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Original Article

Estimating General and Special Combining Abilities for Economic Traits in Turkish Hybrid Opium Poppy (*Papaver somniferum* L.) Lines.

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Abstract

Opium poppy (*Papaver somniferum* L.) is one of the important and oldest cultivated medicinal plant used to extract morphine, papaverine, thebaine, codeine and other alkaloids. This study aimed to determine general and specific combining abilities of F_1 hybrids obtained from various crosses and their parental lines for developing appropriate breeding material for future breeding programs. The results confirmed significant differences (p<1%) for GCA and SCA in the investigated characters of opium poppies. All characteristics showed positive correlation with capsule and seed yield general commbining abilities. Among the selected parents, Line 2010 had good GCA for morphine percentage & morphine yield and total alkaloids percentage. Rest of the varieties or lines did not show statistically different results in a good or bad term. It was concluded that the maximum SCA in terms of morphine percentage and morphine yield belonged to TMO-B×Ofis-8 and Line 2010×Ofis8 hybrids respectively. In terms of total alkaloids percentage N-207 × TMO-A hybrid had the highest specific combining ability.

Keywords: Alkaloids, Breeding, Inheritance, Morphine, *Papaver somniferum* L.

Introduction

Papaver somniferum L. is one of the most important medicinal plants that is cultivated since long period. Turkey has large a genetic resource, among which opium poppy has a special place. Opium poppy (*P. somniferum*) plants, has two major products; One of these is capsules and their alkaloids; the other is seed and the seed oil [1].

Because of high competitive strength among crops and these two important products, the plant is known as a national wealth. Morphine, codeine, thebaine, noscapine and papaverin are more abundantly found in the capsule of poppy that are evaluated for obtaining of medicinally important drugs and for commercial production of semi-synthetic active pharmaceutical raw materials [1]. Among the alkaloids, morphine, codeine and thebaine have drugs characteristics and those like noscapine and papaverine do not have significant commercial value. Morphine is the most abundant and commonly used alkaloid obtained from opium poppy capsuless used as anaelgesic. No anaelgesic has replaced morphine that is highly addictive [20]. Kidney-shaped opium poppy seeds contain 40-50% oil and 20 -30% protein at full maturity level [9]. Opium poppy seed is rich in unsaturated fatty acids especially linoleic acid, oleic acid, omega-6 and omega-9 fatty acids and vitamin E [19].

Although *P. somniferum* is self pollinated crop, yet depending on varietal characteristics of and environmental factors, foreign fertilization occurs at different rates that varies from 15-40% [13]. Besides increasing earliness and resistance to diseases with decreased oil and high morphine, noscapine, codeine and thebaine for the pharmaceutical industry; it is also important to breed for oil and look for the plants that have high resistance to diseases, high oil contents and

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decreased morphine noscapine, codeine and thebaine contents. In order to obtain highly efficient hybrids; It is imperative to develop inbred lines with high combining ability and identify appropriate combinations for specific purpose. Appropriate selection of putative parents from gene pools is one of the best ways to start breeding as this provides a good knowledge of genetic mechanisms involved in the inheritance of characteristics. It also guides the breeders in selecting the most exclusive breeding technique to enhance the genetic potential of the material to be used in the study [22]. On the other hand, selection of appropriate parents for hybridization is based on the ability of a particular line to combine with other lines; this leads to increase chance to produce desirable recombinants more efficiently [20].

The advantage of the diallel analysis is that it provides a systematic approach for determination of appropriate parents and crosses that are superior in investigated traits [23]. The diallel cross design is usually used to obtain information on genetic effects, estimates of general and specific combining abilities and to identify promising heterotic combinations as well as their heterotic patterns [15]. The commbining ability analysis helps in selection of desirable parents together with information pertaining to magnitude and nature of traits that control quantitative characteristics. The general combining ability (GCA) relates to genes having additive effects and are used to assign average efficiency of a line in hybrid combinations.

Specific combining ability (SCA) caused by epistasis and dominance could be defined in cases where, certain combinations perform relatively worse or better than expected on the basis of the average performance of the lines/cultivars used. The diallel analysis is a method for studying combining ability and involved gene action during inheritance of traits. It also helps to select most appropriate method to estimate variable genetic parameters [21].

