ORIGINAL ARTICLE

A study on heterosis and inbreeding depression in sunflower (*Helianthus annuus* L.)

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Abstract

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The experiment was conducted at NWFP Agricultural University, Peshawar to study heterosis and inbreeding depression in 7×7 half diallel crosses of sunflower. The planted materials consisted of parental inbred lines, their F_1 hybrids and F_2 populations using randomized complete block design with three replications. Data were recorded on yield and other important agronomic characters. Significant genetic differences were observed among the parents, their F_1 hybrids and F_2 populations for all the characters under study. Yield and leaf area showed highly significant heterosis in F_1 hybrids ranging from 102 to 309% and 46.3 to 163.9%, respectively, while inbreeding depression in the F_2 population ranged from 17-71% and -9.7-43%, respectively. Leaves per plant showed low level of heterosis in F_1 hybrids (-0.9 to 39.7%), whereas the effect of inbreeding depression in F_2 population was comparatively high (1.1 to 22.2%) for this character. The parent RHA-822 proved itself to be a good general combiner by making higher contribution towards heterosis both in F_1 hybrids and in F_2 populations.

Key words : heterosis, inbreeding depression, F_1 hybrids, F_2 population, sunflower

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The sunflower (*Helianthus annuus* L., 2n = 34) belongs to the family compositae. It was given its name, "helianthus" (Gr-helios = sun, anthos = flower), in Europe in the 18^{th} century. Sunflower is one of the three crop species along with soybean and rapeseed which account for approximately 78% of the world vegetable oil. Heterosis of these crops has been exploited only over the past few decades (Miller, 1998). Hybrid sunflower became a reality with the discovery of cytoplasmic male sterility and effective male fertility restoration system during 1970. Hybrid vigor has been the main driving force for acceptance of this oilseed crop.

Utilization of heterosis has allowed sunflower to become one of the major oilseed in many countries of Eastern and Western Europe, Russia and South America and is an important crop in the USA, Australia, South Africa, China, India and Turkey. Of the approximately 16.5 million hectares of sunflower grown in the major producing countries, 11.5 million hectares are planted to hybrids (Miller, 1998). Present day sunflower cultivars contain more than 40% oil and 18-20% protein. Sunflower oil is of good quality as it contains high proportion of linoleic acid which is a polyunsaturated fatty acid. It is also a good source of calcium, phosphorus, nicotinic acid and vitamin E. There are a number of advantages of growing sunflower for oil compared with other cultivated species. No special machinery is needed to produce this crop. It can be grown as catch crop in many situations. Being drought resistant it is well suited for rain fed as well as irrigated areas. The project was planned with the objective to record the heterotic effects in F_1 hybrids and the inbreeding depression in F_2 population for the better understanding of the plant behaviour in hybrid and selfed conditions.

Materials and Methods

This research was conducted at Plant Breeding and Genetics Department at NWFP Agricultural University, Peshawar. Seven sunflower inbred lines viz. HAR-5, RHA-822, RHA-365, RHA-387, HAR-2 and RHA-859, were crossed in a half diallel fashion to get F_1 seeds. All the F_1 seed was sown during the spring season of 1994, and at the time of pollination about 10 plants were selfed to get F_2 seeds. The parents, F_1 hybrids and F_2 population were field evaluated during spring 1995 using randomized complete block design with three replications. Each experimental plot comprised of four 3 m long rows with row to row distance of 0.60 m and plant to plant distance of 0.25 m. Three seeds per hill were planted and thinned to one plant per hill at 3-4 leaf stage. Fertilizer was applied in the form of urea and DAP at the rate of 120 and 60 kg per hectare, respectively. All the phosphorous and half of the nitrogen was applied at the time of seed bed preparation while the remaining half of nitrogen was applied at the time of first irrigation. Standard cultural practices were carried out from sowing till harvesting.

Data were recorded on the following characters.

1. Leaf area was estimated by measuring length and width of top, middle and bottom leaves of each of the five randomly selected plants.

$$\text{Leaf area (cm}^2\text{)} = \text{length x width x } 0.90$$

2. Leaves per plant were counted after the flower became visible.

3. Head diameter was measured from one edge of the head to the other.

4. Seed weight (thousand seed weight) was determined by counting and weighing 1000 seeds from each plot.

5. Yield per hectare (seed yield) was determined after threshing the seeds and allowing it to dry up to 9-10% moisture content.

