HETEROSIS AND INBREEDING DEPRESSION FOR SEED AND OPIUM YIELD IN OPIUM POPPY (*PAPAVER SOMNIFERUM* L.)

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Abstract: The degree of heterosis in F_1 progenies and inbreeding depression in F_2 generations was studied for seed and opium yield in opium poppy (*Papaver somniferum* L.) in set of crosses derived from partial diallel breeding design. Mid and better parent heterosis for seed yield was recorded in between –48.35 to 87.69% and –54.38 to 71.15% respectively. Likewise, for opium yield it varied from –39.06 to 71.13% and -42.74 to 52.04% for mid and better parent respectively. Significant and desirable heterosis over mid and better parent for seed yield was observed in forty five and twenty six crosses respectively. The crosses ND1002 x NBRI-11 and ND1002 x BR241 showed higher better parent heterosis both for seed and opium yield. Considerable amount of inbreeding depression in F_2 generation were also recorded. Significant inbreeding depression in F_2 generation were observed in seven crosses for seed yield/plant, and twenty two for opium yield/plant indicating deterioration in their performance in F_2 generation. The magnitude of inbreeding depression varied from –125.60 to 24.16% and -60.14 to 33.07% for seed and opium yield/plant respectively.

Keywords: Heterosis, Inbreeding depression, Opium poppy

INTRODUCTION

Opium poppy (*Papaver somniferum* L.) is chief source of raw opium and various pharmaceutically valuable alkaloids namely morphine, codeine, thebaine, narcotine and papaverine (Singh *et. al.* 1995a,). Morphine is the major alkaloid present in opium ranging from 7-17% followed by narcotine (3.0 – 10.0%) (Shukla *et al.*, 1995). These alkaloids are used to prepare several pharmaceutical derivatives and thus the opium poppy serves as renewable resource for pharmaceutical alkaloids. In addition, poppy seeds are highly valuable due to high nutritive value having protein upto 24% and high amount of linoleic acid (upto 68%) in seed oil, which helps in lowering blood cholesterol in human system (Singh *et al*., 1995b). The oil cake with high percentage of digestible protein (32.5%) is used as a concentrate in feeding pigs and other animals reared for meat (Pushpangadan and Singh, 2001). Among the opium producing countries India is one of the largest producer of licit opium, which meets the national and international demand. Despite the important role of this crop in Indian economy, high yielding variety for high latex (opium) and seed yield still lacking. The limited improvement in this crop may be due to narrow genetic base of common ancestry (Singh and Khanna 1991a; Singh *et al*., 1999a). The success of any crop improvement program depends mainly on a judicious selection of promising parents from gene pool, a clear cut understanding of genetic mechanism involved in the inheritance of characters which help the breeders in deciding the most appropriate breeding procedure to enhance the genetic potentialities.

The heterosis or hybrid vigour has been exploited in both self and cross pollinated crops. It has been extensively used in agriculture to increase yield and to broaden adaptability of hybrid varieties and is applied to an increasing number of crop species (Meyer et al., 2004). Heterosis is a complex genetic phenomenon depending upon the balance of additive, dominance and interaction components as well as distribution of genes in the parental lines. Three principal genetic models have been suggested to explain heterosis as: dominance, overdominance and pseudo-overdominance (Crow 1952; Tsaftaris 1995). The dominance hypothesis explains the increased vigor due to the action of favorable dominant alleles (usually at multiple loci) from both parents combined in the hybrid (Xiao et al. 1995) and overdominance hypothesis postulates the existence of loci at which the heterozygous state is superior to either homozygote. The pseudo-overdominance refers to the situation of tightly linked genes with favorable dominant alleles linked in repulsion phase (Meyer et al. 2004). In the present investigation an effort has been made to find out the extent of heterosis and inbreeding depression in opium poppy for seed and opium yield through partial diallel cross.

