

Estimation of Components of Genetic Variation and Graphical Analysis in Opium Poppy (*Papaver somniferum* L.)

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Abstract

Opium poppy (*Papaver somniferum* L.) is an important medicinal plant known for its high valuable alkaloids and poppy seed. The genetics and inheritance pattern of some important characters, like days to 50% flowering, plant height, days to maturity, number of capsule per plant, capsule index, capsule husk yield, seed yield per plant, morphine, codeine, thebaine, papaverine and narcotine content were measured by diallel analysis of first generation progenies from seven parents. There is almost all character for which additive component of genetic variance was significant except number of capsule and codeine content. On the other hand, the dominance component of genetic variance was found significant for all the characters except thebaine and codeine content. Narrow sense heritability was high for plant height, papaverine content and days to maturity. While the degree of genetic advance was high only for capsule index and days to maturity. The validity of hypothesis of additive-dominance model was tested by confirming unit slope of regressions of W_r and V_r and by non-significant value of t^2 . We conclude that isolation of superior genotypes by sib selection and recurrent selection, and exploitation of hybrid vigor in specific parental-cross combinations are good strategies for poppy crop improvement.

Keywords: Crop improvement; Diallel analysis; Genetic advance; Heterozygosity; Over-dominance

Introduction

Papaver somniferum L. is one of the very important species which has been used since the Neolithic. Opium poppy is valued for its alkaloids and seed. It is the most economic narcotic plant species among genus *Papaver*. The cultivation of opium poppy permitted by special legislation in the world [1]. Its worldwide distribution results from its long history in cultivation. The opium poppy plant contains different narcotic alkaloids such as morphine, codeine, thebaine, noscapine and papaverine, and they are also used for the production of semi-synthetic active pharmaceuticals [2] morphine and codeine. These alkaloids are also used as an antispasmodic drug for treatment of different type intestinal and urinary tract spasms, migraine headaches, bronchial asthma, pulmonary arterial embolism and schizophrenia [3-8] and occasionally used to treat erectile disorders [9-12]. Poppy seeds from the opium poppy are used for food by edible oil, cosmetic, and the paint industries [13]. The seeds of poppy do not contain the opium alkaloids, but sometimes can become contaminated with alkaloids as a result of pest damage and during harvesting. The different alkaloids like morphine, codeine, thebaine, papaverine and narcotine of opium poppy are used as an important raw material by different industries of pharmacy to make cough suppressant, painkillers and spasm reduction drugs [14-17]. The cultivation of poppy mostly occurs in countries such as India, Japan, China, France, and Spain. Most poppy cultivation takes place in Turkey and India. The poppy is cultivated in an area of 101874 hectares in the world [18], and

it is cultivated on an area of 61591 hectares, with an annual production of 30730 tons and an average yield of 500 kg ha⁻¹ in Turkey [19]. Since, opium poppy is a very important crop nationally/internationally, therefore, the study of the nature and amount of genetic variability will be the first breeding objective for any plant breeder. Therefore, our purpose of endeavor and objective of study are:

- To workout nature and amount of variability in the accessions of opium poppy.
- Study of genetics and inheritance pattern of important economic traits by diallel mating design followed by graphical analysis.

Materials and Methods

The field experiment was set up in a randomized complete block design in 2015/16 and 2016/17. All the 49 treatments were grown in Randomized Block Design with three replications at CSIR-Central Institute of Medicinal and Aromatic Plants. The experimental material comprised 49 genotypes, including 21 F₁s plants, 21 reciprocals and 7 parents (Table 1). All Parents were homozygous as they were self-pollinated for few generations and selected on the basis of morphological metric traits and these are numbered P1 to P7. The data was recorded for different traits viz., days to 50% flowering, plant height, days to maturity, number of capsules per plant, capsule index, capsule husk yield, seed yield per plant, morphine, codeine, thebaine, papaverine and narcotine content. The material under present investigation was tested for the agreement with basic assumptions to Hayman diallel analysis [20].

