in sunflower. Genetic variation among characters associated with plant growth and resultant morphological and physiological differences serves as the basis for development of lines and cultivars 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%.

Heterotic vigour in F_1s and inbreeding depression in F_2 hybrids. High heterosis for seed yield and its components in sunflower being a cross pollinated crop have been reported since long time. The main requirement for developing a model hybrid plant is to recognize parental lines possessing desirable genes for producing superior F_1 hybrids. Vigour in F_1 hybrids of sunflower remained a dynamic force for the acceptance of this oilseed crop due to their shorter growth cycle, stability in performance, resistance to lodging, higher seed and oil yields are all important attributes in designing optimum plant architecture of hybrids. Inversely to superior performance of F_1 hybrids, the loss of vigour is a common phenomenon in F_2 hybrids which is referred as inbreeding depression and occurs due to homozygosity. In some studies, F_2 hybrid performance was highly correlated with F_1s and their parents. The existence of such populations lends credibility for developing profitable F_2 hybrids. Studies on inbreeding depression, therefore has great advantage if F_2 hybrids with less inbreeding depression are identified. The extent of heterotic effects in F_1s and inbreeding depression in F_2s for various phenological, yield and oil traits of sunflower are presented in Tables 3-6. The trait-wise results are presented hereunder.

Days to initial flowering. Though specific combining ability of parents do not contribute substantially towards the improvement of crop plants except in the situations where exploitation of heterosis is feasible. Best parents on hybridisation are expected to generate transgressive segregants which could be selected as potential homozygous lines for hybrid crop development. The manifestation of heterosis and heterobeltiosis are shown in Table 3, revealed that out of 18, 10 hybrids depicted desirable negative heterotic effects. The desirable negative relative heterosis ranged from -1.61 to -21.26%, while desirable negative better parent heterosis varied from -2.86 to -28.57%. On the basis of relative heterosis and heterobeltiotic performance, hybrids HO-I × PAC-0306, HO-I × PAC-64-A and Peshawar-93 × SF-187 were the most desirable hybrids for earlier flowering. The high negative heterosis in F_1 hybrids suggested that these hybrids involved dominant and over-dominant genes with decreasing effects. Khan *et al*. (2008) and Premalatha *et al*. (2006) reported that the best cross combination TS-18 × TR-13 exhibited negative heterosis (-3.06%) for early flowering and TS-18 × TR-6023 (-37.91%) for early maturity. Among the F_2 hybrids, all the progenies showed inbreeding depression which ranged from -1.92% to -18.78% and such depression in F_2 hybrids may be due to decrease in heterozygosity, deterioration of favourable dominant genes, abnormal segregation during meiosis and occurrence of repulsion phase linkages

Table 3. Heterosis expressed as percent increase (+) or decrease (-) of F_1 hybrids over mid parents and better parents for days to initial flowering, days to maturity, leaves/plant and plant height of eighteen crosses derived from six lines and three testers of sunflower

Crosses	Days to initial flowering		Days to maturity		Leaves/plant		Plant height	
	MPH%	BPH%	MPH%	BPH%	MPH%	BPH%	MPH%	BPH%
T-4-0319 × PAC-0306	17.51	15.79	1.01	0.75	23.81	13.04	59.06	45.90
T-4-0319 × PAC-64-A	-5.54	-8.47	2.48	1.97	20.00	17.39	48.68	43.31
T-4-0319 × SF-187	-11.36	-16.13	-7.23	-8.21	7.32	-4.35	-0.14	-1.73
PAC-0505 × PAC-0306	-9.57	-10.34	-9.10	-9.97	33.33	30.00	-1.64	-12.13
PAC-0505 × PAC-64-A	19.66	18.64	2.94	0.81	9.52	4.55	33.93	25.53
PAC-0505 × SF-187	-1.67	-4.84	2.47	2.30	10.53	5.00	-10.49	-14.24
HO-I × PAC-0306	-21.26	-28.57	-18.33	-21.05	50.00	42.86	-28.12	-40.98
HO-I × PAC-64-A	-14.73	-21.43	-8.22	-10.53	30.23	27.27	-10.31	-23.14
HO-I × SF-187	3.03	-2.86	-3.53	-7.37	2.56	-4.76	-2.80	-12.76
Hysun-33 × PAC-0306	8.94	1.52	7.03	5.62	25.58	12.50	36.69	18.67
Hysun-33 × PAC-64-A	2.40	-3.03	0.40	-0.07	21.74	16.67	25.99	14.56
Hysun-33 × SF-187	-6.25	-9.09	1.24	-0.74	9.52	-4.17	-4.58	-8.81
Peshawar-93 × PAC-0306	13.79	11.86	2.09	-0.81	30.00	23.81	34.79	17.53
Peshawar-93 × PAC-64-A	10.17	10.17	-3.80	-4.96	25.58	22.73	23.46	12.78
Peshawar-93 × SF-187	-14.05	-16.13	-1.73	-5.16	-2.56	-9.52	-3.80	-7.60
CMS-03 × PAC-0306	-1.61	-8.96	3.27	2.99	26.32	26.32	-16.24	-28.15
CMS-03 × PAC-64-A	-7.94	-13.43	5.80	4.87	17.07	9.09	24.16	11.47
CMS-03 × SF-187	6.98	2.99	-0.44	-1.49	8.11	5.26	-8.77	-13.97

