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Estimation of Heterosis for Seed Yield and it's contributing Traits in Opium Poppy (*Papaver somniferum* L.)

S. Aparna[1*], Amit Dadheech[2], Hemlata Sharma[3], Narendra Kumar Padiwal[4], and Mukesh Kumar Yadav[5]

[1]M.Sc. Scholar, Department of Genetics and Plant Breeding,
Maharana Pratap University of Agriculture and Technology, Udaipur (Rajasthan), India.
[2]Assistant Professor, Department of Genetics and Plant Breeding,
Maharana Pratap University of Agriculture and Technology, Udaipur (Rajasthan), India.
[3]Associate Professor and Head, Department of Genetics and Plant Breeding,
Maharana Pratap University of Agriculture and Technology, Udaipur (Rajasthan), India.
[4]Technical Assistant, AICRP on Medicinal and Aromatic Plants,
Maharana Pratap University of Agriculture and Technology, Udaipur (Rajasthan), India.
[5]Ph.D. Scholar, Department of Genetics and Plant Breeding,
Maharana Pratap University of Agriculture and Technology, Udaipur (Rajasthan), India.

(Corresponding author: S. Aparna)*
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ABSTRACT: Opium poppy is a valuable multipurpose crop, with long standing legacy of medicinal and pharmaceutical utilities and have also been emerged as a model crop by virtue of it's versatility and uniqueness. Keeping in mind, the requirements of genetic enhancement and better breeding advancements of the poppy, a line × tester analysis was carried out to assess the heterosis, heterobeltiosis and economic heterosis of fifty four F_1 hybrids developed by crossing 18 lines/females and 3 testers/males of diverse parents along with two suitable checks for thirteen viable economical traits in *Papaver somniferum* L. The hybrids were evaluated in a randomized block design during Rabi 2022-2023 at RCA, MPUAT Udaipur. The analysis of variance concluded the presence of variability among parents and crosses for the characters studied. Significant parents v/s hybrids contrast were observed for all characters, except for days to maturity, indicating the presence of considerable amount of genetic diversity in the experimental material. The cross UOP-78 × UOP-20 exhibited positive significant economic heterosis over the best check Chetak Aphim for seed yield per plant and also maximum relative heterosis and heterobeltiosis for seed yield per plant and harvest index for seed yield. The cross UOP-150 × UOP-80 showed maximum significant positive relative heterosis for capsule husk yield, length of main capsule and capsule size, maximum significant positive heterobeltiosis for capsule husk yield and capsule size and maximum positive economic heterosis for length of main capsule and capsule size. UOP-107 × UOP-80 showed all three heterotic parameters for number of stigmatic rays per capsule and maximum significant relative heterosis and heterobeltiosis for diameter of main capsule was shown by UOP-45 × UOP-80 . UOP-79 × UOP-20 showed maximum positive significant values of relative and economic heterosis for number of effective capsules per plant. Therefore, these promising crosses can be recommended for exploitation of heterosis to obtain appropriate segregants for crop improvement program in opium poppy.

Keywords: Heterosis, Heterobeltiosis, Economic heterosis, Opium poppy, *Papaver somniferum* L.

INTRODUCTION

Opium poppy (*Papaver somniferum* L.) is an ancient medicinal herb harbouring valuable pharmaceutical potential. Opium poppy (*Papaver somniferum* L., 2*n*=22) belongs to family *Papaveraceae*, with it's Latin botanical name meaning "sleep- bringing poppy", referring to the sedative properties of the alkaloids present in the species. The poppy is known to have been domesticated first in the western Mediterranean region of Europe, where it's putative wild ancestor is indigenous. It spread from there through the Balkan Peninsula to Asia Minor from the tertiary period itself (Bazilevskays, 1976; Mortan, 1977). The legal growing of opium for medicinal usage currently takes place in India, Iran, Europe and Turkey and is strictly supervised. Opium poppy is generally self pollinated but also exhibits often cross pollinated behaviour aiding to the existing climatic factors and insect population of the location of cropping (Kumar and Patra 2010). The out crossing is due to insect activity, predominantly bees.

Opium poppy is a multipurpose crop owning high food value as well as excellent medicinal properties, from which over 100 different kinds of benzylisoquinoline alkaloids (BIAs) are extracted (Weid *et al*., 2004) that

are employed in several pharmaceutical as well as nutraceutical industries for remedial purpose. BIAs are a diverse group of about 2500 specialised plant metabolites, many of which have pharmacological properties. Opium poppy produces several BIAs, including the narcotic analgesics morphine and codeine, antimicrobial agent sanguinarine, the muscle relaxant papaverine, and the cough-suppressant and potential anticancer drug noscapine. India is one of the largest producers of opium alkaloids globally, maintained under the control and legislation of the Narcotics Department, Government of India which issues renewable licenses to the farmers annually. The limited research work done in the poppy necessitates further genetic improvement and the development of high yielding varieties of this crop.

A successful breeding programme entails efficient breeding strategies devised with the help of genetic information acquired of the crop for the development of high yielding hybrid varieties. Heterosis is the measure of the heterozygosity manifested in the hybrid progeny relative to either the better parent (heterobeltiosis) or to the mid parent (relative or average heterosis) or to the performance of a standard variety (standard or economic heterosis). In practical crop breeding, standard heterosis is more important than the other heterotic parameters with immense economic value and breeding potential in agriculture. The judicious selection of desirable hybrid recombinants for further advancement in the breeding programme are facilitated by the estimation of the heterosis which also gives information on the extent of genetic variation and diversity of their parents. Therefore, the goal of this study is to discern the appropriate crossbreeds of *Papaver somniferum* L. by analysing the hybrid progenies in terms of their relative heterosis, heterobeltiosis and economic heterosis

MATERIALS AND METHODS

The experimental material employed in the present investigation comprised of 18 lines/females and 3 testers/males *viz*., UOP-20, UOP-30 and UOP-80. Further 54 F_1 hybrids or cross combinations were developed using line × tester mating design by crossing 18 lines and 3 testers and were sown in randomized block design (RBD) with three replications along with two check varieties; Chetak Aphim and JOP-540 during the Rabi season 2022-23 at the Instructional farm of Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, India, located at 24.35° N latitude and 73.42° E longitude and 582.17 m above mean sea level. The plot size for parent and hybrid comprised of one row each. Each row was of 1.5 m length with spacing of 30 cm between rows and 10 cm between plants being adopted. The plants received normal intercultural operations, irrigation, and fertilizer applications (120 kg N, 80 kg P_2O_5, and 60 kg $K_2O.ha^{-1}$). The insect pest was controlled with proper insecticide. Morpho-metric data were recorded on five competitive randomly selected plants of each line for the following thirteen traits- days to 50 percent flowering, days to maturity, peduncle length (cm), plant height (cm), number of leaves per plant, diameter of main capsule (mm), seed yield per plant (g), capsule husk yield per plant (g), harvest index for seed yield (%), number of stigmatic rays per capsule, length of the main capsule (cm), capsule size (cm^2) and the number of effective capsules per plant.