S No	Parent No.	Name	Salient features
1	A-47	Shweta	Tall with broad leaves, white smooth petal flower, yellow pedicle color, very bold big capsule, High yielding variety.
2	A-32	SPS- 20	Tall with deeply fringed leaf, white smooth flower, yellow pedicle with downy mildew tolerant.
3	A-2	CIMAP Ajay	Medium tall plant with very deeply fringed small leaf, white medium fringed flower, yellow pedicle
4	A-75	Sampada	Medium tall variety with medium fringed leaves, black pedicle and white smooth petals flowers, medium size capsules
5	A-73	Shyama	Medium tall, broad leaves, white smooth petal flower, black pedicle
6	A-6	N-3	Medium tall medium fringed leaves, bold capsule, yellow pedicle, white medium fringed petal margin in flower, Downy mildew resistance
7	A-74	Sanchita	Tall, medium broad leaf, white smooth petal flower, yellow pedicle, High yielding variety

Table 1: Salient feature of seven diverse parents selected for 7×7 diallel in opium poppy.

Chemical analysis

For chemical analysis the dry powder of capsule husk (1 g) was first dissolved in methanol and sonicated for 30 min in an ultrasonic bath, and the solution was then centrifuged at 10,000 rpm for 10 min and then samples were then taken for HPTLC analysis. Each standard were separately weighed and stock solution prepared. From each standard stock solution equal volume has taken and mixed to prepare working standard. TLC-densitometric procedure was used to analyze the five major opium alkaloids morphine, codeine, thebaine, papaverine and narcotine [21]. Toluene-acetone-methanol-ammonia (40:40:6:2) was used as a mobile phase. Silica gel plates 60 F254 were scanned after derivatization using Dragendorff reagent no. IIC used to detect alkaloid [22] at 540 nm.

Statistical analysis

Statistical analyses was done using the Statistical Software 4.0 version, available in the Division of Genetics and Plant Breeding of the CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow, India, that is based on the standard methods in Panse and Sukhatme (1967) and Singh and Chaudhary (1979). The pooled mean values of two years for the all thirteen characters were subjected to Hayman diallel analysis (Figures 1-3) [20].



Figure 1: Field view and morphological variation in opium poppy.



Figure 2: Leaf variations among parents of opium poppy.



Figure 3: Variations for stigmatic disc rays and capsule diameter in parents used for the study.

Estimation of components of variation (Griffing's model and Hayman's model)

Analysis of genetic variance components was carried out by numerical analysis as per Hayman's [20] model. The following statistics were computed.

$D = V_{OLO} - E$ (variation due to additive gene effect)

$F = 2V_{OLO} - 4W_{OLO1} - 2(n-2) E/n$ (The mean of 'Fr' over the arrays)

$\hat{H}_1 = V_{OLO} - 4W_{OLO1} + 4V_{IL1} - (3n-2) E/n$ (Component of variation due to dominance effects of genes)

$\hat{H}_2 = 4V_{IL1} - 4V_{OL1} - 2E = H_1[1 - (u-v)^2]$ (Proportion of positive and negative genes in parents where, u was the proportion of positive genes and v was the proportion of negative genes and $u+v=1$)

$h^2 = 4(M_{LI} - M_{LO})^2 - 4(n-1)E/n^2$ (Dominance effect as the algebraic sum over all loci in heterozygous phase in all crosses)

To test each of these components standard error for each was also calculated. For this first of all common multiplier or variance ($=s^2$) was calculated as per following formula:

$$s^2 = (1/2)[\text{Var}(Wr - Vr)]$$

$$s^2 = (1/2)[1/n - 1\{[\sum(Wr_i - Vr_i)]^2 - [\sum(Wr_i - Vr_i)]^2/n\}]$$

Now from Hayman's [20] the specific multiplier for each component was calculated, considering $n=7$, these are for:

$$D = (n^5 + n^4)/n^5$$

$$F = (4n^5 + 20n^4 - 16n^3 + 16n^2)/n^5$$

$$H_1 = (n^5 + 41n^4 - 12n^3 + 4n^2)/n^5$$

$$H_2 = (36n^4)/n^5$$

$$h^2 = (16n^4 + 16n^2 - 32n + 16)/n^5$$

$$E = n^4/n^5$$

Graphical analysis (Wr-Vr graphs)

The validity of the assumptions of diallel theory was tested by 't²' test [20,23] for uniformity of Vr, Wr values.

$$t^2 = \frac{(n-2)}{4} \times \frac{(\text{Var } Vr - \text{Var } Wr)^2}{\text{Var } Vr \times \text{Var } Wr - \text{Cov}^2(Vr, Wr)}$$

The graphical analysis was done according to Hayman [23]. The Vr, Wr points for the parental were depicted along the Vr, Wr axes. Vr is the variance of rth array and Wr is the covariance between the parent and the offspring in the rth array. The relationship between Vr and Wr provides some useful information as follows:

- When the regression line passes through the origin, it indicates complete dominance ($D=H_1$).
- When it passes above the origin, cutting the Wr axis, it suggests the existence of partial dominance ($D>H_1$).
- When it passes above the origin, cutting the Wr axis and touching the limiting parabola, it suggests the absence of dominance.
- But when it passes below the origin, cutting the Vr axis, it denotes the presence of over dominance.
- The position of parental points on the regression line indicates the dominance order of the parents. The parents with more dominant gene are located nearer to the origin, while those with more

recessive genes fall farther from the origin. The parents with equal frequencies of dominant and recessive genes occupy an intermediate position.

Results and Discussion

Graphical analysis was done of the experimental data to get the information about allelic constitution of the parents used in the diallel cross. The validity of hypothesis of additive-dominance model was tested by confirming unit slope of regressions of Wr and Vr and by non-significant value of t² as prescribed by Hayman [23]. In this experimental study, regression coefficient values (b, wr, vr) for thirteen characters viz., days to 50% flowering, plant height, days to maturity, number of capsule per plant, capsule index, capsule husk yield, seed yield per plant, morphine, codeine, thebaine, papaverine and narcotine did not differ significantly from unity indicating the absence of epistasis. This indicated the fulfilment of the assumption that epistasis is absent for these characters.

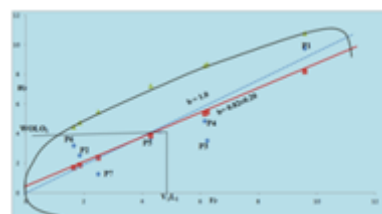


Figure 4: Days to 50% flowering.

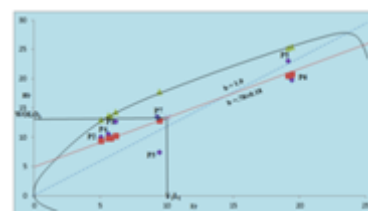


Figure 5: Plant height.

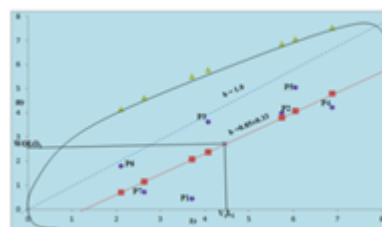


Figure 6: Pedicle length.

The Wr-Vr graphs for all the thirteen traits have been presented in Figures 4-16. The parental array points were scattered all along the regression line for almost all the thirteen traits. This represents the genetic diversity among all the seven parents for all the character studied [24,25]. The relative proportion of recessive and dominant

alleles present in parent was represented by the distribution of array points.

below the origin pointed out over dominance effect. The scattered array point on the regression indicates diversity among parents.

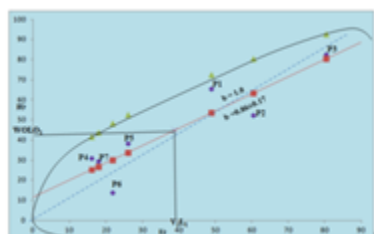


Figure 7: Days to maturity.

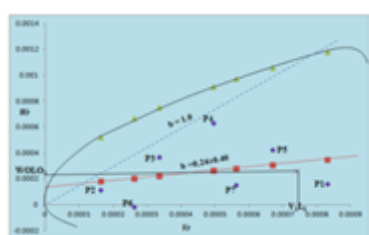


Figure 8: Number of capsule/plant.

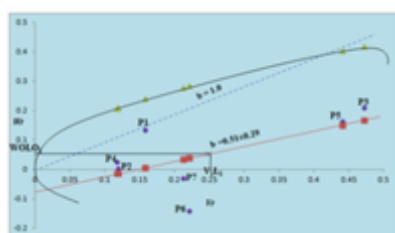


Figure 9: Capsule index.

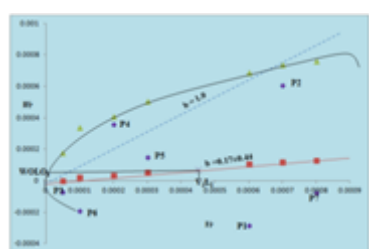


Figure 10: Seed yield/plant.