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

(Baloch *et al*., 1991). The high inbreeding depression was observed in HO-I × PAC-64-A, HO-I × PAC-0306 and HO-I × SF-187 F_2 progenies, yet minimum inbreeding depression was noted in T-4-0319 × SF-187 for days to initial flowering. The greater values of inbreeding depression revealed that dominant or over dominant genes with decreasing effect advocated the expression of days to initial flowering, while less inbreeding depression in some F_2 hybrids may be due to additive genes or incidence of trangressive segregants.

Days to maturity. Seed maturity in sunflower is an important selection criterion for the development of successful hybrids. Since rice and cotton follow sunflower crop therefore, farmers are interested in early maturing hybrids so that rice and cotton could be sown well in time (Saleem *et al*., 2014). The proportion of negative heterosis was quite higher than the positive heterosis over mid parents as well as better parents which indicated that F_1 hybrids could be obtained for both high seed production and early maturity. Negative heterosis is more utilised than the positive heterotic effects because negative values are the evidence of early maturity, although positive values highlights maximum days in maturity causes delay in ripening and maturity of seed. Three hybrids HO-I × PAC-0306, PAC-0505 × PAC-0306 and HO-I × PAC-64-A which were earlier in days to initial flowering also displayed the most desirable negative relative heterosis and better parent heterosis for days to maturity, respectively. The maximum decreases over mid and better parents for days to maturity were also reported by Habib *et al*. (2007). Cytoplasmic genes generally represent a neglected source of variation in inbreeding depression. Maternal age however affects a wide diversity of traits, probably in all taxonomic groups, thus has the potential to influence the inheritance patterns of characters in crop plants. The F_2 hybrids like T-4-0319 × PAC-0306, PAC-0505 × SF-187 and HO-I × PAC-64-A explicated maximum inbreeding depression for days to maturity, however, T-4-0319 × SF-187 showed lowest inbreeding depression among the evaluated F_2 populations.

Leaves/plant. In crop plants, leaf is a source of food, therefore it is correctly called as food manufactured industry, thus maximum number of leaves/plant help plants to prepare more food which is supplied to flowers for healthy grain formation. However, more number of leaves/plant also causes delay in maturity, hence can prolong the vegetative growth but desirable number of leaves is still very important. Heterotic effects presented in Table 3 indicated that most of the hybrids except one exhibited a fair amount of heterosis. Yet, the hybrids HO-I × PAC-0306, PAC-0505 × PAC-0306 and HO-I × PAC-64-A manifested maximum positive relative heterosis and heterobeltiosis for number of leaves/plant. High heterosis in above crosses may be due to accumulation of more dominant genes, occurrence of heterozygosity to a greater number of loci and most importantly due to high × high, low × high and low × low good general combiner male and female parents (Yadav *et al*., 2009). It is generally expected that hybrids which express high heterosis in F_1 hybrids also manifest high inbreeding depression in F_2 due to loss of favourable dominant genes, recovery of more deleterious recessive alleles and decrease in heterozygous loci. The F_2 hybrids like Hysun-33 × SF-187 and Peshawer-93 × PAC-64-A may be the most desirable ones in the sense that they recorded comparatively moderate inbreeding depression with enough number of leaves to be productive if F_2 hybrids are to be exploited for hybrid vigour (Table 4). Results further suggested that these hybrids could be utilised to develop homozygous/pure sunflower lines with improved number of leaves/plant which could be used as potential parents in further breeding programmes. Similar to our findings, Ahmed *et al*. (2005) reported high inbreeding depression for leaves/plant which varied from -0.9 to 22.2%. Least inbreeding depression of 1.1% was recorded for BRS-1 × RHA-365, whereas HAR-5 × RHA-822 exhibited the highest inbreeding depression of 22.2% for this character (Sajjad *et al*., 2005).

