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Estimation of heterosis and pattern of inheritance for elite economic yield traits in opium poppy (*Papaver somniferum* L.)

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Abstract
A line × tester analysis was conducted to assets the heterosis, heterobeltiosis and economic heterosis of sixty F_1's by crossing 12 lines/females and 5 testers/males of diverse parents for fourteen viable economical traits in *Papaver somniferum* L. The analysis of variance concluded that parents *vs* hybrids contrast were recorded 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 alkaloid content (%) indicated, existence of plentiful variability among parents and crosses for all the characters studied. The investigational result revealed that hybrids $L_{10}{\times}T_2$, $L_{10}{\times}T_5$, $L_{12}{\times}T_3$ and $L_{12}{\times}T_4$ exhibited the best heterosis over better as well as economic parent both for more than one traits, namely- no. of capsule, capsule index, seed yield (g/plant), dry husk yield (g/plant), morphine, codeine, thebaine, papervine and nosacapine alkaloid content (%) in desirable direction. Therefore, these promising crosses can be recommended for exploitation of heterosis to obtain appropriate segregants for crop improvement program in opium poppy.

Keywords: Line × tester, heterobeltiosis, heterosis over mid parent, economic heterosis, *Papaver somniferum* L.

1. Introduction
Opium poppy is a world's most important and primitive medicinal plant due to its unique ability to synthesize several life-saving drugs mainly pain killer, analgesic, respiratory sedative, antispasmodic and vasodilator by pharmaceutical companies (Singh *et. al.*, 1995a, Yadav *et. al.*, 2006) [20, 32]. India's is the world largest producer of opium, besides meeting its domestic demand, India exports opium and its derivative of worth Rs. 13 million worldwide (Singh *et al.* 1995b; Shukla & Singh 2004) [21, 18]. This versatile plant produces more than hundred pharmaceutical and neutraceutical active BIAS (benzylisoquinoline alkaloids) compounds. Out of which morphine ($C_{17}H_{19}NO_3$), methyl morphine or codeine ($C_{18}H_{21}NO_3$), dimethyl morphine or thebaine ($C_{19}H_{21}NO_3$), papaervine ($C_{20}H_{21}NO_4$) and narcotine or nosacapine ($C_{22}H_{23}NO_7$) are major ones (Penix *et al.*, 2009; Shukla *et al.*, 2010) [14, 19]. Thus, opium poppy serves as one of the most important renewable resource for pharmaceuticals and nutraceuticals alkaloid based products. Morphine contributes a major percentage (7-17%) of total alkaloids present in opium and used as analgesic worldwide (Shukla *et al.*, 2006; Yadav *et al.*, 2009) [23, 33]. However, production process of alkaloids in opium poppy are structurally complex and their chemical synthesis is not commercially viable (Facchini and Park 2003; Weid *et al.*, 2004; Frick *et al.* 2005; Shukla *et al.*, 2006) [7, 30, 6, 23]. According to (Singh *et al.*, 2014) [24] poppy genotypes are broadly classifies as industrial (grown for alkaloids extraction from capsule latex), culinary (grown for edible seed and seed oil) or dual purpose genotypes (grown for both alkaloid as well as seed). Thus, the productivity and availability of poppy and its absolute products are always concern with high opium yielding, seed yielding or seed oil yielding varieties of opium poppy. India is one of the very few countries that legally grow opium poppy and the government of India notifies the locations and conditions for issuance of license every year by the Central Bureau of Narcotics (CBN) that's why limited research work has been done on this crop. The limited crop improvement in poppy crop may be due to narrow genetic base of common ancestry (Singh *et al.* 1999; Singh & Khanna 1991) [25, 26].
Genetic improvement of quantitative and qualitative traits of any crop through different breeding program desires the information on the nature and magnitude of gene effects.

