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Research Article

Combining ability analysis for latex yield and its related traits in opium poppy (*Papaver somniferum L.*)

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Abstract
Combining ability studies for eight parents and their all possible crosses (excluding reciprocals) of opium poppy were grown at experimental farm of Plant Breeding and Genetics, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur (Rajasthan). This experiment was conducted in random block design with three replications and estimate combining ability for latex yield and yield related traits. Combining ability analysis indicated that mean square due to *gca* and *sca* were significant for all the characters, expect for plant height for *sca*, indicating the importance of both additive as well as non-additive genetic effect for the inheritance of all the characters under pooled over environments. Parents UOP-69, UOP-80 and UOP-99 were good general combiners for most of the important characters specially latex yield per plant, seed yield per plant, effective capsules per plant, seed harvest index and morphine content in pooled over the environments. The parent UOP-53 was also good general combiner for morphine content. The parent UOP-79 possessed good nicking ability for earliness and short plant stature. On pooled basis, the hybrids UOP-80 x UOP-20, UOP-53 x UOP-1185, UOP-79 x UOP-60, UOP-79 x UOP-20, UOP-79 x UOP-1185 and UOP-80 x UOP-1185 also showed high SCA effect for latex, seed and husk yield per plant, it could be used for exploitation of heterosis for latex yield potential and other related traits.

Key words
Combining ability, latex yield, opium poppy, related traits

Introduction

Opium poppy (*Papaver somniferum* L., 2*n*=22) belongs to family *Papaveraceae*, it is a member of the genus *Papaver*, which includes some 100 species and is affiliated to the section *Mecones* comprising five species, among which *Papaver setigerum* L. (2*n*=44) is a close relative and probably the ancestor of the opium poppy (Hammer and Fritsch, 1977). Opium poppy is considered to be a predominantly self-pollinating species with various rates of out-crossing depending upon variety and environmental factors; large colourful flowers with numerous stamens and large amounts of pollen attract insects, especially bees; the transfer of pollen from one flower to another might also be performed by wind.

The combining ability also elucidates the nature of gene action involved in the inheritance of a trait. The nature of gene action for yield and its component characters has a bearing on the development of efficient breeding procedures. The general combining ability is attributed to additive, additive x additive and higher degree of additive x additive interactions and is fixable in nature. On the other hand, specific combining ability is attributed to non additive (*i.e.* dominance, dominance x dominance and additive x dominance) gene action and as such is non-fixable.

The combining ability studies provide useful information for the selection of high order parents for effective breeding, besides elucidating the nature and magnitude of gene interaction involved in the inheritance of various characters. Such information is required to design an efficient breeding programme for further genetic improvement of the crop.

Materials and methods

Eight vigorous and diverse elite parents of opium poppy were crossed using diallel mating design to generate the crosses (excluding reciprocals). The 38 entries ($28F_1$s, eight parents and two standard checks) were evaluated in randomized block design with three replications. The plot size for parents and hybrids comprised one row each. Each row was 4 m long with row to row and plant to plant spacing of 30 and 10 cm, respectively. The agronomic practices followed during the whole crop season were the same as recommended for this crop. Five plants of each parents and hybrids were randomly taken from each replication for recorded observations. However days to 50 per cent flowering data were recorded on whole plot basis. A brief description of the procedure adopted for recording the observations for various traits is as under:

Days to 50 % flowering: The days to 50 per cent flowering was recorded from the date of sowing to date on which 50 per cent plants of each plot flowered.

Peduncle length (cm): Length was measured in centimeters

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Plant height (cm): Height was measured in centimeters from the base (ground level) to the tip of the terminal capsule, with the help of meter scale.

Number of leaves per plant: Leaves were counted after the completion of lancing and the basal dried leaves were included in count.

Number of effective capsules per plant: The number of effective capsules per plant lance was counted.

Diameter of main capsule (mm): It was measured in centimeters with the help of Vernier Caliiper.

