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# Combining ability of opium poppy genotypes over $F_1$ and $F_2$ generations of 8x8 diallel cross

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**ABSTRACT** - *Combining abilities for yield, its component traits and morphine content were examined in opium poppy to understand the inheritance pattern of these traits, and to identify genotypes suitable for genetic improvement of yield and morphine content. The experiment comprising a total of 64 treatments (28 $F_1$+28 $F_2$ and 8 parents) was evaluated in RBD. The results showed that most of the traits are governed by non additive gene action however additive gene action is also important. The parents BR-232, BR-245, BR-234 were found to be good general combiners for yield and its related traits and can be utilized in multiple breeding programs. SCA effects in relation to GCA effects of parents showed that most of the cross combinations with high SCA effects involved high x high, high x low and low x low GCA combiners.*

**Key words**: Diallel analysis, combining ability, correlation, morphine, *Papaver somniferum*.

## INTRODUCTION

Opium poppy (*Papaver somniferum* L.) is one of the most important crop plants for pharmaceutical industries and is the chief source of commercial opium. Opium is one of the oldest known pain killers and is the source of many alkaloids which includes narcotic and analgesic morphine and codeine, the mild analgesic and sedative thebaine, the antitussive and apoptosis inducer noscapine or narcotine and the vasodilator papaverine. Morphine is the major alkaloid present in opium ranging from 7-17% followed by narcotine (3.0 – 10.0%) (Shukla et al. 1995, Shukla et al. 2006, Yadav et al. 2006). Other alkaloids are found in fewer amounts in opium latex such as codeine 2.1-4.4%, thebaine 1.0-3.0% and papaverine 0.5-3.0%. Thebaine is also used in the production of semisynthetic opioid morphine analogous such as oxycodone (Percodan), dihydromorphenone (Dilaudid) and hydrocodone (Vicodin). Thus opium poppy serves as one of the most important renewable resource for pharmaceutical alkaloids. In addition, poppy seeds with no narcotic effect are highly valuable due to high nutritive value having protein up to 24% and high amounts of linoleic acid (up to 68%) in seed oil, which helps in lowering the blood cholesterol in the human system (Singh et al. 1990, 1995a). The oil cake with a high percentage of digestible protein (32.5%) is used as a concentrate in feeding pigs and other animals reared for meat (Verma et al. 1999, Pushpangadan and Singh 2001). Among the opium producing countries, India is one of the largest producers of licit opium, which meets the national and international demand. In recent years the global trends show that the consumption of opium alkaloids and its derivatives are growing. Morphine, which is the main and narcotic component of opium, showed a tenfold demand in the last two decades. Despite the important role of this crop in the

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Indian economy, a high yielding variety for high latex (opium) and seed yield with specific alkaloids has not been developed. 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). The success of any crop improvement program depends mainly on a judicious selection of promising parents from gene pools, a clear cut understanding of genetic mechanisms involved in the inheritance of characteristics which help the breeders in deciding the most appropriate breeding procedure to enhance the genetic potentialities. It is also desirable that selection of suitable parents for hybridization is based on the ability of a particular line to combine with other lines and produce desirable segregants/recombinants. Diallel analysis provides a systematic approach for the identification of appropriate parents and crosses superior to the traits investigated so far.

The combining ability analysis is an important tool for the selection of desirable parents together with information regarding nature and magnitude of controlling quantitative traits. The term general combining ability (GCA) is associated with genes of additive effects, used to designate the average performance of a line in hybrid combinations and specific combining ability (SCA) caused by dominance and epistasis, to define those cases in which certain combinations do relatively better or worse than expected on the basis of the average performance of the lines involved. The diallel analysis is an efficient method for the study of combining ability and gene action involved in the inheritance of traits. It also helps breeders to choose and devise the most efficient selection method by allowing them to estimate several genetic parameters (Verhalen and Murray 1967). In context of gene expression at molecular level Kiekens et al. (2006) and Vuylsteke and Eeuwijk (2008) have shown that estimates of GCA and SCA generated by a diallel design are valid parameters in large-scale detection of transcripts whose abundance is regulated by strong *cis*-acting variants.

Realizing the importance of the crop, the present investigation was under taken with the objectives to estimate the general and specific combining ability variances and their gca effects and to determine the gene actions involved in the inheritance of different quantitative traits.