The genetic information will help to devise efficient breeding strategies for genetic improvement and development of high yielding varieties in opium poppy. Heterosis is the manifestation of heterozygosity expressed as increased vigour, size and resistance to disease, insects and climatic extremes relative to either the better parent (heterobeltiosis) or the mid parent (relative heterosis) value. Practically, in plant breeding standard or economic heterosis (performance of F_1 is compared with a standard variety or check) is more important than herterobeltiosis and average or relative heterosis. The evidence of heterosis and heterobeltiosis enlightens the breeder about selection of perfect hybrid recombinants to work on particularly and also helps to differentiate between the parents and its hybrids better (Korkut, 1981) [10]. Correspondingly, (Jawaharlal *et al*., 2012; Thamodharan *et al*., 2016) [9, 27] also concluded that the magnitude of heterosis provides information on extent of variation and genetic diversity of parents and has direct bearing on the breeding methodology to be adapted for varietal improvement program. The goal of this study is to conclude the appropriate crossbreeds by examining the hybrid progenies in terms of their heterosis over better parent or heterobeltiosis, economic heterosis or standard check and over mid parent for economic viable traits in *Papaver somniferum* L.

2. Material and Methods

2.1 Experimental material and site

The experimental material for the present investigation comprised twelve lines/females and five testers /male i.e. CIM-Ajay, Shyama, Shweta, Sampada and SPS-20. Further, 60 F_1 hybrids or cross combinations were developed using line × tester mating design by crossing 12 lines/females and 5 testers/males were sown 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- 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.

2.2 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) [8]. 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) [29] at 540 nm.

2.3 Statistical analysis

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 the standard method of Singh & Chaudhary (2014) [22]. The recorded pooled mean values of two years for the all the fourteen characters were put to analyse the heterosis by using the method suggested by (Shull, 1908) [17], heterobeltiosis/better parent and economic heterosis was estimated as per the procedures given by (Fonesca & Patterson, 1968) [5] and (Briggle, 1963) [1] respectively.

3. Results and Discussion

The analysis of variance (ANOVA) revealed that highly significant variances due to treatment were obtained for all the fourteen characters studied (Table 1). 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 for 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 alkaloid content (%).In order to know the degree of realized heterosis in different crosses for various traits the heterosis over better parent (B.P.), mid parent (M.P.) involved in the crosses and also over economic parent (E.P.) as check Cv. CIMAP-Ajay was calculated and presented in (Table 2). In this study, heterosis in positive direction was considered desirable for all the traits except days to 50% flowering because early flowering is a desirable trait and plant height because medium size plant is a desirable trait to avoid lodging problem in *P. somniferum*, where negative direction was considered desirable. Heterobeltiosis/better parent and economic heterosis was calculated only in desirable direction.

Table 1: ANOVA for line × tester analysis including parents of fourteen characters in *Papaver somniferum* L.

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							

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 (g/plant), X_9= Dry husk capsule (g/plant), X_{10}= Morphine(%), X_{11}= Codeine(%), X_{12}= Thebaine(%), X_{13}= Papervine(%), X_{14}= Nosacapine(%).

Where d. f. = degree of freedom *- $p<0.05$;**-$p<0.01$ and +, ++ -$p<$ 0.05 and 0.01 significant level respectively.

Table 2: Heterosis (%) over better, mid and economic parents in Line × tester crosses for fourteen elite characters in *Papaver somniferum* L.