Tiwari *et al*. [18], under took a study on combining ability of opium poppy using a total of 15 diverse, inbred lines of opium poppy and three testers were selected on the basis of seed and straw yields. They hybridized line × tester way to make an F1 hybrid (4 & 5). The mean sum of squares due to lines, testers and lines×testers were statistically significant for all studied characteristics. This suggested that the experimental material had sufficient genetic variability. Estimates of specific and GCA variances for all of the characteristics were also significant, indicating both additive and nonadditive gene action in inheritance. The larger magnitude of SCA mean sum of squares proposed that the nonadditive gene action was predominant for capsules per plant, straw and seed yields per plant, and morphine content in straw. None of the inbred lines had good general combiners for all studied traits. Among plants used as females, the economic parent Shubhra had good GCA for all traits. Kumar et.al [11], studied F_1, F_2 and t reciprocals of eight parent diallel cross in opium poppy (*P. somniferum*) for combining ability of seven traits. The mean sum of squares due to GCA, SCA and reciprocals were significant for all studied traits. Among the parents Sanchita, and VG26 for capsules/plant, VN23, VN35I and Vivek for capsule index, VG26 and Sanchita for seed and straw yield/plant, and VN35I and VG20 for morphine content were found good general combiners.

Misra *et al* [12], using Line × tester analysis involving 15 lines and 4 testers in opium poppy to access combining ability and heterosis with respect to latex yield and related components found significance of GCA and SCA variances from mean squares of all the seven traits indicating that additive as well as non-additive genes controlled the traits.

However, additive genes were more important compared to the dominant genes for latex yield because variance due to GCA was highly compared to SCA [25]. The study was carried out to find genetic information by concentrating on GCA and SCA to devise efficient breeding strategies for genetic improvement and development of high yielding varieties in opium poppy reciprocal hybrids.

Material and Methods

The research was carried out at the Experimental farm of the Department of Field Crops, Faculty of Agriculture, Ankara University, Turkey during 2012-13 and 2013-14. A total of 7 parent lines and their reciprocal hybrids were used as plant material in the study.

During first year, the trial was carried out during winter on 02/10/2012 using randomized complete block design with four replications to obtain the necessary material for use in next year's experiment

to yield sufficient number (7×6 = 42) of reciprocal hybrids by cross and inbreeding.

During second year winter, sowing was done on 01.10.2013. Experiment was performed in lattice design with three replications. A total of 7 parent lines and their reciprocal hybrids were used as the plant material. Phenological and morphological observations were recorded [3,7,14]. All morphine analyses were carried out at Bolvadin Alkaloids Factory using HPLC (High Pressure Liquid Chromatography).

General and specific commbining abilities of the investigated characters were determined following Griffing [5], by testing hybrids and parents together. The formulae used in making the analysis of variance with the GCA and SCA are given in Table 1 [8].

Results

The analysis of variance results of opium poppy lines/cultivars and their hybrids for general and specific combining abilities showed significant ($p< 0.01$) differences among investigated characters for GCA relating to opium poppy; capsules and seed yield per hectare, morphine percentage, morphine yield, total alkaloids percentage and total alkaloids yield. Differences among SCA of opium poppy studied traits were also statistically significant ($p< 0.01$). Reciprocal sum of squares in capsule and seed yield per hectare, morphine percentage and total alkaloids percentage for characters were no significant, but morphine yield and total alkaloids yield were significant ($p< 0.01$) (Table 2).

Table 3, depicts effect of GCA on all parents that are positive and have similar level 0.0001, in addition the highest SCA value was 0.0588 and belonged to N-442×TMO-B hybrid, whereas, the lowest value was -0.5618 for N-442×Ofis-8 hybrid. The results show similarity with the findings of Dodiya *et al*. [2], who noted related components efficiency by selecting 15 lines and 3 tests to determine ability and heterosis combination in terms of line ×tester. In terms of the Capsule, seed and latex yield performance, UOP 80 and UOP 71 parallel lines were recorded as most desired with best combinations. The crosses MOP541×UOP 58 followed by Chetak Aphim×UOP 73 have significant positive effects with highest estimates of better parent heterosis for seed and capsule yield. Whereas, Gumuscu and Arslan [7], throughout their experiment in selected opium poppy lines, measured GCA in terms of capsule yield (kg/ha) -8.13 between 6.62 and the SCA was identified between -18.00 and 23.07. Dogramaci [3], also reported that GCA and SCA combining ability variances for capsule yield in opium poppy line and hybrids were significant in both experiments. GCA in the first experiment in terms of capsule yield ranged -17.92 - 16.63; contrarily SCA had range of -42.48 - 94.52. In the second experiment the GCA and SCA respectively were found between -19.12 - 17.39 and -44.06 - 47.31.