## MATERIAL AND METHODS

### Material

The materials used for the present study was comprised of 8 genotypes selected from the opium poppy advanced breeding lines based on their genetic diversity earlier studied by Singh et al (2004a). The details of genotypes and their pedigree are presented in Table 1. These genotypes were used to obtain 28 hybrid combinations according to a diallel crossing scheme (excluding reciprocals). The hybrid $F_1$ seeds were obtained by manual pollination and were sown during crop season 2003-2004 to get the $F_1$ population. The $F_1$ plants were selfed to obtain $F_{2S}$ seeds to raise the $F_2$ generation the following year. Fresh crosses among parents were also made to produce hybrid seeds for raising $F_1$ the following year. The final trial comprising of 28 $F_{1S}$, 28 $F_{2S}$ and 8 parents (64 treatments) was conducted during the 2005-2006 crop season.

### Experimental Site

The experiment for the present investigation was carried out at the experimental plot of Genetics and Plant Breeding Division at the National Botanical Research Institute, Lucknow, which is situated between 26° 40´ N latitude and 80° 45´ E longitude and an altitude of 129 m asl. The average rainfall during the crop period

**Table 1**. Pedigree details and some diagnostic features of the parents used in the 8x8 diallel analysis in opium poppy

| Sl No | Parents | Pedigree | Diagnostic features |
|---|---|---|---|
| 1 | BR-235 | Big Cap x NBRI-6 | Early flowering, medium height, low yielder |
| 2 | BR-236 | IS-24 x NBRI-6 | Early flowering, medium height, good opium and seed yield |
| 3 | BR-233 | IS-19 x GZ | Late maturing, tall, high yielder |
| 4 | BR-232 | IS-7 x GZ | Early flowering, short height, low yield, average morphine |
| 5 | BR-245 | IS-10 x IS-7 | Tall, high seed and opium yield, high morphine |
| 6 | BR-242 | IS-23 x GZ-B | Medium height, stout stature, average yield, high morphine |
| 7 | BR-234 | IS-15 x NBRI-6 | Early maturing, tall, average yield |
| 8 | BR-237 | IS-16 x GZ | Average height, high seed yield, low morphine |

(November – April) ranged from 3.8mm to 21.9mm and the average day/night temperature varied between 22-38.0 °C and 4.1-20.5 °C respectively.

### Experimental Design

The experiment for the present investigation was carried out during crop years 2005-06 in a randomized block design with 3 replications. Five rows/treatment/replication with a spacing of 25 cm between rows and 10 cm between plants were adopted. The rows were 3 meter long. Standard cultural practices were followed throughout the crop season which included pre sowing farmyard manure at the rate of 10 t $ha^{-1}$, 5-6 t $ha^{-1}$ neem cake and 30, 50, 40 kg $ha^{-1}$ N, P, and K respectively as basal dressing. Sixty kg $ha^{-1}$ N in two split after 30 and 60 days after sowing as a top dressing and a spray of the fungicide diethelene biscarbamate (Dithane M-45 0.2%) at 45 and 60 days after sowing was applied to the crop. The field was irrigated as and when required. Ten plants in $F_1$ and twenty in $F_2$ (randomly selected) per treatment per replication were tagged before flowering to record the detail morphometric observations. Opium samples were collected from fully-grown green capsules of tagged plants/replications. Four successive lancings were done at the interval of 3-4 days. The opium obtained from each lancing was pooled and kept for air drying. The morphine content (%) in the opium sample was estimated following Pride and Stern (1954).

### Statistical Analysis

The data of various traits were compiled and mean values of the replicated data were used for statistical analysis using WINDOSTAT software. The mean data of each replication were tested for significance by the method of analysis of variance suggested by Panse and Sukhatme (1967). The breeding values of the parental lines have been evaluated by analyzing the combining ability estimates according to Griffing (1956) for both $F_1$ and $F_2$ generations.