Crosses	Days to 50% flowering			Plant height (cm)			Number of leaves per plant			Pedicel length (cm)			No. of Capsule per plant		
	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)
$L_1 \times T_1$	0.34	0.95**	1.62	7.45	10.39*	7.44	3.35	5.06	3.30	16.96	18.89*	20.89*	6.38	13.40	6.38
$L_1 \times T_2$	-2.87	-0.98**	2.32	-9.73**	-0.88	4.01	5.17	7.97	1.65	31.81**	33.17**	39.08**	-5.99	3.09	0.00
$L_1 \times T_3$	3.92	4.79**	7.07*	-4.27	1.37	1.94	-25.00**	-16.92**	-10.00	-10.17	-7.65	-7.16	-20.88	-0.08	18.76
$L_1 \times T_4$	-11.58**	-7.82**	-2.42	16.32**	16.43**	10.08*	-11.40	-3.14	3.30	-19.51*	-12.45	-0.80	34.93*	58.73**	68.86**
$L_1 \times T_5$	-10.69**	-4.45**	4.04	10.48*	12.39**	8.26*	0.00	4.14	5.00	9.88	11.43	13.58	0.00	22.17	37.52*
$L_2 \times T_1$	-2.66	3.59**	10.71**	-7.54	-2.94	-7.54	-1.59	0.00	1.65	22.31*	25.21**	28.26**	-6.19	-3.19	-6.19
$L_2 \times T_2$	-4.44	-0.78	8.69**	-11.25**	-0.60	2.25	-11.27	-5.98	-8.35	11.87	12.26	18.09	29.28	37.39*	37.52*
$L_2 \times T_3$	-14.49**	-10.21**	-2.69	5.22	13.77**	12.06**	-16.66**	-10.43	8.30	47.64**	52.86**	54.81**	-37.50**	-23.08	-6.19
$L_2 \times T_4$	-8.28**	-6.89**	4.34	-1.18	0.97	-6.63	-7.12	-1.52	-13.35	-5.97	1.60	15.88	4.95	19.97	31.33
$L_2 \times T_5$	-8.08**	-6.98**	7.07*	0.62	4.61	-1.39	-17.47**	-16.80*	0.00	4.63	6.86	9.72	-18.14	-2.68	12.57
$L_3 \times T_1$	-6.11*	-3.91**	-1.68	-19.64**	-14.56**	-8.78*	0.00	0.00	-3.35	10.87	16.72	10.87	-9.57	2.68	18.76
$L_3 \times T_2$	-0.64	-0.34**	4.65	-18.56**	-17.96**	-6.17	-3.35	0.86	5.00	-2.85	4.92	2.56	-9.57	-0.08	18.76
$L_3 \times T_3$	3.22	4.09	8.08**	-34.57**	-32.48**	-25.73**	-12.5*	-4.55	-3.35	-0.72	3.42	-2.96	-8.38	-2.27	37.52*
$L_3 \times T_4$	1.22	3.89*	11.72**	-15.46**	-7.71	-4.04	-17.15**	-10.78	-1.70	-17.47*	-4.61	1.70	-33.29*	-31.68*	-12.38
$L_3 \times T_5$	-4.62	0.50**	11.11**	-3.09	4.01	10.00*	-6.33	-4.09	0.00	-8.97	-3.89	-8.47	-9.00	-6.91	25.14
$L_4 \times T_1$	-3.87	1.99	8.69**	15.77**	19.83**	15.77**	-15.95**	-10.09	-3.35	-1.81	11.71	23.75*	68.86**	68.86**	68.86**
$L_4 \times T_2$	0.58	4.11**	13.74**	-8.38*	1.29	5.56	11.61	24.17**	28.3**	-11.54	-5.25	7.57	29.28	33.27	37.52*
$L_4 \times T_3$	-5.06	-0.65	7.37*	-4.05	2.35	2.19	-19.45**	-17.74**	-3.35	-17.31*	-8.27	0.55	-16.63	0.08	25.14
$L_4 \times T_4$	-18.16**	-17.16**	-7.41*	13.13**	13.92**	6.89	10.03	10.77	28.3**	2.44	3.15	26.25**	34.93*	50.00**	68.86**
$L_4 \times T_5$	-4.04	-2.68**	11.72**	1.21	3.74	-0.82	-8.69	-4.55	5.00	-14.67	-6.59	3.71	-4.50	10.58	31.33
$L_5 \times T_1$	-0.87	5.48**	12.73**	-4.15	-3.00	-1.85	-3.35	6.41	0.00	14.03	16.54	14.03	-37.50**	-24.98	-6.19
$L_5 \times T_2$	4.15	8.16**	18.48**	-8.54*	-3.14	5.38	18.22*	24.99**	-3.35	6.65	11.85	12.53	-20.88	-7.39	18.76
$L_5 \times T_3$	3.85	9.04**	18.18**	-2.74	-0.80	3.58	-22.21**	-7.41	8.30	10.92	12.07	8.37	-25.00*	-25.00*	12.57
