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The Effect of Heterosis on Yield Components of Opium (*Papaver somniferum* L.) Cultivars and Their Reciprocal Crosses

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ABSTRACT

Seven varieties of poppy (*Papaver somniferum* L.) registered in the National Cultivar List. By using their reciprocal crosses, heterosis on capsule yield, seed yield, morphine content and morphine yield was investigated. Experiments were conducted in the experimental fields of Opium Alkaloids Factory during the years 2009 and 2010. Heterosis effect of poppy varieties; capsule yield in terms of -56.76 to 95.81% , seed yield in terms of -57.40 to 89.29%, morphine content in terms of -13.21 to 15.70%, morphine yield in terms of -58.21 - 95.53% showed variation between. Higher heterosis ratios were observed in capsule-seed yields of the hybrids of parents TMO 3 and Kocatepe 96 and in morphine content yields of the hybrids of the parents Ofis 96, Afyonkalesi 95 and Kemerkaya 95.

***Keywords*:** Heterosis, Poppy, *Papaver somniferum* L., yield and yield components.

Introduction

There are 28 genus and about 250 species in the family Papaveraceae. *Papaver* species is considered to be very rich in our country. According to Davis (1988), out of total 39, 19 annual plants and 20 perennial plants (2 subspecies and 7 varieties). İt is stated that 10 rounds of them, 2 sub-species and 4 varieties resides in *Papaver* species are endemic to Turkey. The family Papaveraceae, contains papaver alkaloids of secondary metabolites which are important within the genus (Ceylan 1994). *Papaver somniferum* L. (opium poppy) is a medicinally important genus and is one of the plants to be rich in alkaloids (Er 1997). Among those alkaloids, morphine, tebaine and papaverine are the most important ones (Baytop 1963). Poppies are also used in pharmaceutics in analgesic and antispasmodic drugs because of their pain relieving, local anesthetic and soporific characteristics (Baytop 1999; Gumuscu 2002). *Papaver* species usually shows the distribution of the northern hemisphere in temperate and subtropical regions. Poppy is cultivated in Turkey, India, Australia, France, Hungary, Check Republic and Chine under the inspection of United Nations (TMO 2004).

Among the poppy alkaloids, morphine has the widest range of use. Thus, several researchers conducted experiments to increase the morphine content of poppies. Several others, on the other hand investigated the effects of heterosis on morphine and seed yields together with various other yield contributing parameters of *Papaver somniferum* L. species. Researchers reported the existence of a certain heterosis with regard to morphine contents of parent combinations (Singh and Khanna 1991) and recommended the heterosis breeding for genetic improvement of poppy (Lal and Sharma 1991).

In the present study, current materials from the National Poppy Cultivar List were used to investigate the general and specific combining abilities, genetic variation among the cultivars, heterosis and heterobeltiosis effects and to develop materials with high morphine content and capsule-seed yield through the heterosis effects.

Materials and Methods

Experiments were conducted over the experimental fields of Poppy Breeding and Seed Production Center in Bolvadin Town of Afyonkarahisar Province. The registered poppy cultivars of Suhut 94, TMO 3, Ofis 96, Kocatepe 96, Afyonkalesi 95, Kemerkaya 95, Afyon 95 from the National Cultivar List and reciprocal crosses were used as the plant material of the study (TTSMM 2013). According to long-term meteorological data for the period of January-December, experimental site has a monthly average temperature of 10.8 °C and monthly average precipitation of 31.5 mm. Experimental site has slightly alkaline unsaline loamy soils with high lime content, medium organic matter content, well available phosphorus levels and high potassium levels.

Cultivars were sown over 2 x 2 m plots in 4 rows on 09.10.2008 of the first year. Experiments were conducted in randomized block design with 3 replications. The experimental material is shown in Table 1. Crossbreeding and inbreeding processes were performed to get the relevant material for the yield experiments of the subsequent year and 42 (direct and reciprocal) hybrid lines were obtained by using each cultivar both as female and male. During the second year (2009-10), 49 hybrid lines together with ancestors, were sown over 3 x 2 m (6 m^2) plots in 5 rows on 22.10.2009 in partially balanced lattice experimental design. Diammonium phosphate was applied to each plot at a rate of 40 kg N /ha at the sowing time and 60 kg N /ha before the initial hoeing. Following the ripening of capsules, side rows were omitted to remove the side effect and the remaining plots were harvested on 15.07.2010.

