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ESTIMATION OF THE GENETIC COMPONENTS BY USING LINE × TESTER ANALYSIS METHOD IN OPIUM POPPY (*PAPAVER SOMNIFERUM* L.)

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ABSTRACT

Totally 60 F_1s were developed by using line × tester (L x T) mating design from 12 females (lines) and 5 males (tester) diverse parents of *Papaver somniferum* L. collected from different geographical places of India and also some exotic genotypes are therein were characterized for fourteen economical traits. The mean squares due to GCA and SCA were found significant for all the traits indicated the importance of additive as well as non-additive genetic variance playing a significant role in controlling the expression of all the characters. The ratio GCA/SCA was less than unity (<1) and variances due to SCA was higher than variances due to GCA for all the attributes under study indicated predominance of non-additive gene action over the additive gene action in the inheritance and also suggested high potential of the exploitation of variations for yield and yield attributes, useful for genetic improvement of studied characters. Therefore, obtained best parents and cross combinations in this study can be effectively utilized for improving of yield attributes in *Papaver somniferum* L.

***Keywords*:** Line × tester design, GCA, SCA, Genetic components, Opium poppy.

Introduction

Opium poppy (*Papaver somniferum* L.) is the most ancient and important medicinal plant belongs to the family papaveraceae, mostly utilized in medicinal, nutritional and bakery/food industries since time immemorial (Renfrew, 1973). It is also a valuable source of edible seeds and oil (Lal *et al*., 2011). Singh *et al*. (1990 & 1995) reported that poppy seeds with no narcotic effect are highly valuable due to high nutritive value protein up to 24% and high amount of linoleic acid (up to 68%) in seed oil which help in lowering the cholesterol level in human. Limited research work has been done on this crop because license is required for growing poppy in India to prevent its social abuses. The limited improvement in this crop may be due to the narrow genetic base of common ancestry (Singh and Khanna, 1991; Singh *et al*., 1999).

For an effective breeding programme in opium poppy, there is need to develop a strategy which allows the accumulation of fixable gene effects. Estimation of genetic variance and combining ability for important traits is essential in order to exploit different types of gene action present in population. Combining ability analysis is an important tool for the selection of desirable parents together with the information regarding nature and magnitude of gene effects controlling quantitative traits. It offers an opportunity to identify superior parents, which in combinations would provide desirable segregants or maybe hybridized either to exploit heterosis or to accumulate fixable genes.

Line× tester mating design defined by Kemthorne, (1957) is an appropriate biometrical tool to identify superior parents and hybrids based on general and specific combining ability respectively and to study nature of gene action. This design provides more information of quantitative traits as additive and non-additive gene action. Therefore, the current study was undertaken to understand the combining ability and genetic nature of parents and their hybrids as regards yield and yield component through studies involving of 12 lines (females) and 5 testers (male) in line × tester mating design.

Material Method

Experimental Material

About one hundred landraces were bringing together from different geographical places of India and also some exotic genotypes are therein. The selection of parents is based on diversity analysis using (D^2 analysis) of a set of germplasm/accessions. The experimental material for the present investigation comprised twelve lines/females (L_1 to

L_{12}) and 5 testers /males i.e. CIM-Ajay, Shyama, Shweta, Sampada and SPS-20 (Table 1). Further, 60 F_1s were developed by using line × tester mating design by crossing 12 lines/females and 5 testers/males were sown.

Experimental site

The field experiment was set up in Randomized Complete Block design (RCBD) with three replications during Rabi season 2017-18 and 2018-19 at CSIR-Central institute of Medicinal & Aromatic Plants, Lucknow, India, located at 26.5° N latitude and 80.50° E longitude and 120 m above sea level. Plants were grown in rows of 4m long and 50 cm apart. 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 in each line for following fourteen traits like days to 50% flowering, plant height (cm), leaves/plant, pedicel length (cm), capsules/plant, capsule index, days to maturity, seed yield (g)/plant, capsule husk yield (g)/plant, alkaloid content (%) in poppy straw includes five major alkaloid i.e. morphine, codeine, thebaine, papaverine and narcotine or noscapine.

Chemical analysis

For chemical analysis the 1gm of dry powder of capsule husk was first dissolved in methanol and it's sonicated for 30 min in an ultrasonic bath, and then solution was centrifuged at 10,000 rpm for 10 min and after that samples were taken for HPTLC analysis. Each standard were separately weighed and stock solution were 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 (Gupta and Verma, 1996). 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. llC used to detect alkaloid (Wagner and Bladt, 1996) at 540 nm.

Statistical analysis:

The recorded pooled mean data of two years for the all the fourteen characters were analysed by using line × tester design (Kempthorne, 1957) for the analysis of variance, mean squares, GCA and SCA variance effects, and allied genetic parameters. Statistical analyses was done using the Statistical Software 4.0 version, available in the Division of Plant Breeding & Genetic Resource Conservation of the CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow, India, that is based on (Singh and Chaudhary, 1979) and (Panse and Sukhatme,1967).

About one hundred landraces were bringing together from different geographical places of India and also some exotic genotypes are therein. The selection of parents is based on diversity analysis using (D^2 analysis) of a set of germplasm/accessions. The experimental material for the present investigation comprised twelve lines/females (L_1 to L_{12}) and 5 testers /males i.e. CIM-Ajay, Shyama, Shweta, Sampada and SPS-20 (Table 1). Further, 60 F_1s were developed by using line × tester mating design by crossing 12 lines/females and 5 testers/males were sown.

Result and Discussion

The analysis of variance (ANOVA) revealed that highly significant variances due to treatment were obtained for all the fourteen characters studied (Table 2). Further, treatment variance was segregated into parent, hybrid and parent v/s hybrid. Variance due to parent were highly significant for all the character except dry husk capsule, while pedicel length were non-significant. The variances due to crosses or hybrids were highly significant for all the fourteen characters studied. However, the variances due to parent × hybrid were found only 50% significant for the characters and rest non-significant for the traits like days to flowering (50%), no. of leaves/plant, pedicel length, no. of capsule/plant, Seed yield, dry husk capsule and codeine content (%). The variances due to females were highly significant for all the fourteen traits. Whereas, in variances due to males the traits like days to flowering (50%), no. of leaves/plant, pedicel length, no. of capsule/plant and morphine except these traits, all were found significant. Further, variances due to Line × Tester (female's × males) were also found significant for all the traits.

Estimates of general combing ability effects (GCA) effects:

The general combining ability (gi = GCA) effects of each parent were examined in relation to the *per se* performance i.e. means and the associated g.c.a. variance ($\hat{\sigma}_{gi}^2$) and s.c.a. variance ($\hat{\sigma}_{si}^2$) for fourteen economical traits (Table 3).

Days to 50% flowering

As the early flowering was a desirable character, so among all the parents i.e. lines and testers, lowest mean value with negative GCA effect considered desirable for days to 50% flowering. Hence, L_1 had comparatively lowest mean value (100.30) with negative GCA effect (gi= -5.27) with *per se* performance followed by L_6 (113.00) with negative GCA effect (gi= -5.74) and L_9 (115.33) with GCA effect (gi= -4.01) indicating better general combining ability. However, L_5 showed highest GCA effect (gi= 7.06) with mean value (112.66) toward positive direction indicating poor general combining ability followed by L_{10} mean value (108.33) with GCA effect (gi= 4.86) and L_{12} mean value (110.00) with GCA effect (gi=4.19).

Plant height (cm)

The parent L_{12} among all the parents i.e. lines and testers showed the highest positive GCA effect (gi = 5.69) with mean (106.63) followed by T_5 positive GCA effect (gi = 3.15) with mean value (107.50) and L_{10} (3.97) with GCA effect (gi= 117.90). But the parents toward significant negative direction were considered as good general combiner for plant height viz. L_{11} with mean value (100.40) and significant negative GCA effect (gi= -4.33) with *per se* performance followed by L_2 (99.30) with GCA effect (gi= -4.16) followed by L_3 lowest negative significant GCA effect (gi= -11.51) and T_3 with highest significant negative GCA effect (gi= -2.81) with comparatively high mean value (124.53) and (116.83) respectively, were counted beneficial for plant height.

Number of leaves per plant

The parents L_4 was recorded for the high mean value (23.00) along with the positive GCA effects (gi=1.96) indicating good combining ability with *per se* performance followed by L_{11} having positive GCA effect (gi= 1.96) along with mean value (21.33).

Pedicel length (cm)

The parent L_4 recorded the highest mean value (24.26) with significant positive GCA effect (gi=1.82) while, L_2 showed highest positive GCA effect (gi= 4.42) with mean value (20.93) followed by L_1 positive GCA effect (gi= 1.98) and mean value (20.63) for pedicel length. Whereas, L_7 and L_9 exhibited negative GCA effect (gi= -2.63), (gi= -2.38) with mean value (19.36) and (18.66) respectively.

No. of capsules/plant

The parent L_{12} (7.00) showed positive GCA effect (gi= 1.08) with per se performance followed by L_4 (5.33) and (gi= 1.08) considered as good general combiner. Whereas, Parent L_9 showed negative GCA effect (gi= - 1.26) with mean value (10.33) indicating poor combiner.

Capsule index

Among all parents i.e. lines and testers, parent T_2 had highest positive GCA effect (3.19) with mean value (1.26) followed by parent L_{12} with highest mean value (2.16) and significant positive GCA effect (gi= 0.36) hence it was a best general combiner for capsule index. The parent L_2 (1.38) had highest negative GCA effect (gi = -0.27) followed by L_1 negative GCA effect (gi= -0.15) with high mean value (1.48) showed poor combining ability.