Plant height. Negative heterosis for plant height is considered desirable in sunflower breeding because such hybrids would attained shorter plant height, hence they will be assumed as resistant to lodging and also respond better to higher doses of inputs, specially to inorganic fertilisers. Negative desirable heterotic effects were noted in ten F_1 hybrids over mid-parent ranging from -0.14 to -28.12% and over better parents vary from -1.71 to -40.98% (Table 3). Similar to present findings, Jarwar *et al*. (2004) recorded negative heterotic effects for plant height while (Ali *et al*., 2011; Ahmad *et al*., 2005; Kaya, 2005a; Hladni *et al*., 2005; Goksoy and Turan, 2004), observed both, negative and positive heterosis and heterobeltiosis which ranged from -8.4 to +16.3% and -21.3 to +3.4% for plant height. In present studies, the positive mid parent heterosis varied from 23.46 to 59.06 and better parent from 11.47 to 45.90%. Abdullah *et al*. (2010) observed significant heterosis among experimental hybrids varied from 12.1 to 26.2%

for plant height. The inbreeding depression for plant height varied from -3.34% to -26.27% which is in the lowest range of inbreeding depression indicated more heterozygous loci and lower degradation of dominant or over-dominant type of genes involved in F_2 populations. The higher inbreeding depressions however were recorded in F_2 hybrids HO-I × PAC-64-A (-26.27%), HO-I × PAC-0306 (-25.58%) and PAC-0505 × PAC-0306 (-21.19%). Whereas, lower inbreeding depression was noted in PAC-0505 × SF-187 hybrid which was attributable to less degradation of favourable dominant genes (Table 4).

Head diameter. The head or capitulum's diameter is considered as an economic agronomic trait. Its size in sunflower ranges from 15.0 to 30.0 cm. Bigger heads are expected to set more number of seeds, hence contribute positively in increasing seed yield. All the F_1 hybrids demonstrated fair amount of heterotic effects for head diameter (Table 5). Sixteen F_1 hybrids exhibited positive relative heterosis varying from 5.88 to 54.29% while fifteen F_1 crosses showed positive heterobeltiosis (5.26-50.00%). The superior hybrids were HO-I × PAC-0306, PAC-0505 × PAC-0306 and T-4-0319 × PAC-0306 which gave maximum relative and better parent heterotic effects. The high heterotic effects of above hybrids may be due to additive × additive type of genes or complementary effect of additive genes because such crosses involved parents with high × high, high × low and low × low good performing parents, respectively. Parameswari *et al*. (2004) obtained positive heterosis for yield, head diameter in five F_1 hybrids and observed that those hybrids were superior in 'per se' performance and also for heterosis in seed yield. The positive heterosis from 25.6 to 58.3% for head diameter was reported by Abdullah *et al*. (2010). Results for head diameter depicted in Table 6 demonstrated that some of the F_2s recorded transgressive segregants hence gave no decline in head diameter. No inbreeding depression from F_1 to F_2 hybrids was recorded in the crosses T-4-0319 × SF-187, PAC-0505 × SF-187, HO-I × SF-187 and Hysun-33 × SF-187. No inbreeding depression in these hybrids suggested that such hybrids carried most of the additive genes for head diameter.

Some other F_2 hybrids like T-4-0319 × PAC-0306, Peshawer-93 × PAC-0306 and PAC-0505 × PAC-64-A ranked as next group which displayed relatively less inbreeding depression. In consonance to our findings, Sajjad *et al*. (2005) observed inbreeding depression from F_1 to F_2 ranging from 8.7 to 48.1% head diameter.

Table 4. Inbreeding depression in F_2 hybrids for days to initial flowering, days to maturity, leaves/plant of and plant height of eighteen crosses of sunflower derived from crosses of six female lines crossed with three testers