MATERIAL AND METHODS

Twenty diverse parental lines of opium poppy (*Papaver somniferum* L.) selected on the basis of different morpho-agronomic traits from the germplasm lines which are being maintained at National Botanical Research Institute, Lucknow (Singh *et al*., 1997). These lines were crossed in partial diallel design (Kempthorne and Curnow 1961) to obtain 90 cross combinations and final experiment consists of 90 F_1s, 90 F2s and 20 parents. The trial was conducted in randomized block design with three replications. The details of experimental design, data collection, environment, cultural practices site etc are explained by Yadav et al (2009). The phenotypic data on seed and opium yield of parental lines and their progenies were used to calculate heterosis and inbreeding depression using WINDOSTAT software (www.windostat. org). The heterosis in term of increase vigour of F_1 over mid parent and better parent were calculated by using the formulae:

Heterosis (%) over mid parent $= \frac{\overline{F_1} - \overline{M}P}{\overline{M}P} \times 100$

Heterosis (%) over better parent $= \frac{\overline{F_1} - \overline{B}P}{\overline{B}P} \times 100$

Where:

$\overline{F}_1$ = Mean value of F_1

$\overline{B}P$ = Mean value of better parent

$\overline{M}P$ = Mean value of mid parent

The inbreeding depression was measured as the decrease in the performance of F_2 population over the mean performance of F_1 was calculated as:

Inbreeding depression (%) $= \frac{\overline{F_1} - \overline{F_2}}{\overline{F_1}} \times 100$

Where:

$\overline{F}_1$ = Mean value of F_1

$\overline{F}_2$ = Mean value of F_2

The significance of heterosis was tested by comparing difference of mean value of F_1 and parents with critical difference (CD) value for heterosis and in case of inbreeding depression CD were compared mean value of F_{1S} and F_{2S} to test the significance.

RESULTS AND DISCUSSION

Heterotic response has been expressed as a deviation of F_1 either of mid parental value or better parent i.e. heterosis accounts for any increase or decrease in performance of F_1 over its parents. The first important step in the exploitation of heterosis is to know its magnitude and direction. Mather (1955) envisaged heterosis as an expression of genetic balance which depends upon an adjustment and interaction of polygenes. According to Paterniani and Lonnquist (1963) the expression of heterosis is due to accumulation of desirable genes in a hybrid plant through the crossing of parents differing in their genetic makeup and it has very often been related to the magnitude of the genetic diversity. Coyne (1965) have reported that genetic basis of heterosis for a complex trait like yield could be explained by the multiplicative interaction on the phenotypic level of component trait. Xiao *et al*. (1995) suggested expression of heterosis on the basis of dominance rather than over dominance.. Heterosis (F_1-P_1) can be high or low depending upon the mean of the parent in question. Obviously, there is every possibility of getting a cross with high *per se* performance but with low heterosis, in case the parental mean is also high. Contrary to this there can be a cross with poor *per se* performance but with high heterotic response, in case the parental performance is very poor. It means that choice of the best cross combination on the basis of high heterosis would not necessarily be the one which would give high *per se* performance also. Therefore, both *per se* performance and heterotic response should be taken, into account while making selection of crosses for further exploitation.

In the present investigation heterosis in F_1 over mid and better parent and inbreeding depression in F_2 were studied. The heterosis over mid and better parent (Table1) revealed that the degree and direction of heterotic response varied for both the trait as well as from cross to cross. This is in accordance with those of Singh *et al*. (1999b), Shukla *et al*. (2000). The *per se* performance of F_1 progenies for seed yield/plant ranged from 2.3 to 11.9 g with an average of 7.6±0.4 g. The mid parent heterosis varied from –48.35 to 87.69% with maximum in BR230 x IS-16 (87.69%) followed by ND1002 x NBRI-11 (81.17%), ND1002 x IS-16 (68.17%) and BR230 x UO1285 (66.87%). Better parent heterosis varied from –54.38 to 71.15% with maximum observed by the cross ND1002 x NBRI-11 (71.15%) followed by ND1002 x BR241 (58.82%), BR230 x UO1285 (57.39%) and