Days to maturity (days)

As late maturity was a desirable character, parent L_4 (173.30) among parents, line and tester had highest positive GCA effect (gi= 2.69) followed by L_6 (177.30), L_3 (159.30), T_5 (179.30) and T_4 (162.60) with positive GCA effect (gi= 2.36), (gi= 1.49), (gi= 1.09) and (gi= 0.96) respectively. While L_{10} had highest negative GCA effect (gi= -4.37) with mean value (171.00) and T_1 had lowest negative GCA effect (gi= -0.78) with mean value (178.30).

Seed yield (g/plant)

The parent L_{10} recorded highest positive GCA effect (gi=3.25) with mean value (7.96) followed by L_{12} (gi= 2.99) having mean value (8.41) and in tester T_1 having lowest positive GCA effect (gi = 1.05) with high mean value (8.88) for seed yield g/plant indicating best general combiners whereas, lowest negative GCA effect were exhibited by L_5 (gi= -2.15) followed by L_6 (gi= -2.02) and T_2 (gi= -1.11) respectively.

Dry husk yield (g/plant)

Result of the study indicated that L_{10} among all the parents i.e. lines and testers showed the highest positive GCA effect (gi= 2.45) mean value (6.02) followed by L_{12} (gi= 1.79) mean value (5.39) and in testers T_1 having lowest positive GCA effect (gi= 0.91) with mean value (6.60) considered as better general combiners. Parents L_5, L_6 and T_2 had negative GCA effect (gi).

Total morphine alkaloids (%)

The parent L_{12} had highest positive GCA effect (gi= 0.0370) with high mean value (0.0860) followed by L_8 (gi= 0.0230) with mean value (0.0300) and L_{10} (gi= 0.0120) with mean value (0.0700) considered as best general combiner for morphine alkaloids. Whereas, the lowest negative GCA effect was recorded for the parent L_2 (gi= -0.0210) followed by L_5 (gi= 0.0150) and L_3 (gi= -0.0130) specified as poor combiners for morphine alkaloids.

Codeine (%)

The parent L_{11} was recorded for highest negative GCA effect (gi= -0.0623) with mean value (0.1530) considered as poor general combiner for codeine alkaloids followed by parent L_1 (gi= -0.0350), T_1 (gi= -0.044) and T_3 (gi= -0.0223). Whereas, the highest positive GCA effect was recorded for the parent T_2 (gi= 0.0318) followed by L_7 (gi= 0.0317), T_4 (gi= 0.0287) and L_4 (gi= 0.0257) with comparatively high mean value showed good combiners for codeine alkaloids.

Thebaine (%)

The parent L_2 was recorded for highest mean value (0.2767) and negative GCA effect (gi = -0.0424) and considered as high mean with poor general combiner for thebaine alkaloid. Likewise, the parents L_1, L_3, L_4, L_5, L_7, L_9, L_{11}, T_1 and T_2 had negative gca effects for thebaine content in percent. Whereas, L_{12} had highest positive gca effect (gi= 0.1195) with mean value (0.0700) followed by parent L_6 (gi= 0.1168), L_{10} (gi= 0.0295), T_3 (gi= 0.0274) and T_4 (gi= 0.0193) specified as superior general combiners.

Papaverine (%)

Among all the parents, L_{12} was recorded highest positive GCA effect (gi = 0.1175) with high mean value (0.0947) followed by L_{10} (gi = 0.0401) L_6 (gi = 0.0316) and T_3 (gi= 0.0186). The parent L_1 was recorded for highest mean value (0.1300) and negative gca effect (gi = -0.0208) and considered as high mean with poor general combiner for papaverine alkaloid. Parents L_2, L_3, L_4, L_7, L_8, L_{11} and T_1 had also negative gca effect.

Noscapine (%)

The parent L_{12} had highest positive GCA effect (gi= 0.0294) with mean value (0.1533) followed by L_8 (gi= 0.0227) with mean value (0.0677) and T_5 (gi= 0.01094) with comparatively high mean value (0.2200) considered as virtuous general combiners for nosacapine alkaloid percent. Whereas, parents L_3, L_5, L_9, L_{11} and T_1 had negative GCA effect indicated poor combiners for noscapine alkaloid content.

Based on GCA effects the above mentioned parental genotypes of different economic traits could be utilized in multiple crossing programs involving all possible combinations followed by line × tester mating design to exploit the maximum variability towards the development of high yielding varieties in opium poppy. It was reported earlier by Kumar *et al*., (1994); Nie *et al*., (1991); Singh *et al*., (2016) that cultivars with high individual GCA effects can be utilized in breeding programs for producing a relatively higher percentage of superior yielding progeny. Srivastava *et al*., (2007) also reported that good general combiner plays an important role in developing population through crossing among them in all possible combinations.

Abdel Moneam, (2014) and Kumar *et al*., (2013) also reported that exploiting the parents with high GCA effects for developing desirable hybrids. High GCA effects are mostly due to additive gene effects or additive x additive interaction effects (Griffing, 1956). However, some parents with high mean values exhibited low GCA effects. Hence, both performances *per se* and GCA effects should be taken into account for parental selection (El-Malky *et al*., 2016 and Lahiri *et al*., 2020).

Estimates of specific combining ability effects:

Sprague and Tatum, (1942) reported that the SCA effect is due to non-additive genetic proportion. Based on the nature and magnitude of SCA effects desirable crosses can sorted out from the lines × testers set showing high SCA effects in Lines × tester analysis for all the fourteen traits presented in (Table 4). The early flowering for days to 50% flowering was desirable character hence, the crosses towards significant negative direction with low SCA effect were selected for days to 50% flowering viz. $L_2 \times T_3$, $L_4 \times T_4$, $L_7 \times T_5$ and $L_{11} \times T_2$ however, some negative crosses which was not found significant were also chosen belonging to their parents with low mean and low SCA effect viz. $L_1 \times T_1$, $L_1 \times T_2$, $L_6 \times T_4$ $L_9 \times T_3$ and $L_9 \times T_5$ would be considered beneficial; whereas, there was not any single positive significant SCA effect hybrids were recorded for days to 50% flowering. The crosses $L_2 \times T_3$, $L_3 \times T_5$ and $L_{12} \times T_1$ found high positive SCA effect but the cross $L_3 \times T_3$ towards significant negative SCA effect with low mean value and alike, days to 50% flowering crosses towards negative direction with low SCA and mean value belonging to their parents viz. $L_3 \times T_1$, $L_2 \times T_1$, $L_2 \times T_4$, $L_{11} \times T_1$ and $L_{11} \times T_2$ can be also estimates for plant height at full maturity. However, there was no significant positive or negative SCA value was recorded for No. of leaves/plant although, selection of best hybrids has been done on the basis of highest mean value with high positive SCA effect, so the crosses $L_4 \times T_4$, $L_4 \times T_2$ and $L_{11} \times T_2$ were selected for number of leaves per plant.Cross $L_2 \times T_3$ for pedicel length; $L_7 \times T_1$, $L_{10} \times T_2$ and $L_{12} \times T_3$ for No. of capsules per plant;, $L_1 \times T_1$, $L_1 \times T_2$, $L_2 \times T_1$, $L_2 \times T_2$, $L_2 \times T_3$, $L_3 \times T_4$, $L_4 \times T_1$, $L_5 \times T_1$, $L_5 \times T_4$, $L_6 \times T_1$, $L_6 \times T_4$, $L_7 \times T_4$, $L_8 \times T_5$, $L_9 \times T_3$, $L_9 \times T_5$, $L_{10} \times T_4$, $L_{10} \times T_5$, $L_{11} \times T_2$, $L_{11} \times T_4$, $L_{12} \times T_3$ and $L_{12} \times T_5$ for capsule index (mm). Moreover, the late maturity was a desirable trait that's why the crosses toward positive SCA effect with high mean value were selected $L_1 \times T_5$, $L_2 \times T_1$, $L_2 \times T_4$, $L_3 \times T_5$, $L_7 \times T_1$, $L_8 \times T_2$, $L_9 \times T_3$, $L_{10} \times T_3$, $L_{11} \times T_3$, $L_{12} \times T_5$ for days to maturity; Crosses $L_1 \times T_4$, $L_6 \times T_1$, $L_9 \times T_1$, $L_{10} \times T_2$ and $L_{12} \times T_3$ for seed yield (g/plant); $L_{10} \times T_2$ and $L_{12} \times T_3$ for dry husk capsule yield (g/plant); $L_1 \times T_4$, $L_6 \times T_1$, $L_{10} \times T_2$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ for total crude morphine alkaloids (%); $L_1 \times T_3$, $L_4 \times T_5$, $L_5 \times T_2$, $L_6 \times T_1$, $L_7 \times T_4$, $L_8 \times T_2$, $L_9 \times T_4$, $L_{10} \times T_4$, $L_{11} \times T_1$, $L_{12} \times T_3$ and $L_{12} \times T_4$ for codeine content (%); $L_2 \times T_1$, $L_6 \times T_3$, $L_6 \times T_4$, $L_7 \times T_1$, $L_8 \times T_1$, $L_9 \times T_5$, $L_{10} \times T_2$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ for thebaine content (%); $L_1 \times T_3$, $L_2 \times T_4$, $L_3 \times T_5$, $L_4 \times T_5$, $L_5 \times T_1$, $L_6 \times T_2$, $L_8 \times T_1$, $L_9 \times T_1$, $L_9 \times T_2$, $L_{10} \times T_2$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ for papaverine content (%) and $L_1 \times T_1$, $L_1 \times T_3$, $L_2 \times T_5$, $L_4 \times T_5$, $L_6 \times T_2$, $L_7 \times T_4$, $L_8 \times T_2$, $L_9 \times T_1$, $L_9 \times T_5$, $L_{10} \times T_4$, $L_{11} \times T_1$, $L_{12} \times T_3$ and $L_{12} \times T_4$ for noscapine content in (%) were desirable combinations on the basis of significant positive SCA effects observed in the hybrids. Consequently the hybrids for traits like no. of capsule/plant, seed yield (g/plant), dry husk yield and alkaloids content (%) were found desirable in terms of enhancement of economic yields in *Papaver somniferum* crop.