Crosses	Days to initial flowering			Days to maturity			Leaves/plant			Plant height		
	F_1	F_2	ID%	F_1	F_2	ID%	F_1	F_2	ID%	F_1	F_2	ID%
T-4-0319 × PAC-0306	66.0	57.00	-13.64	90.0	70.00	-22.22	26.0	21.33	-17.96	219.1	197.03	-10.08
T-4-0319 × PAC-64-A	54.0	50.00	-7.41	92.0	75.00	-18.48	27.0	22.67	-16.04	215.2	180.12	-16.31
T-4-0319 × SF-187	52.0	51.00	-1.92	82.0	80.00	-2.44	22.0	20.33	-7.59	152.5	135.24	-11.29
PAC-0505 × PAC-0306	52.0	45.13	-13.21	80.0	67.00	-16.25	26.0	18.67	-28.19	140.0	110.33	-21.19
PAC-0505 × PAC-64-A	70.0	61.00	-12.86	91.7	79.67	-13.08	23.0	18.00	-21.74	200.0	160.40	-19.80
PAC-0505 × SF-187	59.0	53.00	-10.17	89.5	70.00	-21.74	21.0	26.67	-15.86	145.2	140.37	-3.34
HO-I × PAC-0306	50.0	42.14	-15.72	75.0	61.33	-18.23	30.0	19.00	-36.67	115.2	85.73	-25.58
HO-I × PAC-64-A	55.0	44.67	-18.78	85.0	68.00	-20.00	28.0	19.67	-29.76	150.0	110.60	-26.27
HO-I × SF-187	68.0	58.00	-14.71	88.0	72.67	-17.42	20.0	16.00	-20.00	170.3	138.30	-18.77
Hysun-33 × PAC-0306	67.0	60.00	-10.45	96.2	80.67	-16.13	27.0	22.33	-17.30	202.0	170.46	-15.61
Hysun-33 × PAC-64-A	64.0	61.00	-4.69	91.0	76.25	-16.21	28.0	20.67	-10.13	195.0	158.56	-18.69
Hysun-33 × SF-187	60.0	54.00	-10.00	90.3	73.00	-19.19	23.0	21.33	-7.26	155.2	131.40	-15.35
Peshawar-93 × PAC-0306	66.0	56.67	-14.14	93.2	90.00	-3.47	26.0	24.33	-6.42	198.0	169.23	-14.53
Peshawar-93 × PAC-64-A	65.0	62.00	-4.62	89.2	72.00	-19.30	27.0	17.33	-6.19	190.0	150.57	-20.75
Peshawar-93 × SF-187	52.0	48.00	-7.69	89.0	78.00	-12.36	19.0	15.33	-19.30	155.7	132.40	-14.94
CMS-03 × PAC-0306	61.0	58.13	-4.70	92.0	80.00	-13.04	24.0	19.00	-20.83	125.8	110.20	-12.42
CMS-03 × PAC-64-A	58.0	54.00	-6.90	95.2	90.00	-5.41	24.0	17.67	-26.39	195.2	159.33	-18.38
CMS-03 × SF-187	69.0	59.00	-14.49	88.0	77.00	-12.50	20.0	15.00	-25.00	150.7	130.40	-13.45
Average	60.4	54.2	-	88.7	75.6	-	24.50	19.74	-	170.8	142.82	-

ID = inbreeding depression in F_2 hybrids.

Table 5. Heterosis expressed as percent increase (+) or decrease (-) of F_1 hybrids over mid parents and better parents for head diameter, number of seed/plant and 1000-achene weight of eighteen F_1 crosses derived from six lines and three testers of sunflower

Crosses	Head diameter		1000-achene weight		Seed yield kg/ha		Oil yield kg/ha	
	MPH%	BPH%	MPH%	BPH%	MPH%	BPH%	MPH%	BPH%
T-4-0319 × PAC-0306	31.43	27.78	24.38	18.07	50.05	39.99	102.36	84.18
T-4-0319 × PAC-64-A	26.32	20.00	16.49	3.70	35.52	34.60	68.97	67.96
T-4-0319 × SF-187	11.76	5.56	-2.43	-4.48	0.15	-12.84	0.08	-14.75
PAC-0505 × PAC-0306	33.33	26.32	22.05	12.85	78.39	63.52	163.96	151.95
PAC-0505 × PAC-64-A	28.21	25.00	21.68	5.72	56.89	52.90	120.29	108.35
PAC-0505 × SF-187	14.29	5.26	-4.83	-9.33	-9.86	-20.24	-9.44	-25.99
HO-I × PAC-0306	54.29	50.00	41.16	39.53	104.74	99.39	194.00	182.47
HO-I × PAC-64-A	31.58	25.00	39.47	31.74	76.57	61.75	137.42	107.36
HO-I × SF-187	5.88	0.00	-1.90	-6.00	-1.70	-20.97	-9.79	-30.93
Hysun-33 × PAC-0306	7.69	-4.55	22.43	15.17	74.11	58.89	118.42	111.85
Hysun-33 × PAC-64-A	23.81	18.18	21.24	7.03	51.97	31.03	71.73	51.19
Hysun-33 × SF-187	-15.79	-27.27	0.63	-2.40	4.72	-19.93	1.14	-22.03
Peshawar-93 × PAC-0306	27.78	21.05	11.16	7.15	65.96	65.87	116.66	105.93
Peshawar-93 × PAC-64-A	12.82	10.00	14.09	3.02	62.63	52.63	106.02	95.68
~~Peshawar-93 × SF-187~~	~~-8.57~~	~~-15.79~~	~~-4.92~~	~~-5.43~~	~~-3.41~~	~~-20.77~~	~~-10.73~~	~~-26.80~~
CMS-03 × PAC-0306	20.00	16.67	18.80	17.51	57.05	44.53	98.75	72.73
CMS-03 × PAC-64-A	26.32	20.00	20.25	11.22	51.26	48.05	81.41	73.32
CMS-03 × SF-187	-11.76	-16.67	-4.07	-6.08	-3.33	-14.79	-9.22	-19.15