The analysis of variance was carried out for each character in accordance with the guidelines provided by Panse and Sukhatme (1985) for the randomized block design (RBD). The recorded mean values for the all the thirteen characters were put for the analysis of heterosis by using the method suggested by Shull (1908), heterobeltiosis/better parent and economic heterosis was estimated as per the procedures given by Fonesca & Patterson (1968); Briggle (1963), respectively.

RESULTS AND DISCUSSION

The analysis of variance revealed the presence of variability among parents and crosses for all the characters studied. On partition of genotypic variance into parents, crosses, parents v/s crosses showed the presence of significant difference between parents and parents v/s crosses. Non significant variation among parents was observed only for the character days to maturity while none of the characters exhibited non significance among the crosses subjected to analysis. The characters *viz*., days to 50 per cent flowering, days to maturity, capsule husk yield per plant, number of stigmatic rays per capsule were found to show non significant variation amongst parents v/s crosses. This ensured the existence of considerable variation in experimental material for the characters under study as given in Table 1**.** The estimates of heterosis of the characters investigated are demonstrated in Tables 2.

A. Days to 50 per cent flowering

The estimates revealed that two crosses exhibited significant negative behaviour for all three parameters of relative heterosis, heterobeltiosis and economic heterosis. Cross UOP-88 × UOP-30 showed significant negative relative heterosis (-2.82), heterobeltiosis (-2.27) and economic heterosis (-2.27) and cross UOP-88 × UOP-80 exhibited significant negative heterosis (-3.23), heterobeltiosis (-3.04) and economic heterosis (-3.41). Four crosses displayed significance for both negative relative heterosis and negative heterobeltiosis *viz*., UOP-69 × UOP-30 (-2.62 and -2.62 respectively), UOP-94 × UOP-30 (-2.25 and -2.25 respectively), UOP-121 × UOP-30 (-2.81 and -2.63 respectively), UOP-125 × UOP-30 (-3.33 and -2.25 respectively). Thirteen crosses exhibited significant negative relative heterosis ranging from -1.89 (UOP-150 × UOP-80) to -3.33 (UOP-125 × UOP-30). Three crosses, UOP-79 × UOP-20 (-2.27), UOP-116 × UOP-20 (-2.27) and UOP-95 × UOP-20 (-3.03) exhibited significant negative economic heterosis over the best check Chetak Aphim.

B. Days to maturity

Crosses UOP-95 × UOP-30 (-1.66) and UOP-95 × UOP-20 (-1.94) exhibited significant negative relative heterosis for days to maturity. None of the examined crosses showed significant negative heterobeltiosis for this character. The table shows that fifteen crosses exhibited significant negative economic heterosis

ranging from -1.91 (UOP-94 × UOP-30, UOP-116 × UOP-30, UOP-125 × UOP-30, UOP-45 × UOP-80, UOP-88 × UOP-80, UOP-125 × UOP-80, UOP-150 × UOP-80) to -3.55 (UOP-95 × UOP-30) over the best check Chetak Aphim.

C. Peduncle length

The positive significant relative heterosis for the trait was exhibited by ten crosses which ranged from 5.27 (UOP-94 × UOP-80) to 9.96 (UOP-95 × UOP-20). While none of the crosses analysed showed positive significant heterobeltiosis for this character, the economic heterosis over best check JOP-540 was noticed in seventeen crosses and it ranged from 6.35 (UOP-94 × UOP-20) to 18.10 (UOP-154 × UOP-80).

D. Plant height

Out of fifty four crosses, thirty two crosses manifested significant negative relative heterosis for plant height which ranged from -2.33 (UOP-78 × UOP-80) to -14.97 (UOP-107 × UOP-20). The significant negative heterobeltiosis was observed in twenty two crosses which ranged from -2.66 (UOP-94 × UOP-30) to -13.50 (UOP-107 × UOP-20). Five crosses exhibited significant negative economic heterosis ranging from UOP-94 × UOP-30 (-2-25) to UOP-107 × UOP-20 (-6.60) over best check Chetak Aphim.

E. Number of leaves per plant

The estimates of relative heterosis for the character indicated that seventeen crosses exhibited positive significant relative heterosis which ranged from 6.75 (UOP-16 × UOP-30) to 20.89 (UOP-137 × UOP-30). The positive significant heterobeltosis was observed in eight crosses and it ranged from 8.15 (UOP-47 × UOP-20 and UOP-150 × UOP-80) to 18.08 (UOP-79 × UOP-30). Forty eight crosses expressed significant positive economic heterosis over best check Chetak Aphim, ranging from 10.59 (UOP-146 × UOP-80) to 32.35 (UOP-150 × UOP-80).

F. Diameter of main capsule

A total of eighteen crosses exhibited positive significant relative heterosis for diameter of main capsule ranging from, 3.35 (UOP-146 × UOP-30) to 16.33 (UOP-45 × UOP-80). Significant heterobeltiosis in desirable direction was observed in fifteen crosses ranging from 3.83 (UOP-116 × UOP-80) to 15.95 (UOP-45 × UOP-80). None of the crosses manifested positive significant economic heterosis over best check JOP-540.

Table 1: Analysis of variance of thirteen characters in Opium poppy.