In this study, heterosis effects only in economically significant traits were included. Heterosis was calculated by using the differences between parent and F_1 mean values taken from the variance analyses results [(% Heterosis = F_1 – PM / PM x100), where PM = (1^{st} P + 2^{nd} P) / 2; PM: Mean value of two parents; P: Parent)] (Guler 1977; Kaymak 1980; Gumuscu 2002). Capsule samples were taken from the randomly selected 10 plants of which the other analyses have already been carried out. Then, morphine analyses were carried out at Laboratory of Opium Alkaloids Factory by using an HPLC (High Pressure Liquid Chromatography) device.

Results and Discussion

Mean values for capsule yield, seed yield, morphine content and morphine yield of poppy parents and hybrids are provided in Table 2. Heterosis value for investigated traits of poppy hybrids are represented in Table 3.

Heterosis effects on capsule yield per hectare of poppy parents varied between -56.76 to 95.81% with the highest heterosis in line 27 (4x6) and the lowest heterosis in line 23 (4x1) (Table 3). While the capsule yield per hectare of the female plant with the highest heterosis combination was 1320.0 kg and the capsule yield per hectare of the male plant was 2021.0 kg, hybrid plant had a capsule yield per hectare of 3271.0 kg. Saini and Kaicker (1982) determined the heterosis value as 52.8% in capsule yield of poppy. Patidar (1994) carried out a study with 4 females, 31 males and 124 hybrids during 1988-99 and reported the heterosis values of parents for capsule yields as between 71.6 to 131.2%. Gumuscu (2002) reported the heterosis of some poppy lines and hybrids as between -33.92 to 45.30% for capsule yield.

Heterosis effects on seed yield per hectare of poppy parents varied between -57.40 to 89.29% with the highest heterosis in line 27 (4x6) and the lowest heterosis in line 3 (1x3) (Table 3). While the seed yield per hectare of the female plant with the highest heterosis combination was 1443.3 kg and the seed yield per hectare of the male plant was 2404.3 kg, hybrid plant had a seed yield per hectare of 3547.0 kg. Shukla et al., (2000) carried out heterosis for seed yield with 10 hybrids obtained from semi-diallel 5 different parents of poppy (*Papaver somniferum* L.) and indicated that higher variations in parents resulted in higher heterosis ratios in hybrids. Gumuscu (2002) determined the heterosis in seed yields of some poppy lines and hybrids as between -32.05 to 45.89%. Dodiya et al., (2005) carried out a study on heterosis and combining ability of poppy (*Papaver somniferum* L.) and evaluated the heterosis and combining ability with regard to seed yield. Shukla and Singh (2006) implemented a study about heterosis-related genetic incompatibility in poppy and evaluated 27 parents (24 male and 3 inseminator) and 72 hybrids of them with regard genetic incompatibility and heterosis in different characteristics and observed a heterosis of 86.58% in seed yield. Dubey et al., (2007) investigated combining ability and heterosis of poppy with regard to seed yield and other agronomic characteristics and observed a close relationship between latex yield and standard heterosis. Yadav et al., (2009) analyzed combining ability of F_1 and F_2 generations of 20 parents partially diallel poppy with regard to 5 quantitative

and 5 qualitative characteristics. Researchers indicated that high seed yields and morphine contents might be achieved by including high combining ability cultivars into multiple hybridization programs or by working with a population including entire possible hybrids of two-parent couplings.