Table 1 Variance calculation formulae of general and specific commbining abilities [5]

Source of varience	Degrees of freedom (df)	Sum of the Squares	Mean square
General ability	P-1	Sg	Mg
Specific ability	P(P-1)/2	Ss	Ms
Reciprocal effect	P(P-1)/2	Sr	Mr
Error	m	Sc	Mc

General combining ability (Sg)= $\frac{1}{2} P\Sigma_{i} (X_i+X_j)^2 - 2/P^2(X..)^2$

Specific combining ability (Ss)= $\frac{1}{2}\Sigma_{i<j} \Sigma X_{ij}(X_{ij}+ X_{ji})- \frac{1}{2}P\Sigma_{i}(X_j+X_i)^2 + 1/P^2(X..)^2$

Reciprocal effect (Sr)= $\frac{1}{2}\Sigma_{i<j} \Sigma(X_{ij}- X_{ji})^2$

The effect of general ability in lines (g_i)= $\frac{1}{2}P (X_i+ X_j)- 1/P^2(X..)$

The effect of specific ability (Sij)= $\frac{1}{2} (X_{ij}+ X_{ji})- 1/2P (X_i+X_j+X_j+X_{,i}) +1/P^2(X..)$

The effect of reciprocal hybridisation in lines (rij)= $\frac{1}{2} (X_{ij}-X_j)$

P: Parents Total

Xi: the i'th male parent value

Xj: the j'th value female parent

X..: The sum of all variants at trial

Xij: A F1 value of one hybrid (for example A × B)

Xji: A reciprocal F1 value of one hybrid (for example B × A)

Table 2 The analysis of variance results of opium poppy lines/cultivars and their hybrids for general and specific combining abilities

Yield of capsule	Degrees of freedom (df)	Sum of the Squares	Mean square	F
GCA Sum of the Squares	6	31224.1	5204.02	10.95**
SCA Sum of the Squares	21	157452.1	7497.7	15.78**
Reciprocal sums of squares	21	10802.3	514.4	1.08
Eror	96	45627.5	475.3	-
Yield of seed	df	Ss	Ms	F
GCA Sum of the Squares	6	47580.3	7930.1	25.49**
SCA Sum of the Squares	21	221728.5	10558.5	33.94**
Reciprocal sums of squares	21	13779.8	656.18	2.11
Eror	96	29868.7	311.13	-
Morphine percentage	df	Ss	Ms	F
GCA Sum of the Squares	6	2.51	0.42	21.0**
SCA Sum of the Squares	21	11.18	0.53	26.5**
Reciprocal sums of squares	21	0.73	0.04	2.0
Eror	96	1.75	0.02	-
Morphine yield	df	Ss	Ms	F
GCA Sum of the Squares	6	1.92	0.32	16**
SCA Sum of the Squares	21	14.50	0.69	34.5**
Reciprocal sums of squares	21	1.48	0.07	3.5**
Eror	96	1.53	0.02	-
Total alkaloids percentage	df	Ss	Ms	F
GCA Sum of the Squares	6	6.34	1.06	21.2**
SCA Sum of the Squares	21	26.21	1.25	25**
Reciprocal sums of squares	21	1.67	0.08	1.6
Eror	96	4.98	0.05	-

** $p< 0.01$

Table 3 The effects of GCA and SCA on yield of capsule for hybrids and parents

Serial No	Parents	1	2	3	4	5	6	7	gi
1	Ofis-8	-	0.0016	0.0022	0.0018	0.0019	0.0016	0.0025	0.0001
2	TMOT	0.0201	-	0.0022	0.0020	0.0019	0.0016	0.0024	0.0001
3	TMO-A	-0.0083	-0.0148	-	0.0015	0.0024	0.0018	0.0022	0.0001
4	TMO-B	-0.0413	0.0463	-0.0174	-	0.0021	0.0020	0.0022	0.0001
5	N-207	-0.0250	-0.0110	-0.0276	-0.0111	-	0.0023	0.0025	0.0001
6	Line2010	0.0532	-0.0144	-0.0164	-0.0649	0.0412	-	0.0018	0.0001
7	N-442	-0.5618	0.0041	-0.0151	0.0588	-0.0297	-0.0180	-	0.0001

G.C.A. Standard Error (gi-gj) = 0.01 S.C.A. Standard Error (sij-sik) = 2.32
S.C.A. Standard Error (sij-skl) = 2.26 Reciprocal Standard Error (rij-rkl) = 2.65