## RESULTS AND DISCUSSION

The analysis of variance for the experiment showed significant differences among the treatments (parents, $F_1$s and $F_2$s) for all the traits studied indicating the presence of substantial genetic variability. However, a non significant difference among $F_{1S}$ vs $F_{2S}$ was observed which showed that there was a low degree of inbreeding depression in the $F_2$ population for the traits studied. Analysis of variance for general and specific combining ability was carried out to ascertain the nature and magnitude of gene actions involved in the inheritance of different traits. The estimates of variance showed that the mean square due to GCA and SCA were highly significant in both $F_1$ and $F_2$ generations for all the traits (Table 2). Similar results were also noticed by Valério et al (2009) in the case of wheat. This indicated that parents and crosses differ significantly in both generations. The significant differences of GCA and SCA variances exhibited the importance of both additive and non-additive gene actions for all the characteristics though the relative magnitude of variances differed. The estimates of components of combining ability variances viz. $\sigma^2 g$ (general combining ability) and $\sigma^2 s$ (specific combing ability) were obtained for all the traits. A ratio of 1:1

**Table 2.** Estimates of variance componets for general combining ability (GCA) and specific combining ability (SCA) for different quantitative traits in opium poppy

| Source | Generations | GCA | SCA | Error | GCA/SCA | $\sigma^2 g$ | $\sigma^2 s$ | $\sigma^2 g/\sigma^2 s$ | $(\sigma^2 s/\sigma^2 g)^{0.5}$ |
|---|---|---|---|---|---|---|---|---|---|
| df | - | 7 | 28 | 70 | - | - | - | - | - |
| Days to 50% Flowering | $F_1$ $F_2$ | 11.68** 8.21** | 6.61** 8.56** | 0.27 0.84 | 1.76 0.96 | 0.50 0.04 | 6.33 7.73 | 0.08 0.01 | 3.56 13.90 |
| Plant height | $F_1$ $F_2$ | 91.34** 101.52** | 37.82** 48.79** | 2.99 2.28 | 2.41 2.08 | 5.35 5.28 | 34.82 46.51 | 0.15 0.11 | 2.55 2.97 |
| Leaves $plant^{-1}$ | $F_1$ $F_2$ | 2.66** 1.56** | 1.82** 1.02** | 0.15 0.14 | 1.46 1.53 | 0.08 0.05 | 1.66 0.88 | 0.05 0.06 | 4.56 4.20 |
| Capsule $plant^{-1}$ | $F_1$ $F_2$ | 0.35** 0.04** | 0.18** 0.14** | 0.03 0.04 | 1.94 0.28 | 0.02 0.01 | 0.16 0.01 | 0.13 1.00 | 2.83 1.00 |
| Capsule size | $F_1$ $F_2$ | 2.44** 4.03** | 1.37** 1.23** | 0.06 0.12 | 1.78 3.27 | 0.11 0.28 | 1.31 1.08 | 0.08 0.26 | 3.45 1.96 |
| Capsule weight | $F_1$ $F_2$ | 5.61** 3.45** | 3.44** 3.22** | 0.12 0.17 | 1.63 1.07 | 0.22 0.02 | 3.33 3.05 | 0.07 0.01 | 3.89 12.35 |
| Seed yield | $F_1$ $F_2$ | 3.05** 1.38** | 1.96** 1.25** | 0.08 0.13 | 1.56 1.10 | 0.11 0.01 | 1.88 1.12 | 0.06 0.01 | 4.13 10.58 |
| Opium yield | $F_1$ $F_2$ | 2028.54** 11937.76** | 818.61** 676.67** | 22.97 29.21 | 2.47 17.64 | 120.99 51.71 | 795.64 647.46 | 0.15 0.08 | 2.56 3.54 |
| Morphine | $F_1$ $F_2$ | 4.61** 4.20** | 2.40** 1.58** | 0.20 0.18 | 1.90 2.60 | 0.22 0.26 | 2.19 1.40 | 0.10 0.19 | 3.16 2.32 |