Heterosis effects on morphine content of poppy parents varied between -13.21 to 15.70% with the highest heterosis in line 25 (4x3) and the lowest heterosis in line 35 (5x7) (Table 3). While the morphine content of the female plant with the highest heterosis combination was 0.63% and the morphine content of the male plant was 0.58%, hybrid plant had a morphine content of 0.70%. Sharma and Singh (1983) and Dubedout (1993) reported morphine contents of hybrids as between the values of parents. Popov et al., (1974) determined the morphine contents as between 0.45 to 0.60% for parents and between 0.7 to 0.9% for F_1 hybrids. Singh and Khanna (1975) indicated a heterosis in opium yield of poppy and did not observe a heterosis in morphine contents. Srivastava and Sharma (1987) carried out a three-year study on opium yield and morphine contents of parents and hybrids and observed respectively 32 to 66% and 25 to 39% higher values in hybrids than the parents. Singh and Khanna (1991) reported heterosis in morphine contents of parent combinations. Patidar (1994) determined better parent heterosis as 46.3% for opium yield and as 37.1% for morphine content. Sudhir and Shukla (1998) observed high heterosis ratios in morphine contents and low inbreeding depression for hybrids. Gumuscu (2002) reported the heterosis in morphine contents of some poppy lines and hybrids as between -24.21 to 44.62%. Shukla and Singh (2006) evaluated 27 parents and 72 hybrids and reported heterosis and genetic incompatibility in them with regard to different characteristics and observed heterosis 43.4% for opium yield and 11.74% for morphine content.

Heterosis effects on morphine yield of poppy parents varied between -58.21 to 95.53% with the highest heterosis in line 27 (4x6) and the lowest heterosis in line 23 (4x1) (Table 3). While the morphine yield of the female plant with the highest heterosis combination was 8,4 kg/ha and the morphine yield of the male plant was 9,5 kg/ha, hybrid plant had a morphine yield of 17,5 kg/ha. Khanna and Shukla (1988) observed a heterosis in triploids of F_1 generations in hybrids of *P. somniferum* L. and *P. setigerum*. Sharma et al., (1988) indicated high heterosis in raw opium yields of the materials. Patidar (1994) reported better parent heterosis as 46.3% for opium yield and 37.1% for morphine content. Lal and Sharma (1995) observed significant positive heterosis in opium yield and negative heterosis in alkaloid content. Gumuscu (2002) determined the heterosis in morphine yields of some poppy lines and hybrids as between 4.21 to 44.62%.

Since yield, earliness, plant height-like characteristics are generally affected by several genes and interactions, it has been impossible to develop homozygote dominant individuals even with long-term inbreeding studies. Hybridization most of the time allows to improve variability at the desired course and to get the varieties with new characteristic combinations (Aydemir 1982). Interactions among allele genes located in different locus of hybrid plants are thought to eliminate such limitations (Demlary 1977; Demir and Turgut 1999). It was also reported that F_1 tomato hydrides had better adaptations to adverse environmental conditions than the standard cultivars because of heterosis (Philouze 1976). Although, hybrid power is generally used in foreign-pollinating cultivars, it is also used in self-pollinating plants such as pepper, cucumber, poppy in which several seeds are obtained with the pollination of a single flower and hybrids are developed in this way (Eser et al., 2006). High number of seeds in capsules (5,000-20,000 seeds) makes the poppy available for hybrid seed production. Degree of kinship between parent lines is a significant issue in development of hybrid lines. Further, diverse the kinship, higher is the heterosis. Heterosis is most of the time not observed in kin-inbreed generations from the same origin (Demir and Turgut 1999). Therefore, in the present study, all the registered poppy cultivars in National Cultivar List were taken as the material and heterosis-induced genetic variations among the cultivars were investigated.

Variation analysis revealed the highest seed and capsule yields for hybrid 27 (4x6) and the highest morphine content for hybrid 44 (7x1). Heterosis and heterobeltiosis values in all of the investigated parameters of poppy hybrids were found to be significant. Higher heterosis ratios were observed in seed yields of the hybrids of parents 2 and 4 and in capsule yields of the hybrids of the parents 2, 3, 7 and 4. The hybrids with higher heterosis in their capsule and seed yields also had the higher general and specific combining abilities. With regard to morphine contents, higher heterosis ratios were observed in some hybrids of the parents 3, 5 and 6. Those hybrids had also higher general combining abilities.