6. Harvest index was calculated as the ratio of seed yield to total plant weight per plot.

The data about parents, F_1 hybrids and F_2 populations were statistically analyzed independently using MSTAT-C. Least significance difference (LSD) test was used for mean separation. Mid parent heterosis for F_1 hybrids and inbreeding depression for F_2 populations were estimated using the following formulae;

$$\text{Mid parent Heterosis (\%)} = \frac{F_1 - MP}{MP} \times 100$$

Where

F_1 = Mean of F_1 hybrid for a trait.

MP = Mean of mid parent,

$$\frac{(\text{parent 1} + \text{parent 2})}{2} \text{ for a trait}$$

Inbreeding depression on F_2 from F_1 (%) =

$$\frac{(F_1 - F_2)}{F_1}$$

Where

F_2 = Mean of F_2 population for a trait.

Significance of heterosis was determined as follow by using t-test (Wynne *et al.* 1970).

$$t = (\overline{F}_1 ij - \overline{MP} ij / \sqrt{3/8\sigma^2} E$$

Where

$\overline{F}_1 ij$ = the mean of the ijth F_1 cross

$\overline{MP} ij$ = the mid parent value for the ijth cross

$\sigma^2 E$ = estimate of error variance

Results and Discussions

Results pertaining to different morphological characters of seven sunflower inbred lines, and their twenty F_1 hybrids and F_2 populations are discussed in the following paragraphs.

1. Leaf area per plant (cm^2): Highly significant genetic differences were observed among parents (Table 1), F_1 hybrids and F_2 populations for leaf area per plant (Table 2). Among the parents, maximum leaf area of 198.9 cm^2 was observed for HAR-5, while minimum (83.1 cm^2) value was observed for RHA-859 (Table 1). All F_1 hybrids had highly significant heterosis ranging from 46.3 (HAR-5 x HAR-2) to 263.9% (RHA-822 x RHA-859). As expected, leaf area of 17 F_2 populations was less than their respective F_1 hybrids. Least inbreeding depression of 16.8% was observed for HAR-5 x RHA-365, while HAR-5 x RHA-822 exhibited the highest inbreeding depression of 43.0% for leaf area. The negative values of inbreeding depression for HAR-5 x HAR-2, RHA-365 x RHA-859 and RHA-387 x HAR-2 indicated increased leaf area of these crosses in F_2 population than their respective F_1 hybrids. This study is in accordance with the work of Giriraj and Virupakshappa (1992), who have observed high heterotic effects for this character. Moreover, Rashed *et al.* (1989) have noted significant inbreeding depression for this character, which is in line with the findings of the present work.

2. Leaves per plant: Analysis of variance revealed highly significant genetic differences among parents (Table 1), F_1 hybrids and F_2 populations (Table 2). Among the inbred lines HAR-5 showed maximum number of leaves (31), whereas RHA-859 has the minimum leaves (24.3) per plant (Table 1). Heterosis was significant for all F_1 hybrids except BRS-1 x RHA-387 (Table 2). Mid parent heterosis for this character ranged from -0.9 to 39.7%. Least inbreeding depression of 1.1% was recorded for BRS-1 x RHA-365, whereas HAR-5 x RHA-822 exhibited the highest inbreeding depression of 22.2% for this character.

These results are in line with the findings of Sassikumar and Gopalan (1999) and Yilmaz and Emiroglu (1995), who have reported heterosis of 22.7 and 2 to 14%, respectively, for this character

3. Head diameter (cm): Statistical analysis of the data for this character revealed highly significant differences among the parents (Table 1), F_1 hybrids and their respective F_2 populations (Table 2). Mean data for head diameter among the inbred lines ranged from 11.3 to 18.0 cm (Table 1). The mean data on head diameter of F_1 hybrids and F_2 population varied from 23.5 to 32.4 cm and 13.5 to 27.4 cm, respectively (Table 2). None of the F_2 population exceeded its F_1 hybrids and as a result no negative inbreeding depression was observed. Inbreeding depression for the F_1 to the F_2 ranged from 8.7 to 48.1% for this character. This is in accordance with the findings of Chaudry and Anannd (1984), who have reported positive inbreeding depression of 68.71% for the F_1 to the F_2 for head diameter. Rashed *et al.* (1989) have also observed significant level of inbreeding depression for this character. The current values of heterosis observed in most of the F_1 crosses are not significantly different; however these values are still higher than those of Sassikumar and Gopalan (1999), who have reported 25.2% heterosis for this

Table 1. Mean for leaf area per plant (cm^2), leaves per plant, head diameter (cm), seed weight (g), yield (kg/ha) and harvest index (%) of seven sunflower inbred lines evaluated at NWFP Agricultural University, Peshawar.