Towards negative direction hybrids namely, $L_1 \times T_3$, $L_1 \times T_4$, $L_1 \times T_5$, $L_2 \times T_5$, $L_3 \times T_1$, $L_3 \times T_3$, $L_4 \times T_3$, $L_4 \times T_4$, $L_4 \times T_5$, $L_5 \times T_2$, $L_5 \times T_3$, $L_5 \times T_5$, $L_6 \times T_3$, $L_6 \times T_5$, $L_7 \times T_1$, $L_7 \times T_3$, $L_8 \times T_1$, $L_8 \times T_2$, $L_8 \times T_3$, $L_8 \times T_4$, $L_9 \times T_2$, $L_9 \times T_4$, $L_{10} \times T_1$, $L_{10} \times T_3$, $L_{11} \times T_1$, $L_{11} \times T_3$, $L_{12} \times T_2$ and $L_{12} \times T_4$ for capsule index (mm); However, the hybrids namely, $L_1 \times T_3$, $L_2 \times T_3$, $L_2 \times T_5$, $L_3 \times T_2$, $L_4 \times T_1$, $L_7 \times T_3$, $L_8 \times T_1$, $L_8 \times T_5$, $L_{10} \times T_4$, $L_{11} \times T_4$ and $L_{12} \times T_2$ exhibited significant negative SCA effect for days to maturity but considered undesirable; $L_1 \times T_1$, $L_6 \times T_5$, $L_8 \times T_2$, and $L_{12} \times T_5$ for seed yield (g/plant); $L_6 \times T_2$, $L_8 \times T_3$, $L_8 \times T_4$, $L_{10} \times T_1$, $L_{12} \times T_1$ and $L_{12} \times T_5$ for total crude morphine alkaloids (%); $L_2 \times T_3$, $L_3 \times T_4$, $L_4 \times T_4$, $L_5 \times T_1$, $L_7 \times T_5$, $L_8 \times T_4$, $L_8 \times T_5$, $L_9 \times T_1$, $L_{10} \times T_3$, $L_{11} \times T_2$, $L_{12} \times T_1$, $L_{12} \times T_2$ and $L_{12} \times T_5$ for codeine content (%); $L_2 \times T_3$, $L_6 \times T_1$, $L_6 \times T_5$, $L_7 \times T_3$, $L_8 \times T_4$, $L_9 \times T_3$, $L_{10} \times T_1$, $L_{10} \times T_4$, $L_{11} \times T_3$, $L_{12} \times T_1$, $L_{12} \times T_2$ and $L_{12} \times T_5$ for thebaine content (%); $L_1 \times T_2$, $L_1 \times T_4$, $L_2 \times T_3$, $L_3 \times T_3$, $L_4 \times T_4$, $L_5 \times T_4$, $L_6 \times T_5$, $L_7 \times T_3$, $L_8 \times T_5$, $L_9 \times T_3$, $L_{10} \times T_1$, $L_{10} \times T_3$, $L_{11} \times T_3$, $L_{12} \times T_1$, $L_{12} \times T_2$ and $L_{12} \times T_5$ for papaverine content (%) and $L_1 \times T_2$, $L_1 \times T_4$, $L_3 \times T_3$, $L_4 \times T_3$, $L_6 \times T_4$, $L_7 \times T_5$, $L_8 \times T_4$, $L_9 \times T_2$, $L_9 \times T_3$, $L_{10} \times T_3$, $L_{10} \times T_5$, $L_{11} \times T_2$, $L_{11} \times T_5$, $L_{12} \times T_1$ and $L_{12} \times T_2$ for noscapine content in percent were the hybrids in F_1s recorded negative significant SCA effects and therefore, considered as undesirable. However, there was no negative SCA effect had distinguished in no. of leaves/plant, pedicel length, no. of capsule/plant and dry husk yield (g/plant).

Therefore, the selected hybrids for desirable traits are expected to produce desirable segregants and can be exploited successfully further breeding programs in opium poppy. High SCA effects were caused by the dominance and interaction or epistatic effects (non-fixable genes) that occurred among the crossed parents. They include additive × dominance and dominance × dominance interactions (Griffing, 1956 and El-Malky *et al*., 2016). Similar findings were reported earlier by Basbag *et al*., (2007); Hassan *et al*., (2012); Shukla *et al*., (2016); Yamunara, (2009); Zeinab Montazeril *et al*., (2014). It is evident that in this study all the cross combinations, which expressed high SCA values for different traits involved high x high, high x low and low x low general combining ability parents showing the presence of additive and non-additive type of gene actions. Alike verdicts were described by Kumar *et al*., (1994); Nie *et al*., (1991); Mishra and Rai, (1996) that most of the crosses exhibiting high SCA effect have at least one or both parent with high GCA effect indicating that such combinations are expected to produce desirable transgressive segregant.

Estimates of Proportional contribution to the total variance, gene action, degree of dominance, heritability and genetic gain:

In the present investigation, the nature of genetic variance component and type of gene actions were determined. The estimates of variance due to GCA ($\hat{\sigma}^2 g$) and SCA ($\hat{\sigma}^2 s$) were computed and $\hat{\sigma}^2 g / \hat{\sigma}^2 s$ was compared with GCA/SCA and found that the ratio was less than unity for all the attributes studied indicated predominance of non-additive gene action over the additive gene action in the inheritance (Table 5). Therefore, non-additive gene action seemed to be mainly responsible for the expression of economic character i.e. (seed and alkaloid yield) yields and its components. Similar findings were also demonstrated by (Moterle *et al*., 2012; Singh *et al*., 2014; Santha *et al*., 2016; Manoj Kumar *et al*., 2010; Immanuel Selvaraj *et al*., 2011; Reddy *et al*., 2012; Suresh Babu *et al*., 2012; Fellahi Zea *et al.*, 2013; Lal *et al.*, 2020) that the non-additive effect was proportionally of greater importance in the expression of yield and yield attributes in different crops. Therefore, obtained best parents and cross combinations in this study could be effectively utilize for the improvement of yields component in *Papaver somniferum* L. Bhateria *et al.*, (2006) found that predominance of both additive and non-additive gene actions significantly affected the inheritance of seed yield and its related traits.

The influence of maternal (females/lines) variance was higher than paternal variance (males/testers) among all the traits except codeine alkaloids content (Table 6). Contribution for female variance was highest for days to 50% flowering (44.676) followed by pedicel length (42.278) and thebaine content (38.121). Whereas, low female contribution were lead by attributes like papaverine content (25.514) followed by days to maturity (24.698), no. of leaves/plant (24.135), no. of capsule/plant (18.463), codeine content (11.236) and noscapine content (9.134).The paternal influence was not so obvious among all the traits except for codeine content. The results depicted that maternal and maternal × paternal interaction contributed more to genetic variation of cognate traits. Males/testers contribution variances ranged highest for codeine content (14.699) to lowest for morphine content (0.786). The way of female × male (L× T) interaction variances had highest for all the traits among fourteen characters studies. It was highest for noscapine content (88.110) followed by no. of capsule/plant (76.479), codeine content (74.065), morphine content (71.881) and papaverine content (71.666). Whereas, lowest female × male interaction was recorded for days to 50% flowering (54.368) (Fig.1). These results showed that lines, testers and the interaction lines × testers brought much variation in the expression of the studied traits; consonant results were also observed previously by (Mushonga, 1991).

The narrow sense heritability $\hat{h}^2_{(ns)}$ estimated low for all the studied traits ranged from 0.0463-2.306%. (Falconer and Mackay, 1996) conveyed that the lower narrow sense heritability was caused by low additive effects and high dominant gene action. Genetic advance over mean in percent ranged from lowest (0.00017) for total alkaloids morphine content (%) to the highest (96.03) for plant height. It was high for days to 50% flowering (90.40) and pedicel length (27.50) whereas, low genetic advance was observed for morphine, codeine and papaverine content (%). To assess the combining ability pattern among best selected hybrids on the basis of *per se* performance and high SCA effects (Table 7) the crosses $L_1{\times}T_1$ for days to flowering (50%), $L_3{\times}T_3$ for plant height, $L_4{\times}T_4$ for No. of leaves/plant, $L_2{\times}T_3$ for pedicel length and hybrid $L_{12}{\times}T_3$ followed by $L_{10}{\times}T_2$ was excellent specific combiner for no. of capsule/plant, capsule index, days to maturity, seed yield g/plant and dry husk yield g/plant whereas, for alkaloids hybrid $L_7{\times}T_4$ was best for codeine alkaloid while the crosses $L_{12}{\times}T_3$ and $L_{12}{\times}T_4$ was best specific combiner for all studied alkaloids i.e. Morphine, codeine, thebaine, papaverine and noscapine content. Therefore, these crosses could be exploited for large area cultivation for their genetic improvement.