$L_5 \times T_4$	0.30	1.85**	14.14**	-0.71	3.32	1.67	-12.85*	2.52	-6.65	-11.91	-0.82	8.57	4.13	13.57	56.29**
$L_5 \times T_5$	-4.34	-3.20**	11.41**	1.45	3.69	3.88	-14.28*	-3.56	1.65	-0.49	1.94	0	16.63	21.72	75.05**
$L_6 \times T_1$	-15.04**	-9.43**	-3.03	8.47*	10.10*	8.48*	1.65	1.65	-10.00	-19.47*	-16.75	-13.83	44.50**	53.05**	62.66**
$L_6 \times T_2$	-7.96**	-4.28**	5.05	-10.26**	-2.58	3.40	-1.65	2.64	1.65	-18.67*	-18.10*	-12.98	-5.50	-2.83	6.38
$L_6 \times T_3$	-10.03**	-5.49**	2.63	-10.78**	-6.63	-4.99	-12.5*	-4.55	-1.65	-1.54	2.94	5.36	-16.63	-4.71	25.14
$L_6 \times T_4$	-11.21**	-9.76**	1.31	11.09**	12.59**	7.80	-27.13**	-21.53**	5.00	-15.85*	-9.92	3.71	-25.04	-21.07	-6.19
$L_6 \times T_5$	-10.41**	-9.51**	4.34	1.12	1.61	-0.91	-4.76	-2.44	-15.00*	-2.81	0.24	4.01	-31.79*	-24.98	-6.19
$L_7 \times T_1$	0.29	6.00**	12.42**	9.07*	9.46*	9.08*	-8.35	0.00	0.00	-17.98	-16.79	-18.04	87.62**	114.36**	87.62**
$L_7 \times T_2$	0.60	3.67**	12.73**	-6.12	0.85	8.18*	10.91	16.20*	-8.35	-3.13	0.94	2.20	0.00	17.27	6.38
$L_7 \times T_3$	5.70*	10.14**	18.48**	-6.90	-3.02	-0.22	-11.08	4.97	1.65	-21.89*	-21.62*	-23.69*	-41.63**	-22.17	-12.38
$L_7 \times T_4$	1.51	2.22**	13.74**	9.92*	12.67**	9.14*	19.97**	-6.63	6.70	26.83**	-18.11*	-9.82	-5.10	18.65	18.76
$L_7 \times T_5$	-15.03**	-13.39**	-1.01	9.18*	9.90*	8.41*	1.62	13.33	-6.65	-1.15	0.61	-0.65	-13.64	11.74	18.76
$L_8 \times T_1$	3.03	3.55**	3.03	9.05*	12.47**	9.05*	8.35	15.08*	6.70	16.08	20.39*	16.08	13.64	31.60*	56.29**
$L_8 \times T_2$	-0.32	2.82	5.05	-12.34**	-3.41	1.00	23.67**	25.92**	8.35	-10.92	-5.23	-6.01	-18.14	-7.69	12.57
$L_8 \times T_3$	-0.32	1.60**	2.63	0.08	6.38	6.59	25.00**	-13.59*	13.30	-17.79	-15.69	-19.69*	-12.50	-8.68	31.33
$L_8 \times T_4$	2.44	8.06**	13.13**	15.95**	16.34**	9.57*	-24.26**	-13.83*	-10.00	0.81	15.00	24.25*	-40.93**	-38.14**	-18.76
$L_8 \times T_5$	-3.75	4.08**	12.12**	7.75	10.04*	5.59	-6.33	1.71	-11.70	-13.91	-10.49	-13.48	27.29*	27.29*	75.05**
$L_9 \times T_1$	-4.91	2.29**	10.71**	-8.86*	-8.23*	-8.87*	1.65	9.89	-1.70	2.20	5.64	2.20	-41.92**	-23.37	12.57
$L_9 \times T_2$	-14.73**	-10.44**	-0.67	-9.86**	-2.86	3.86	-7.25	-3.76	1.65	-12.63	-7.35	-7.82	-51.60**	-37.50**	-6.19
$L_9 \times T_3$	-11.27**	-5.84**	3.33	-1.28	2.53	5.13	-22.21**	-8.93	-15.00*	-22.92*	-21.23*	-24.69**	-41.92**	-34.53**	12.57
$L_9 \times T_4$	-10.97**	-8.64**	3.64	9.86*	12.23**	8.32*	-8.53	5.83	-6.65	-36.99**	-28.34**	-22.34*	-61.28**	-52.94**	-24.95
$L_9 \times T_5$	-12.43**	-12.40**	2.02	9.95*	10.29*	8.41*	-9.52	0.00	6.70	8.33	12.24	8.87	-38.72**	-28.31*	18.76
$L_{10} \times T_1$	3.69	8.35**	13.43**	-10.26**	-7.03	-3.56	-16.65*	-13.76	-5.00	-10.30	-5.88	-1.00	0.00	8.58	18.76
$L_{10} \times T_2$	5.23	7.24**	15.15**	-1.11	2.33	13.95**	-1.76	-0.89	-16.65*	-5.90	-3.78	3.86	57.98**	66.67**	87.62**