Inbred lines	Leaf Area/ plant (cm^2)	Leaves/ plant	Head Diameter (cm)	Seed Weight (g)	Yield (kg/ha)	Harvest Index (%)
HAR-5	198.9A	31.0A	18.0A	44.7A	1158A	13.9A
BRS-1	167.1C	30.2AB	15.2BC	47.2A	1296A	12.7AB
RHA-822	170.9C	25.6BE	16.7AB	49.0A	1388A	13.8A
RHA-365	163.2C	26.0D	14.3CD	41.0AB	1172A	11.3B
RHA-387	160.2C	29.2BC	13.2D	30.4CD	987AB	7.0C
HAR-2	186.2B	28.5C	16.0B	35.2BC	1237A	11.4B
RHA-859	83.1D	24.3E	11.3E	24.0D	617B	5.6C
F-test	**	**	**	**	**	*
LSD (5%)	11.9	1.45	1.61	8.07	413.5	2.02

*** and ** indicate significance at 5% and 1% probability levels, respectively.**
Means followed by the same letter (s) in a column are not significantly different at 5% level of probability.

character. The present study is also supported by the work of Gill *et al.* (1998) and Gangappa *et al.* (1997), who have reported high heterotic effects for this character. Inbred line RHA-822 gave good performance as a parent of F_1 hybrids and F_2 population.

4. Seed weight (g): Analysis of variance revealed highly significant genetic differences for this character among inbred lines, F_1 hybrids and their respective F_2 populations (Table 1 and 2). Mean data among different inbred lines ranged from 24.0 to 49.0 g (Table 1). The crosses RHA-822 x RHA-365 and HAR-5 x RHA-822 exhibited the highest value of 81.3 and 66.4 g in F_1 hybrids and in F_2 population, respectively (Table 2). Mid parent heterosis was significant among different F_1 hybrids except one of the F_1 hybrid (BRS-1 x RHA-365). No negative value of inbreeding depression was observed showing the superiority in weight of seeds of all F_1 hybrids compared to their F_2 combinations.

Positive heterotic effects for this character have been also reported by Goksoy *et al.* (2001a), Radhika *et al.* (2001), Gill and Punia (1996), and Zinovatnaya *et al.* (1996). Similarly Sassikumar and Gopalan (1999) have reported heterosis of 14.52% for 100-seed weight.

5. Yield (kg/ha): Significant genetic differences were observed among the means of inbred lines (Table 1), their F_1 hybrids and F_2 populations (Table 2).The parental means indicated that RHA-822 outyielded all other inbred lines with a yield of 1388.9 kg/ha, whereas RHA-859 gave the lowest yield of 617.3 kg/ha (Table 1). The highest yield in F_1 hybrids and in F_2 populations was recorded for RHA-822 x RHA-365 and RHA-822 x HAR-2, respectively (Table 2). Highly significant heterosis was observed for yield ranging from 102 (BRS-1 x RHA-387) to 331% (RHA-365 x HAR-859) among different F_1 hybrids. As expected all F_1 hybrids had yield higher than their respective F_2 population as a result negative inbreeding depression was not observed. Least inbreeding depression of 17% was observed for HAR-5 x HAR-2, whereas RHA-387 x RHA-859 showed maximum inbreeding depression of 71% for yield.

The works of Cheres *et al.* (2000), Nehru *et al.* (2000), Gangappa *et al.* (1997), Radhika *et al.* (1999), Kandhola *et al.* (1995), and Sugoor *et al.* (1994) who have reported different levels of heterosis for yield, also support the current study. Moreover, Singh *et al.* (2002), Gokosoy *et al.* (2001 b), Kumar *et al.* (1999), Yenice and Arslan (1997), and Yilmaz and Emiroglu (1995) have also

Table 2. Mean of F_1 hybrids and F_2 populations along with mid parent heterosis (% Het) values for F_1 hybrids and inbreeding depression (% ID) values for F_2 population for leaf area per plant (cm^2), leaves per plant, Head diameter (cm), seed weight (g), yield (kg/ha), and harvest index (%) of various sunflower crosses evaluated at NWFP Agricultural University, Peshawar.