The regression line passed through the Wr-axis above the origin indicating partial dominance for this trait like days to 50% flowering, plant height, days to maturity, capsule index, morphine, thebaine, codeine, papaverine and narcotine content. While for characters like pedicle length, number of capsules per plant, seed yield, capsule husk yield and morphine content the regression line cut the Wr-axis just

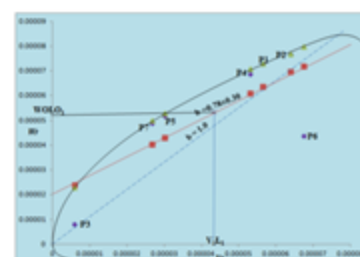


Figure 11: Capsule husk yield/plant.

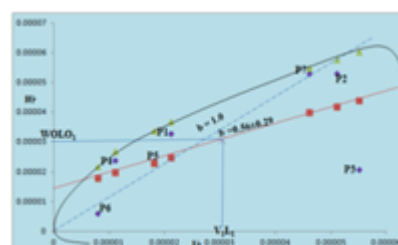


Figure 12: Morphine content.

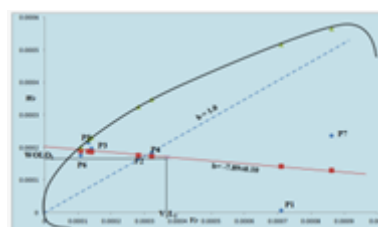


Figure 13: Codeine content (%).

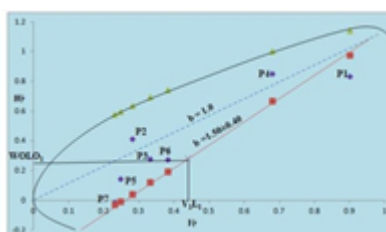


Figure 14: Thebaine content (%).

The additive and non-additive genetic variances were estimated with the help of diallel Griffing's model, [26] and Hayman's model [20,23] for all thirteen traits in the opium poppy are presented in Tables 2 and 3, respectively. By using Griffing's model [26], it is depicted from the observations that the non-additive variance σ_s^2 was higher than the additive genetic σ_g^2 variance for all the traits except for

plant height, days to maturity and thebaine content and narcotine content in percent.

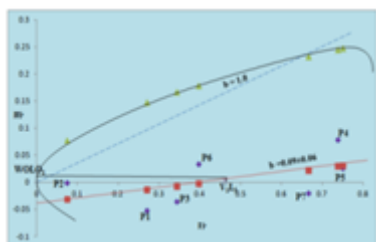


Figure 15: Papaverine content (%).

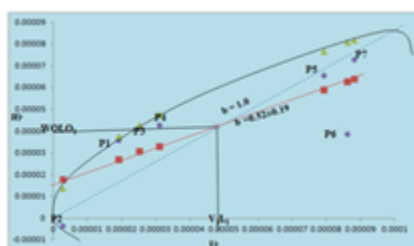


Figure 16: Narcotine content.

The ratio of σ_g^2/σ_s^2 which is less than unity clearly expressed that non fixable components were predominant over fixable component. For plant height, days to maturity, thebaine content and narcotine content σ_g^2/σ_s^2 is greater than unity which clearly indicating that fixable components were predominant over non-fixable component. The additive variance (σ_g^2) was larger than the environmental variance (σ_e^2) for characters namely plant height, days to 50% flowering, pedicle

length, days to maturity codeine content, thebaine content, papaverine content and narcotine content in percent. Hence, favorable or unfavorable environments did not influence the predominance of non-fixable genetic variance. The trait namely number of capsule/plant, capsule index, seed yield, capsule husk yield and morphine content (%) influenced by environmental factors as the environmental variance (σ_e^2) was higher than the additive variance (σ_g^2) (Table 2).

The uniformity of W_r , V_r indicates the validity of assumptions made by the Hayman [20]. The t^2 values were calculated which was found insignificant for all the characters except number of capsule/plant and codeine content. The insignificant t^2 values indicated absence of epistasis for all characters except number of capsule/plant and codeine content suggesting the fulfillment of diallel analysis.