Seed yield per plant (g): Capsules per plant was harvested and the threshing than seed yield per plant was recorded.

Husk yield per plant (g): After threshing of capsules plant per plant in grams was recorded on single pan electronic balance.

Latex yield per plant (g): The latex yield was obtained by lancing young green capsule per plant (g) than oven dry latex yield was recorded.

Harvest index for seed yield (%): It is a ratio of seed yield to biological yield expressed in percentage using this formula:

$$\text{Harvest index} = \frac{\text{Seed yield per plant (G)}}{\text{Biological yield per plant (G)}} \times 100$$

Morphine content (%): The morphine content of latex was estimated in the Department of Molecular Biology & Biotechnology, Rajasthan College of Agriculture, Udaipur following the procedure suggested by Pride and Stern (1954).

The data were subjected to combining ability analysis for using Method 2 model I of Griffing's (1956) pooled analysis was carried out.

Results and discussion

The mean square from pooled over the environments for combining ability for different characters revealed that variance due to sca, gca and environments were significant for all the traits, expect for plant height for *sca* as well as environments. Further the interaction mean square *i.e.* gca x environment and sca x environment were also significant for all the characters suggesting inconsistency of gca and sca variance over the environments, expect for peduncle length and day to 50% flowering for *gca* x environment and sca x environment and only plant height for gca x environment. Ratio of these two interaction variances *i.e.* gca x environment : sca x environment was more than one for all the characters, except for peduncle length, effective capsule per plant, number of leaves per plant, days to 50% flowering and morphine content. The higher magnitude of gca variance indicated the predominant role of the non-additive gene effect was evident for plant height, diameter of main capsule, latex yield (oven dry) per plant, seed yield per plant, husk yield per plant and seed harvest index (Table 1).

Plant height: Out of eight parents, only UOP-79 (-1.90) and UOP-20 (-1.53) showed significant negative *gca* effect for plant height under pooled over the environments, while UOP-60 (1.70) and UOP-99 (1.83) under POE_{12} showed positive *gca* effect. Significant negative *sca* effect was indicated by one cross UOP-53 x UOP-20 (-5.97) under $POE_{12,}$ while UOP-80 x UOP-20 (4.78) under POE_{12} exhibited positive significant *sca* effect.

Peduncle length: Significant GCA effect for peduncle length ($+^{ve}$ *gca* effect) was observed for UOP-80 (0.59) under pooled over the environments. Whereas, significant negative *gca* effects was not recorded. The SCA effects for peduncle length was significant for 4 crosses UOP-1185 x UOP-60, UOP-80 x UOP-20, UOP-79 x UOP-60 and UOP-1185 x UOP-60 (1.59,1.28,1.28 and 1.18) under POE_{12}. The hybrid, UOP-1185 x UOP-60 (1.59) recorded the highest *sca* effect for peduncle length under pooled over the environments followed by UOP-80 x UOP-20(1.28) and UOP-79 x UOP-60 (1.28).

Diameter of main capsule: Significant *gca* effect for diameter of main capsule was observed for UOP-53 (-1.85), UOP-79 (1.49), UOP-80 (1.19), UOP-69 (1.50) and UOP-60 (-1.10) under pooled over the environments. The highest magnitude of *gca* effect was indicated by UOP-79 under POE_{12} (1.49). The parent UOP-69 also showed highest positive *gca* effect (1.50) under pooled over environments followed by UOP-79 (1.49) and UOP-80 (1.19). Positive *sca* effect was depicted for one cross UOP-53 x UOP-1185 (3.41) and UOP-80 x UOP-20 (3.03) under $POE_{12,}$ respectively.

Effective capsules per plant: Out of eight parents, UOP-99 (0.12), UOP-60 (0.11) and UOP-20 (0.11) showed positive significant *gca* effect for number of effective capsules per plant under pooled over the environments. The magnitude of positive *sca* effect was observed in seven crosses under POE_{12}. The hybrids UOP-80 x UOP-99 (0.59) followed by UOP-20 x UOP-60 (0.52), UOP-79 x UOP-1185 (0.45), UOP-1185 x UOP-60 (0.40) and UOP-69 x UOP- 20 (0.29) exhibited highest positive *sca* effect under pooled over environments for number of effective capsules per plant.