Crosses	Leaf area per plant (cm^2)				Leaves per plant				Head diameter (cm)			
	F_1	F_2	% Het	%ID	F_1	F_2	% Het	% ID	F_1	F_2	% Het	% ID
HAR-5XBRS-1	276.1gh	218.8hi	50.9**	20.8	33.6de	29.3cf	9.6**	12.6	27.9ch	22.2cde	68.2	20.4
HAR-5XRHA-822	443.3ab	252.7eh	139.8**	43.0	36.8b	28.6dg	30.1**	22.2	28.0ch	29.4hi	61.3	30.7
HAR-5XRHA-365	352.4ef	293.2bcd	94.6**	16.8	34.2cd	29.1cf	20.1**	13.1	28.4bg	22.2cde	75.6	21.8
HAR-5XRHA-387	307.6fg	226.8ghi	71.4**	26.3	39.2a	32.3b	30.3**	17.6	30.2abc	20.4eh	93.6	32.5
HAR-5XHAR-2	281.6gh	309.1ab	46.3**	-9.7	33.1def	30.1cd	11.3**	9.1	25.6hi	22.3cde	50.7	12.8
HAR-5XRHA-859	343.8ef	234.6fgh	143.8**	31.8	31.7fi	28.2eh	14.5**	10.0	27.4dh	17.0j	87.1	38.0
BRS-1XRHA-822	375.2cde	259.2dg	122.0**	30.9	32.2eh	29.9ce	15.5**	7.4	29.7bcd	21.7dg	86.1	26.8
BRS-1XRHA-365	365.0de	227.9ghi	121.0**	37.6	31.0gj	30.7bc	10.3**	1.1	26.6fgh	19.7gh	80.4	26.0
BRS-1XRHA-387	258.3h	193.6i	57.8**	25.0	29.4j	26.7h	-0.9	9.2	23.5i	16.7j	65.6	29.1
BRS-1XHAR-2	344.6ef	244.2fgh	95.1**	29.1	30.7hij	29.3cf	4.5*	4.6	28.8bf	20.1fgh	84.7	30.2
BRS-1XRHA-859	343.9ef	285.6be	174.9**	17.0	32.3eh	30.0cd	18.5**	7.2	30.0abc	23.6bcd	126.5*	21.3
RHA-822XRHA-365	483.3a	321.5ab	189.3**	33.5	36.0bc	30.2cd	39.7**	16.2	32.4a	24.7b	109.0*	23.8
RHA-822XRHA-387	414.0bcd	299.3bc	150.1**	27.7	33.6de	29.1cf	22.5**	13.4	26.7eh	17.3ij	78.1	35.0
RHA-822XHAR-2	420.6bc	336.3a	135.6**	20.0	36.8b	34.9a	36.1**	5.0	30.0abc	27.4a	83.4	8.7
RHA-822XRHA-859	462.1ab	314.7ab	263.9**	31.9	31.6fi	27.7fgh	26.5**	12.1	30.2abc	21.8def	115.5*	27.9
RHA-365XRHA-387	304.0fgh	219.7hi	88.0**	27.7	32.6dg	29.7cde	17.9**	8.9	30.8ab	18.5hij	123.4*	40.0
RHA-365XRHA-859	283.7gh	300.2abc	130.3**	-5.8	32.0ei	27.0gh	27.2**	15.5	28.4dg	24.1bc	121.1*	14.9
RHA-387XHAR-2	307.4fg	312.4ab	77.5**	-1.6	33.2def	29.7cde	15.1**	10.5	26.7eh	22.1cf	82.9	17.2
RHA-387XRHA-859	305.6fgh	197.4i	151.1**	35.4	34.2cd	28.8def	27.8**	15.7	26.2gh	13.5k	111.4	48.1
HAR-2XRHA-859	367.3de	271.0cf	172.8**	26.2	31.6fi	27.1gh	19.5**	14.0	27.2dh	19.6gh	99.2	27.9
Significance	**	**	-	-	**	**	-	-	**	**	-	-
LSD (5%)	48.09	36.87	-	-	1.83	1.68	-	-	2.54	2.09	-	-

*** and ** indicate significance at 5% and 1% probability levels, respectively.**
Means followed by the same letter (s) in a column are not significantly different at 5% level of probability.

Table 2. (Continued)