Conclusions

Amongst all parents i.e. in line and tester for improving economically significant yield contributing traits the maternal line L_4 and L_{12} was good combiner for no. of capsule/plant. Whereas, maternal line L_{10}, L_{12} and paternal tester T_1 was good combiners for traits seed yield/plant and dry husk yield/plant. In alkaloids the maternal line L_{12} are better combiner for morphine, thebaine, papaverine and noscapine except codeine while L_{10} is best for morphine, thebaine and papervine; L_6 for thebaine and papervine; L_8 for morphine and noscapine. However, in terms of paternal testers T_2 for codeine, T_3 for thebaine, papaverine and T_5 for noscapine were found to be good general combiners which can be taken up to generate desirable segregates for further selection. In this study, none of the crosses showed significant SCA effects for all the characters. On the basis of *per se* performance and high SCA effects the economically viable crosses $L_{12}{\times}T_3$ followed by $L_{10}{\times}T_2$ was excellent specific combiner for no. of capsule/plant, capsule index, days to maturity, seed yield g/plant and dry husk yield g/plant although, for alkaloids hybrid $L_7{\times}T_4$ was best for codeine alkaloid while the crosses $L_{12}{\times}T_3$ and $L_{12}{\times}T_4$ was best specific combiner for all studied alkaloids i.e. Morphine, codeine, thebaine, papaverine and noscapine content. Hence, further these parental lines and their hybrids can be utilize to enhance the genetic improvement of their traits through heterosis and transgressive breeding approaches.

Table 1: Parents and their crosses involved in Line × Tester analysis.

Tester	Parents used as a testers or males	Accessions code	Origin /Place of collection	Morphological/phenotypic characteristics
T1	CIMAP-Ajay (Variety/cultivar)	G-39	CSIR-CIMAP, Lucknow, U.P. (India)	Medium tall, deeply fringed small leaves, white medium fringed flower, yellow pedicel color.
T2	Sampada (Variety/cultivar)	G-45	CSIR-CIMAP, Lucknow, U.P. (India)	Medium tall variety with medium fringed leaves, white smooth petals, black pedicel color and medium size capsules.
T3	SPS-20	G-50	CSIR-CIMAP, Lucknow, U.P. (India)	Tall deeply fringed leaves, white fringed petal, yellow pedicel, downy mildew tolerant.
T4	Shweta (Variety/cultivar)	G-31	CSIR-CIMAP, Lucknow, U.P. (India)	Tall, broad fringed leaves, white smooth petal flower, yellow pedicel, very bold big capsules, high yielding variety.

T5	Shyama (Variety/cultivar)	G-25	CSIR-CIMAP, Lucknow, U.P. (India)	Medium tall, broad leaves, white smooth petal, black pedicel colour with medium size capsules.
Lines	**Parents used as a lines or females**	**Accessions code**	**Origin/ Place of collection**	**Morphological/phenotypic characteristics**
L1	G-25109/bulk	G-20	IARI, New Delhi (India)	Tall, broad leaves, white smooth petal, yellow pedicel colour with disease susceptible.
L2	Sanchita (Variety/cultivar)	G-44	CSIR-CIMAP, Lucknow, U.P. (India)	Tall, medium broad leaves, white smooth petal, black pedicel, high yielding variety.
L3	Dr-44	G-4	CSIR-CIMAP, Lucknow, U.P. (India)	Dwarf, deeply fringed small leaves, small white medium fringed flower and without latex medium size capsules.
L4	Sapna (Variety/cultivar)	G-17	CSIR-CIMAP, Lucknow, U.P. (India)	Tall, fringed leaves, white peduncle and flowers, small size capsules, early maturing.
L5	I-14 (Recombinant)	G-14	CSIR-CIMAP, Lucknow, U.P. (India)	Medium tall, deep fringed leaves, white medium fringed petal, yellow pedicel colour and Downy mildew resistance.
L6	Pop. 40	G-9	CSIR-CIMAP, Lucknow, U.P. (India)	Tall, broad leaves, flower with dark purple smooth petal, yellow pedicel color.
L7	Mtu-1 (Mutant)	G-21	CSIR-CIMAP, Lucknow, U.P. (India)	Dwarf, medium broad leaves, white smooth petal, black pedicel small capsules and cliestogamous.
L8	N-3	G-29	CSIR-CIMAP, Lucknow, U.P. (India)	Medium tall medium fringed leaves, bold capsule, yellow pedicel, white medium fringed petal margin in flower, downy mildew resistance.
L9	Sujata (Variety/cultivar)	G-6	CSIR-CIMAP, Lucknow, U.P. (India)	Very tall, broad leaves, white flower with bold capsules, opium-less and alkaloids free variety.
L10	T-4 (Thai)	G-12	Thailand	Tall, broad leaves, flower with white and dark pink mix smooth petals, yellow pedicel color.
L11	GS-11 Bhadama	G-32	Ghazipur (U.P.), India	Tall, medium fringed with white smooth petals, black pedicel with small capsule size.
L12	ABR	G-49	Thailand	Medium tall, medium fringed leaves, flowers with white and scarlet reddish pink mix, slightly fringed petals, and black pedicel colour, late flower.

Table 2: ANOVA for combining ability for fourteen characters in Opium poppy (Lines × Testers analysis Kempthorne, 1957, method)

Sources of variation	**d.f.**	**Character's Mean Sum of Squares (m.s.s)**						
		X_1	X_2	X_3	X_4	X_5	X_6	X_7
Replications	2	153.50	137.00	276.42	53.64	31.69	0.03	499.75
Treatments	76	104.98**	220.13**	11.86**	23.40**	7.79**	0.32**	69.86**
Parents	16	101.07**	190.11**	15.66**	10.55	6.92**	0.27**	138.67**
Hybrids (H)	59	106.44**	219.57**	10.95**	27.25**	8.14**	0.33**	48.38**
Parents × Hybrids	1	81.50	733.50**	5.05	1.91	1.48	0.18**	238.00**
Females	11	255.06**++	352.36**	14.17**	61.80**++	8.06**	0.54**	64.09**
Males	4	15.00	200.56*	8.59	8.61	6.07	0.32**	36.50**
Females × Males	44	77.59**	188.10**`	10.35**	20.31**	8.35**	0.28**	45.53**
Error	152	25.81	59.71	5.61	10.39	2.91	0.001	5.23
Total	230							

Sources of variation	d.f.	Character's Mean Sum of Squares (m.s.s)						
		X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
Replications	2	40.50	27.87	0.0006	0.0050	0.0026	0.0015	0.0016
Treatments	76	25.97**	13.47**	0.0027**	0.0175**	0.0223**	0.0185**	0.0101**
Parents	16	16.88**	8.32*	0.0015**	0.0171**	0.0095**	0.0023**	0.0106**
Hybrids (H)	59	28.78**	14.83**	0.0030**	0.0179**	0.0260**	0.0224**	0.0100**
Parents × Hybrids	1	5.27	16.20	0.0075**	0.00001	0.0084**	0.0424**	0.0104**
Females	11	46.59**	24.23**+	0.0044**	0.0108**	0.0532**++	0.0307**	0.0049**
Males	4	28.51**	23.04**	0.0003	0.0388**	0.0218**	0.0093**	0.0041**
Females × Males	44	24.36**	11.73**	0.0029**	0.0178**	0.0196**	0.0216**	0.0118**
Error	152	5.28	4.34	0.0004	0.0012	0.0006	0.0006	0.0007
Total	230							

Table 3: General combining ability effects (gi), g.c.a. ($\hat{\sigma}_g^2$) and s.c.a. variances ($\hat{\sigma}_{si}^2$) for fourteen characters of seventeen (5 male and 12 female) parents in *Papaver somniferum* L.

GCA Lines/Testers	X1	X2	X3	X4	X5	X6	X7
L_1 (Lines)	-5.27**	3.07	-0.11	1.98*	0.011	-0.15**	1.16
$\bar{X}$	100.30	103.83	19.33	20.63	4.67	1.48	163.30
L_2	-2.21	-4.16*	-0.71	4.42**	-0.66	-0.27**	-1.37*
$\bar{X}$	112.60	99.30	20.66	20.93	5.00	1.38	174.60
L_3	-1.07	-11.51**	-0.37	-0.49	-0.46	0.07**	1.49*
X	103.60	124.53	20.00	17.96	7.00	1.21	159.30
L_4	-1.01	2.61	1.96**	1.82*	1.08*	-0.11**	2.69**
$\bar{X}$	112.00	102.26	23.00	24.26	5.33	1.15	173.30
L_5	7.06**	-1.11	-0.64	1.10	0.28	-0.17**	-0.17
$\bar{X}$	112.66	112.33	16.33	19.10	8.00	1.08	180.00
L_6	-5.74**	-0.86	-0.64	-1.18	-0.52	-0.02*	2.36**
$\bar{X}$	113.00	106.46	20.00	21.36	6.00	1.35	177.30
L_7	3.39*	3.71	-0.24	-2.63**	-0.12	-0.15**	0.63
$\bar{X}$	111.00	108.93	16.66	19.36	4.00	1.05	183.30
L_8	-0.67	3.09	-0.31	-0.59	0.28	0.01	-2.24**
$\bar{X}$	98.00	103.03	17.66	18.53	7.34	1.32	177.00
L_9	-4.01**	-0.18	-0.97	-2.38**	-1.26**	0.27**	0.56
$\bar{X}$	115.33	108.16	17.00	18.66	10.33	1.33	179.00
L_{10}	4.86**	3.97*	-0.24	0.21	0.81	0.08**	-4.37**
$\bar{X}$	108.33	117.90	18.66	22.03	6.33	1.42	171.00
L_{11}	0.46	-4.33*	1.96**	-1.36	-0.52	0.10**	-1.71**
$\bar{X}$	113.00	100.40	21.33	18.96	7.00	1.48	176.30
L_{12}	4.19**	5.69**	0.29	-0.87	1.08*	0.36**	0.96
$\bar{X}$	110.00	106.63	20.66	19.40	7.00	2.16	175.60
T_1 (Testers)	-0.75	-1.07	-0.37	0.63	0.44	-0.13**	-0.78*
$\bar{X}$	99.00	109.70	20.00	19.96	5.34	1.26	178.30
T_2	0.77	-0.86	0.56	0.34	-0.33	3.19**	-1.12**
$\bar{X}$	104.30	126.40	18.33	21.06	5.67	1.26	177.60
T_3	0.33	-2.81*	-0.46	-0.53	-0.36	0.06**	-0.15
$\bar{X}$	102.00	116.83	24.00	19.50	8.00	1.42	168.30
T_4	-0.58	1.59	0.48	-0.40	-0.19	-0.07**	0.96*
$\bar{X}$	109.30	103.66	23.33	24.60	6.67	1.35	162.60
T_5	0.22	3.15*	-0.21	-0.04	0.44	0.10**	1.09**
$\bar{X}$	115.30	107.50	21.00	20.06	7.33	2.12	179.30
SE (GCA Lines)	1.312	1.995	0.611	0.832	0.441	0.008	0.590
SED (GCA Lines)	1.855	2.822	0.865	1.177	0.623	0.011	0.835
SE (GCA Testers)	0.847	1.288	0.395	0.537	0.284	0.005	0.381
SED (GCA Testers)	1.197	1.821	0.558	0.759	0.402	0.007	0.539