$L_{10} \times T_3$	3.38	6.51**	13.13**	-5.85	-5.41	1.19	-16.66*	-6.24	-8.35	-1.49	4.50	8.72	-33.38**	-25.61	0.00
$L_{10} \times T_4$	3.65	4.14**	14.44**	-2.09	4.23	5.22	-1.41	9.55	15.00*	-18.17*	-13.66	0.85	-5.10	-2.62	18.76
$L_{10} \times T_5$	-7.51**	-4.65**	7.68*	10.77**	15.88**	19.05**	4.76	10.94	10.00	-1.49	3.11	8.72	31.92*	41.58**	81.43**
$L_{11} \times T_1$	-7.07**	-0.94**	6.06*	-8.68*	-4.65	-8.69*	4.74	8.11	11.70	4.71	7.39	4.71	19.00	35.12*	56.29**
$L_{11} \times T_2$	-9.44**	-5.84**	3.33	-18.98**	-9.70*	-6.65	15.65*	24.41**	23.35**	-12.82	-8.19	-7.97	-9.57	-0.08	18.76
$L_{11} \times T_3$	-7.37**	-2.69**	5.66	1.11	8.78*	7.68	-6.92	-1.48	11.65	-2.56	-1.19	-4.81	-45.88**	-42.27**	-18.76
$L_{11} \times T_4$	-1.76	-0.13**	12.12**	2.47	4.15	-3.16	-8.53	-4.43	6.70	-33.21**	-24.56	-17.69	-28.57*	-26.85	-6.19
$L_{11} \times T_5$	-173	-0.74**	14.44**	11.04**	14.83**	8.81*	-4.68	-3.95	1.65	7.03	10.05	7.57	-4.50	-2.30	31.33
$L_{12} \times T_1$	-0.61	4.59**	10.40**	20.26**	21.97**	20.26**	-8.07	-6.54	-5.00	-11.52	-10.26	-11.52	4.71	18.90	37.52*
$L_{12} \times T_2$	3.64	6.39**	15.15**	-14.64**	-7.39	-1.64	4.88	11.11	8.30	1.89	6.08	7.52	-23.86	-15.86	0.00
$L_{12} \times T_3$	3.03	6.89**	14.44**	-3.94	0.46	2.31	-20.83**	-14.91*	-5.00	14.51	14.86	11.92	37.50**	46.67**	106.38**
$L_{12} \times T_4$	-2.43	-2.14**	8.38**	18.38**	20.09**	15.07**	-5.70	0.02	10.00	-32.11**	-24.09**	-16.33	33.29*	36.50*	75.05**
$L_{12} \times T_5$	-3.75	-1.46**	12.12**	9.88*	10.33*	7.68	0.00	0.82	5.00	1.84	3.55	2.35	-18.14	-16.26	12.57