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

1000-Achene weight. Varieties with bolder seeds are assumed to give maximum 1000-achene weight, consequently produce higher seed yield/plant. Heterotic effects depicted in Table 5 indicated that majority of the F_1 hybrids expressed positive relative heterosis in the range of 0.63 to 41.16% and heterobeltiosis from 3.02 to 39.53%. The magnitude of high positive mid-parent and better parent heterosis were much higher than their corresponding negative heterosis. Among the F_1 hybrids, the top three hybrids were HO-I × PAC-0306, HO-I × PAC-64-A and T-4-0319 × PAC-0306 with high relative heterosis and heterobeltiosis for 1000-achene weight. High heterosis in the above hybrids involved the parents with high × high and low × high good general combiner parents, respectively, showing that additive and complementary additive genes were responsible for expressing high heterotic effects in such hybrids (Yadav *et al*., 2009). For 1000-seed weight, the heterosis values ranging from 26.5% and 48.8% relative to parental average were reported by Hladni *et al*. (2007). High percentage of heterosis ranging from 79.9 to 173.1% for 1000 seed weight was noted by Abdullah *et al*. (2010). Similar to other traits, 1000-achene weight also displayed lower percent of inbreeding depression (Table 6). The lower inbreeding depression was observed in F_2 hybrids such as Hysun-33 × SF-187, HO-I × SF-187, PAC-0505 × SF-187 and T-4-0319 × SF-187. Lower degradation of dominant genes in F_2 or the involvement of additive genes may have contributed in these F_2 hybrids.

Seed yield kg/ha. Significant and desirable positive mid-parent heterosis was observed in fourteen F_1 hybrids, while twelve hybrids manifested heterobeltiosis revealing that hybrids could produce higher seed yield due to dominant or over dominant genes. 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 HO-I × PAC-0306, PAC-0505 × PAC-0306 and HO-I × PAC-64-A expressed high relative heterosis of 104.74%, 78.39% and 76.57% and heterobeltiosis of 99.39%, 63.52% and 61.75%, respectively (Table 5). Significant heterosis and heterobeltiosis values were observed for all the hybrids in terms of 1000-seed weight and seed yield was also reported by Abdullah *et al*. (2010). 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 magnitude of average heterosis for seed yield (kg/ha) was noted by Gowtham (2006). Khan *et al*. (2008) obtained highest positive mid and high parent heterotic effects from hybrid TS-18 × 291RGI for yield/ha. The F_2 progenies like Hysun-33 × SF-187, HO-I × SF-187, PAC-0505 × SF-187 and T-4-0319 × SF-187 demonstrated no inbreeding depression rather they gave enhanced seed yield in F_2s against the F_1s (Table 6), hence these could be potential F_2 hybrids to increase seed yield kg/ha. Sajjad *et al*. (2005) reported least inbreeding depression of 17% in HAR-5 × HAR-2, whereas RHA-387 × RHA-859 hybrid showed maximum inbreeding depression of 71% for seed yield.

Oil yield kg/ha. The major objective in developing new hybrids is increasing seed yield and oil content of sunflower. Grain yield and single seed oil content in single seed play a vital role in oil yield production. Plant traits like days to 50% flowering, days to maturity, plant height, 100-seed weight and oil content are very important in connection with oil yield (Rao, 2013). The results on heterosis for oil yield kg/ha depicted in Table 5 suggested that hybrids HO-I × PAC-0306 and PAC-0505 × PAC-0306 gave high relative heterosis of nearly 200% and better parent heterosis of 182.47% for oil yield kg/ha. Both the hybrids expressing high heterosis involved the parents with high general combining ability, hence additive × additive genes contributed to the expression of hybrid vigour. Other crosses viz., HO-I × PAC-64-A also gave fair amount of relative heterosis and heterobeltiosis. The extent of heterotic effects for oil yield kg/ha were 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 in accordance with those of Gowtham (2006), who observed heterosis over mid parent, better parent and standard check and noted higher magnitude of average heterosis of 38.13% in oil yield kg/ha. Habib *et al*. (2006) also observed high positive heterosis over mid and better parents for oil yield. Out-crossing individuals transmit, on average, one copy of allele being a mother and another dissimilar allele being a father parent to the progenies. The results in Table 6 revealed that two F_2 progenies HO-I × SF-187 and PAC-0505 × SF-187 manifested no inbreeding depression, while lower inbreeding depression was observed in T-4-0319 × SF-187 and Hysun-33 × SF-187. By and large, high inbreeding depression ranging from