Nevertheless, by use of Hayman's model, the additive component of variance (D) was found highly significant for all the characters except number of capsules/plant and codeine content in percent whereas, dominance component ($\hat{H}_1$) of genetic variance was significant for all the characters except codeine and thebaine content in (%), exhibiting that the expression of all these characters was controlled by both additive and dominance gene. The overall dominance effect was determined by $\hat{h}_2$ estimating sum total over all the loci in heterozygous state which was found positive and significant for days to 50% flowering. While the insignificant $\hat{h}_2$ estimates were observed for plant height, pedicle length, days to maturity, number of capsules, seed yield, capsule husk yield, morphine, thebaine, papaverine and narcotine content. However, insignificant and negative $\hat{h}_2$ estimates were recorded for capsule index. This suggests that substantial amount of heterozygosity in the parents was present showing significant $\hat{h}_2$ estimates and was insignificant for others. The estimates of $\hat{H}_1$ were also higher than estimates of $\hat{h}_2$ for all the traits (Table 3). The estimates for F component were positive and significant for days to 50% flowering, plant height, pedicle length, capsule index, and capsule husk yield suggesting excess of positive gene controlling these characters. The estimates for F component were negative and insignificant for thebaine and narcotine content respectively.

Variance components	DF	PH	PL	DM	NC	CI	SY	CHY	M	C	T	P	N
σ_g^2	2.03	5.71	0.87	19.3	-0.03	0.00002	0.009	0.026	-0.0000008	0.00005	0.000029	0.000014	0.000023
$\sigma_s^2=\sigma_D^2$	2.21	4.17	3.41	17.38	0.15	0.0002	0.1886	0.365	0.000451	0.00031	0.000013	0.000015	0.000024
σ_r^2	1.19	8.26	3.8	10.11	0.03	0.0002	0.2328	0.218	0.000130	0.00024	0.000002	0.000017	0.000034
σ_e^2	0.6	0.27	0.26	3.56	0.081	0.0003	0.0886	0.083	0.0000016	0.000001	0.0000003	0.0000009	0.0000014
σ_A^2	1.07	11.4	1.74	38.6	-7.76	0.00005	0.018	0.052	-0.0000017	0.0001	0.000059	0.000028	0.000018
σ_g^2/σ_s^2	0.91	1.36	0.25	1.11	-0.2	0.1	0.047	0.071	-0.00177	0.161	2.2307	0.93333	1.0434
$\sqrt{(\sigma_s^2/\sigma_g^2)}$	1.043	0.854	1.979	0.948	-2.236	3.162	4.577	3.746	-23.743	2.489	0.6695	1.035	0.978

σ_g^2 =g.c.a. variance, $\sigma_s^2=\sigma_D^2$ =s.c.a. variance, σ_r^2 =reciprocal variance, σ_e^2 =environmental variance, *= $p<0.05$; **= $p<0.01$, DF=Days to 50% flowering, PH=Plant height (cm), PL=Pedicle length (cm), DM=days to maturity, NC=Number of capsule/plant, CI=Capsule index, SY=Seed yield/plant (g), CHY=Capsule husk yield/plant, M=Morphine content (%), C=Codeine content (%), T=Thebaine content (%), P=Papaverine content (%), N=Narcotine content(%),respectively.

Table 2: Estimates of variance components and allied genetic parameters for different traits in poppy.

Other allied parameters were also calculated for all thirteen characters on the basis of Hayman's model presented in Table 4. It was found that estimates of dominance were higher than unity for Days to

50% flowering, pedicle length, no of capsule/plant, capsule index, seed yield/plant, capsule husk yield, morphine, codeine and narcotine content suggesting over dominance while, plant height, days to

maturity, thebaine and papaverine content was less than unity showing partial dominance.