Sr. No.	Characters	Rep	Genotype	Parents	Crosses	P Vs C	Error
		[2]	[76]	[20]	[53]	[1]	[152]
1.	Days to 50% flowering	3.16	7.44**	8.52**	6.94**	0.80	1.22
2.	Days to maturity	4.11	2.67**	1.71	2.81**	2.37	1.65
3.	Peduncle length (cm)	2.37	10.71**	9.41**	9.86**	91.11**	0.85
4.	Plant height (cm)	0.36	76.47**	49.54**	82.28**	321.45**	1.09
5.	Number of leaves per plant	1.06	3.00**	2.89**	2.41**	8.83**	0.39
6.	Diameter of main capsule (mm)	1.32	25.16**	8.49**	31.57**	3.91*	0.72
7.	Seed yield per plant (gm)	1.43	3.62**	3.85**	3.45**	1.95*	0.48
8.	Capsule husk yield per plant (gm)	0.04	2.95**	3.90**	2.75**	0.05	0.03
9.	Harvest index for seed yield	59.04	146.72**	111.89**	155.52**	284.20**	31.92
10.	Number of stigmatic rays per capsule	0.33	1.48**	1.10**	1.66**	0.16	0.27
11.	Length of main capsule (cm)	0.02	0.65**	0.37**	0.62**	9.25**	0.05
12.	Capsule size (cm2)	0.77	15.27**	5.69**	16.82**	142.25**	0.79
13.	Number of effective capsules per plant	0.11	2.37**	1.03**	2.42**	64.24**	0.04

*, ** Significant at 5% and 1% respectively. [] Degrees of freedom.

G. Seed yield per plant

The estimates of relative heterosis for seed yield per plant revealed that out of thirty nine crosses, six crosses exhibited positive significant relative heterosis which ranged from 26.34 (UOP-146 × UOP-80) to 51.57 (UOP-78 × UOP-20). Six crosses showed positive significant heterobeltiosis and the magnitude varied from 22.56 (UOP-154 × UOP-30) to 46.59 (UOP-78 × UOP-20). The cross UOP-78 × UOP-20 (10.80) exhibited positive significant economic heterosis over the best check Chetak Aphim.

H. Capsule husk yield per plant

The estimates of relative heterosis for the character indicated that twenty six crosses exhibited positive significant relative heterosis which ranged from 6.49 (UOP-78 × UOP-30) to 45.95 (UOP-150 × UOP-80). Thirteen crosses exhibited positive significant heterobeltosis for husk yield per plant ranging from 8.88 (UOP-45 × UOP-30) to 34.26 (UOP-150 × UOP-80). Sixteen crosses expressed positive significant economic heterosis over the best check Chetak Aphim ranging from 7.36 (UOP-94 × UOP-20) to 40.04 (UOP-154 × UOP-20).

I. Harvest index for seed yield

The estimates of relative heterosis for the character indicated that six crosses exhibited positive significant relative heterosis which ranged from 16.21 (UOP-146 × UOP-80) to 44.25 (UOP-78 × UOP-20). Out of thirty nine crosses, three crosses manifested positive significant heterobeltiosis *viz*., UOP-150 × UOP-80 (16.67), UOP-154 × UOP-20 (34.82), UOP-78 × UOP-20 (40.94). None of the crosses exhibited positive significant economic heterosis over the best check Chetak Aphim.

J. Number of stigmatic rays per capsule

The positive significant relative heterosis was observed in eleven crosses which ranged from 5.98 (UOP-116 × UOP-30) to 13.19 (UOP-107 ×UOP-80). Of fifty four crosses, five crosses exhibited positive significant heterobeltiosis for the character and ranged from 6.84 (UOP-137 × UOP-20) to 10.67 (UOP-107 × UOP-80). A total of seventeen crosses exhibited positive significant economic heterosis ranging from 6.95 (UOP-94 × UOP-30 and UOP-79 × UOP-80) to 13.51 (UOP-107 × UOP-80) over the best check Chetak Aphim.

K. Length of main capsule

Three crosses exhibited positive significant relative heterosis *viz*., UOP-45 × UOP-30 (15.11), UOP-78 × UOP-20 (18.16), UOP-150 × UOP-80 (21.67). While none of the crosses exhibited positive significant heterobeltiosis for the character, three crosses manifested positive significant economic heterosis which are, UOP-45 × UOP-30 (18.02), UOP-78 × UOP-20 (27.21), UOP-150 × UOP-80 (29.01) over the best check Chetak Aphim.

L. Capsule size

The positive significant relative heterosis for capsule size was observed in three crosses *viz*., UOP-45 × UOP-30 (29.26), UOP-78 × UOP-20 (34.28), UOP-150 × UOP-80 (37.67). The same three crosses exhibited positive significant heterobeltiosis *i.e*. UOP-45 × UOP-30 (16.47), UOP-78 × UOP-20 (21.58) and UOP-150 × UOP-80 (25.07). The positive significant economic heterosis over the best check Chetak Aphim was expressed by four crosses ranging from 10.16 (UOP-154 × UOP-20) to 35.37 (UOP-150 × UOP-80).

M. Number of effective capsules per plant

The estimates of relative heterosis for the character indicated that forty five crosses exhibited positive significant relative heterosis which ranged from 10.47 (UOP-45 × UOP-80) to 100.96 (UOP-79 × UOP-20). The positive significant heterobeltiosis was observed in thirty eight crosses and it ranged from 8.39 (UOP-116 × UOP-30) to 31.52 (UOP-76 × UOP-20). Thirteen crosses expressed significant positive economic heterosis overbest check Chetak Aphim, ranging from 8.39 (UOP-116 x UOP-30) to 31.89 (UOP-79 × UOP-20).

Similar results on economic heterosis, heterobeltiosis and relative heterosis in opium poppy for seed yield and yield contributing traits were reported by Patidar (1994); Yadav *et al*. (2007); Dubey *et al*. (2007); Kumar *et al*. (2008); Singh and Pandey (2011); Nesara *et al*. (2020).

Table 2: Extent of heterosis for Days to 50% flowering, Days to maturity and Peduncle length.