Table 6. Inbreeding depression in F_2 hybrids for head diameter, 1000-achene weight, seed yield and oil yields kg/ha of eighteen crosses of sunflower derived from crosses of six female lines with three testers

Crosses	Head diameter			1000-achene weight			Seed yield kg/ha			Oil yield kg/ha		
	F_1	F_2	ID%	F_1	F_2	ID%	F_1	F_2	ID%	F_1	F_2	ID%
T-4-0319 P× AC-0306	23.0	19.00	-17.39	59.3	52.40	-11.68	2125.43	1355.57	-36.22	1062.7	578.38	-45.58
T-4-0319 × PAC-64-A	24.0	20.67	-13.88	52.1	42.76	-17.94	2043.57	1415.35	-30.74	980.9	551.99	-43.73
T-4-0319 × SF-187	19.0	22.00	+15.79	48.0	43.63	-9.10	1786.82	1886.68	+5.58	699.0	666.56	-4.64
PAC-0505 × PAC-0306	24.0	18.00	-25.00	60.0	46.70	-22.17	2580.00	1422.24	-44.87	1311.9	549.98	-58.08
PAC-0505 × PAC-64-A	25.0	21.00	-16.00	56.2	47.26	-15.92	2412.37	1422.24	-41.04	1216.8	512.01	-57.92
PAC-0505 × SF-187	20.0	23.00	+15.00	48.2	44.77	-7.11	1634.98	1730.35	+5.83	607.66	611.33	+0.62
HO-I × PAC-0306	27.0	19.33	-28.41	63.0	48.13	-23.60	2621.41	1366.68	-47.86	1336.9	555.83	-58.43
HO-I × PAC-64-A	25.0	19.67	-21.33	58.1	45.33	-21.99	2422.10	1488.91	-38.53	1211.1	615.36	-49.19
HO-I × SF-187	18.0	19.33	+7.41	45.3	42.30	-6.62	1620.06	1735.33	+7.11	567.0	584.28	+3.04
Hysun-33 × PAC-0306	21.0	18.33	-12.70	59.0	50.53	-14.36	2088.92	1422.24	-31.92	1002.7	597.34	-40.43
Hysun-33 × PAC-64-A	26.0	22.00	-15.38	54.8	48.16	-12.16	1962.18	1429.64	-27.14	882.9	559.71	-36.62
Hysun-33 × SF-187	16.0	19.00	+18.75	50.0	48.53	-2.93	1641.36	1760.57	+7.26	640.1	598.59	-6.48
Peshawar-93 × PAC-0306	23.0	19.33	-15.96	52.1	44.46	-14.73	2180.68	1632.90	-25.12	1081.8	707.54	-34.60
Peshawar-93 × PAC-64-A	22.0	19.15	-12.95	50.1	44.80	-10.63	2285.62	1691.79	-25.98	1142.8	744.39	-34.87
Peshawar-93 × SF-187	16.0	14.33	-10.44	46.0	39.26	-14.69	1624.22	1467.77	-9.63	600.9	503.93	-16.15
CMS-03 × PAC-0306	21.0	18.66	-11.14	54.2	42.33	-21.94	2260.45	1379.56	-38.97	1107.6	620.80	-43.95
CMS-03 × PAC-64-A	24.0	20.67	-13.88	51.3	43.12	-15.99	2315.35	1511.13	-34.73	1111.3	629.69	-43.34
CMS-03 × SF-187	15.0	13.00	-13.33	45.2	38.16	-15.65	1746.71	1264.24	-27.62	663.7	412.98	-37.78
Average	21.6	19.25	-	52.9	45.2	-	2075.1	1521.3	-	957.1	588.93	-

ID = inbreeding depression in F_2 hybrids.