Variance components	DF	PH	PL	DM	NC	CI	SY	CHY	M	C	T	P	N
$\hat{D}$ (Additive component)	11.513** ± 1.069	33.085** ± 2.271	8.033** ± 1.037	103.81** ± 7.946	0.0001 ± 0.180	0.001** ± 0.0002	0.276** ± 0.0914	1.361** ± 0.201	0.00069* ± 0.00031	0.00037 ± 0.00025	0.000094** ± 0.000012	0.000065** ± 0.000012	0.000075** ± 0.000017
$\hat{E}$ (Environmental component)	0.614 ± 0.378	0.274 ± 0.803	0.278 ± 0.366	3.541 ± 2.809	0.081 ± 0.06	0.00038** ± 0.00007	0.0929** ± 0.0323	0.0831 ± 0.0711	0.000001 7 ± 0.00011	0.000001 3 ± 0.000089	0.0000003 3 ± 0.0000043	0.000001 ± 0.000004	0.0000001 4 ± 0.0000062
F (Mean cov. of D)	6.946** ± 2.565	12.895* ± 5.449	5.310** ± 2.488	30.114 ± 19.064	0.027 ± 0.433	0.0017** ± 0.0005	0.394 ± 0.219	1.640** ± 0.482	0.00109 ± 0.000746	0.000062 ± 0.000060	-0.000024 ± 0.000029	0.0000081 ± 0.000028	-0.000019 ± 0.000042
$\hat{H}_1$ (Dominance component)	12.404** ± 2.574	19.388** ± 5.469	14.414** ± 2.496	73.093** ± 19.131	1.688** ± 0.435	0.0014** ± 0.0005	0.898** ± 0.220	1.843** ± 0.484	0.0022** ± 0.00074	0.0011 ± 0.00060	0.000053 ± 0.000029	0.000061* ± 0.000029	0.000095* ± 0.000042
$\hat{H}_2$ (Proportion of +/- genes)	7.740** ± 2.268	14.671** ± 4.819	11.970** ± 2.200	61.084** ± 16.857	1.593** ± 0.383	0.00079 ± 0.00044	0.653** ± 0.194	1.281** ± 0.426	0.0015* ± 0.00066	0.0011* ± 0.00053	0.000046 ± 0.000026	0.000055* ± 0.000025	0.000082* ± 0.000037
$\hat{h}^2$ (Overall dominance effect)	6.153** ± 1.523	2.553 ± 3.236	0.983 ± 1.477	0.346 ± 11.322	0.289 ± 0.257	-0.00008 ± 0.00029	0.0105 ± 0.130	0.352 ± 0.286	0.000021 ± 0.00044	0.00016 ± 0.00035	0.0000049 ± 0.000017	0.0000002 ± 0.000017	0.0000070 ± 0.000025

*=p<0.05; **=p<0.01; DF=Days to 50% flowering, PH=Plant height (cm), PL=Pedicel length (cm), DM=days to maturity, NC=Number of capsule/plant, CI=Capsule index, SY=Seed yield/plant (g), CHY=Capsule husk yield/plant, M=Morphine content (%), C=Codeine content (%), T=Thebaine content (%), P=Papaverine content (%), N=Narcotine content (%), respectively.

Table 3: Estimates of genetic components of variance in 7 × 7 diallel crosses for thirteen characters in opium poppy.

Proportion	DF	PH	PL	DM	NC	CI	SY	CHY	M	C	T	P	N
$(H_1/D)^{1/2}$	1.038	0.765	1.339	0.839	100.84	1.067	1.804	1.163	1.79	1.767	0.75	0.973	1.123
$(H_2/4H_1)$	0.156	0.189	0.207	0.208	0.235	0.132	0.181	0.173	0.179	0.237	0.216	0.222	0.216
$\{1/4(4DH_1)^{1/2} + (1/2)F\} / \{1/4(4DH_1)^{1/2} - (1/2)F\}$	1.819	1.683	1.655	1.417	10.84	4.552	2.309	3.147	2.602	1.099	0.705	1.137	0.792
$Coor(r)=(Wr+Vr).Yr$	0.9142	-0.497	-0.097	-0.845	0.025	-0.0322	0.324	0.849	0.405	-0.34	0.172	0.0079	0.383
r^2	0.8359	0.247	0.0095	0.714	0.0006 6	0.0010 4	0.105	0.721	0.164	0.116	0.0299	0.00006 2	0.146
h^2/H_2	0.794	0.174	0.0821	0.0056	0.181	0.106	0.016	0.275	0.0135	0.145	0.106	0.0039	0.085
ΣFri	48.627	90.268	37.174	210.79	0.194	0.0124	2.758	11.486	0.0076	0.0004 3	0.00017 1	0.00005 7	0.0001
t^2	0.0898	0.317	0.1914	0.0701	55.519	0.0192	0.274	6.602	0.000008 7	19.548	0.017	0.173	1.794
$\hat{h}^2$ (ns)%	64.41 %	75.90 %	44.12 %	69.40 %	6.53%	15.80%	19.80 %	25.90 %	21.4%	39.80%	84.10%	68.30%	72.10 %
GA over mean	3.75	3.003	4.449	20.05	4.009	64.76	11.72	3.96	0.1071	0.0177	0.0192	0.0025	0.389

Here, DF=Days to 50% flowering, PH=Plant height (cm), PL=Pedicel length (cm), DM=days to maturity, NC=Number of capsule/plant, CI=Capsule index, SY=Seed yield/plant (g), CHY=Capsule husk yield/plant, M=Morphine content (%), C=Codeine content (%), T=Thebaine content(%), P=Papaverine content (%), N=Narcotine content (%), respectively

Table 4: Proportion of the genetic component of variance in 7 × 7 diallel crosses for thirteen characters in opium poppy.