Crosses	Seed weight (g)				Yield (kg/ha)				Harvest index (%)			
	F_1	F_2	% Het	%ID	F_1	F_2	% Het	%ID	F_1	F_2	% Het	%ID
HAR-5XBRS-1	61.7be	54.4ab	34.3**	11.8	3395dg	2160cg	155**	36	12.2cf	11.5be	-15.0*	6.4
HAR-5XRHA-822	66.4bc	56.5a	41.8**	15.0	5000ab	2592abc	264**	48	15.8a	13.8a	5.4	12.2
HAR-5XRHA-365	59.4cf	47.5bf	38.8**	20.0	4259ae	2530ad	236**	40	13.8ae	13.2abc	1.1	4.7
HAR-5XRHA-387	60.8cde	44.8def	62.1**	26.4	4382ae	1975dg	273**	54	14.8abc	12.1ad	28.5**	18.7
HAR-5XHAR-2	57.1dg	49.4ae	42.9**	13.4	2777fg	2284bf	114**	17	11.9def	13.3abc	-13.7*	-11.9
HAR-5XRHA-859	53.6efg	42.3ef	56.1**	21.2	3186efg	1666g	222**	47	11.4ef	13.6ab	8.4	-19.1
BRS-1XRHA-822	54.9efg	50.8ad	14.1*	7.4	3456dg	2080cg	157**	39	12.0cf	12.8abc	-9.2	-6.8
BRS-1XRHA-365	48.1gh	50.3ad	9.2	-4.5	2932fg	1913efg	137**	34	12.8bf	12.1ad	6.7	5.2
BRS-1XRHA-387	44.5h	40.7f	14.8*	8.6	2314g	1018h	102**	56	11.7def	7.6f	18.8*	34.5
BRS-1XHAR-2	51.7fgh	46.7f	25.5**	9.6	3271dg	1851fg	158**	43	13.3af	13.8a	10.7	-3.8
BRS-1XRHA-859	49.7gh	50.6d	39.7**	-1.8	3564dg	2469be	251**	26	11.7def	13.3abc	32.9**	-13.5
RHA-822XRHA-365	81.3a	53.5abc	80.7**	34.2	5246a	2839ab	309**	45	14.1ae	12.7abc	12.4	9.5
RHA-822XRHA-387	59.9dg	47.1bf	43.5**	17.2	2932fg	1759fg	146**	40	10.5f	13.9a	1.6ns	-31.9
RHA-822XHAR-2	70.5b	52.4abc	67.4**	25.7	4938abc	3086a	276**	37	14.4ad	11.1cde	14.2*	22.6
RHA-822XRHA-859	66.3bc	51.2ad	81.6**	22.7	4144ad	2002dg	313**	52	13.3af	11.3cde	41.5**	15.0
RHA-365XRHA-387	59.0cf	53.8abc	65.3**	8.8	4012af	1851fg	271**	53	15.4ab	9.4ef	68.8**	38.8
RHA-365XRHA-859	62.5be	48.3bf	92.4**	22.8	3858bf	2314bf	331**	40	13.2af	12.5abc	62.1**	4.7
RHA-387XHAR-2	65.3bcd	44.7def	99.2**	31.5	3734cf	1944efg	236**	47	11.3ef	11.2cde	23.4*	1.0
RHA-387XRHA-859	60.2cf	21.4g	121.6**	64.6	2997fg	863h	273**	71	9.2g	7.0f	53.3**	23.9
HAR-2XRHA-859	59.4cf	51.9ad	100.8**	12.8	3209dg	2006dg	246**	37	13.7ae	10.2de	67.6**	26.0
Significance	**	**	-	-	**	**	-	-	*	**	-	-
LSD (5%)	9.13	7.47	-	-	1235	563	-	-	2.83	2.25	-	-

*** and ** indicate significance at 5% and 1% probability levels, respectively.**
Means followed by the same letter (s) in a column are not significantly different at 5% level of probability.

reported heterotic values of 278%, 65.7%, -24.75 to 40.36%, 77.90% and 30 to 73%, respectively for this character.

Harvest index (%): The differences among the inbred lines a well as F_2 population were highly significant, whereas the differences among the genotypes in F_1 hybrids were significant only at 5% level of probability (Table 1 and 2). Among the inbred lines, HAR-5 gave the highest value of harvest index (13.9%) closely followed by RHA-822 with a value of 13.8% (Table 1). The value of harvest index among different F_1 hybrids ranged from 9.2 (RHA-387 x RHA-859) to 15.8% (HAR-5 x RHA-822), whereas harvest index for F_2 population ranged from 7.0 to 13.8% among different F_2 combinations (Table 2). Heterosis for harvest index among different F_1 hybrids ranged from -15.0 (HAR-5 x BRS-1) to 68.8% (RHA-365 x RHA-387). Least inbreeding depression of -31.9% was observed for RHA-822 x RHA-387, whereas maximum inbreeding depression of 38.8% was observed for RHA-365 x RHA-387. The negative inbreeding depression noted for some crosses indicated that some of the F_2 population have higher harvest index compared to their F_1 hybrids. Madrap and Makne (1994) have also reported high levels of heterosis for harvest index.

Conclusion

It can be concluded from this study that RHA-822 should be chosen as a parent to cross with other inbred lines for future breeding programs because of its high general combining ability in the majority of cases. The finding that most of the F_1 hybrids were superior to their F_2 populations and F_2 populations showed considerable inbreeding depression in majority of the cases, the possibility of getting F_2 seed with a performance of anyway near F_1 seed in still far from the reality. However, more cross combinations should be evaluated for a broader picture and more valid conclusions.

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