Table 4 The effects of GCA and SCA on yield of opium poppy for hybrids and parents

Serial No	Parents	1	2	3	4	5	6	7	gi
1	Ofis-8	-	0.0014	0.0018	0.0015	0.0016	0.0014	0.0021	0.0001
2	TMOT	0.0141	-	0.0018	0.0017	0.0015	0.0013	0.0019	0.0001
3	TMO-A	-0.0071	-0.0116	-	0.0013	0.0020	0.0016	0.0019	0.0001
4	TMO-B	-0.0549	0.0181	-0.0182	-	0.0017	0.0016	0.0018	0.0001
5	N-207	-0.0301	-0.0084	-0.0424	-0.0100	-	0.0018	0.0022	0.0001
6	Line2010	0.0284	-0.0164	-0.0413	0.1471	0.0355	-	0.0015	0.0001
7	N-442	0.0588	0.0033	-0.0124	0.0595	-0.0532	-0.0198	-	0.0001

G.C.A. Standard Error (gi-gj) = 0.01 S.C.A. Standard Error (sij-sik) = 2.27
S.C.A. Standard Error (sij-skl) = 2.22 Reciprocal Standard Error (rij-rkl) = 2.55

Yield of Capsule

The estimates of GCA and SCA on yield of capsule in parents and hybrids of opium poppy are presented in Table 3.

Yield of Seed

The estimates of GCA and SCA on yield of seed (kg/ha) in parents and hybrids of opium poppy are presented in Table 4.

As seen in Table 4, the effect of GCA on all parents are positive and have similar levels (0.0001), in addition the highest SCA value was 0.1471 and belonged to Line 2010×TMO-B hybrid. Also the lowest value was -0.0071 and observed in TMO-A×Ofis-8 hybrid. Tiwaria et.al [18], researching combining ability in opium poppy (*P. somniferum*) found that the mean sum of squares due to lines, testers and lines×testers were significant for all the investigated characteristics. GCA and SCA variances for all of the studied characteristics were also significant. None of the inbred lines were observed as good general combiners for all the studied traits. Among females, the economic parent Shubhra showed good GCA for all traits. Yadav *et al* [23], investigated combining ability of opium poppy genotypes over F1 and F2 generations of 8×8 diallel cross, their 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 good general combiners for yield and its related traits and could 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 affected high×high, high×low and low×low GCA combiners. Yadav *et al*. [24], selected twenty opium poppy parents, and with factorial diallel cross obtaind F1 and F 2 generations. The traits were analyzed for combining ability for some quantitative and quality (alkaloids) charecters. The results indicated significant differences among the parents for combining ability for all the traits. The GCA and SCA components of variances were significant for all characters. Among the parents IS-16, IS-13 and NBRI-1 for seed yield/plant and husk yield/plant were found good general combiners. Gumuscu and Arslan [1], reported that combanition ability in terms of seed yield were -10.6 between 8.09 and the SCA were identified between -22.00 and 16.47. Dogramaci [3] reported that GCA variances for seed yield in opium poppy line and hybrids were significant in first experiments but the SCA was significant in both experiments. The GCA in the fırst experiment in terms of seed yield modified between -28.92 and 20.18 and SCA was identified between-47.95 and 94.20. In the second experiment, the GCA and SCA were founded between -21.04-13.67 and-38.5-64.25. Their results as mentioned above were similar to the results obtained from this study. Our results show that the, inclusion of good general and specific combiners in a multiple crossing program or an intermating population involving all possible crosses among them are subject to bi-parental mating and are expected to offer maximum promise in breeding for higher opium, seed yield and alkaloid contents. As seen in Table 5, the effect of GCA on all parents are positive. The highest GCA value among parents was 0.0096 and belonged to the Line 2010. Indeed, the lowest value of GCA was 0.0057 and observed in TMO-A line. In addition, the highest SCA value was 100.00 and belonged to TMO-B×Ofis-8 hybrid whereas the lowest value was -71.4286 and observed in TMO-B×TMO-A hybrid.

Morphine Percentage

The estimates of GCA and SCA on Morphine percentage in parents and hybrids of opium poppy are presented in Table 5.