BR230 x IS-16 (56.41%). Significant and desirable heterosis over mid and better parent for seed yield/plant was observed in forty five and twenty six crosses respectively. Earlier studies on the aspect of heterotic response for yield i.e. seed yield and opium yield and its related traits viz. capsule number, capsule size, were reported by Singh and Khanna (1991b), Shukla (1998). Shukla and Singh (2000) reported considerable amount of heterosis for seed and opium yield. The crosses ND1002 x NBRI-11 (71.2%) and ND1002 x BR241 (58.8%) for seed yield exhibited highest heterosis over better parent, highest *per se* performance in F_1 and significant inbreeding depression to the extent of 24.16 and 23.46 percent respectively. The crosses BR230 x IS-16 (56.41%), MOP541 x BR241 (40.69%) and UO601 x BR231 (34.31%) had significant positive heterosis over better parent for seed yield, had negative inbreeding depression and high *per se* in F_2 than F_1. The higher performance of F_2 than F_1 of these crosses indicates that some transgressive segregants could be obtained for seed yield in advanced generation through selection scheme as pedigree method. The *per se* performance of F_1 progenies for opium yield varied from 117.000 to 310.667 mg with population mean of 227.159±9.377 mg. The mid parent heterosis ranged from –39.06 to 71.13% with highest for BR226 x IS-13 (71.13%) followed by ND1002 x BR241 (63.80%) and UO601 x IS-13 (64.32%). Heterosis over better parent varied from –42.74 to 52.04% with maximum for ND1002 x BR241 (52.04%) followed by ND1002 x NBRI-11 (49.27%) and BR227 x Papline (40.74%). Out of 90 crosses, 25 crosses showed positive and significant heterosis over better parent.

Significant inbreeding depression in F_2 generation were observed in seven crosses for seed yield/plant, and twenty two for opium yield/plant indicating deterioration in their performance in F_2 generation. The *per se* performance of the F_2 for seed yield/plant ranged from 5.933 to 10.867 g with population mean of 8.013±0.484 g. The magnitude of inbreeding depression for seed yield/plant recorded in F_2 generation varied from –125.60 to 24.16% and maximum was recorded for the cross ND1002 x NBRI-11 (24.16%) followed by ND1002 x BR241 (23.46%) and MOP541 x BR234 (21.03%). The mean of opium yield/plant among F_2 generation varied from 123.667 to 305.000 mg with population mean of 228.119±8.247 mg. The maximum inbreeding depression was noticed in the cross BR226 x IS-16 (33.07%), followed by NBRI-1 x NBRI-11 (31.01%), BR246 x Papline (30.73%) and UO602 x IS-16 (30.13%). The results further showed that the hybrids which had maximum heterosis also had proportionate inbreeding depression in F_2. This seems to be due to non allelic interactions of higher magnitude. In the present investigation, those crosses which do not show significant inbreeding or showed negative inbreeding depression in F_2 (BR230 x IS-16, UO601 x BR231, MOP541 x BR241, GZ x ND1002 and BR246 x IS-13 for seed yield and UO601 x Papline, UO602 x BR230, UO601 x NBRI-11, GZ x BR227 and BR234 x IS-16 for opium yield) may be advanced through pedigree method to select out the desirable segregants for breeding improved varieties of opium poppy.

Table1. Magnitude of heterosis (%) and inbreeding depression (%) for seed and opium yield in opium poppy (*Papaver somniferum* L.)