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Number of leaves per plant: Significant positive *gca* effect for number of leaves per plant was observed for the parents UOP-69, UOP-1185 and UOP-99 (0.36, 0.44 and 0.32) under pooled over the environments. Positive *sca* effect was depicted for UOP-53 x UOP-1185, UOP-53 x UOP-60, UOP-69 x UOP-20, UOP-79 x UOP-1185, UOP-79 x UOP-99 and UOP-80 x UOP-20 under POE_{12} (0.90,,0.87,1.20,1.17,1.62 and 1.20). Under pooled over the environments the crosses UOP-79 x UOP-99 (1.62) showed highest positive *sca* effect followed by UOP-80 x UOP-20 (1.20) and UOP-79 x UOP-1185 (1.17).

Days to 50% flowering: For early flowering (-^{ve} *gca* effect) the parent UOP-79 (-1.66) only exhibited significant *gca* effects under pooled over the environments. Significant *sca* effects in negative direction (for early flowering) were observed in UOP-53 x UOP-1185, UOP-69 x UOP-99, UOP-79 x UOP-20, UOP-79 x UOP-1185 and UOP-1185 x UOP-60 under POE_{12} (-3.58,-3.53,-3.87,-3.95 and -3.15). Significant *sca* effects under positive direction (for late flowering) were observed in UOP-20 x UOP-60 (3.77) under $POE_{12.}$ On the pooled basis, the cross UOP-79 x UOP-1185 (-3.95) exhibited the highest *sca* effect followed by UOP-79 x UOP-20 (-3.87), UOP-53 x UOP-1185 (-3.58), UOP-69 x UOP-99 (-3.53) and UOP-1185 x UOP-60 (-3.15) for early flowering. Significant *sca* effects under positive direction (for late flowering) was observed under only one cross UOP-20 x UOP-60 (3.77) under POE_{12} for this character.

Latex yield (oven dry) per plant: Only one parent UOP-69 (0.04) exhibited significant positive *gca* effect under pooled over the environments. The parent UOP-99 (0.05) showed maximum magnitude of *gca* effect under positive direction followed by UOP-69 (0.04), UOP-80 (0.03) and UOP-79 (0.01) under pooled over the environments. Positively significant *sca* effect was observed for 11 crosses under pooled over the environments. The cross combination UOP-53 x UOP-1185 (0.05), UOP-69 x UOP-80 (0.02), UOP-79 x UOP-20 (0.02), UOP-79 x UOP-60 (0.03) and UOP-80 x UOP-20 (0.05) had recorded higher positive *sca* effect under pooled over the environments. Under pooled over the environments, the hybrids UOP-53 x UOP-1185 (0.05) and UOP-80 x UOP-20 (0.05) exhibited maximum magnitude of *sca* effect followed by UOP-69 x UOP-80 (0.03), UOP-79 x UOP-60 (0.03),UOP-69 x UOP-79(0.02), UOP-79 x UOP-20 (0.02), UOP-79 x UOP-1185 (0.02), UOP-79 x UOP-99 (0.02) and UOP-80 x UOP-1185 (0.02) for increased latex yield (oven dry) per plant.

Seed yield per plant: Out of eight parents, only UOP-80 (0.33) parent exhibited significant positive *gca* effect for seed yield per plant under pooled over the environments. Significant positive *sca* effect was recorded for 14 crosses under $POE_{12,}$ respectively. The highest significant *sca* effect was showed by the crosses UOP-69 x UOP-80 (1.62) followed by UOP-53 x UOP-1185 (1.58), UOP-80 x UOP-1185 (1.58), UOP-80 x UOP-20 (1.41), UOP-79 x UOP-60 (1.04) and UOP-53 x UOP-20 (0.95) under pooled over the environments for increased seed yield per plant.