Crosses	Capsule Index			Days to maturity (days)			Seed yield (g/plant)			Dry husk capsule (g/plant)			Morphine (%)		
	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)
$L_1 \times T_1$	-22.97**	-17.09**	-10.02**	-5.40**	-1.29	-5.44**	-54.90**	-42.56*	-54.90**	-56.96**	-41.68	-56.97**	-15.15	2.75	-15.15
$L_1 \times T_2$	-8.78**	-1.35	6.79**	-2.59**	1.49	-2.97**	-26.39	-7.52	-27.36	-26.22	-2.64	-31.92	-62.50**	-48.20**	-45.45**
$L_1 \times T_3$	-20.27**	-18.11**	-6.31**	0.00	1.51	-5.61**	-31.75**	-6.10	-14.18	-8.44	23.35	-10.11	56.60**	-52.08*	-65.15**
$L_1 \times T_4$	-31.55**	-28.64**	-20.05**	5.939**	6.17**	-2.97**	16.95	56.01**	33.63*	8.06	48.22*	12.21	27.91*	70.54**	66.67**
$L_1 \times T_5$	-42.86**	-32.72**	-4.26**	-0.73	3.91**	-0.17	36.38	53.29*	-0.15	72.40*	78.33*	-11.97	-60.00**	-44.06**	-39.39*
$L_2 \times T_1$	-12.29**	-8.45**	-4.26**	-2.80**	-1.79*	-2.80**	-15.91	11.17	-15.91	-21.77	3.36	-21.77	-54.55**	-46.43*	-54.55**
$L_2 \times T_2$	-17.14**	-13.20**	-9.47**	-5.97**	-5.17**	-6.34**	0.08	32.33	0.15	-5.15	21.86	-12.48	-58.33**	-43.66**	-39.39*
$L_2 \times T_3$	-31.28**	-30.48**	-23.20**	-5.73**	-3.99**	-7.68**	-39.69**	-14.33	-24.17	-18.78	6.65	-20.26	-100.00**	-100.00**	-100.00**
$L_2 \times T_4$	-29.43**	-28.73**	-22.97**	1.15	4.74**	-0.95	-32.12*	-6.29	-22.44	-21.01	5.69	-17.98	-53.48**	-39.39*	-39.39*
$L_2 \times T_5$	-54.16**	-44.44**	-23.13**	-7.03**	-5.85**	-6.56**	59.29**	87.31**	16.63	128.79**	129.26**	17.52	-67.00**	-54.79**	-50.00**
$L_3 \times T_1$	-10.32**	-8.87**	-10.81**	-4.09**	1.30	-4.09**	-10.92	7.64	-10.92	-11.73	12.47	-11.73	-54.55**	-50.82**	-54.55**
$L_3 \times T_2$	13.96**	16.13**	13.34**	-6.53**	-1.45	-6.89**	-30.55*	-16.06	-30.51	-13.46	7.01	-20.15	-65.63**	-56.58**	-50.00**
$L_3 \times T_3$	-9.18**	-2.09	1.58	1.96*	4.76**	-3.76**	-8.03	20.93	15.65	1.54	28.52	-0.30	-10.71	-8.26	-24.24
$L_3 \times T_4$	24.12**	31.02**	32.83**	8.24**	9.35**	-1.29	-47.26**	-34.21*	-40.86**	-44.32*	-28.09	-42.18*	-76.74**	-71.83**	-69.69**