Sl. No.	Crosses	Seed yield/plant (g)		Opium yield/Plant (mg)		Seed yield/plant			Opium yield/plant		
		F_1	F_2	F_1	F_2	MP	BP	ID	MP	BP	ID
1	GZ x ND1001	7.9	8.4	226.7	210.3	25.26*	21.43*	-6.30	16.14**	7.59	7.21
2	GZ x BR246	7.1	7.1	171.3	205.0	12.77	8.16	0.00	-17.56**	-27.40**	-19.65*
3	GZ x ND1002	8.3	9.5	117.0	179.3	30.18**	26.53**	-15.32	-39.06**	-42.74**	-53.28*
4	GZ x BR226	7.2	7.6	191.7	222.3	-8.47	-21.74**	-5.56	-11.81*	-24.84**	16.00
5	GZ x BR227	7.6	7.4	235.7	219.0	12.81	9.05	3.06	27.85**	24.69**	7.07
6	GZ x BR230	9.6	9.0	195.7	233.0	63.07**	46.43**	5.92	3.16	-2.00	-19.08*
7	GZ x BR231	6.3	8.5	165.3	196.7	-6.00	-7.84	-35.11**	-23.10**	-33.95**	-18.95*
8	GZ x BR234	8.1	7.3	194.7	153.0	13.35	4.76	9.09	5.70	3.18	21.40*
9	GZ x BR241	7.5	6.6	161.7	195.0	12.00	9.80	12.05	-8.83	-10.02	-20.62
10	NBRI-1 x BR246	6.0	7.5	206.7	269.7	-12.56	-22.65**	-24.86	-12.61**	-12.80*	-30.48**
11	NBRI-1 x ND1002	8.7	8.1	149.0	217.7	24.11**	11.11	6.15	-32.48**	-37.13**	-46.09**
12	NBRI-1 x BR226	6.8	8.1	212.7	223.7	-20.39**	-26.45**	-20.20	-13.55**	-16.60**	-5.17
13	NBRI-1 x BR227	9.0	7.7	219.3	232.7	21.62**	15.38	14.07*	2.97	-7.45	-6.08
14	NBRI-1 x BR230	8.9	8.3	210.0	224.7	37.44**	14.53	6.72	-3.82	-11.39*	-6.98
15	NBRI-1 x BR231	7.8	7.5	199.0	192.3	6.85	0.00	4.27	-18.33**	-20.51**	3.35
16	NBRI-1 x BR234	9.3	7.4	219.3	203.0	20.83**	19.66**	20.71**	3.05	-7.45	7.45
17	NBRI-1 x BR241	9.9	8.4	262.0	262.0	36.07**	27.53**	15.44*	27.18**	10.55	0.00
18	NBRI-1 x NBRI-11	9.0	7.8	291.3	201.0	21.72**	14.96	13.01	35.82**	22.93**	31.01**
19	NBRI-5 x ND1002	9.6	8.9	267.3	237.3	25.49**	5.11	6.94	15.81**	3.89	11.22
20	NBRI-5 x BR226	10.0	9.5	264.0	215.0	9.09	8.70	5.33	3.06	2.59	18.56*
21	NBRI-5 x BR227	4.2	9.4	216.3	235.0	-48.35**	-54.38**	-125.6**	-3.06	-15.93**	-8.63
22	NBRI-5 x BR230	8.7	8.3	223.7	279.3	21.86**	-4.38	4.58	-2.12	-13.08*	-24.89*
23	NBRI-5 x BR231	8.2	8.4	280.0	277.7	3.35	-9.85	-2.02	10.31*	8.81	0.83
24	NBRI-5 x BR234	6.9	8.5	252.7	244.7	-18.42**	-24.82**	-24.27*	13.30*	-1.81	3.17
25	NBRI-5 x BR241	6.9	9.9	285.7	281.7	13.39	-24.45**	-43.00**	32.15**	11.01*	1.40