Husk yield per plant: Out of eight parents, only UOP-69 (0.48) parent exhibited significant positive *gca* effect for husk yield per plant under pooled over the environments. Under pooled over the environments, parent UOP-69 (0.48) followed by UOP-80 (0.28) showed significant positive *gca* effect for the highest husk yield per plant. Significant positive *sca* effect was recorded for 10 crosses under $POE_{12,}$ respectively. The highest significant *sca* effect was showed by the crosses UOP-53 x UOP-1185 (2.04) followed by UOP-69 x UOP-80 (1.50), UOP-80 x UOP-1185 (1.40), UOP-79 x UOP-60 (1.28) and UOP-79 x UOP-20 (1.03) under pooled over the environments for increased husk yield per plant.

Seed harvest index: The parents, UOP-53 (0.85) and UOP-99 (1.14) under POE_{12} had recorded significant positive *gca* effect. Significant positive *sca* effect was observed for the crosses UOP-53 x UOP-20 (2.85), UOP-79 x UOP-1185 (3.15), UOP-80 x UOP-20 (2.67) and UOP-20 x UOP-1185 (2.57) under pooled over the environments.

Morphine content: Out of eight parents, UOP-53 (0.39), UOP-79 (0.13) and UOP-69 (0.12) exhibited significant positive *gca* effect under pooled over the environments. Positive significant *sca* effect was depicted by 11crosses under POE_{12}. The hybrids, UOP-53 x UOP-69 (0.70) exhibited highest *sca* effect under pooled over the environments for high morphine content followed by UOP-69 x UOP-79 (0.54), UOP-69 x UOP-99 (0.49), UOP-53 x UOP-1185 (0.32),UOP-79 x UOP-99 (0.31) and UOP-80 x UOP-1185 (0.31).

The parents UOP-69, UOP-80 and UOP-99 were found to be good general combiners for latex yield, seed yield and/or for one or two yield contributing components, as well as possessed good performance in plant height, peduncle length, diameter of main capsule, effective capsule per plant, number of leaves per plant, days to 50% flowering, latex yield per plant (oven dry), seed yield per plant, husk yield per plant, seed harvest index and morphine content (%). The parents UOP-79 possessed good nicking ability for earliness and short plant stature. All these parents may be extensively used in crossing programme to accumulate all the desired characters in one genotype.

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For latex yield and seed yield, the hybrids, UOP-80 x UOP-20, UOP-53 x UOP-1185, UOP-79 x UOP-60, UOP-79 x UOP-20, UOP-79 x UOP-1185 and UOP-80 x UOP-1185 exhibited high *sca* effects in pooled over the environments. Therefore, the hybrid UOP-53 x UOP-1185 and UOP-80 X UOP-20 may be advanced for isolation of superior genotypes and selected genotypes may be intermated to mope up fixable genetic variance. However, other crosses UOP-53 x UOP-1185, UOP-69 x UOP-99 and UOP-1185 x UOP-60 may also be utilized for breeding early high yielding varieties. This suggests the possibility of exploitation of these crosses through both heterosis breeding and selection of transgressive desirable segregants in further breeding programme.

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Table 1. Pooled analysis of variance for combining ability in 8 x 8 diallel set of opium poppy for eleven characters

Characters	Source of Variance					
	Env.	GCA	SCA	GCA x E	SCA x E	Pooled Error
DF	[1]	[7]	[28]	[7]	[28]	[140]
Plant height	0.45	38.13**	12.92	16.85	16.18**	8.49
Peduncle length	50.36**	2.17*	1.75**	1.03	1.07	0.84
Diameter of main capsule	63.25**	31.90**	5.76*	8.73*	5.28*	3.15
Effective capsules per plant	7.52**	0.26**	0.25**	0.11**	0.20**	0.02
Number of leaves per plant	11.02**	3.89**	2.44**	2.08**	2.09**	0.33
Day to 50% flowering	733.72**	12.28**	11.99**	3.44	4.29	3.94
Latex yield (oven dry) per plant	0.05**	0.03**	0.03**	0.02**	0.01**	0.01
Seed yield per plant	57.53**	0.68**	1.93**	1.08**	0.60**	0.03
Husk yield per plant	28.83**	1.33**	1.55**	0.68**	0.49**	0.03
Seed harvest index	170.76**	21.61**	8.89**	13.03**	3.74	3.48
Morphine content	0.13**	0.99**	0.33**	0.19**	0.25**	0.01