GCA Lines/Testers	X8	X9	X10	X11	X12	X13	X14
L_1 (Lines)	-0.80	-0.63	0.0030	-0.0350**	-0.0157*	-0.0208**	0.0127
$\bar{X}$	5.06	3.14	0.0430	0.1200	0.0633	0.1300	0.2367
L_2	-0.51	-0.05	-0.0210**	0.0157	-0.0424**	-0.0283**	-0.0006
$\bar{X}$	4.55	3.39	0.0460	0.3430	0.2767	0.0533	0.0867
L_3	-0.95	-0.26	-0.0130**	0.0011	-0.0491**	-0.0324**	-0.0199**
X	5.82	3.76	0.0560	0.1830	0.0433	0.0233	0.0233
L_4	1.52*	1.00	-0.0079	0.0257**	-0.0237**	-0.0176**	-0.0013
$\bar{X}$	6.75	4.28	0.0530	0.2300	0.0500	0.0633	0.1367
L_5	-2.15**	-1.89**	-0.0150**	0.0171	-0.0384**	0.0043	-0.0266**
$\bar{X}$	11.44	6.79	0.0860	0.1200	0.1067	0.0743	0.0900
L_6	-2.02**	-1.62**	-0.0080	-0.0043	0.1168**	0.0316**	0.00006
$\bar{X}$	7.19	4.65	0.0330	0.0660	0.0400	0.0613	0.0500
L_7	-0.77	-0.70	-0.0053	0.0317**	-0.0504**	-0.0216**	0.0134
$\bar{X}$	5.03	2.87	0.0330	0.2760	0.0233	0.0817	0.1433
L_8	0.59	0.45	0.0230**	-0.0143	0.0008	-0.0356**	0.0227**
$\bar{X}$	9.35	4.96	0.0300	0.2360	0.0700	0.0633	0.0677
L_9	-0.32	-0.35	0.0054	0.0157	-0.0291**	0.0043	-0.0206**
$\bar{X}$	11.92	8.85	0.0730	0.1530	0.0360	0.0203	0.0700
L_{10}	3.25**	2.45**	0.0120*	0.0004	0.0295**	0.0401**	0.0074
$\bar{X}$	7.96	6.02	0.0700	0.2730	0.0500	0.0400	0.1233
L_{11}	-0.82	-0.19	-0.0090	-0.0623**	-0.0177**	-0.0414**	-0.0166*
$\bar{X}$	10.62	6.34	0.0660	0.1530	0.0560	0.0767	0.1677
L_{12}	2.99**	1.79**	0.0370**	0.0091	0.1195**	0.1175**	0.0294**
$\bar{X}$	8.41	5.39	0.0860	0.1460	0.0700	0.0947	0.1533
T_1 (Testers)	1.05**	0.91*	-0.0022	-0.044**	-0.0290**	-0.0251**	-0.016**
$\bar{X}$	8.88	6.60	0.0660	0.2700	0.0700	0.0967	0.1400
T_2	-1.11**	-1.03**	0.0020	0.0318**	-0.0212**	0.0032	0.0079
$\bar{X}$	8.89	6.09	0.0960	0.1900	0.0760	0.0920	0.1600
T_3	-0.59	-0.42	-0.0024	-0.0223**	0.0274**	0.0186**	-0.0035
$\bar{X}$	11.17	6.48	0.0530	0.2460	0.0430	0.0700	0.0767
T_4	-0.04	-0.15	-0.0018	0.0287**	0.0193**	0.0063	0.00067
$\bar{X}$	10.15	6.85	0.0860	0.2100	0.0560	0.0967	0.1833
T_5	0.69	0.69	0.0045	0.0057	0.0035	-0.0030	0.01094*
$\bar{X}$	6.51	3.37	0.1000	0.3130	0.0660	0.0700	0.2200
SE (GCA Lines)	0.594	0.537	0.0048	0.0091	0.0062	0.0063	0.0068
SED (GCA Lines)	0.839	0.760	0.0068	0.0128	0.0087	0.0089	0.0097
SE (GCA Testers)	0.383	0.347	0.0031	0.0058	0.0039	0.0041	0.0044
SED (GCA Testers)	0.542	0.491	0.0044	0.0083	0.0056	0.0057	0.0062

Where; * $p < 0.05$; ** = $p < 0.01$, respectively.

Where X_1= Days to flowering (50%), X_2= Plant height (cm), X_3= No. of leaves/plant, X_4= Pedicel length, X_5= No. of capsule/plant, X_6= Capsule index, X_7= Days to maturity, X_8= Seed yield, X_9= Dry husk capsule, X_{10}= Morphine, X_{11}= Codeine, X_{12}= Thebaine, X_{13}= Papervine, X_{14}= Nosacapine.

Table 4: Specific combining ability effects (s.c.a.) of (12 × 5) line× tester crosses for fourteen characters in *Papaver somniferum* L.

SCA Lines × Testers	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
$L_1 \times T_1$	-0.12	2.27	0.91	0.92	-1.51	0.08**	-2.74	-4.83*	-3.36	0.0055	-0.0280	0.0296	-0.0341	0.0753**
$\bar{X}$	100.60	117.86	20.66	24.13	5.67	1.14	168.60	4.01	2.84	0.0560	0.1000	0.0700	0.0237	0.2133
$L_1 \times T_2$	-0.97	-1.71	-0.36	4.85	-1.07	0.14**	1.92	-0.13	0.22	-0.0180	-0.0205	0.0085	-0.0427*	-0.0652**
$\bar{X}$	101.30	114.10	20.33	27.76	5.33	1.35	1.73	6.45	4.49	0.0360	0.1830	0.0560	0.0433	0.0967
$L_1 \times T_3$	4.13	-2.02	-1.67	-3.52	-0.04	-0.05**	-3.72*	0.43	1.05	-0.0270	0.0636*	-0.0367	0.1150**	0.1095**
X	106.00	111.83	18.00	18.53	6.33	1.18	168.30	7.62	5.93	0.0230	0.2130	0.0600	0.2167	0.2600
$L_1 \times T_4$	-4.28	2.51	0.05	-2.37	2.46	-0.10**	-0.16	4.13*	2.26	0.0580**	-0.0441	0.0246	-0.0428*	-0.0813**
$\bar{X}$	96.60	120.76	20.66	19.80	9.00	1.01	173.00	11.87	7.41	0.1100	0.1560	0.1130	0.0463	0.0733
$L_1 \times T_5$	1.24	-1.05	1.07	0.13	0.16	-0.07*	4.70*	0.39	-0.18	-0.0170	0.0289	-0.0262	0.0045	-0.0383
$\bar{X}$	103.00	118.76	21.00	22.67	7.33	1.21	178.00	8.87	5.81	0.0400	0.2060	0.0460	0.0843	0.1267
$L_2 \times T_1$	5.82	-6.92	1.17	-0.05	-1.51	0.28**	4.45*	-1.65	-1.62	0.0035	0.0073	0.0696**	-0.0103	-0.0213
$\bar{X}$	109.60	101.43	20.33	25.60	5.00	1.21	173.30	7.47	5.16	0.0300	0.1860	0.0830	0.0400	0.1033
$L_2 \times T_2$	2.28	3.60	-1.76	-1.79	1.60	0.06**	-1.54	1.93	0.93	0.0093	0.0315	0.0285	-0.0053	0.0048