The proportion of genes with positive and negative effect was determined with the help of two parameters $\hat{H}_2/4\hat{H}_1$ and $Coor(r)=(Wr+vr)Yr$. The former statistic determines the symmetry or asymmetry of distribution, the later explain the simple proportion of genes showing

positive and negative effects. By comparing ($W_{r_i}+V_{r_i}$) with Y_{r_i} we can estimate the direction of dominance. If the correlation is negative, it shows parents containing most increasing genes have the lowest value of $W_{r_i}+V_{r_i}$ and thus contain most dominant genes and correlation will be positive if the case is reverse. The estimates of the ratio $\hat{H}_2/4\hat{H}_1$ were close to expected value of 0.25 for no of capsule and codeine content suggesting symmetrical distribution of positive and negative dominant genes in parents. For days to 50% flowering, plant height, pedicle length, capsule index, seed yield, capsule husk yield, thebaine, papaveine and narcotine content was far from the expected value revealing an asymmetrical distribution of positive and negative genes among the parents.

$$\text{The ratio } \left\{ \frac{1}{4}(4DH_1)^2 + \left(\frac{1}{2}\right)F \right\} / \left\{ \frac{1}{4}(4DH_1)^2 - \left(\frac{1}{2}\right)F \right\}$$

Which gives the relative value of dominant and recessive genes, was found greater than unity for all the characters except two alkaloid characters i.e., thebaine and narcotine content. The measurement of completely dominant or recessive parents may not be predicted with confidence for any of the traits, as the r^2 values were considerably less than 1. The Set of genes which control the character and exhibit dominance was determined by $\hat{h}^2/\hat{H}_2$ which was less than unity for all the characters. The ratio $\hat{h}^2/\hat{H}_2$ denotes an appropriate number of genes or group of genes controlling the characters, exhibiting dominance.

Narrow sense heritability $\hat{h}^2_{(ns)}$ ranged from 6.53% (lowest) for number of capsule/plant to 84.1% (highest) for thebaine content. It was high for plant height (75.9%), narcotine content (72.1%), days to maturity (69.4%), papaverine content (68.3%), and days to flowering (64.41%) in order. Other characters pedicle length (44.12%), codeine content (39.8%), capsule husk yield (25.9%) and morphine (21.4%) were moderately heritable. The rest three traits, namely, seed yield (19.8%), capsule index (15.8%) and capsule number/plant (6.53%) were expressed low heritability in narrow sense in percent (Table 4). Our results are also in agreement with many research workers [24,27-30].

The genetic advance provides information regarding degree of genetic gain obtained in a selected trait under a particular selection pressure. It is basically a function of selection intensity, heritability and phenotypic variance. Thus, it provides information over heritability and helps breeders in selection programme. Genetic advance over mean ranged from 64.76% (capsule index) which is highest and to 0.0025% (papaverine content) which is the lowest value. It was high for capsule index (64.76%) followed by days to maturity (20.05%) and seed yield (11.72%), respectively. Medium genetic advance over mean were found for pedicle length (4.449%), number of capsule (4.009%), capsule husk yield (3.96%), days to 50% flowering (3.75%), plant height (3.003%). Low genetic advance over mean was recorded for narcotine (0.389%), morphine content (0.1071%), thebaine (0.0192%), codeine (0.0177%), and papaverine content (0.0025%), respectively.

Conclusion

The additive component (D) of genetic variance was found highly significant for all the characters except number of capsules/plant and codeine content in percent whereas, dominance component ($\hat{H}_1$) of genetic variance was significant for all the characters except codeine and thebaine content. The estimation of narrow sense heritability is a very useful selection parameter in plant breeding. It is found high for number of capsule/plant, thebaine content, plant height, narcotine

content, days to maturity, papaverine content and days to flowering. However, genetic advance was high for capsule index and days to maturity. Based on this genetic information in this study, hybridizations, isolation of superior genotypes by sib selection and recurrent selection, and exploitation of hybrid vigor in specific parent cross-combinations are suggested for poppy crop improvement.

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