df = degree of freedom; *, ** significance at 5% and 1% respectively indicated that both estimates of $\sigma^2g$ and $\sigma^2s$ were of equal importance for the expression of the particular trait, whereas any deviation from 1:1 ratio indicated the relative importance of any one of these two components. The value of degree of dominance expressed as $(\sigma^2s/\sigma^2g)^{1/2}$ indicated complete dominance when it was unity, whereas the value above and below unity indicated over dominance and partial dominance respectively. The higher magnitude of $\sigma^2s$ than $\sigma^2g$ indicated preponderance of non-additive gene action for all the traits and the ratio of $\sigma^2g/\sigma^2s$ were also low and the average degree of dominance more than unity showed over dominance, which confirmed the above findings. Similar findings were also reported by Singh et al. (1995b, 2001) for capsules plant$^{-1}$, capsule weight plant$^{-1}$, leaves plant$^{-1}$, opium yield plant$^{-1}$ and seed yield plant$^{-1}$. But contrary to this additive genetic variance reported per day at 50% flowering (Kandalkar and Nigam 1993), and capsule weight plant$^{-1}$, opium yield plant$^{-1}$, capsules plant$^{-1}$ and seed yield plant$^{-1}$ (Singh et al. 2004b). The discrepancies in the results on the nature of gene action reported by different workers might be due to differences in parental diversity in the material, size of the population, design adopted and environmental conditions in which the experiment was conducted. In the present investigation, all the traits showed over-dominance except the capsules plant$^{-1}$ in $F_2$ generation, where a complete dominance was operating. Over dominance has also been reported by Singh et al. (1995b, 2001), for plant height, capsules plant$^{-1}$, capsule weight plant$^{-1}$, opium yield plant$^{-1}$ and seed yield plant$^{-1}$ and partial dominance were reported for capsules plant$^{-1}$, capsule weight plant$^{-1}$, seed yield plant$^{-1}$ and opium yield plant$^{-1}$ (Singh et al. 2004b).

## General Combining Ability Effects

A basic requirement in any effective hybridization programme is to identify superior genotypes which could excel in their combining ability. General combining ability effects have successfully been used in making the choice of the parents and also for the isolation of the germplasm base for further improvement. This information on yield and other agronomic traits is important and could greatly help in the proper classification of parental lines. The estimated GCA effects associated with each parents ($\hat{g}i$) are shown in table 3. The high value of $\hat{g}i$ is due to the fact that in the cross combinations one parent is much better or worse

**Table 3.** Estimates of general combining ability (GCA) effects for different quantitative traits in opium poppy (*Papaver somniferum* L.)

| Traits | Generations | Parents | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BR-235 | BR-236 | BR-233 | BR-232 | BR-245 | BR-242 | BR-234 | BR-237 | S.E.(gi.) | r |
| Days to 50% Flowering | $F_1$ $F_2$ | -0.03- 0.67* | 0.56** 0.91** | 1.77** 1.48** | -1.08** -0.76* | 0.91** 0.51 | 0.09 0.14 | -1.45** -0.55* | -0.78 -1.05** | 0.15 0.27 | 0.68** 0.60** |
| Plant height | $F_1$ $F_2$ | -0.72 2.27** | -0.66** 0.51 | 3.67** 0.58 | -4.13** -4.92** | 1.52** 2.52** | -0.38 -0.20 | 4.47** 3.76** | -2.76** -4.52** | 0.51 0.44 | 0.87** 0.58** |
| Leaves plant$^{-1}$ | $F_1$ $F_2$ | 0.19 0.08 | -0.22 0.04 | 0.30* -0.04 | -0.80** -0.37** | 0.49** 0.06 | 0.03 0.45** | -0.64** -0.71** | 0.63** 0.47** | 0.11 0.10 | 0.73** 0.91** |
| Capsule plant$^{-1}$ | $F_1$ $F_2$ | 0.06 0.04 | 0.14** -0.00 | 0.28** 0.09 | -0.09 -0.01 | 0.03 -0.07 | 0.08 0.08 | -0.22** -0.08 | -0.28** 0.04 | 0.05 0.05 | 0.44* 0.65** |
| Capsule size | $F_1$ $F_2$ | -0.79** -0.82** | 0.27** 0.60** | -0.67** -0.86** | 0.33** 0.042 | 0.25** 0.27* | -0.12 -0.01 | 0.61** 0.96** | 0.12 -0.19 | 0.07 0.10 | 0.92** 0.94** |
| Capsule weight | $F_1$ $F_2$ | -0.51** 0.17 | -0.47** -0.63* | 0.52** 0.65** | -0.54** -0.93** | -0.86** 0.36** | 0.12 0.19 | 1.29** 0.61** | 0.67** -0.41** | 0.10 0.12 | 0.86** 0.45* |
| Seed yield | $F_1$ $F_2$ | -0.36** 0.06 | 0.16 -0.34** | 0.43** 0.27* | -0.77** -0.74** | -0.48** 0.29** | -0.04 0.13 | 0.79** 0.35** | 0.59** -0.03 | 0.09 0.10 | 0.86** 0.68** |
| Opium yield | $F_1$ $F_2$ | -14.92** -15.16** | 0.38 3.06 | 14.91** 6.85** | -2.92* -8.87** | 20.87** 19.14** | 10.51** -8.19** | -15.82** -2.41 | -13.02** 5.58** | 1.42 1.59 | 0.74** 0.76** |
| Morphine | $F_1$ $F_2$ | -0.46** 0.09 | -0.85** -1.29** | 0.22- 0.32** | 0.17 0.95** | 0.97** 0.44** | 0.79** 0.21 | -0.07 -0.12 | -0.79** 0.04 | 0.13 0.12 | 0.94** 0.39 |