*,** Significant at 5 and 1 per cent level respectively

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Table 2. Estimates of general and specific combining ability effects for different characters in 8 x 8 diallel set of opium poppy

Parents / crosses	Plant height	Peduncle length	Diameter of main capsule	Effective capsules per plant	Number of leaves per plant	Day to 50% flowering	Latex yield (oven dry) per plant	Seed yield per plant	Husk yield per plant	Seed harvest index	Morphine content
UOP-53 (P1)	0.28	-0.36	-1.85 **	-0.11**	-0.88 **	0.80	-0.03 **	-0.09 *	-0.27**	0.85 *	0.39 **
UOP-69 (P2)	0.68	-0.02	1.50 **	-0.15 **	0.36 **	0.28	0.04 **	0.04	0.48 **	-1.95**	0.12**
UOP-79 (P3)	-1.90**	0.01	1.49**	-0.11**	-0.32 **	-1.66 **	0.01	-0.16 **	0.01	-1.10 **	0.13**
UOP-80 (P4)	-0.63	0.59**	1.19 **	0.03	0.02	0.18	0.03**	0.33 **	0.28 **	0.13	0.02
UOP-20 (P5)	-1.53 *	-0.36	-0.23	0.11**	-0.10	0.07	-0.02 *	-0.05	-0.10 **	0.43	-0.03 *
UOP-1185 (P6)	-0.43	0.19	-0.57	-0.01	0.44 **	0.65	-0.03 **	0.02	-0.13 **	0.49	-0.26 **
UOP-60 (P7)	1.70**	0.22	-1.10**	0.11**	0.14	0.20	-0.04 *	-0.24	-0.20 **	0.01	-0.27 **
UOP-99 (P8)	1.83 **	-0.26	-0.44	0.12 **	0.32 **	-0.546	0.05 **	0.15	-0.06	1.14**	-0.10 **
UOP-53 x UOP-69	1.31	-0.94	-1.37	0.03	-1.18**	-1.05	-0.01	-0.44**	-0.40**	-0.65	0.70**
UOP-53 x UOP-79	-2.27	0.36	0.10	0.13	-1.50**	0.57	-0.03**	-0.71**	-1.03**	2.11	0.03
UOP-53 x UOP-80	0.46	-1.06	-0.57	0.00	-0.68	1.72	-0.01	-1.00**	-0.91**	-0.17	-0.13*
UOP-53 x UOP-20	-5.97**	-0.11	-5.15**	-0.25*	-1.05**	0.50	0.01	0.95**	0.20	2.85*	-0.33**
UOP-53 x UOP-1185	1.09	0.68	3.41**	-0.28**	0.90*	-3.58**	0.05**	1.58**	2.04**	-2.49*	0.32**
UOP-53 x UOP-60	1.29	-0.86	-1.35	0.00	0.87*	-0.63	-0.01	0.20	-0.14	2.09	-0.57**
UOP-53 x UOP-99	1.33	-0.54	0.29	0.08	0.18	-2.38	-0.01	-0.12	-0.10	0.10	0.15**
UOP-69 x UOP-79	-2.67	-0.14	-0.57	-0.08	-1.42**	1.75	0.02*	-0.04	-0.23	1.33	0.54**
UOP-69 x UOP-80	1.39	-0.06	-0.47	-0.13	-1.43**	-1.77	0.03**	1.62**	1.50**	0.74	-0.02