26	NBRI-5 x NBRI-11	7.4	8.7	244.7	219.3	-7.88	-18.98**	-18.02	8.90	-4.92	10.35
27	NBRI-5 x IS-13	7.7	7.7	212.3	220.0	12.14	-15.69*	-0.43	19.40**	-17.49**	-3.61
28	MOP541 x BR226	8.6	8.5	262.0	243.3	11.21	-6.52	0.78	5.93	2.75	7.12
29	MOP541 x BR227	9.2	8.4	240.3	233.3	38.69**	31.43**	8.70	12.13*	0.28	2.91
30	MOP541 x BR230	5.9	7.7	190.3	267.3	2.33	-6.38	-31.82	-13.35*	-20.58**	-40.46**
31	MOP541 x BR231	5.9	7.9	205.7	236.7	-10.20	-13.73	-35.23*	-16.05**	-17.84**	-15.07*
32	MOP541 x BR234	8.4	6.6	242.7	182.0	20.29*	9.09	21.03	13.31*	1.25	25.00**
33	MOP541 x BR241	9.6	10.6	301.0	280.0	46.43**	40.69**	-10.80	45.18**	25.59**	6.98
34	MOP541 x NBRI-11	6.7	8.9	218.3	237.3	2.02	-2.88	-31.68*	1.16	-8.90	-8.70
35	MOP541 x IS-13	6.1	6.8	195.0	230.7	12.88	-2.13	-10.87	15.38*	-18.64**	-18.29
36	MOP541 x Papline	6.4	7.5	189.7	209.3	-1.03	-4.00	-16.67	-10.32	-20.86**	-10.37
37	UO601 x BR227	7.4	8.5	179.7	222.3	13.92	5.24	-14.93	-12.78*	-19.43**	-23.75*
38	UO601 x BR230	7.6	8.2	191.3	243.3	36.53**	28.09*	-7.89	9.46	-14.20*	-27.18*
39	UO601 x BR231	9.1	10.9	255.0	284.7	43.46**	34.31**	-18.98	7.75	1.86	-11.63
40	UO601 x BR234	8.5	9.3	260.0	257.3	24.69**	10.39	-9.41	26.32**	16.59**	1.03
41	UO601 x BR241	7.1	8.1	245.7	228.7	11.52	4.41	-14.55	23.45**	10.16	6.92
42	UO601 x NBRI-11	9.0	7.2	280.7	248.7	39.90**	29.81**	20.37	35.26**	25.86**	11.40*
43	UO601 x IS-13	7.7	7.5	264.0	275.7	46.84**	30.34**	3.02	64.32**	18.39**	-4.42
44	UO601 x Papline	7.5	8.3	298.7	268.0	19.58*	13.00	-9.73	47.01**	33.93**	10.27
45	UO601 x UO1285	6.3	6.8	308.0	238.0	6.21	5.62	-7.98	40.21**	38.12**	22.73*
46	UO602 x BR230	7.5	6.0	256.3	225.7	41.25**	37.80**	20.35**	35.87**	28.38**	11.96
47	UO602 x BR231	5.0	8.5	216.3	180.0	-18.48*	-26.47**	-70.00**	1.09	-13.58*	16.80
48	UO602 x BR234	7.7	7.1	189.7	205.3	16.96	0.00	8.23	3.55	0.53	-8.26
49	UO602 x BR241	2.3	7.1	203.0	206.3	18.48*	6.86	2.29	15.12*	14.26	-1.64
50	UO602 x NBRI-11	7.4	7.5	209.7	190.0	18.82*	6.25	-1.81	13.44*	9.20	9.38*
51	UO602 x IS-13	4.5	7.0	180.7	215.3	-11.26	-18.29	-56.72*	30.92**	1.69	-19.19