SE= Standard Error; r= correlation coefficient; *, ** significance at 5% &1% respectively than the other. While considering the gca effect of the parents, it was noticed that none of the parents were found to be good general combiners for all the traits. Out of 8 parents; 2 each for days to 50% flowering and plant height, 1 for leaves/plant, 4 for capsule size, 2 each for capsule weight/plant, seed yield/plant and opium yield and 1 for morphine content exhibited significant GCA in a desirable direction in both generations. The BR-234, BR-232 and BR-237 parents were found to be good general combiners for early flowering. Likewise the BR-232, BR-237 and BR242 parents were found good combiners for short stature plants which is considered a desirable trait of opium poppy. The parents BR-245, BR-237 for leaves plant$^{-1}$, BR-233, BR-236 for capsules plant$^{-1}$, BR-234, BR-245 and BR-232 for capsule size, BR-233, BR-234 both for capsule weight plant$^{-1}$ and seed yield plant$^{-1}$, BR-245, BR233 for opium yield plant$^{-1}$ and BR-245, BR-232 for morphine content were found to be good general combiners. The similarity in the estimate of the GCA effects in $F_1$ and $F_2$ generations indicated that the best combiners are stable in their performance over generations.

Correlations between *per se* performances of the parental genotypes and GCA effects for all the traits were found to be significant indicating that the performance *per se* can also be used to select good combining parents for these traits. In the present study the parent BR-232 for days to 50% flowering and plant height showed the significant negative GCA were early flowering and short stature in *per se* performance. High mean values as well as high positive GCA effects of parent BR-245 for morphine content and opium yield/ plant, BR-234 for capsule size, capsule weight/plant, and seed yield/plant, were recorded. The results obtained from the GCA effects and correlation coefficient suggests that for genetic improvement in seed and opium yield as well as for enhancing the morphine content with early maturing short stature genotypes the use of parents BR-232, BR-245, BR-234, in multiple breeding programs among them will promise the desired goal.

**Specific Combining Ability Effects**

The specific combing ability (SCA) effects estimated for all the traits are presented in table 4. SCA is the major component which is being utilized in the heterosis breeding program. The specific combining ability estimates reveals that out of 28 cross combinations 3 for days to 50% flowering, 4 each for plant height and leaves plant$^{-1}$, 5 for capsule size, 3 for capsule weight plant$^{-1}$, 4 for seed yield plant$^{-1}$, 8 for opium yield plant$^{-1}$ and 3 for morphine content were found significant in a desirable direction in both generations. By looking at the SCA effects of crosses in both the generation separately, it was found that the more number of crosses showing significant SCA effects in the $F_1$generation rather than their $F_2$ generation for all the traits except capsules plant$^{-1}$ where none of the crosses showed significant positive SCA effects in the $F_1$ generation in comparison to six in the $F_2$ generation. The results showed the possibilities of exploiting hybrid vigour for all the traits except capsules plant$^{-1}$. The best specific cross combination noticed in both generations for days to 50% flowering and plant height were BR-242 x BR-237 and BR-234 x BR-237. The crosses, BR-245 x BR-234, BR-235 x BR-236 showed a high SCA effect for leaves plant$^{-1}$. Good specific combiners for capsules plant$^{-1}$ were BR-232 x BR-234 and BR-235 x BR-236. Crosses BR-236 x BR-233, BR-236 x BR-232, BR-232 x BR-245 were found with high SCA effects for capsule size. BR-233 x BR-234, BR-236 x BR-232, BR-235 x BR-245 showed high SCA for capsule weight plant$^{-1}$. The best specific cross combinations for seed yield plant$^{-1}$ were BR-236 x BR-232, BR-233 x BR-234, and BR-235 x BR-245. For opium yield the crosses BR-245 x BR-242, BR-236 x BR-233, BR-242 x BR-234 and BR-235 x BR-232 showed highly significant and positive SCA effects. BR-232 x B-245, BR-234 x BR-237 and BR-232 x BR-234 exhibited high SCA effects for morphine content. SCA effects in relation to GCA effects of parents showed that most of the cross combinations with high SCA effects involved high x high, high x low and low x low GCA combiners. For example the cross combination BR-245 x BR-242 for opium yield, BR-232 x BR-245 for morphine content involved high x high and BR-236 x BR-232 for seed yield involved low x low combiners. But in most of the cases there was involvement of at least one parent with a high GCA effect. The cross combinations involving high x high combiners indicated the additive x additive gene interaction between favourable alleles contributed by two parents which are considered to be fixable in nature. *Inter-se* crossing in all possible combinations and selections