-16.15 to -58.08% was recorded for oil yield in kg/ha. Low inbreeding depression some how favour the development of F_2 hybrids if feasible in sunflower breeding. Yadav *et al*. (2009) very nicely presented the relationship between general combining ability of parents and expression of heterosis. They stated that if the heterosis is manifested by the parents with high × high, low × high and low × low general combining ability, it suggests the involvement of additive, additive genes with complementary effects and over-dominant and epistasis gene interactions, respectively.

Conclusion

Six female lines like T-4-0319, PAC-0505, HO-I, Hysun-33, Peshawar-93 and CMS-03 and three testers PAC-0306, PAC-64-A and SF-187 were crossed in a line × tester mating design. The analysis of variance revealed significant differences among parents, F_1s and F_2 hybrids for all the traits studied. The existence of significant genetic variability among the plant traits is particularly useful because variations in studied traits would allow further improvement in sunflower seed yield and oil traits. The F_1 hybrids HO-I × PAC-0306 and HO-I PA × C-64-A exhibited desirable negative mid and better parent heterosis for days to initial flowering, days to maturity and plant height. These hybrids also manifested desirable positive heterotic effects for leaves/plant, head diameter, 1000-achene's weight, seed yield and oil yield. The F_2 hybrids Hysun-33 × SF-187 and Peshawer-93 × PAC-64-A may be the most desirable ones in the sense that they recorded comparatively moderate inbreeding depression with enough number of leaves to be productive if F_2 hybrids are to be exploited for hybrid vigour. Low inbreeding depression for various traits indicated that such hybrids some how favour the usefulness of F_2 hybrid sunflower.

References

Abdullah, K., Mehmet, O.Z., Mehmet, S., Abdurrahim, T.G., Metin, T.Z. 2010. Combining ability and heterosis for yield and yield components in sunflower. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, **38:** 259-264.

Ahmad, S., Khan, M.S., Swati, M.S., Shah, G.S., Khalil, I.H. 2005. A study on heterosis and inbreeding depression in sunflower (*Helainthus annuus* L.). *Songklanakarin Journal of Science and Technology*, **27:** 1-8.

Ali, A., Afzal, M., Rasool, I.J., Hussian, S., Ahmad, M. 2011. Sunflower (*Helainthus annuus* L.) hybrids performance at different plant spacing under agro-ecological conditions of Sargodha, Pakistan. In: *9th International Conference On Food Engineering and Biotechnology*, vol. **9,** pp. 317-322, IACSIT Press, Singapore.

Aslam, S., Khan, S.M., Saleem, M., Qureshi, A.S., Khan, A., Islam, M. Khan, S.M. 2010. Heterosis for the improvement of oil quality in sunflower (*Helianthus annuus* L.). *Pakistan Journal of Botany*, **42:** 1003-1008.

Attia, S.A.M., EL-Seidy, E.H., El-Gammaal, A.A., Awad, R.M.M. 2012. Heritability, genetic advance and associations among characters of sunflower hybrids. *Journal of Agricultural Research*, **38:** 254-264.

Aubaidan, B., Mohd, M., Albared, M., Author, F. 2014. Comparative study of k-means and kmeans++ clustering algorithms on crime domain. *Journal of Computer Science*, **10:** 1197-1206.

Bajaj, R.K., Aujla, K.K., Kaur, N., Sharma, S.R. 2003. Estimation of heterosis and inbreeding depression in sunflower (*Helianthus annuus* L.). *Journal of Research Punjab Agricultural University*, **40:** 146-150.

Baloch, M.J., Tunio, G.H., Lakho, A.R. 1991. Expression of heterosis in F_1 and its deterioration in intra-hirsutum F_2 hybrids. *Pakphyton*, **3:** 95-106.

Fehr, W.R. 1987. Principles of Cultivar Development. In: *Theory and Technique*, vol. **1,** pp. 115-116, Macmillan Publishing Co., New York, USA.

Gomez, K.A., Gomez, A.A. 1984. *Statistical Procedure for Agriculture Research*, pp. 25-31, 2nd edition, John Wiley and Sons Inc., New York, USA.

Goksoy, A.T., Turan, Z.M. 2004. Combining abilities of certain characters and estimation of hybrid vigour in sunflower (*Helianthus annuus* L.). *Acta Agronomica Hungarica*, **52:** 361-368.

Gowtham, P. 2006. Genetic analysis of yield and oil quality traits in sunflower (*Helianthus annuus* L.) *M.Sc. Thesis*, pp. 500-580, University of Agricultural Sciences, Karnataka, India.

Habib, H., Mehdi, S.S., Rashid, A., Zafar, M., Anjum, M.A. 2007. Heterosis and heterobeltiosis studies for flowering traits, plant height and seed yield in sunflower (*Helianthus annuus* L.). *International Journal of Agriculture & Biology*, **9:** 355-358.