52	UO602 x Papline	4.8	6.9	162.7	187.7	-20.33*	-27.50**	-42.07	-9.88	-11.27	-15.37*
53	UO602 x UO1285	7.2	6.8	139.7	223.7	27.06**	22.73*	5.56	-29.10**	-35.44**	-60.14**
54	UO602 x IS-16	7.1	6.2	177.0	123.7	59.70**	30.49*	13.55	37.03**	-0.38	30.13**
55	ND1001 x BR231	6.3	5.9	169.7	228.3	-3.09	-7.84	5.32	-26.39**	-32.32**	-34.08**
56	ND1001 x BR234	9.0	8.3	217.7	263.7	30.12**	16.88	8.15	9.02	3.32	-21.13*
57	ND1001 x BR241	7.3	9.0	236.7	232.0	12.37	6.86	-23.85	22.73**	12.34	1.97
58	ND1001 x NBRI-11	7.9	7.7	208.3	266.3	21.43*	14.42	2.52	3.48	-1.11	-27.84*
59	ND1001 x IS-13	7.6	8.6	226.7	264.7	40.99**	23.37*	-13.66	46.71**	7.59	-16.76*
60	ND1001 x Papline	9.1	7.7	242.7	226.0	42.71**	37.00	15.33	23.18**	15.19	6.87
61	ND1001 x UD1285	7.7	8.2	238.3	269.7	27.78**	25.00*	-6.96	11.63*	10.17	-13.15
62	ND1001 x IS-16	7.0	7.2	196.0	231.3	45.83*	14.13	-3.33	34.55**	-6.96	-18.03*
63	BR246 x BR234	7.3	8.5	232.3	220.3	6.57	-5.19	-16.89	9.42	-1.55	5.16
64	BR246 x BR241	7.2	8.1	227.3	263.3	12.50	5.88	-12.04	10.62	-3.67	-15.84
65	BR246 x NBRI-11	7.5	8.1	219.3	244.0	15.98	8.17	-8.44	2.49	-7.06	-11.25
66	BR246 x IS-13	8.2	7.4	230.3	225.7	54.72**	36.67**	10.16	37.79**	-2.40	2.03
67	BR246 x Papline	7.1	8.3	290.7	201.3	12.63	7.00	-15.89	38.63**	23.16**	30.73**
68	BR246 x UO1285	5.5	6.5	235.3	231.7	-7.30	-8.33	-18.79	4.05	-0.28	1.56
69	BR246 x IS-16	7.3	7.7	152.3	235.0	54.23**	21.67	-5.94	-3.79	-35.45**	-54.27**
70	ND1002 x BR241	10.8	8.3	310.7	254.0	66.58**	58.82**	23.46*	63.80**	52.04**	18.24**
71	ND1002 x NBRI-11	11.9	9.0	305.0	248.3	81.17**	71.15**	24.16*	53.91**	49.27**	18.58*
72	ND1002 x IS-13	6.8	8.8	210.7	242.0	26.32*	10.27	-29.90*	39.21**	3.10	-14.87
73	ND1002 x Papline	7.5	7.5	261.7	206.7	16.36	12.00	-0.45	35.00**	28.06**	21.02*
74	ND1002 xUO1285	6.5	7.1	194.3	227.3	8.59	5.95	-9.18	-7.61	-10.17	-16.98
75	ND1002 x IS-16	8.1	7.1	184.7	230.3	68.17**	31.35**	12.76	29.59**	-9.62	-24.73*
76	BR226 x NBRI-11	11.3	9.2	285.0	239.7	39.67**	22.46**	18.34*	27.52**	11.76*	15.91*
77	BR226 x IS-13	7.6	8.2	302.3	258.0	10.14	-17.39	-7.89	71.13**	18.56**	14.66*
78	BR226 x Papline	8.3	8.2	300.0	240.0	4.20	-10.14	1.21	36.88**	17.65**	20.00**
79	BR226 x UO1285	6.7	10.4	304.7	266.0	-10.62	-26.81**	-54.46**	29.28**	19.48**	12.69*
80	BR226 x IS-16	5.5	6.9	255.0	170.7	-13.16	-40.22**	-24.85*	51.94**	0.00	33.07**
81	BR227 x IS-13	7.1	7.6	222.0	167.0	22.41*	1.43	-7.04	54.52**	17.46*	24.77**
82	BR227 x Papline	7.7	7.1	266.0	217.3	12.20	9.52	7.39	42.88**	40.74**	18.30**
83	BR227 x UO1285	8.7	8.6	246.0	305.0	35.75**	24.76**	1.53	21.38**	13.71*	-23.98*
84	BR227 x IS-16	4.8	7.2	170.7	176.3	-8.28	-31.43**	-50.00*	26.58**	-9.70	-3.32
85	BR230 x Papline	6.7	8.3	257.7	218.7	13.48	1.00	-23.76*	34.55**	29.05**	15.14*
86	BR230 x UO1285	9.2	8.3	286.0	229.0	66.87**	57.39**	10.47	37.50**	32.20**	19.93*
87	BR230 x IS-16	8.1	9.5	152.0	174.3	87.69**	56.41**	-16.39	8.44	-23.87**	-14.69
88	BR231 x UO1285	8.3	8.7	293.3	240.0	31.05**	22.06*	-5.22	25.71**	17.18**	18.18*
89	BR231 x IS-16	6.9	7.8	161.3	153.0	34.42**	1.47	-13.53	-2.52	-35.55**	5.17
90	BR234 x IS-16	8.4	7.7	213.0	269.0	51.04**	9.52	8.70	58.17**	12.90	-26.29**
	Min	2.3	5.9	117.0	123.7	-48.35	-54.38	-125.60	-39.06	-42.74	-60.14
	Max	11.9	10.9	310.7	305.0	87.69	71.15	24.16	71.13	52.04	33.07
	Average	7.6	8.0	227.2	228.1	20.11	7.95	-7.77	15.48	1.01	-2.88
	SD	1.5	0.9	45.0	33.1	24.27	22.65	22.75	23.58	20.08	20.20

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