At the end of this study, hybrid lines with high heterosis level in some traits and with high general-specific combining abilities were obtained. Heterosis level of the traits were different from each other since yield, morphine content, earliness and plant

height-like characteristics are controlled by several genes and the effects of each gene in heterosis are ambiguous. Therefore, heterosis may be at high level in one parameter and low in another. As indicated in an earlier study of Yadav et al., 2009, high seed yields and morphine contents might be achieved by including high combining ability cultivars into multiple hybridization programs or by working with a population including entire possible hybrids of two-parent couplings. Here in this study, new poppy lines were identified and data were provided to be used as the material of further studies. Poppy breeding studies are still on-going in the light of the current findings.

Table 1. Materials used in this research

Variety number	Variety name	Seed color	Breeding method	Seed yield (kg/ha)	Capsule yield (kg/ha)	Morphine content (%)
1st parent	Suhut 94	Blue	Selective breeding	1100-1400	1100-1300	0.60-0.70
2nd parent	TMO 3	Pink	Hybridization	810-1120	850-1320	0.85-0.90
3rd parent	Ofis 96	Yellow	Selective breeding	1130-1400	1000-1350	0.55-0.71
4th parent	Kocatepe 96	White	Hybridization	1100-1250	1200-1300	0.60-0.85
5th parent	Afyonkalesi95	Yellow	Hybridization	950-1200	900-1250	0.55-0.85
6th parent	Kemerkaya 95	Yellow	Selective breeding	900-1300	1000-1100	0.45-0.55
7th parent	Afyon 95	Yellow	Selective breeding	1140-1400	1170-1250	0.50-0.72

Table 2. Mean values for investigated traits of poppy parents and hybrids

No	Hybrid	Capsule yield (kg/ha)	Seed yield (kg/ha)	Morphine content (%)	Morphine yield (kg/ha)	No	Hybrid	Capsule yield (kg/ha)	Seed yield (kg/ha)	Morphine content (%)	Morphine yield (kg/ha)
1	1st p.	1611.3	1749.7	0.73	11.7	**26**	4x5	1475.9	1754.2	0.53	7.7
2	1x2	1274.3	1479,9	0.67	8.7	**27**	4x6	1670.5	1873.8	0.55	9.0
3	1x3	1686.7	2037.5	0.66	11.0	**28**	4x7	1321.5	1663.2	0.64	8.5
4	1x4	1465.7	1596.5	0.68	10.1	**29**	5th p.	1631.7	2065.0	0.43	7.0
5	1x5	1621.5	1907.4	0.58	9.4	**30**	5x1	1621.5	1907.4	0.58	9.4
6	1x6	1816.2	2027.0	0.60	10.6	**31**	5x2	1284.5	1637.5	0.52	6.3
7	1x7	1467,2	1816.4	0.69	10.2	**32**	5x3	1696.9	2195.2	0.51	8.6
8	2nd p.	937.3	1210.0	0.61	5.6	**33**	5x4	1826.4	2184.7	0.45	8.3
9	2x1	1274.3	1479.9	0.67	8.7	**34**	5x6	1477.4	1974.0	0.54	7.8
10	2x3	1349.7	1767.7	0.60	7.9	**35**	5x7	1475.9	1754.2	0.53	7.7
11	2x4	1128.7	1326.7	0.62	7.0	**36**	6th p.	2021.0	2304.3	0.47	9.5
12	2x5	1284.5	1637.5	0.52	6.3	**37**	6x1	1816.2	2027.0	0.60	10.6
13	2x6	1479.2	1757.2	0.54	7.6	**38**	6x2	1479.2	1757.2	0.54	7.6
14	2x7	1130.2	1546.5	0.63	7.1	**39**	6x3	1891.5	2314.8	0.53	9.9
15	3rd p.	1762.0	2325.3	0.58	10.2	**40**	6x4	1826.4	2184.7	0.45	8.3
16	3x1	1686.7	2037.5	0.66	11.0	**41**	6x5	1672.0	2093.7	0.56	9.1
17	3x2	1349.7	1767.7	0.60	7.9	**42**	6x7	1670.5	1873.8	0.55	9.0
18	3x4	1541.0	1884.3	0.61	9.3	**43**	7th p.	1323.0	1883.0	0.65	8.6
19	3x5	1696.9	2195.2	0.51	8.6	**44**	7x1	1467.2	1816.4	0.69	10.2
20	3x6	1891.5	2314.8	0.53	9.9	**45**	7x2	1130.2	1546.5	0.63	7.1
21	3x7	1542.5	2104.2	0.62	9.4	**46**	7x3	1542.5	2104.2	0.62	9.4
22	4th p.	1320.0	1443.3	0.63	8.4	**47**	7x4	1477.4	1974.0	0.54	7.8
23	4x1	1465.7	1596.5	0.68	10.1	**48**	7x5	1672.0	2093.7	0.56	9.1
24	4x2	1128.7	1326.7	0.62	7.0	**49**	7x6	1321.5	1663.2	0.64	8.5
25	4x3	1541.0	1884.3	0.61	9.3						