**Table 4**. Estimates of specific combining ability (SCA) effects for different quantitative traits in opium poppy (*Papaver somniferum* L.) of 28 $F_1$ and $F_2$ crosses

| Sl.No | Crosses | Days to 50% flowering | | Plant height | | Leaves plant$^{-1}$ | | Capsules plant$^{-1}$ | | Capsule size | | Capsule weight plant$^{-1}$ | | Seed yield plant$^{-1}$ | | Opium yield plant$^{-1}$ | | Morphine | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ | $F_1$ | $F_2$ |
| 1 | BR-235 x BR-236 | -0.45 | -2.78** | -0.46 | 1.59 | 1.38** | 0.74* | 0.39 | 0.31 | -0.01 | -0.30 | 0.49 | -0.64 | 0.25 | -0.54 | 11.44* | 3.08 | 1.66** | 0.38 |
| 2 | BR-235 x BR-233 | -0.80 | -4.19** | 11.75** | 9.96** | 0.12 | 0.83* | 0.41 | -0.05 | 0.03 | 0.22 | 0.17 | 0.49 | 0.54* | 0.91** | -8.09 | 0.07 | 2.23** | -0.35 |
| 3 | BR-235 x BR-232 | 0.95 | 1.39 | 2.98 | -1.53 | 1.87** | -0.06 | 0.26 | -0.28 | 0.93** | 0.65 | -2.10** | 0.87* | -1.75** | 0.66* | 18.41** | 24.33** | -0.89* | 1.41** |
| 4 | BR-235 x BR-245 | -0.27 | -0.89 | -2.66 | 2.47 | 0.77 | 0.17 | 0.07 | -0.02 | 0.26 | 0.34 | 2.78** | 1.31** | 2.45** | 1.03** | 1.61 | -4.42 | 0.27 | -0.46 |
| 5 | BR-235 x BR-242 | -1.11 | -2.28* | 0.81 | 4.08** | -0.58 | -0.66 | 0.52 | 0.26 | -0.11 | 0.81* | 1.36** | 0.60 | 0.57* | 0.26 | -10.69* | -5.09 | 0.26 | 0.84* |
| 6 | BR-235 x BR-234 | 1.59 | 4.17** | 3.95* | -6.21** | 1.34** | -0.28 | 0.09 | 0.09 | 0.39 | 0.10 | 0.15 | -0.74 | -0.56* | -0.63 | 4.98 | 6.13 | -0.51 | 0.56 |
| 7 | BR-235 x BR-237 | 2.42 | 5.00** | -2.47 | 6.41** | 0.15 | 1.19** | -0.23 | 0.45* | 0.68** | 1.26** | -0.15 | 3.75** | -0.45 | 1.95** | 8.84* | 11.47* | -0.79 | -1.11** |
| 8 | BR-236 x BR-233 | 0.44 | -1.06 | -2.41 | 5.73** | -1.61** | 0.10 | -0.22 | 0.66** | 1.68** | 1.10** | -2.28** | 1.55** | -1.58** | 1.05** | 28.28** | 38.63** | 1.37** | 0.73 |
| 9 | BR-236 x BR-232 | 1.70 | -0.09 | 9.95** | 7.13** | 1.32** | 0.42 | 0.13 | -0.03 | 1.96** | 1.46** | 3.11** | 1.93** | 2.46** | 1.59** | 9.11* | 1.03 | 1.62** | -0.61 |
| 10 | BR-236 x BR-245 | 2.41 | 1.03 | 0.74 | -2.76 | 0.74 | 0.88* | -0.07 | -0.33 | 0.43 | -0.40 | -3.32** | -0.16 | -2.24** | 0.03 | -28.69** | 7.28 | -0.54 | -0.49 |
| 11 | BR-236 x BR-242 | -0.59 | 2.14* | 3.53** | -0.70 | 1.05** | -0.84* | -0.13 | -0.29 | -0.51* | 1.29** | 0.27 | 1.13** | 0.47 | 0.93** | 46.01** | -33.66** | -1.34** | 0.66 |
| 12 | BR-236 x BR-234 | -0.09 | 2.19* | -0.66 | 5.66** | -0.24 | -0.35 | 0.68 | -0.35 | -0.12 | 0.26 | -0.86** | -2.54** | -1.45** | -1.09** | -22.99** | 5.57 | 0.13 | -0.29 |
| 13 | BR-236 x BR-237 | 1.26 | 3.18** | 0.13 | -6.27** | -1.17** | -1.21** | 0.29 | -0.17 | -0.33 | 0.07 | 2.76** | -1.46** | 2.18** | -1.71** | -28.79** | 13.23** | -0.07 | -0.19 |
| 14 | BR-233 x BR-232 | -0.65 | 1.23 | 1.39 | -14.95** | 0.49 | 1.03** | 0.40 | -0.71** | -0.85** | -2.42** | -1.55** | -1.74** | -0.55 | -0.88 | -23.01** | -11.42* | 1.15** | -1.18** |