Crosses	Days to 50% flowering			Days to maturity			Peduncle length (cm)		
	Het	Hb	EH	Het	Hb	EH	Het	Hb	EH
UOP-45 × UOP-20	5.61**	-	-	0.70	-	-1.37	-1.95	-	0.49
UOP-47 × UOP-20	0.76	-	-	0.28	-	-1.91*	7.23**	0.31	7.12*
UOP-69 × UOP-20	-1.70	-0.76	-1.52	2.10**	-	-0.27	8.16**	5.50	3.21
UOP-76 × UOP-20	3.28**	-	-	0.14	-	-1.64	6.43*	-	10.29**
UOP-78 × UOP-20	-1.15	-1.15	-1.89	0.84	-	-1.64	-14.06**	-	-
UOP-79 × UOP-20	-1.34	-1.15	-2.27*	2.80**	-	-	-2.25	-	4.16
UOP-88 × UOP-20	0.00	-	-0.38	0.84	-	-1.37	7.28*	5.34	1.66
UOP-94 × UOP-20	-0.57	-	-0.38	0.14	-	-1.37	2.91	-	6.35*
UOP-95 × UOP-20	-1.73	-1.16	-3.03**	-1.94*	-1.12	-3.55**	9.96**	-	14.12**
UOP-107 × UOP-20	0.19	-	-1.89	0.42	-	-1.91*	1.32	-	-
UOP-16 × UOP-20	0.19	-	-	-0.70	-0.28	-2.73**	0.41	-	2.09
UOP-116 × UOP-20	-1.34	-1.15	-2.27*	0.28	-	-1.64	8.26**	3.45	5.61
UOP-121 × UOP-20	0.00	-	0.00	1.67*	-	0.00	-3.62	-	-
UOP-125 × UOP-20	-2.43**	-0.38	-1.14	0.56	-	-1.09	-3.98	-	0.84
UOP-137 × UOP-20	2.89**	-	-	1.11	-	-0.82	5.79*	-	7.78*
UOP-146 × UOP-20	0.00	-	0.00	0.69	-	-0.82	8.40**	3.20	6.17
UOP-150 × UOP-20	0.19	-	0.00	-0.42	0.00	-2.46**	-4.58	-	-
UOP-154 × UOP-20	-3.18**	-1.15	-1.89	1.96*	-	-0.27	-8.48**	-	-
UOP-45 × UOP-30	-0.38	-	-1.52	0.42	-	-1.09	-14.39**	-	-
UOP-47 × UOP-30	-2.45**	-1.89	-1.89	1.39	-	-0.27	3.64	1.27	13.32**
UOP-69 × UOP-30	-2.62**	-2.62*	-1.52	0.14	-	-1.64	-10.90**	-	-
UOP-76 × UOP-30	5.34**	-	-	0.97	-	-0.27	-10.82**	-	0.84
UOP-78 × UOP-30	0.57	-	-	1.39	-	-0.55	-8.22**	-	5.17
UOP-79 × UOP-30	-1.14	0.00	-1.14	1.11	-	-0.82	-11.15**	-	3.07
UOP-88 × UOP-30	-2.82**	-2.27*	-2.27*	-0.83	-0.56	-2.46**	-12.68**	-	-
UOP-94 × UOP-30	-2.25*	-2.25*	-1.14	-0.97	-0.55	-1.91*	-19.83**	-	-
UOP-95 × UOP-30	-1.52	0.00	-1.89	-1.66*	-1.39	-2.73**	-20.29**	-	-
UOP-107 × UOP-30	0.77	-	-0.38	0.70	-	-1.09	-2.40	-	4.89
UOP-16 × UOP-30	-0.37	-0.37	-	0.42	-	-1.09	-3.78	-	6.91*
UOP-116 × UOP-30	-0.76	-	-0.76	-0.55	-0.55	-1.91*	-6.80**	-	-

UOP-121 × UOP-30	-2.81**	-2.63*	-1.89	0.28	-	-0.82	-2.84	-	8.74**
UOP-125 × UOP-30	-3.33**	-2.25*	-1.14	-0.83	-0.55	-1.91*	2.65	0.41	17.49**
UOP-137 × UOP-30	4.20**	-	-	0.55	-	-0.82	2.42	1.88	14.01**
UOP-146 × UOP-30	-2.06*	-1.88	-1.14	0.41	-	-0.55	-7.08**	-	-
UOP-150 × UOP-30	-1.88*	-1.51	-1.14	1.53*	-	0.00	-12.44**	-	-
UOP-154 × UOP-30	-2.59**	-1.50	-0.38	0.56	-	-1.09	-16.45**	-	-
UOP-45 × UOP-80	1.16	-	-0.76	-0.42	-0.28	-1.91*	-10.24**	-	-
UOP-47 × UOP-80	2.09*	-	-	-0.83	-0.56	-2.46**	0.50	0.24	7.04*
UOP-69 × UOP-80	-0.38	-	0.00	0.70	-	-1.09	-13.62**	-	-
UOP-76 × UOP-80	0.00	-	-1.52	0.14	-	-1.09	-11.36**	-	-
UOP-78 × UOP-80	3.24**	-	-	0.00	-	-1.91*	-6.42**	-	4.57
UOP-79 × UOP-80	-0.76	-0.38	-1.52	0.56	-	-1.37	-13.68**	-	-
UOP-88 × UOP-80	-3.23**	-3.04**	-3.41**	-0.28	0.00	-1.91*	-0.03	-	1.33
UOP-94 × UOP-80	0.75	-	-	-0.41	0.00	-1.37	5.27*	1.82	15.74**
UOP-95 × UOP-80	0.38	-	-0.76	-0.28	0.00	-1.37	1.40	-	11.93**
UOP-107 × UOP-80	5.41**	-	-	-0.42	0.00	-2.19*	0.99	-	5.67
UOP-16 × UOP-80	1.13	-	-	0.69	-	-0.82	-2.52	-	5.54
UOP-116 × UOP-80	0.38	-	-0.38	0.00	0.00	-1.37	-11.10**	-	-
UOP-121 × UOP-80	-2.08*	-1.52	-1.89	-0.28	0.00	-1.37	-9.72**	-	-
UOP-125 × UOP-80	-1.49	-	0.00	-0.83	-0.55	-1.91*	-1.18	-	10.29**
UOP-137 × UOP-80	3.08**	-	-	-1.11	-1.11	-2.46**	0.77	-	9.32**
UOP-146 × UOP-80	-1.32	-0.76	-1.14	0.69	-	-0.27	2.36	0.75	7.01*
UOP-150 × UOP-80	-1.89*	-1.52	-1.89	-0.42	-0.28	-1.91*	-8.93**	-	-
UOP-154 × UOP-80	-2.61**	-0.76	-1.14	0.56	-	-1.09	8.20**	5.36	18.10**

*,** Significant at 5% and 1% respectively

Table 3: Extent of heterosis for Plant height, Number of leaves per plant and Diameter of main capsule.