$L_3 \times T_5$	-30.15**	-11.09**	17.05**	-0.73	5.14**	-0.17	31.03	38.41	-3.97	81.65*	91.42**	3.48	-50.00**	-35.89*	-24.24
$L_4 \times T_1$	5.53**	10.36**	5.52**	-5.61**	-4.18**	-5.61**	29.27	46.94**	29.27	25.85	52.59*	25.85	-15.15	-5.88	-15.15
$L_4 \times T_2$	-2.14	2.07	-2.68	-1.13	0.17	-1.51*	-14.57	-2.96	-14.60	7.99	7.99	-15.11	-55.21**	-42.28**	-34.85*
$L_4 \times T_3$	4.96**	15.09**	16.81**	-1.39	-0.03	-4.32**	-38.62**	-23.47	-22.82	-33.90	-20.43	-35.11	-18.86	-18.87	-34.85*
$L_4 \times T_4$	-20.13**	-13.78**	-14.52**	1.50	4.65**	-1.51*	21.57	46.07**	38.92*	32.31	62.79**	37.38*	-73.25**	-66.91**	-65.15**
$L_4 \times T_5$	-53.23**	-39.43**	-21.63**	-0.56	1.22	0	81.75**	84.88**	37.90*	72.35*	92.82**	11.92	-57.00**	-43.79**	-34.85*
$L_5 \times T_1$	3.71*	11.60**	3.63*	-4.83**	-4.38**	-3.93**	-57.38**	-52.02**	-45.11**	-58.03**	-57.45**	-56.82**	-69.76**	-65.79**	-60.61**
$L_5 \times T_2$	9.28**	20.46**	11.52**	-5.56**	-4.92**	-4.66**	-44.72**	-37.77**	-28.79	-49.40**	-46.29*	-47.58*	-86.45**	-85.71**	-80.30**
$L_5 \times T_3$	-19.27**	12.95**	11.52**	-4.44**	-1.23	-3.53**	-64.75**	-64.33**	-54.59**	-53.90**	-52.85**	-52.58**	-61.63**	-52.52**	-50.00**
$L_5 \times T_4$	-8.88**	0.74	-2.92*	-5.00**	-0.18	-4.09**	-31.55**	-27.48*	-11.85	-25.25	-24.98	-22.42	-46.51**	-46.51**	-30.30
$L_5 \times T_5$	-53.55**	-38.49**	-22.09**	-5.56**	-5.37**	-4.66**	-20.72	1.06	2.11	-17.46	10.184	-15.09	-47.00**	-43.01**	-19.69
$L_6 \times T_1$	12.32**	16.13**	20.21**	-2.64**	-2.36**	-2.64**	34.79*	48.96**	34.82*	22.69	43.89*	22.69	34.85*	79.79**	34.85*
$L_6 \times T_2$	-0.74	2.98*	6.31**	-1.46	-1.38	-1.85*	-21.22	-12.93	-21.16	-28.78	-19.28	-34.29	-93.75**	-90.69**	-90.91**
$L_6 \times T_3$	-9.18**	-7.22**	1.49	-2.43**	0.12	-2.97**	-60.11**	-51.48**	-49.84**	-55.86**	-48.64*	-56.67**	-56.60**	-46.51	-65.15**
$L_6 \times T_4$	14.31**	14.31**	22.34**	-3.38**	0.79	-3.93**	-36.98**	-26.25	-27.99	-49.80**	-40.22	-47.88*	-58.14**	-39.49*	-45.45**
$L_6 \times T_5$	-58.55**	-49.35**	-30.47**	-2.96**	-2.41**	-2.41**	-58.68**	-56.60**	-66.53**	-39.79	-30.20	-57.53**	-50.00**	-24.81	-24.24