Hallauer, A.R., Miranda, J.B. 1986. *Quantitative Genetics in Maize Breeding*, 268 pp., 2nd edition, Iowa State University Press, Ames, IA, USA.

Hladni, N., Skoric, D., Kiraljevic-Balalic, M. 2003. Components of phenotypic variability for head diameter in sunflower (*Helianthus annuus* L.). *Genetica*, **35:** 67-75.

Hladni, N., Skoric, D., Kiraljevic-Balalic, M. 2005. Heterosis for seed yield and yield components in sunflower. *Genetica*, **37:** 253-260.

Hladni, N., Skoric, D., Kiraljevic-Balalic, M., Sakac, Z., Miklic, V. 2007. Heterosis for agronomically important traits in sunflower (*Helianthus annuus* L.). *Helia*, **30:** 191-198.

Jarwar, A.D., Islamuddin, M., Kalhoro, R.B., Lashari, M.I. 2004. Heterosis and heterobeltiosis studies in sunflower. *Indus Journal of Plant Science*, **3:** 229-234.

Kamati, C.B. 2009. Genetic studies on fertility restoration, heterosis and combining ability involving diverse CMS sources in sunflower (*Helianthus annuus* L.). Dharwad Annual Report, 2012.

Kant, R., Srivastava, R.K. 2012. Heterosis and inbreeding depression studies in Urdbean (*Vigna mungo* L.) (Hepper). *Journal of Food Legumes*, **25:** 102-108.

Karasu, A., Mehmet, O.Z., Sincik, M., Goksoy, A.T., Turan, Z.M. 2010. Combining ability and heterosis for yield and yield components in sunflower. *Notulae Botanicae Horti Agrobotanici Culj-Napoca*, **38:** 259-264.

Kaya, Y. 2005. Determining combining ability in sunflower (*Helianthus annuuus* L.). *Turkish Journal of Agriculture and Forestry*, **29:** 243-250.

Khan, S.A., Qureshi, A.S., Ashraf, M., Khan, S.M., Ajmal, S., Halil, I.H. 2008. Estimates of heterosis for seed yield and oil contents in sunflower (*Helianthus annuus* L.). *Sarhad Journal of Agriculture*, **24:** 43-48.

Parameswari, C., Muralidharan, V., Subbalakshmi, B., Manivana, N. 2004. Genetic analysis of yield and important traits in sunflower hybrids. *Journal of Oil Seeds Research*, **21:** 168-170.

Premalatha, N., Kumaravadivel, N., Veerabadhiran, P. 2006. Heterosis and combining ability for grain yield and its components in sorghum (*Sorghum bicolor* L.). *Indian Journal of Genetics and Plant Breeding*, **66:** 123-126.

Rao, V.T. 2013. Association analysis in sunflower (*Helianthus annuus* L.). *International Journal of Applied Biology and Pharmaceutical Technology*, **4:** 1-4.

Saeedi, M.G., Torabi, M., Hamidi, S., Ranji, H. 2014. Mobile communications for using in telemedicine. *American Medical Journal*, **5:** 8-12.

Sajjad, A., Muhammad, S.K., Muhammad, S., Shah G.S., Iftikhar, H.K. 2005. A study on heterosis and inbreeding depression in sunflower (*Helianthus annuus* L.). *Songklanakarin Journal of Science and Technology*, **27:** 1-8

Saleem, U.D., Khan, M.A., Gull, S., Usman, K., Saleem, F.Y., Siyal, O.U. 2014. Line × tester analysis of yield and yield related attributes in different sunflower genotypes. *Pakistan Journal of Botany*, **46:** 659-665.

Khan, S.A., Ahmad, H., Khan, A., Saeed, M., Khan, S.M., Ahmad, B. 2009. Using line x tester analysis for earliness and plant height traits in sunflower (*Helianthus annuus* L.). *Recent Research in Science and Technology*, **1:** 202-206.

Siddiqi, M.H., Ali, S., Bakht, J., Khan, A., Khan S.A., Khan, N. 2012. Evaluation of sunflower lines and their crossing combinations for morphological characters, yield and oil contents. *Pakistan Journal of Botany*, **44:** 687-69.

Yadav, H.K, Shukla, S., Singh, S.P. 2009. Genetic combining ability estimates in the F_1 and F_2 generations for yield, its component traits and alkaloid content in opium poppy (*Papaver somniferum* L.). *Euphytica*, **168:** 23-32.