Crosses	Plant height (cm)			Number of leaves per plant			Diameter of main capsule		
	Het	Hb	EH	Het	Hb	EH	Het	Hb	EH
UOP-45 × UOP-20	9.20**	-	-	-2.89	-	11.76**	-8.13**	-	-
UOP-47 × UOP-20	14.60**	-	-	8.64*	8.15*	22.97**	4.31**	3.95*	-
UOP-69 × UOP-20	-3.58**	-0.36	-	4.84	4.16	18.44**	-2.96	-	-
UOP-76 × UOP-20	-0.98	-	-	9.86**	3.47	17.65**	-3.37*	-	-
UOP-78 × UOP-20	-12.18**	-9.12**	-1.87	13.80**	13.58**	29.15**	13.60**	13.58**	2.05
UOP-79 × UOP-20	-5.92**	-3.92**	-0.49	6.83	1.40	15.29**	-2.37	-	-
UOP-88 × UOP-20	0.14	-	-	2.34	1.99	15.97**	-10.72**	-	-
UOP-94 × UOP-20	-0.75	-	-	2.86	-	22.35**	-2.84	-	-
UOP-95 × UOP-20	-11.20**	-9.47**	-2.25*	-15.41**	-	-	-3.52*	-	-
UOP-107 × UOP-20	-14.97**	-13.50**	-6.60**	1.50	-	18.24**	11.98**	10.83**	-
UOP-16 × UOP-20	-2.53**	-	-	5.37	0.49	25.91**	0.77	-	-
UOP-116 × UOP-20	3.27**	-	-	-0.68	-	22.15**	4.74**	1.66	-
UOP-121 × UOP-20	2.18**	-	-	5.67	2.76	23.65**	-8.09**	-	-
UOP-125 × UOP-20	-0.26	-	-	10.11**	6.47	21.06**	6.16**	2.53	-
UOP-137 × UOP-20	-0.53	-0.07	-	13.04**	5.02	19.41**	3.69*	1.86	-
UOP-146 × UOP-20	-2.92**	-2.76**	-	-1.28	-	13.18**	8.31**	8.14**	-
UOP-150 × UOP-20	-2.93**	-2.80**	-	6.26	6.03	21.09**	-10.69**	-	-
UOP-154 × UOP-20	-13.41**	-12.50**	-5.52**	2.68	-	20.74**	15.31**	14.67**	3.00
UOP-45 × UOP-30	-12.99**	-8.66**	-1.63	17.54**	12.05**	30.50**	13.27**	8.51**	2.59
UOP-47 × UOP-30	7.10**	-	-	5.48	2.17	15.12**	-9.42**	-	-
UOP-69 × UOP-30	-5.88**	-4.56**	-	6.40	3.25	15.88**	-9.84**	-	-
UOP-76 × UOP-30	-4.13**	-1.35	-	15.33**	12.53**	18.82**	-6.70**	-	-
UOP-78 × UOP-30	-5.34**	-4.15**	-	3.51	-	13.26**	-1.45	-	-
UOP-79 × UOP-30	0.91	-	-	20.03**	18.08**	24.68**	-8.54**	-	-
UOP-88 × UOP-30	-8.34**	-4.48**	-	6.78	3.31	16.68**	1.75	-	-
UOP-94 × UOP-30	-5.04**	-2.06*	-	5.47	-	21.18**	-20.69**	-	-
UOP-95 × UOP-30	-13.74**	-11.35**	-0.53	-2.86	-	7.85	-8.42**	-	-
UOP-107 × UOP-30	-9.71**	-7.00**	-	7.57*	1.41	20.94**	0.96	-	-
UOP-16 × UOP-30	-8.38**	-7.57**	-	6.75*	-	23.24**	-23.67**	-	-
UOP-116 × UOP-30	-5.13**	-0.61	-	3.99	-	23.68**	-22.27**	-	-
UOP-121 × UOP-	-8.26**	-4.40**	-	2.75	-	16.06**	0.06	-	-

30									
UOP-125 × UOP-30	-5.54**	-1.43	-	-15.28**	-	-	1.69	0.71	-
UOP-137 × UOP-30	-5.83**	-0.80	-	20.89**	16.30**	22.79**	-10.05**	-	-
UOP-146 × UOP-30	-5.73**	-1.00	-	6.81	2.19	18.12**	3.35*	0.61	-
UOP-150 × UOP-30	-3.95**	-	-	13.10**	8.83*	24.29**	-11.05**	-	-
UOP-154 × UOP-30	-14.94**	-11.79**	-2.75**	14.43**	6.95	29.91**	11.67**	8.29**	2.38
UOP-45 × UOP-80	9.89**	-	-	-6.29	-	11.91**	16.33**	15.95**	1.07
UOP-47 × UOP-80	7.28**	-	-	-2.00	-	15.18**	-0.16	-	-
UOP-69 × UOP-80	1.73*	-	-	-3.22	-	13.53**	6.39**	6.10**	-
UOP-76 × UOP-80	0.64	-	-	12.74**	2.64	25.62**	1.57	-	-
UOP-78 × UOP-80	-2.33**	-	-	2.90	-	21.24**	-0.38	-	-
UOP-79 × UOP-80	5.70**	-	-	8.99*	-	22.35**	6.98**	6.58**	-
UOP-88 × UOP-80	1.11	-	-	-1.94	-	15.38**	0.37	-	-
UOP-94 × UOP-80	-9.29**	-8.09**	-0.21	-14.12**	-	5.88	8.76**	6.07**	-
UOP-95 × UOP-80	1.74*	-	-	-1.44	-	17.71**	-1.00	-	-
UOP-107 × UOP-80	-5.78**	-4.42**	-	1.66	0.36	22.82**	11.65**	11.14**	-
UOP-16 × UOP-80	-3.30**	-	-	-14.74**	-	5.59	-10.84**	-	-
UOP-116 × UOP-80	0.83	-	-	-2.22	-	24.50**	8.55**	3.83*	-
UOP-121 × UOP-80	-7.62**	-7.34**	-	-12.51**	-	6.18	-6.49**	-	-
UOP-125 × UOP-80	0.59	-	-	5.52	-	20.59**	-4.09*	-	-
UOP-137 × UOP-80	0.27	-	-	13.53**	2.02	24.85**	3.09	2.79	-
UOP-146 × UOP-80	-7.45**	-7.03**	-	-7.06*	-	10.59*	2.65	1.29	-
UOP-150 × UOP-80	-13.45**	-13.09**	-6.41**	11.88**	8.15*	32.35**	12.43**	7.61**	2.60
UOP-154 × UOP-80	-2.28**	-1.52	-	5.32	4.93	28.41**	13.77**	12.71**	0.11