Table 5 The effects of GCA and SCA on Morphine percentage for hybrids and parents

Serail No	Parents	1	2	3	4	5	6	7	gi
1	Ofis-8	-	0.2036	0.1899	0.3096	0.2269	0.3416	0.2147	0.0079
2	TMOT	-9.0909	-	0.2103	0.2121	0.2088	0.2486	0.2753	0.0066
3	TMO-A	-5.8824	4.2017	-	0.2337	0.1789	0.3089	0.1516	0.0057
4	TMO-B	100.00	-1.3939	-71.4286	-	0.2137	0.3616	0.3191	0.0077
5	N-207	1.9062	-6.4103	-33.3333	-55.555	-	0.2994	0.1847	0.0074
6	Line 2010	16.5017	5.5556	-5.3763	-2.4950	-2.8952	-	0.2803	0.0096
7	N-442	-3.8168	0.5706	-1.8051	4.5620	-21.7391	-7.3099	-	0.0070

G.C.A. Standard Error (gi-gj) = 1.05 S.C.A. Standard Error (sij-sik) = 3.35
S.C.A. Standard Error (sij-skl) = 3.39 Reciprocal Standard Error (rij-rkl) = 3.67

Table 6 The effects of GCA and SCA on morphine yield for hybrids and parents

Serial No.	Parents	1	2	3	4	5	6	7	gi
1	Ofis-8	-	0.1333	0.1732	0.2359	0.1815	0.2316	0.2318	0.0094
2	TMOT	2.1930	-	0.1986	0.1865	0.1655	0.1621	0.2793	0.0083
3	TMO-A	-0.6206	-1.8678	-	0.1534	0.1892	0.2390	0.1405	0.0067
4	TMO-B	-7.3964	-1.7301	-1.7668	-	0.1944	0.3036	0.2948	0.0082
5	N-207	4.0984	-0.7602	-2.3923	-0.9907	-	0.3014	0.1983	0.0086
6	Line 2010	4.7619	-2.8736	-1.5385	-1.8136	-14.4092	-	0.2157	0.0110
7	N-442	-3.1387	0.4558	-0.6821	2.8902	-1.9708	-1.5908	-	0.0076

G.C.A. Standard Error (gi-gj) = 1.32 S.C.A. Standard Error (sij-sik) = 3.97
S.C.A. Standard Error (sij-skl) = 3.85 Resiprok Standart Error (rij-rkl) = 3.98

Morphine Yield

The estimates of GCA and SCA on morphine yield in parents and hybrids of opium poppy are presented in Table 6.

Gumuscu [6], investigated some selected opium poppy lines and their hybrids, the results indicated significant differences among the parents and hybrids just for SCA for morphine percentage. Yadav *et al*. [23], reported that combaning ability in terms of Morphine percentage has a significant difference among the parents. The GCA and SCA components of variances were significant also. Among the parents, NBRI-5 was found good general combiner for morphine, codeine, and thebaine. Dogramaci [3], reported that GCA variances for seed yield in opium poppy line and hybrids was not significant in both experiments but the SCA were significant in both experiments. In the fırst experiment GCA introduced modifications between -0.04 and 0.09 in terms of morphine percentage. Also SCA was identified between -0.06 and 0.04. In the second experiment the GCA and SCA were found between -0.07-0.07 and -0.21 - 0.14 respectively. The above mentioned results are in agreement with the findings of our research.

As seen in Table 6, the effect of GCA on all parents are positive. The highest GCA value among parents was 0.0110 and belonged to the Line 2010. In contrast, the lowest value was recorded 0.0067, which has observed in TMO-A line. In addition, the highest SCA value was 4.7619 for Line 2010×Ofis-8 hybrid; whereas, the lowest value was -71.4286 and observed for Line 2010×N-207 hybrid.

Dodiya *et al*. [2], showed the predominant role of non-additive type of genetic component involved in the inheritance of all the characters. The parental lines UOP 1385 and UOP 29 were found the best general combiners for morphine content and also three crosses for morphine content were found good specific cross combiners. Similarly, Tiwaria *et al* [18] researching combining ability in opium poppy (*P. somniferum*), inbred lines and three testers of opium poppy selected on the basis of seed and straw yields and hybridized to produced F1 generation Found that the mean sum of squares due to lines, testers and lines × testers were significant for all the investigated characteristics. GCA and SCA variances for all of the studied characteristics were also significant. Among the parents, Shubhra showed high SCA for seed yields per plant in any of the crosses. Kumar *et al*. [10], studied eight opium poppy parents and their reciprocal crosses in F1 and F2 generation in opium poppy (*P. somniferum*) for combining ability of seven traits. The mean sum of squares due to GCA, SCA and reciprocals were significant for studied traits. Among the parents, VG20 for morphine content was found good general combiner. Similarly, the findings of Dogramaci [3], are also in line with the findings of our result. The researcher reported that GCA variances for morphine yield in opium poppy line and hybrids were not significant in both experiments but the SCA was significant in both experiments. The GCA in the fırst experiment in terms of morphine yield ranged -0.06 to 0.06. Also SCA was identified between -0.25 and 0.54. In the second experiment the GCA and SCA were found between -0.15 to 0.18 and -0.28 to 0.77.