$\bar{X}$	107.60	112.17	18.33	23.57	7.33	1.15	167.00	8.89	5.77	0.0400	0.2860	0.0500	0.0733	0.1533
$L_2 \times T_3$	-8.59*	16.32*	0.93	6.41*	-0.71	0.14**	-4.85*	-0.74	-0.19	-0.0260	-0.0776**	-0.0534**	-0.0540**	-0.0383
$\bar{X}$	96.34	122.93	20.00	30.90	5.00	0.97	164.60	6.74	5.26	0.0001	0.1230	0.0160	0.0400	0.1033
$L_2 \times T_4$	-0.68	-8.58	1.65	-1.48	1.13	-0.01	6.04**	-1.14	-0.30	0.0130	0.0012	-0.0386	0.0483*	0.0020
$\bar{X}$	103.30	102.43	21.66	23.13	7.00	0.98	176.60	6.89	5.41	0.0400	0.2530	0.0230	0.1300	0.1433
$L_2 \times T_5$	1.17	-4.41	-1.98	-3.07	-0.51	-0.19**	-4.09*	1.59	1.18	0.0002	0.0376	-0.0062	0.0213	0.0484*
$\bar{X}$	106.00	108.17	17.33	21.90	6.00	0.97	166.60	10.36	7.75	0.0330	0.2660	0.0400	0.0937	0.2000
$L_3 \times T_1$	-7.65	-0.94	0.51	1.39	-0.38	-0.15**	-0.74	-0.76	-0.74	-0.0045	0.0519	0.0230	0.0205	0.0047
$\bar{X}$	97.34	100.07	20.00	22.13	6.33	1.13	171.00	7.91	5.83	0.0300	0.2160	0.0300	0.0667	0.1100
$L_3 \times T_2$	-2.84	1.71	-1.09	0.02	0.40	0.01	-5.41**	-0.35	0.63	-0.0053	0.0295	0.0018	0.0021	0.0274
$\bar{X}$	103.60	102.93	19.33	20.47	6.33	1.44	166.00	6.17	5.27	0.0330	0.2700	0.0160	0.0767	0.1567
$L_3 \times T_3$	0.93	-17.79**	1.59	-0.21	1.43	-0.18**	-0.72	3.24	1.33	0.0157	-0.0463	-0.0334	-0.0433*	-0.0445*
$\bar{X}$	107.00	81.47	21.00	19.37	7.33	1.29	171.60	10.27	6.58	0.0500	0.1400	0.0300	0.0467	0.0733
$L_3 \times T_4$	5.52	1.59	-1.02	0.59	-1.41	0.35**	2.51	-2.34	-1.69	-0.0147	-0.0874**	-0.0186	-0.0209	0.0313
$\bar{X}$	110.60	105.27	19.33	20.30	4.67	1.68	176.00	5.25	3.82	0.0200	0.1500	0.0360	0.0567	0.1533
$L_3 \times T_5$	4.04	15.44*	0.01	-1.79	-0.04	-0.02	4.36*	0.21	0.46	0.0088	0.0523	0.0272	0.0416*	-0.0189
$\bar{X}$	110.00	120.67	19.66	18.27	6.67	1.48	178.00	8.53	6.83	0.0500	0.2600	0.0660	0.1100	0.1133
$L_4 \times T_1$	2.62	11.87	-2.48	1.64	0.76	0.24**	-4.61*	0.33	0.47	0.0168	0.0306	0.0376	0.0158	-0.0340
$\bar{X}$	107.60	127.00	19.33	24.70	9.00	1.34	168.30	11.48	8.31	0.0560	0.2200	0.0700	0.0767	0.0909
$L_4 \times T_2$	6.08	0.46	2.90	-1.29	-0.13	-0.02	3.05	-1.41	-0.29	-0.0006	-0.0018	0.0132	-0.0392	-0.0412
$\bar{X}$	112.60	115.8	25.66	21.47	7.33	1.23	175.60	7.58	5.60	0.0430	0.2630	0.0530	0.0500	0.1067
$L_4 \times T_3$	0.20	-1.27	-2.41	-1.83	-0.77	-0.20**	-2.92	-2.65	-2.23	0.0077	-0.0076	-0.0254	-0.0379	-0.0665**
$\bar{X}$	106.30	112.10	19.33	20.07	6.67	1.48	170.60	6.85	4.28	0.0430	0.2030	0.0630	0.0660	0.0700
$L_4 \times T_4$	-13.55**	-0.52	2.98	3.17	1.39	-0.07*	0.97	2.27	2.29	-0.0167	-0.1454**	-0.0306	-0.0489*	0.0427
$\bar{X}$	91.66	117.26	25.66	25.20	9.00	1.08	175.60	12.34	9.06	0.0230	0.1160	0.0500	0.0430	0.1833
$L_4 \times T_5$	4.64	-10.54	-0.98	-1.68	-1.24	-0.34**	3.50	1.45	-0.24	-0.0032	0.1243**	0.0052	0.1103**	0.0991**
$\bar{X}$	110.60	108.80	21.00	20.70	7.00	0.99	178.30	12.25	7.38	0.0430	0.3630	0.0700	0.1930	0.2500
$L_5 \times T_1$	-1.45	-3.74	0.11	0.43	-2.44	0.28**	1.25	-2.60	-2.08	-0.0058	-0.0573*	-0.0009	0.0571**	-0.0153
$\bar{X}$	111.60	107.67	19.33	22.76	5.00	1.31	171.30	4.87	2.85	0.0260	0.1230	0.0160	0.1400	0.0833
$L_5 \times T_2$	2.68	3.98	1.50	0.42	-0.33	-0.05*	0.25	1.01	0.45	-0.0233	0.1368**	0.0345	0.0221	0.0341
$\bar{X}$	117.30	115.60	21.66	22.46	6.33	1.41	170.00	6.33	3.46	0.0130	0.3930	0.0600	0.1330	0.1567
$L_5 \times T_3$	2.80	3.96	-0.47	0.46	-0.64	-0.08**	1.28	-1.79	-0.48	0.0011	-0.0223	-0.0074	-0.0199	-0.0178
$\bar{X}$	117.00	113.63	18.67	21.63	6.00	1.41	172.00	4.03	3.13	0.0330	0.1800	0.0660	0.1060	0.0933
$L_5 \times T_4$	-0.28	-2.54	0.25	0.36	1.53	0.14**	-0.83	1.44	1.24	0.0138	-0.0501	-0.0259	-0.0476*	-0.0287
$\bar{X}$	113.00	111.53	20.33	21.67	8.33	1.23	171.00	7.83	5.12	0.0460	0.2030	0.0400	0.0660	0.0867
$L_5 \times T_5$	-3.75	-1.66	-1.38	-1.69	1.89	-0.28**	-1.96	1.95	0.87	0.0142	-0.0071	-0.0002	-0.0116	0.0277
$\bar{X}$	110.30	113.96	18.00	19.96	9.33	0.99	170.00	9.07	5.60	0.0530	0.2230	0.0500	0.0930	0.1533
$L_6 \times T_1$	-4.32	7.35	1.11	-2.85	2.02	0.33**	1.05	4.36*	2.88	0.0508**	0.0639*	-0.1463**	-0.0035	-0.0120
$\bar{X}$	96.00	119.00	20.33	17.20	8.67	1.52	173.60	11.97	8.09	0.0890	0.2230	0.0260	0.1060	0.1133
$L_6 \times T_2$	2.15	1.56	-0.50	-2.38	-0.20	-0.01	2.72	1.55	1.05	-0.0366*	-0.0518	-0.0174	0.1181**	0.0541*
$\bar{X}$	104.00	113.43	19.67	17.37	5.67	1.35	175.00	7.00	4.34	0.0060	0.1830	0.1630	0.2560	0.2033
$L_6 \times T_3$	0.26	-5.67	1.86	2.15	0.83	-0.09**	-0.25	-1.51	-1.03	-0.0155	-0.0076	0.0939**	-0.0239	0.0088
$\bar{X}$	101.60	104.23	21.00	21.03	6.67	1.29	173.00	4.45	2.86	0.0230	0.1730	0.3230	0.1300	0.1467
$L_6 \times T_4$	-0.15	3.95	-3.08	1.68	-1.01	0.30**	-3.03	-0.13	-0.71	-0.0027	-0.0321	0.1453**	-0.0316	-0.0653**
$\bar{X}$	100.30	118.26	17.00	20.70	5.00	1.55	171.30	6.39	3.44	0.0360	0.2000	0.3660	0.1100	0.0767
$L_6 \times T_5$	2.04	-7.17	0.61	1.39	-1.64	-0.54**	-0.49	-4.27*	-2.20	0.0042	0.0276	-0.0755**	-0.0589**	0.0144
$\bar{X}$	103.30	108.70	20.00	20.76	5.00	0.88	174.00	2.97	2.80	0.0500	0.2360	0.1300	0.0730	0.1667
$L_7 \times T_1$	1.88	3.45	-1.28	-2.23	2.96*	-0.09**	3.78*	1.03	0.56	0.0108	-0.0020	0.0543**	0.0165	-0.0053
$\bar{X}$	111.30	119.66	18.33	16.36	10.00	0.97	174.60	9.88	6.68	0.0530	0.1930	0.0600	0.0730	0.1333
$L_7 \times T_2$	0.68	2.23	-0.23	2.09	-0.60	-0.02	0.78	0.95	0.75	-0.0033	-0.0212	0.0165	-0.0085	-0.0192
$\bar{X}$	111.60	118.67	20.33	20.40	5.67	1.19	171.30	7.65	4.95	0.0430	0.2500	0.0300	0.0760	0.1433
$L_7 \times T_3$	6.80	-5.01	1.79	-2.21	-1.57	-0.12**	-4.85*	0.78	0.76	0.0177	-0.0503	-0.0421*	-0.0439*	0.0155
$\bar{X}$	117.30	109.46	21.34	15.23	4.67	1.12	166.60	7.99	5.56	0.0600	0.1660	0.0200	0.0560	0.1667
$L_7 \times T_4$	3.05	0.85	-1.82	0.45	-0.07	0.25**	2.37	-1.48	-1.21	-0.0094	0.1718**	-0.0206	0.0251	0.0547*
$\bar{X}$	112.60	119.73	18.67	18.00	6.33	1.36	175.00	6.28	3.85	0.0330	0.4400	0.0330	0.1130	0.2100
$L_7 \times T_5$	-12.42**	-1.51	1.54	1.91	-0.71	-0.02	-2.09	-1.28	-0.86	-0.0158	-0.0984**	-0.0082	0.0110	-0.0456*
$\bar{X}$	98.00	118.93	21.34	19.83	6.33	1.27	170.60	7.21	5.05	0.0330	0.1460	0.0300	0.0900	0.1200
$L_8 \times T_1$	-3.38	4.03	2.11	2.53	0.89	-0.27**	-4.67*	1.54	2.06	0.0295	0.0140	0.1063**	0.0605**	0.022
$\bar{X}$	102.00	119.63	21.67	23.17	8.33	0.95	163.30	11.77	9.35	0.1000	0.1630	0.1630	0.1030	0.1700
$L_8 \times T_2$	-2.91	-5.02	2.16	-1.57	-0.67	-0.09**	5.32**	-3.76*	-1.99	0.0286	0.0648*	-0.0147	0.0021	0.0748**
$\bar{X}$	104.00	110.80	22.66	18.76	6.00	1.29	173.00	4.31	3.35	0.1030	0.2900	0.0500	0.0730	0.2467
$L_8 \times T_3$	-4.79	3.06	-1.47	-3.45	0.36	-0.11**	-0.32	1.12	0.25	-0.0335*	0.0389	0.0299	0.0167	0.0295
$\bar{X}$	101.60	116.93	18.00	16.03	7.00	1.29	168.30	9.71	6.21	0.0360	0.2100	0.1430	0.1030	0.1900