*,** Significant at 5% and 1% respectively

Table 4: Extent of heterosis for Seed yield per plant, Capsule husk yield per plant and Harvest index for seed yield.

Crosses	Seed yield per plant (gm)			Capsule husk yield per plant (gm)			Harvest index for seed yield		
	Het	Hb	EH	Het	Hb	EH	Het	Hb	EH
UOP-45 × UOP-20	-7.65	-	-	-46.64**	-	-	8.56	-	-
UOP-47 × UOP-20	-6.33	-	-	2.92	0.67	-	-11.42	-	-
UOP-69 × UOP-20	-9.52	-	-	-25.71**	-	-	-6.45	-	-
UOP-76 × UOP-20	-3.81	-	-	30.45**	19.48**	13.11**	1.67	1.57	-
UOP-78 × UOP-20	51.57**	46.59**	10.80**	30.71**	19.48**	13.11**	44.25**	40.94**	12.70
UOP-79 × UOP-20	-24.26**	-	-	-8.62**	-	-	-21.23**	-	-
UOP-88 × UOP-20	-7.19	-	-	8.16**	-	-	-2.08	-	-
UOP-94 × UOP-20	-28.29**	-	-	-12.46**	-	7.36*	-14.90	-	-
UOP-95 × UOP-20	-11.12	-	-	-8.21**	-	-	-6.14	-	-
UOP-107 × UOP-20	-0.79	-	-	12.48**	-	-	-2.98	-	-
UOP-16 × UOP-20	-2.04	-	-	0.47	-	13.04**	-4.76	-	-
UOP-116 × UOP-20	-9.00	-	-	14.73**	-	-	-9.14	-	-
UOP-121 ×	-7.02	-	-	-11.95**	-	-	-9.78	-	-

UOP-20									
UOP-125 × UOP-20	-19.15*	-	-	-11.09**	-	-	-24.69**	-	-
UOP-137 × UOP-20	-23.25**	-	-	0.75	-	-	-14.74	-	-
UOP-146 × UOP-20	-7.48	-	-	36.56**	21.33**	14.87**	-2.48	-	-
UOP-150 × UOP-20	-1.21	-	-	7.64*	-	-	-3.84	-	-
UOP-154 × UOP-20	49.87**	37.58**	3.99	21.36**	2.89	40.04**	38.74**	34.82**	7.82
UOP-45 × UOP-30	34.10**	23.75**	8.46	18.63**	8.88**	23.00**	36.70**	11.26	12.86
UOP-47 × UOP-30	-0.49	-	-	21.81**	19.32**	12.62**	-4.00	-	-
UOP-69 × UOP-30	-11.12	-	-	-5.73*	-	-	-13.48	-	-
UOP-76 × UOP-30	-30.26**	-	-	12.03**	2.75	-	-27.84**	-	-
UOP-78 × UOP-30	1.33	-	-	6.49*	-	-	-2.37	-	-
UOP-79 × UOP-30	-24.68**	-	-	9.57**	-	-	-27.68**	-	-
UOP-88 × UOP-30	-0.28	-	-	35.64**	25.11**	18.09**	-15.41*	-	-
UOP-94 × UOP-30	-36.00**	-	-	-23.70**	-	-	-27.14**	-	-
UOP-95 × UOP-30	19.49*	11.33	-	-12.23**	-	-	-1.74	-	-
UOP-107 × UOP-30	-10.68	-	-	12.84**	-	-	-21.61**	-	-
UOP-16 × UOP-30	-11.24	-	-	-15.76**	-	-	-17.02*	-	-
UOP-116 × UOP-30	-25.19**	-	-	19.53**	2.30	-	-23.81**	-	-
UOP-121 × UOP-30	-18.48*	-	-	-2.29	-	-	-19.09**	-	-
UOP-125 × UOP-30	-18.74*	-	-	-12.02**	-	-	-31.02**	-	-
UOP-137 × UOP-30	-25.98**	-	-	-53.08**	-	-	-22.97**	-	-
UOP-146 × UOP-30	6.19	0.45	-	45.72**	29.64**	22.37**	2.11	-	-
UOP-150 × UOP-30	-9.69	-	-	14.30**	0.97	-	-13.32	-	-
UOP-154 × UOP-30	42.44**	22.56**	7.42	6.85**	-	23.14**	26.84**	10.60	12.19
UOP-45 × UOP-80	-7.44	-	-	12.46**	-	11.99**	0.42	-	-
UOP-47 × UOP-80	-13.18	-	-	-15.40**	-	-	-11.78	-	-
UOP-69 × UOP-80	-9.39	-	-	-54.40**	-	-	-11.36	-	-
UOP-76 × UOP-80	8.69	-	-	21.00**	15.79**	-	-0.04	-	-
UOP-78 × UOP-80	-20.04*	-	-	-37.88**	-	-	-20.94**	-	-
UOP-79 × UOP-80	-13.97	-	-	-28.81**	-	-	-18.10*	-	-
UOP-88 × UOP-80	-20.05*	-	-	-7.35*	-	-	-26.71**	-	-
UOP-94 × UOP-80	-37.81**	-	-	-15.31**	-	0.28	-25.67**	-	-
UOP-95 × UOP-80	-14.52	-	-	-6.36*	-	-	-12.81	-	-
UOP-107 × UOP-80	-5.56	-	-	25.46**	14.08**	-	-13.10	-	-
UOP-16 ×	-6.89	-	-	4.34	-	12.97**	-8.04	-	-