Total Alkaloids Percentage

The estimates of GCA and SCA on total alkaloids percentage in parents and hybrids of opium poppy are presented in Table 7.

As seen in Table 7, the effect of GCA on all parents are positive. The highest GCA value was 0.0060 and belonged to the Line 2010 also the lowest value was 0.0040 and observed in TMOT and TMO-A parents.

Table 7 The effects of GCA and SCA on total alkaloids percentage for hybrids and parents

Serail No	Parents	1	2	3	4	5	6	7	gi
1	Ofis-8	-	0.1449	0.1554	0.1927	0.1522	0.2534	0.1384	0.0050
2	TMOT	-3.7037	-	0.1327	0.1652	0.1353	0.1733	0.1449	0.0040
3	TMO-A	-5.6180	5.2632	-	0.1636	0.1285	0.2263	0.1092	0.0040
4	TMO-B	-5.2083	-1.4535	-8.9286	-	0.1465	0.2502	0.1661	0.0049
5	N-207	3.5971	-1.4368	33.3333	-13.513	-	0.1527	0.1117	0.0042
6	Line 2010	-31.250	-4.6729	1.1792	-2.1617	-41.6667	-	0.1491	0.0060
7	N-442	-0.8403	0.2922	-0.6868	-1.0846	1.4286	-19.2308	-	0.0041

G.C.A. Standard Error (gi-gj) = 0.93 S.C.A. Standard Error (sij-sik) = 2.77
S.C.A. Standard Error (sij-skl) = 2.76 Reciprocal Standard Error (rij-rkl) = 2.89

In addition, the highest SCA value was 33.33 and belonged to N-207×TMO-A hybrid whereas the lowest value was-41.6667 and observed in Line 2010×N-207 hybrid.

Shukla and Singh [16], investigated the combination ability in opium poppy (*P. somniferum*) using line×tester analysis. The highest special hybrid combinations in terms of opium yield in F2 generation were found in IS-4×NB-5, IS-6×Gz, IS-17×NB-5, IS-22×NB-6 and IS-23× NB-6 hybrids. Hybrids with significant level of SCA effect contain high×high, high×low and low×low combinations. Dubey *et al*. [4], also investigated combining ability and heterosis effect of 7 parents, 21 hybrid and Chetak Aph with IC-42 as two types of control in opium poppy (*P. somniferum*). Among parents, UOP-82 showed a good GCA in terms of opium yield. Similarly, the findings of Singh and Pandey [17], approve our results. They studied GCA and SCA and heterosis for morphine content and opium yield per plant in selected 8 parents and 28 hybrids obtaind from diallel reciprocals in opium poppy. Among the parents, BR 233 was identified as the best general combiner for morphine content, while BR 232 that had was the best general combiner for opium yield per plant.

Discussion

Highly significant GCA effects were evident for all characters; therefore, it is possible to obtain good selection responses for these characteristics using present experimental set up. The genotypes played a significant role compared to phenotypes as expressed by variable GCA results for morphine percentage and yield. The noticeable point in this research was that, during crossing, the same line/cultivar showed the most or the least SCA in hybrids. According to the results of this research, considering investigated characters, Line 2010 was superior to the other parents for GCA in morphine and alkaloid percentage and yield. Therefore, it is much easier to select the progenies based on these characteristics, as the environmental effects are non-significant. However, most of the desired traits like alkaloid and morphine content, capsule and seed yield are polygenic and it is possible to improve them through methods applied in traditional breeding. The results from this study indicate that, by using the correct breeding parents and selection procedures, alkaloid content, morphine quality, seed and capsule yield could be improved. Knowldege about the charachteristics to be improved before start of selection facilitate in breeding without wastage of time. This also ensures the progress towards right ends and help in improvement of more than one character simultaneously. Therefore, it would be appropriate to use for high and improved yield and morphine percentage as specified in this study. The study's emphasis has been based on the importance of combinig ability, which its results will contribute significantly to the Turkish economy.

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