L_8× T_4	6.45	1.93	-2.75	5.19	-2.47	-0.18**	3.57	-0.77	-1.29	-0.0507**	-0.0587*	-0.0919**	-0.0376	-0.0980**
$\bar{X}$	112.00	120.20	17.66	24.80	4.33	1.09	173.30	8.36	4.92	0.0200	0.1630	0.0130	0.0360	0.0667
L_8× T_5	4.64	-3.99	-0.06	-2.69	1.89	0.66**	-3.89*	1.87	0.98	0.0262	-0.0591*	-0.0295	-0.0416*	-0.0283
$\bar{X}$	111.00	115.83	19.66	17.27	9.33	2.10	166.00	11.75	8.06	0.1030	0.1400	0.0600	0.0230	0.1467
L_9× T_1	7.62	-12.36	1.44	1.55	0.09	0.02	-2.81	3.74*	2.59	0.0068	-0.0960**	0.0063	0.0571**	0.0553*
$\bar{X}$	109.60	99.97	20.33	20.40	6.00	1.50	168.00	13.05	9.07	0.0600	0.0830	0.0330	0.1400	0.1600
L_9× T_2	-5.24	1.39	-2.83	-0.15	-0.13	-0.25**	-1.81	-2.18	-2.40	0.0159	-0.0018	-0.0114	0.0487*	-0.0586**
$\bar{X}$	98.34	113.93	17.00	18.40	5.00	1.39	168.60	4.96	2.15	0.0730	0.2530	0.0230	0.1600	0.0700
L_9× T_3	-0.79	4.75	-0.14	-2.65	0.89	0.39**	6.55**	-0.38	0.41	0.0004	0.0356	-0.0601**	-0.0499*	-0.0472*
$\bar{X}$	102.30	115.33	18.67	15.03	6.00	2.06	178.00	7.28	5.56	0.0530	0.2360	0.0230	0.0760	0.0700
L_9× T_4	0.45	3.84	1.58	-2.31	-1.27	-0.56**	0.44	-1.42	-1.43	-0.0034	0.0678*	-0.0153	-0.0243	-0.0047
$\bar{X}$	102.60	118.83	21.34	15.50	4.00	0.98	173.00	6.81	3.98	0.0500	0.3200	0.0600	0.0900	0.1167
L_9× T_5	-2.02	2.38	-0.06	3.56	0.42	0.41**	-2.36	0.25	0.83	-0.0198	-0.0057	0.0805**	-0.0316	0.0551*
$\bar{X}$	101.00	118.93	19.00	21.73	6.33	2.12	170.30	9.21	7.10	0.0400	0.2230	0.1400	0.0730	0.1867
L_{10}× T_1	1.42	-10.69	-2.95	-1.67	-1.64	-0.40**	3.45	-0.77	-0.16	-0.0565**	-0.0006	-0.0390*	-0.0663**	-0.0393
$\bar{X}$	112.30	105.80	16.67	19.76	6.33	0.89	169.30	12.11	9.12	0.0030	0.1630	0.0460	0.0520	0.0933
L_{10}× T_2	1.55	8.29	-2.23	-0.41	2.80*	0.03	-0.54	5.62**	3.90*	0.0393*	-0.0298	0.0832**	0.0496*	0.0120
$\bar{X}$	114.00	125.00	18.33	20.73	10.00	1.48	165.00	16.35	11.25	0.1030	0.2100	0.1760	0.1960	0.2767
L_{10}× T_3	0.01	-3.75	0.46	1.42	-1.84	-0.11**	3.82*	-2.92	-2.65	-0.0163	-0.0623*	-0.0321	-0.1220**	-0.0818**
$\bar{X}$	112.00	111.00	20.00	21.70	5.33	1.37	170.30	8.33	5.31	0.0430	0.1230	0.1100	0.0400	0.0633
L_{10}× T_4	2.25	-3.73	2.52	-0.27	-1.01	0.36**	-4.96**	-2.01	-1.44	-0.0301	0.0998**	-0.0939**	0.0133	0.0473*
$\bar{X}$	113.30	115.43	23.00	20.13	6.33	1.71	162.60	9.79	6.78	0.0300	0.3360	0.0400	0.1630	0.1967
L_{10}× T_5	-5.22	9.88	2.21	0.93	1.69	0.11**	-1.76	0.01	0.35	0.0635**	-0.0071	0.0818**	0.1258**	-0.0463*
$\bar{X}$	106.60	130.60	22.00	21.70	9.67	1.63	166.00	12.61	9.43	0.1300	0.2060	0.200	0.2660	0.1133
L_{11}× T_1	-1.52	-8.02	0.51	1.03	1.69	-0.35**	0.78	1.99	1.65	-0.0152	0.1086**	-0.0149	0.0195	0.0647**
$\bar{X}$	105.00	100.17	22.34	20.90	8.33	0.95	169.30	10.81	8.28	0.0230	0.2100	0.0230	0.0560	0.1733
L_{11}× T_2	-55.71**	-5.99	1.90	-1.20	0.47	0.55**	2.12	-0.24	-0.86	0.0073	-0.0572*	-0.0294	0.0011	-0.0559*
$\bar{X}$	102.30	102.40	24.67	18.37	6.33	2.01	170.30	6.41	3.84	0.0500	0.1200	0.0160	0.0660	0.0767
L_{11}× T_3	-2.93	11.68	0.59	0.29	-1.51	-0.24**	4.48*	-3.69	-1.85	0.0084	-0.0330	-0.0514**	-0.0466*	0.0288
$\bar{X}$	104.60	118.13	22.33	19.00	4.33	1.25	173.60	3.47	3.46	0.0460	0.0900	0.0430	0.0340	0.1500
L_{11}× T_4	4.32	-4.62	-1.35	-2.39	-1.01	0.05*	-5.63**	0.15	-0.38	0.0012	-0.0007	-0.0099	0.0281	0.0313
$\bar{X}$	111.00	106.23	21.34	16.43	5.00	1.42	164.60	7.88	5.18	0.0400	0.1730	0.0760	0.0960	0.1567
L_{11}× T_5	5.84	6.95	-1.65	2.27	0.36	-0.01	-1.76	1.79	1.45	-0.0018	-0.0177	0.0105	-0.0019	-0.0689**
$\bar{X}$	113.30	119.37	20.33	21.47	7.00	1.52	168.60	10.25	7.88	0.0430	0.1330	0.1760	0.0570	0.0667
L_{12}× T_1	-0.92	13.72*	-1.15	-2.68	-0.91	0.03	0.78	-2.35	-2.25	-0.0418**	-0.0926**	-0.1256**	-0.1327**	-0.0947**
$\bar{X}$	109.30	131.93	19.00	17.66	7.33	1.60	172.00	10.27	6.37	0.0430	0.0800	0.0500	0.0630	0.0600
L_{12}× T_2	2.22	-10.53	0.56	1.41	-2.13	-0.34**	-6.87**	-2.98	-2.38	-0.0126	-0.0785**	-0.1134**	-0.1478**	-0.0752**
$\bar{X}$	114.00	107.90	21.66	21.46	5.33	1.39	164.00	7.48	4.30	0.0760	0.1700	0.0700	0.0760	0.1033
L_{12}× T_3	2.00	-4.24	-1.07	3.14	3.56*	0.54**	1.48	8.12**	4.62**	0.0717**	0.1690**	0.2179**	0.3101**	0.0995**
$\bar{X}$	113.30	112.23	19.00	22.34	11.00	2.29	173.30	19.10	11.91	0.1560	0.3630	0.4500	0.5500	0.2667
L_{12}× T_4	-3.08	5.35	0.98	-2.62	1.73	-0.53**	-1.29	1.29	2.67	0.0412**	0.0778**	0.1760**	0.1391**	0.0687**
$\bar{X}$	107.30	126.23	22.00	16.70	9.33	1.10	171.60	12.84	10.24	0.1260	0.3230	0.4000	0.3660	0.2400
L_{12}× T_5	-0.22	-4.30	0.67	0.75	-2.24	0.30**	5.90**	-4.06*	-2.66	-0.0585**	-0.0757**	-0.1583**	-0.1686**	0.0017
$\bar{X}$	111.00	118.13	21.00	20.43	6.00	2.10	179.00	8.20	5.75	0.0330	0.1460	0.0530	0.0490	0.1833
SE (SCA Line× Tester)	2.93	4.46	1.36	1.86	0.99	0.017	1.32	1.33	1.20	0.0108	0.0203	0.0138	0.0141	0.0153
SED (SCA Line× Tester)	4.15	6.31	1.93	2.63	1.39	0.025	1.86	1.87	1.70	0.0153	0.0286	0.0195	0.0199	0.0216

Where; * $p < 0.05$; ** = $p < 0.01$, respectively.