| 15 | BR-233 x BR-245 | 1.59 | -1.45 | -4.15** | -5.62** | 0.90 | -3.33** | 0.53 | 0.08 | -0.00 | 0.49 | 2.85** | 0.29 | 1.83** | -0.18 | 38.44** | 7.89 | -1.84** | -0.49 |
| 16 | BR-233 x BR-242 | -0.08 | 1.33 | 1.20 | -0.89 | 1.28** | 0.69 | 0.17 | -0.01 | 0.78** | 1.50** | -0.25 | 1.19** | -0.80 | 0.45 | -16.86** | -20.11** | 0.76 | -1.23** |
| 17 | BR-233 x BR-234 | -3.75 | -0.98 | -3.87* | -1.30 | 1.16** | 0.26 | -0.25 | -0.17 | 0.36 | 0.24 | 2.45** | 2.45** | 1.81** | 1.49** | 10.14* | 10.58* | -0.47 | 0.94 |
| 18 | BR-233 x BR-237 | 2.25 | 2.01* | 4.68** | -5.79** | 1.56** | 0.20 | 0.17 | -0.06 | 1.14** | 0.27 | -0.36 | -2.46** | -0.51 | -1.85** | 23.68** | 4.65 | 0.65 | 0.74 |
| 19 | BR-232 x BR-245 | -2.71 | 0.31 | -3.02 | -1.43 | -0.61 | 0.18 | -0.19 | -0.09 | 1.80** | 0.79** | -0.98** | -1.19** | -1.30** | -0.83 | 37.61** | 3.62 | 2.44** | 1.29** |
| 20 | BR-232 x BR-242 | 1.21 | 0.35 | -2.77 | 1.17 | -0.89* | -0.87** | 0.27 | 0.34 | -0.33 | 0.44 | 2.02** | -0.09 | 1.27** | 0.33 | 16.31** | 27.48** | 0.68 | 0.35 |
| 21 | BR-232 x BR-234 | -1.48 | -0.06 | 10.37** | 16.87** | -0.91* | -0.22 | 0.39 | 0.99** | 0.26 | 0.62 | -0.89** | 0.29 | -0.23 | 0.50 | 0.98 | 23.98** | 1.08** | 0.88* |
| 22 | BR-232 x BR-237 | 2.11 | -0.10 | -1.06 | -1.72 | -0.18 | -0.35 | -0.53 | 0.13 | 0.48 | 0.59 | 2.52** | 0.72 | 1.04** | 0.56 | 29.84** | 6.35 | -0.75 | 3.12** |
| 23 | BR-245 x BR-242 | -4.93 | -0.59 | 3.90 | 9.28** | -0.06 | 1.37** | 0.57 | 0.24 | 1.48** | 0.14 | -1.76** | 3.61** | -1.62** | 1.09** | 45.84** | 30.27** | 1.31** | -0.26 |
| 24 | BR-245 x BR-234 | 3.02 | -0.01 | 12.71 | -0.01 | 1.84** | 1.64** | 0.02 | -0.13 | 0.15 | 1.43** | 0.46 | 0.07 | 0.12 | 0.07 | 10.51* | 10.83 | 0.88 | -0.67 |
| 25 | BR-245 x BR-237 | -1.08 | -0.75 | 2.49 | 2.94 | 0.66 | -1.11** | -0.21 | -0.11 | -0.53* | -0.06 | -0.88** | 0.36 | -1.23** | 0.79 | -14.62** | 38.33** | 1.54** | -0.19 |
| 26 | BR-242 x BR-234 | 2.31 | 0.03 | 3.62 | -1.96 | -0.08 | 0.02 | -0.58 | -0.10 | 0.45 | -0.33 | 2.16** | 0.36 | 1.94** | 0.50 | 28.88** | 27.76** | 0.56 | -2.56** |
| 27 | BR-242 x BR-237 | -5.36 | -8.64** | -2.30** | -6.78** | 0.99** | 1.01** | -0.48 | -0.82** | 1.32** | -1.24** | -0.71* | -2.22** | -1.11** | -1.31** | -0.59 | 17.49** | 1.11** | 0.03 |
| 28 | BR-234 x BR-237 | -4.96 | -4.45** | -6.55** | -5.41** | 0.61 | -0.35 | 0.17 | 0.08 | 0.08 | -0.29 | -0.89** | 0.18 | 0.15 | 0.06 | -4.26 | 7.05 | 1.84** | 1.26** |
| S.E. (sij) | | 0.47 | 0.83 | 1.56 | 1.37 | 0.36 | 0.34 | 0.6 | 0.17 | 0.22 | 0.32 | 0.31 | 0.37 | 0.26 | 0.32 | 4.35 | 4.90 | 0.41 | 0.39 |
| Correlation | | 0.88** | 0.90** | 0.81** | 0.88** | 0.85** | 0.89** | 0.88** | 0.98** | 0.77** | 0.75** | 0.89** | 0.92** | 0.90** | 0.91** | 0.84** | 0.80** | 0.81** | 0.84** |