UOP-80									
UOP-116 × UOP-80	-17.53*	-	-	30.04**	15.70**	-	-18.42*	-	-
UOP-121 × UOP-80	-26.01**	-	-	21.21**	12.19**	13.60**	-27.76**	-	-
UOP-125 × UOP-80	-9.28	-	-	-30.81**	-	-	-20.99**	-	-
UOP-137 × UOP-80	-6.31	-	-	1.13	-	-	-13.50	-	-
UOP-146 × UOP-80	26.34**	23.37**	1.17	40.12**	29.86**	11.92**	16.21*	6.58	0.17
UOP-150 × UOP-80	42.49**	30.35**	6.90	45.95**	34.26**	15.71**	26.30**	16.67*	9.64
UOP-154 × UOP-80	10.93	-	-	-8.52**	-	1.68	-6.55	-	-

*,** Significant at 5% and 1% respectively

Table 5: Extent of heterosis for Seed yield per plant, Capsule husk yield per plant and Harvest index for seed yield.

Crosses	Number of stigmatic rays per capsule			Length of main capsule (cm)			Capsule size (cm^2)		
	Het	Hb	EH	Het	Hb	EH	Het	Hb	EH
UOP-45 × UOP-20	2.04	-	2.57	-11.53**	-	-	-18.86**	-	-
UOP-47 × UOP-20	-1.70	-	2.57	-13.86**	-	-	-10.17*	-	-
UOP-69 × UOP-20	-2.46	-	2.84	-24.09**	-	-	-26.45**	-	-
UOP-76 × UOP-20	-10.24**	-	-	-6.29	-	0.72	-9.04*	-	-
UOP-78 × UOP-20	6.49*	6.35	10.83**	18.16**	6.97	27.21**	34.28**	21.58**	32.77**
UOP-79 × UOP-20	1.78	-	9.68**	-12.02**	-	-	-14.21**	-	-
UOP-88 × UOP-20	7.43*	6.58	10.78**	-19.67**	-	-	-28.19**	-	-
UOP-94 × UOP-20	5.25	4.97	9.68**	-21.18**	-	-	-23.45**	-	-
UOP-95 × UOP-20	5.47	-	2.84	-23.24**	-	-	-25.70**	-	-
UOP-107 × UOP-20	0.77	-	1.75	-20.89**	-	-	-11.42**	-	-
UOP-16 × UOP-20	-0.56	-	2.13	-24.60**	-	-	-24.02**	-	-
UOP-116 × UOP-20	-9.11**	-	-	-33.64**	-	-	-30.23**	-	-
UOP-121 × UOP-20	5.61	4.65	10.78**	-14.56**	-	-	-21.48**	-	-
UOP-125 × UOP-20	6.04*	3.95	8.04*	-36.46**	-	-	-32.34**	-	-
UOP-137 × UOP-20	11.14**	6.84*	11.05**	-14.85**	-	-	-11.80**	-	-
UOP-146 × UOP-20	-13.81**	-	-	-7.66	-	-	-0.07	-	-
UOP-150 × UOP-20	-0.66	-	2.57	-26.74**	-	-	-34.28**	-	-
UOP-154 × UOP-20	6.65*	5.53	9.68**	-9.90**	-	4.59	3.87	0.87	10.16*
UOP-45 × UOP-30	12.29**	9.77**	11.60**	15.11**	7.38	18.02**	29.96**	16.47**	23.81**
UOP-47 × UOP-30	-4.60	-	-	-26.26**	-	-	-33.18**	-	-
UOP-69 × UOP-30	3.05	0.51	7.49*	-21.34**	-	-	-29.05**	-	-
UOP-76 × UOP-30	-19.10**	-	-	-9.19*	-	-	-15.18**	-	-
UOP-78 × UOP-30	1.69	0.45	4.68	-30.31**	-	-	-31.36**	-	-
UOP-79 × UOP-30	-2.27	-	4.21	-9.49*	-	-	-17.27**	-	-
UOP-88 × UOP-30	1.92	1.60	3.94	-10.94**	-	-	-9.38*	-	-
UOP-94 × UOP-30	3.75	2.36	6.95*	-17.19**	-	-	-34.44**	-	-
UOP-95 × UOP-30	-6.34*	-	-	-11.37**	-	-	-18.75**	-	-
UOP-107 × UOP-30	4.38	2.50	4.21	-9.58*	-	-	-8.78*	-	-
UOP-16 × UOP-30	0.98	0.89	2.57	-15.78**	-	-	-35.69**	-	-
UOP-116 × UOP-30	5.98*	3.16	10.78**	-9.71*	-	-	-29.88**	-	-
UOP-121 × UOP-30	1.49	-	5.31	-9.15*	-	-	-9.20*	-	-
UOP-125 × UOP-30	6.91*	5.95	7.71*	-35.12**	-	-	-34.03**	-	-
UOP-137 × UOP-30	-5.41	-	-	-24.01**	-	-	-31.70**	-	-
UOP-146 × UOP-30	-9.35**	-	-	-7.56	-	-	-4.70	-	-
UOP-150 × UOP-30	2.05	1.60	4.21	-0.45	-	-	-11.46**	-	-
UOP-154 × UOP-30	10.58**	10.54**	12.47**	-8.28*	-	2.34	2.45	0.81	7.17
UOP-45 × UOP-80	3.97	1.20	3.80	-18.30**	-	-	-4.98	-	-
UOP-47 × UOP-80	-1.85	-	1.75	-19.26**	-	-	-19.41**	-	-
UOP-69 × UOP-80	-9.66**	-	-	-9.87*	-	-	-4.20	-	-
UOP-76 × UOP-80	-6.11*	-	0.93	-21.13**	-	-	-19.46**	-	-
UOP-78 × UOP-80	2.12	1.31	5.58	-7.78*	-	0.45	-7.84	-	-
UOP-79 × UOP-80	-0.13	-	6.95*	-4.18	-	4.23	2.53	-	-
UOP-88 × UOP-80	2.80	2.67	5.31	-35.94**	-	-	-35.49**	-	-
UOP-94 × UOP-80	-0.40	-	3.12	-18.19**	-	-	-10.66*	-	-
UOP-95 × UOP-80	3.11	-	-	-21.23**	-	-	-21.65**	-	-
UOP-107 × UOP-80	13.19**	10.67**	13.51**	-11.48**	-	0.00	-1.12	-	-
UOP-16 × UOP-80	3.22	2.67	5.31	-20.28**	-	-	-28.97**	-	-