Where X_1= Days to flowering (50%), X_2= Plant height (cm), X_3= No. of leaves/plant, X_4= Pedicel length, X_5= No. of capsule/plant, X_6= Capsule index, X_7= Days to maturity, X_8= Seed yield, X_9= Dry husk capsule, X_{10}= Morphine, X_{11}= Codeine, X_{12}= Thebaine, X_{13}= Papervine, X_{14}= Nosacapine

Table 5: Estimates of genetic components of variance in (12×5) Line× Tester crosses for fourteen characters in Opium poppy.

Variance Components	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
$\hat{\sigma}^2_{A\,(F=0)}$	1.468	1.602	0.0301	0.353	0.0106	0.0026	0.1449	0.225	0.1578	0.0000055	0.0000062	0.00033	0.000045	0.000092
$\hat{\sigma}^2_{A\,(F=1)}$	0.734	0.801	0.0151	0.177	0.0053	0.0013	0.0725	0.113	0.0789	0.0000027	0.0000031	0.000163	0.000022	0.000046
$\hat{\sigma}^2_{D\,(F=0)}$	69.054	171.19	6.333	13.224	7.2443	0.3760	53.738	25.439	9.8548	0.0033724	0.02204	0.02539	0.02795	0.01478

$\hat{\sigma}^2_{D\ (F=1)}$	17.263	42.798	1.583	3.306	1.8111	0.0940	13.435	6.359	2.4637	0.0008431	0.00551	0.00635	0.006989	0.00369
$\hat{\sigma}^2_g$	0.367	0.401	0.0075	0.088	0.0026	0.00064	0.0362	0.0563	0.0394	0.0000014	0.0000016	0.000082	0.000011	0.000023
$\hat{\sigma}^2_S = \hat{\sigma}^2_D$	17.263	42.798	1.583	3.306	1.8112	0.0940	13.435	6.359	2.4637	0.0008431	0.005511	0.00635	0.006989	0.003695
$\hat{\sigma}^2_g / \hat{\sigma}^2_S$	0.0213	0.0094	0.0047	0.0266	0.0014	0.0068	0.0027	0.0089	0.0159	0.001661	0.00029	0.0129	0.00157	0.00622
$\sqrt{(\hat{\sigma}^2_S)/(\hat{\sigma}^2_g)}$	6.858	10.331	14.528	6.129	26.393	12.119	19.265	10.628	7.908	24.540	58.689	8.799	25.206	12.675

Where, X_1= Days to 50% flowering; X_2= Plant height (cm); X_3= Number of leaves/plant; X_4= Pedicel length; X_5= No. of capsule; X_6= Capsule index; X_7= Days to maturity; X_8= Seed yield; X_9= Dry husk capsule; X_{10} = Morphine; X_{11}= Codeine; X_{12} = Thebaine; X_{13} = Papervine; X_{14} = Nosacapine

$\hat{\sigma}^2_A$ = Additive variance, $\hat{\sigma}^2_D$ = Dominant variance, $\hat{\sigma}^2_g$ = g.c.a. variance, $\hat{\sigma}^2_S = \hat{\sigma}^2_D$ = s.c.a. variance

Table 6: Proportional contribution of Lines, Testers and Line× Testers

Genetic components	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
Fessssmales (L)	44.676	29.919	24.135	42.278	18.463	30.088	24.698	30.174	30.476	27.3329	11.2359	38.121	25.514	9.1336
Males (T)	0.955	6.193	5.319	2.142	5.057	6.572	5.115	6.714	10.537	0.7856	14.6991	5.688	2.8205	2.7564
Females× Males (L× T)	54.368	63.888	70.545	55.581	76.479	63.340	70.187	63.112	58.988	71.8814	74.0649	56.191	71.666	88.110
Cov. H.S. (Lines)	11.831	10.951	0.254	2.766	0.0191	0.0169	1.237	1.4820	0.8338	0.0001	-0.00047	0.00224	0.00061	0.00046
Cov. H.S. (Testers)	4.929	4.563	0.106	1.153	0.0079	0.00708	0.515	0.6175	0.3474	0.00004	-0.00019	0.00093	0.00025	0.00019
Cov. H.S. (Average)	0.367	0.401	0.0075	0.088	0.0026	0.00064	0.036	0.0563	0.0394	0.0000014	0.0000016	0.000082	0.000011	0.000023
Cov. F.S.	28.680	60.965	1.783	6.292	1.5361	0.12440	14.359	9.0840	4.966	0.000723	0.007064	0.01003	0.006605	0.002154
Heritability ^h2% $_{(ns)}$	1.68	0.78	0.209	1.27	0.112	1.328	0.387	0.958	1.147	0.229	0.0463	2.306	0.293	1.059
Genetic Gain (%) over mean	90.40	96.03	2.42	27.5	0.672	0.0044	4.19	10.54	10.34	0.00017	0.00018	0.00312	0.00037	0.00148

Where, X_1= Days to 50% flowering; X_2= Plant height (cm); X_3= Number of leaves/plant; X_4= Pedicel length; X_5= No. of capsule; X_6= Capsule index; X_7= Days to maturity; X_8= Seed yield; X_9= Dry husk capsule; X_{10} = Morphine; X_{11}= Codeine; X_{12} = Thebaine; X_{13} = Papervine; X_{14} = Nosacapine

Table 7: Combining ability pattern among the best selected hybrids for the fourteen characters in the *Papaver somniferum* L.

Characters	**Hybrids**	**g.c.a. of parents**	**s.c.a**	**Mean ($\bar{x}$)**	$\hat{\sigma}_g^2 / \hat{\sigma}_s^2$	**Genetics /genes (control)**	**Heritability (^h2)%**	**Genetic advance (GA %) over mean**
Days to flowering (50%)	$L_1 \times T_1$	High × high	Low	Low	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	High
Plant height (cm)	$L_3 \times T_3$	High × high	Low	Low	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	High
No. of leaves/plant	$L_4 \times T_4$	High × high	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	Low
Pedicel length	$L_2 \times T_3$	High × low	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	High
No. of capsule/plant	$L_{12} \times T_3$	High × low	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	Low
Capsule index	$L_{12} \times T_3$	High × high	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	Low
Days to maturity	$L_9 \times T_3$	High × low	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	Low
Seed yield	$L_{12} \times T_3$	High × low	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	Low
Dry husk capsule	$L_{12} \times T_3$	High × low	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	Low
Morphine	$L_{12} \times T_3$	High × low	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	Low
Codeine	$L_7 \times T_4$	High × high	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	Low

Thebaine	$L_{12}\times T_3$	High × high	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	Low
Papervine	$L_{12}\times T_3$	High × high	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	Low
Nosacapine	$L_{12}\times T_3$	High × low	High	High	$\hat{\sigma}_g^2 < \hat{\sigma}_s^2$	Non-additive	Low	Low

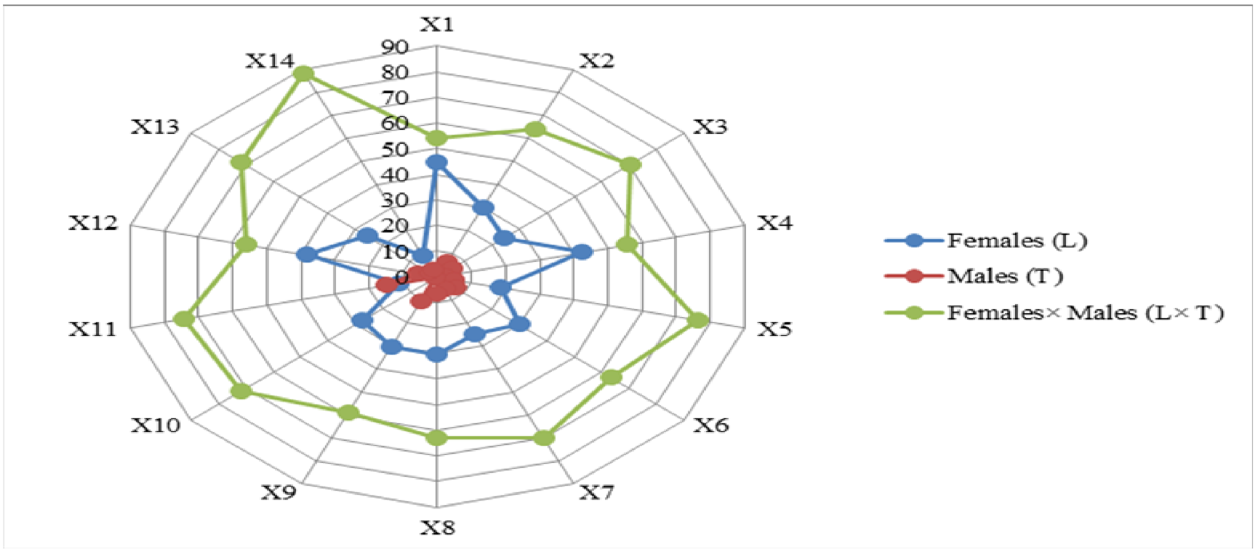

Fig. 1: Graphical representation for proportional contribution of Lines, Testers and Line× Testers

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