Table 3. Heterosis (%) value for capsule and seed yield per hectare, morphine content and morphine yield

H: Heterosis		Capsule yield	Seed yield	Morphine content	Morphine yield	No	Hybrid	Capsule yield	Seed yield	Morphine content	Morphine yield
No	**Hybrid**	***H.***	***H.***	***H.***	***H.***	**No**	**Hybrid**	***H.***	***H.***	***H.***	***H.***
2	1x2	-8.32	-10.92	1.49	-8.67	**27**	4x6	95.81	89.29	-1.82	95.53
3	1x3	-51.86	-57.40	-0.76	-51.60	**28**	4x7	40.52	28.55	0.00	-10.59
4	1x4	-22.22	14.73	8.82	-16.42	**30**	5x1	-13.89	-37.92	-3.45	-45.45
5	1x5	-36.89	-24.22	-3.45	-36.90	**31**	5x2	-28.77	-41.76	9.62	-15.87
6	1x6	-2.91	1.81	8.33	7.55	**32**	5x3	-29.85	-33.00	8.91	-23.26
7	1x7	-32.52	-15.47	-2.90	-33.99	**33**	5x4	-34.42	23.33	6.67	17.58
9	2x1	10.36	4.67	7.46	16.76	**34**	5x6	52.48	42.15	1.85	56.41
10	2x3	-14.30	-34.00	1.60	-11.39	**35**	5x7	-24.09	-12.38	-13.21	-33.77
11	2x4	23.48	47.91	9.68	35.71	**37**	6x1	-42.90	-28.80	0.00	-41.51
12	2x5	50.51	35.57	1.92	63.49	**38**	6x2	-3.64	-11.49	9.26	11.26
13	2x6	-40.73	-34.46	11.11	-29.80	**39**	6x3	-17.21	-13.91	4.76	-11.68
14	2x7	-0.75	-18.27	-1.59	-2.82	**40**	6x4	-29.24	-26.52	0.00	-29.70
16	3x1	-22.33	-40.61	-2.29	-23.29	**41**	6x5	-29.31	-23.33	14.29	-16.02
17	3x2	-45.93	-43.03	14.29	-37.97	**42**	6x7	-33.89	-26.10	3.64	-29.61
18	3x4	-43.95	-22.87	14.05	-36.56	**44**	7x1	-15.64	-23.97	10.14	-7.39
19	3x5	-30.85	-34.99	8.91	-25.58	**45**	7x2	60.24	26.30	-6.35	50.70
20	3x6	-18.12	-14.97	10.48	-9.64	**46**	7x3	-27.18	-33.12	-0.81	-26.60
21	3x7	74.24	40.96	-4.07	69.15	**47**	7x4	28.20	10.64	1.5	32.05
23	4x1	-56.76	-43.44	-4.41	-58.21	**48**	7x5	-20.45	-35.39	-3.57	-20.44
24	4x2	59.63	46.69	4.84	68,57	**49**	7x6	-44.96	-39.43	4.69	-43.53
25	4x3	-31.00	-28.50	15.70	-20.43		**Mean**	**-8.67**	**-9.57**	**3.58**	**-5.54**
26	4x5	-4.75	-4.19	3.77	1.30						

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