UOP-116 × UOP-80	1.62	-	6.67	-17.19**	-	-	-9.59*	-	-
UOP-121 × UOP-80	0.52	-	4.76	-33.36**	-	-	-37.56**	-	-
UOP-125 × UOP-80	-1.08	-	0.11	-21.14**	-	-	-23.96**	-	-
UOP-137 × UOP-80	-2.15	-	-	-13.19**	-	-	-10.52*	-	-
UOP-146 × UOP-80	-9.33**	-	-	-24.69**	-	-	-22.69**	-	-
UOP-150 × UOP-80	8.29**	8.29*	11.08**	21.67**	6.23	29.01**	37.67**	25.07**	35.37**
UOP-154 × UOP-80	-1.74	-	0.38	-33.51**	-	-	-24.44**	-	-

*,** Significant at 5% and 1% respectively

Table 6: Extent of heterosis for Number of effective capsules per plant.

Crosses	Number of effective capsules per plant		
	Het	Hb	EH
UOP-45 × UOP-20	17.68**	1.84	-
UOP-47 × UOP-20	50.25**	32.40**	-
UOP-69 × UOP-20	72.93**	68.35**	-
UOP-76 × UOP-20	93.75**	87.52**	3.99
UOP-78 × UOP-20	83.03**	60.90**	17.69**
UOP-79 × UOP-20	100.96**	73.99**	31.89**
UOP-88 × UOP-20	45.83**	15.22**	10.14**
UOP-94 × UOP-20	85.48**	59.96**	22.38**
UOP-95 × UOP-20	13.66**	1.90	-
UOP-107 × UOP-20	35.18**	34.92**	-
UOP-16 × UOP-20	-2.19	-	-
UOP-116 × UOP-20	52.09**	35.00**	-
UOP-121 × UOP-20	54.50**	33.76**	1.40
UOP-125 × UOP-20	37.89**	37.45**	-
UOP-137 × UOP-20	44.24**	25.47**	-
UOP-146 × UOP-20	48.95**	30.19**	-
UOP-150 × UOP-20	41.95**	19.91**	-
UOP-154 × UOP-20	70.42**	46.64**	12.80**
UOP-45 × UOP-30	51.46**	50.14**	13.92**
UOP-47 × UOP-30	28.68**	27.11**	-
UOP-69 × UOP-30	55.20**	32.27**	-
UOP-76 × UOP-30	41.04**	19.61**	-
UOP-78 × UOP-30	11.55**	10.51*	-
UOP-79 × UOP-30	36.74**	35.61**	2.80
UOP-88 × UOP-30	33.17**	18.51**	13.29**
UOP-94 × UOP-30	32.87**	31.17**	0.35
UOP-95 × UOP-30	31.85**	27.77**	-
UOP-107 × UOP-30	48.23**	29.46**	-
UOP-16 × UOP-30	15.63**	1.31	-
UOP-116 × UOP-30	48.40**	45.40**	8.39*
UOP-121 × UOP-30	24.19**	23.15**	-
UOP-125 × UOP-30	39.91**	21.67**	-
UOP-137 × UOP-30	4.12	3.82	-
UOP-146 × UOP-30	39.13**	38.74**	3.43
UOP-150 × UOP-30	-3.61	-	-
UOP-154 × UOP-30	55.77**	53.36**	17.97**
UOP-45 × UOP-80	10.47**	0.23	-
UOP-47 × UOP-80	13.83**	1.35	-
UOP-69 × UOP-80	30.96**	2.40	-
UOP-76 × UOP-80	39.44**	8.56*	1.12
UOP-78 × UOP-80	20.61**	7.66*	0.28
UOP-79 × UOP-80	47.35**	33.63**	24.48**
UOP-88 × UOP-80	1.37	0.07	-
UOP-94 × UOP-80	-4.86	-	-
UOP-95 × UOP-80	17.24**	2.63	-
UOP-107 × UOP-80	54.51**	23.42**	14.97**
UOP-16 × UOP-80	27.27**	1.95	-
UOP-116 × UOP-80	-0.64	-	-
UOP-121 × UOP-80	-12.17**	-	-
UOP-125 × UOP-80	21.70**	-	-
UOP-137 × UOP-80	38.10**	24.62**	16.08**
UOP-146 × UOP-80	3.18	-	-
UOP-150 × UOP-80	36.10**	26.80**	18.11**
UOP-154 × UOP-80	-30.10**	-	-

*,** Significant at 5% and 1% respectively

CONCLUSIONS

Based on the findings, it was found that the cross UOP-78 × UOP-20 exhibited positive significant economic heterosis over the best check Chetak Aphim for seed yield per plant and also maximum relative heterosis and heterobeltiosis for seed yield per plant and harvest index for seed yield. The cross UOP-150 × UOP-80 showed maximum significant positive relative heterosis for capsule husk yield, length of main capsule and capsule size, maximum significant positive heterobeltiosis for capsule husk yield and capsule size and maximum positive economic heterosis for length of main capsule and capsule size. This cross also showed negative heterosis for days to 50 per cent flowering.UOP-107 × UOP-80 showed all three heterotic parameters for number of stigmatic rays per capsule and maximum significant relative heterosis and heterobeltiosis for diameter of main capsule was shown by UOP-45 × UOP-80. UOP-79 × UOP-20 showed maximum positive significant values of relative and economic heterosis for number of effective capsules per plant.

Thus, in the present study, cross UOP-78 × UOP-20 is found most promising with respect to it's economic heterotic parameters and hence can be handled according to appropriate breeding methods for varietal development in opium poppy.

FUTURE SCOPE

The identified crossbreeds could be further advanced for hybridization and genetic improvement strategies to develop high yielding varieties in opium poppy for enhanced seed yield.

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Conflict of Interest. None.

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