UOP-69 x UOP-20	0.79	-0.94	0.69	0.29**	1.20**	0.02	0.01	0.53**	0.35**	2.26	0.23**
UOP-69 x UOP-1185	2.53	0.84	0.92	-0.41**	-0.02	0.93	0.01*	-0.30*	-0.63**	1.08	0.28**
UOP-69 x UOP-60	-2.61	0.14	1.29	-0.38**	-0.72	-0.62	-0.02*	-0.88**	-0.46**	-2.35	-0.65**
UOP-69 x UOP-99	-0.24	0.96	-0.20	-0.30**	-0.57	-3.53**	-0.03**	-0.48**	-0.62**	0.41	0.49**
UOP-79 x UOP-80	-0.02	0.08	1.75	-0.52**	-0.58	-0.15	0.01	0.03	0.20	-0.02	-0.13*
UOP-79 x UOP-20	1.71	0.36	1.48	-0.35**	-1.12**	-3.87**	0.02*	0.63**	1.03**	-1.63	-0.49**
UOP-79 x UOP-1185	2.94	0.81	-0.60	0.45**	1.17**	-3.95**	0.02*	0.64**	-0.08	3.15**	0.01
UOP-79 x UOP-60	2.81	1.28*	-0.10	0.23*	-0.70	-0.17	0.03**	1.04**	1.28**	-0.39	-0.24**
UOP-79 x UOP-99	-0.99	0.26	-0.39	-0.61**	1.62**	0.42	0.02*	0.47**	0.35**	0.65	0.31**
UOP-80 x UOP-20	4.78*	1.28*	3.03**	0.10	1.20**	-0.88	0.05**	1.41**	0.80**	2.67*	-0.34**
UOP-80 x UOP-1185	0.01	-0.44	-1.18	0.07	-0.02	-0.30	0.02*	1.58**	1.40**	0.49	0.31**
UOP-80 x UOP-60	-0.79	-0.47	0.46	-0.32**	0.28	-0.68	0.01	-0.17	-0.32**	0.53	-0.01
UOP-80 x UOP-99	-1.92	0.51	0.24	0.59**	-0.57	1.07	0.01	0.31*	-0.04	1.60	-0.10
UOP-20 x UOP-1185	0.91	1.18*	1.42	0.23*	-0.05	-1.52	-0.02*	-0.68**	-0.93**	2.57*	-0.21**
UOP-20 x UOP-60	0.61	-0.69	0.60	0.52**	0.42	3.77**	-0.02*	0.76**	0.80**	-0.51	0.26**
UOP-20 x UOP-99	-1.52	-0.21	-0.79	0.09	-0.93*	0.18	-0.01	-0.60**	-0.47**	-0.39	-0.09
UOP-1185 x UOP-60	3.18	1.59**	-0.90	0.40**	-0.47	-3.15*	0.01	-0.82**	-0.86**	0.88	-0.12*
UOP-1185 x UOP-99	-1.96	-0.26	-1.55	-0.36**	-1.32**	-0.90	-0.03**	0.49**	0.10	1.60	0.19**
UOP-60 x UOP-99	2.41	-0.46	-0.46	-0.32**	-0.68	1.88	0.02*	0.55**	0.65**	-1.03	-0.10*
Gi	0.61	0.19	0.37	0.03	0.12	0.41	0.02	0.04	0.03	0.39	0.01
Gi-Gj	0.92	0.29	0.56	0.04	0.18	0.62	0.02	0.06	0.05	0.59	0.02
Sii	1.86	0.59	1.14	0.09	0.37	1.27	0.05	0.12	0.11	1.19	0.05
Sij	1.62	0.51	0.99	0.08	0.32	1.10	0.04	0.11	0.10	1.04	0.04
Sij-ik	2.76	0.87	1.68	0.14	0.55	1.88	0.07	0.19	0.17	1.77	0.07
Sij-Skl	2.60	0.82	1.59	0.13	0.51	1.77	0.07	0.17	0.16	1.67	0.07

*,** Significant at 5 and 1 percent level respectively.