*, ** significance at 5% &1% respectively

in advance generation is advocated to obtain better recombinants in such cases. The correlation coefficient between the mean performance of crosses (both $F_1$ and $F_2$) and SCA effects showed highly significant correlation between SCA effects and *per se* performance for all the traits suggesting selection of cross combination towards improvement of yield and yield related component traits which may also be carried out on the basis of *per se* performance.

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# Capacidade de combinação em genótipos de papoula em gerações $F_1$ e $F_2$ em esquema dialélico 8x8

**RESUMO** - *A capacidade de combinação de papoula foi avaliada em relação à produção e seus componentes, bem como ao conteúdo de morfina, a fim de entender o padrão da herança dessas características e para a identificação de genótipos adequados para o melhoramento genético do rendimento e teor de morfina. O experimento foi constituído de um total de 64 tratamentos (28 $F_1$ + 28 $F_2$ e 8 genitores) e avaliado no delineamento em blocos casualizados. Os resultados mostraram que a maioria das características é controlada pela ação gênica não aditiva, no entanto, a ação gênica aditiva também exerce um papel importante. Os parentais BR-232, BR-245, BR-234 foram considerados bons nas diversas combinações para produção e características relacionadas, e podem ser utilizados em diversos programas de melhoramento. Os efeitos CCE em relação aos CGC dos parentais mostraram que a maioria das combinações de cruzamentos com efeitos altos de CCE envolveu genitores com combinações de GCA alto x alto, alto x baixo e baixa x baixo.*

**Palavras-chave:** Dialelo, capacidade de combinação, correlação, morfina, *Papaver somniferum*.

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