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Crosses	Capsule Index			Days to maturity (days)			Seed yield (g/plant)			Dry husk capsule (g/plant)			Morphine (%)		
	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)
$L_7 \times T_1$	-23.69**	-16.39**	-23.68**	-4.75**	-3.43**	-2.08*	11.29	42.15*	11.29	1.32	41.18	1.32	-19.69	7.07	-19.69
$L_7 \times T_2$	-5.55**	3.21*	-6.08**	-6.55**	-5.07**	-3.93**	-13.94	9.95	-13.88	-18.70	10.48	-24.98	-55.21**	-33.33	-34.85*
$L_7 \times T_3$	-20.69**	-8.77**	-11.37**	-9.06**	-5.23**	-6.56**	-28.42*	-1.26	-9.99	-14.15	18.96	-15.71	13.21	39.53	-9.09
$L_7 \times T_4$	0.74	13.24**	7.34**	-4.53**	1.19	-1.85*	-38.09*	-17.19	-29.27	-43.79*	-20.83	-41.67*	-61.63**	-44.54*	-50.00**
$L_7 \times T_5$	-40.17**	-19.85**	0.24	-6.93**	-5.90**	-4.32**	10.75	24.97	-18.88	49.70	61.75	-23.42	-67.00**	-50.38**	-50.00**
$L_8 \times T_1$	-27.80**	-26.32**	-24.78**	-4.66**	-6.23**	-8.41**	25.93	29.15	32.53*	41.60*	61.69**	41.61*	66.66**	108.33**	51.52**
$L_8 \times T_2$	-2.27	0.00	1.82	-2.59**	-0.46	-2.97**	-53.89**	-52.74**	-51.48**	-44.99*	-39.31	-49.19**	7.29	63.49**	56.06**
$L_8 \times T_3$	-8.51**	-5.70**	1.82	-1.00	-0.50	-5.61**	-13.07	-5.36	9.31	-4.10	8.64	-5.85	-32.07	-13.25	-45.45**
$L_8 \times T_4$	-19.91**	-18.76**	-14.21**	1.94*	4.21**	-2.80**	-17.57	-14.19	-5.82	-28.16	-16.65	-25.41	-75.00**	-65.52**	-69.69**
$L_8 \times T_5$	-0.94	22.16**	65.98**	-7.42**	-4.95**	-6.89**	25.68	48.22**	32.28*	62.50*	93.38**	22.12	3.00	58.46**	56.06**
$L_9 \times T_1$	13.64**	15.83**	18.39**	-6.15**	-5.96**	-5.78**	9.47	25.47	46.94**	2.56	17.50	37.53*	-14.28	-13.67	-9.09
$L_9 \times T_2$	5.29**	7.86**	9.94**	-5.81**	-5.44**	-5.44**	-58.35**	-52.28**	-44.09**	-75.74**	-71.26**	-67.47**	-23.95*	-13.61	10.60
$L_9 \times T_3$	45.19**	50.20**	62.35**	-0.56	2.51**	-0.17	-38.92**	-36.92**	-18.01	-37.13**	-27.41	-15.69	-27.39	-15.87	-19.69
$L_9 \times T_4$	-27.41**	-26.84**	-22.65**	-3.35**	1.29	-2.97**	-42.92**	-38.33**	-23.38	-54.95**	-49.22**	-39.59*	-37.50**	-37.11**	-24.24
$L_9 \times T_5$	-0.14	23.04**	67.32**	-5.02**	-4.94**	-4.49**	-22.73*	-0.02	3.71	-19.77	16.15	7.58	-60.00**	-53.76**	-39.39*
$L_{10} \times T_1$	-36.94**	-33.36**	-29.44**	-5.05**	-3.06**	-5.05**	36.36*	43.78**	36.36*	38.24*	44.59*	38.24*	-95.71**	-95.59**	-95.45**
$L_{10} \times T_2$	4.52**	10.61**	16.81**	-7.09**	-5.34**	-7.46**	83.96**	94.04**	84.09**	84.84**	85.91**	70.56**	7.29	24.09	56.06**
$L_{10} \times T_3$	-3.46**	-3.46**	7.89**	-0.41	0.38	-4.49**	-25.43*	-12.98	-6.27	-17.99	-14.98	-19.48	-38.57*	-30.08	-34.85*
$L_{10} \times T_4$	20.48**	23.09**	34.65**	-4.91**	-2.52**	-8.81**	-3.55	8.08	10.21	-1.02	5.34	2.73	-62.50**	-61.54**	-54.55**
$L_{10} \times T_5$	-23.41**	-8.05**	28.41**	-7.42**	-5.22**	-6.89**	58.34**	74.31**	41.99**	56.57**	100.64**	42.82*	30.00**	52.94**	96.97**
$L_{11} \times T_1$	-35.66**	-30.55**	-24.55**	-5.05**	-4.51**	-5.05**	1.78	10.84	21.69	25.50	28.02	25.50	-65.15**	-65.15**	-65.15**
$L_{11} \times T_2$	35.26**	46.39**	58.64**	-4.11**	-3.76**	-4.49**	-39.63**	-34.27*	-27.81	-39.47*	-38.26	-41.86*	-47.92**	-38.27**	-24.24

$L_{11} \times T_3$	-15.67**	-13.65**	-1.10	-1.53*	0.75	-2.64**	-68.91**	-68.13**	-60.90**	-46.60*	-46.02*	-47.58*	-30.30	-22.69	-30.30
$L_{11} \times T_4$	-4.71**	-0.28	11.84**	-6.63**	-2.86**	-7.68**	-25.79*	-24.10	-11.26	-24.33	-21.38	-21.43	-53.48**	-47.37**	-39.39*
$L_{11} \times T_5$	-28.26**	-15.59**	20.21**	-5.97**	-5.17**	-5.44**	-3.48	19.68	15.39	24.34	62.27*	19.44	-57.00**	-48.19**	-34.85*
$L_{12} \times T_1$	-25.93**	-6.62**	26.28**	-3.53**	-2.79**	-3.53**	15.65	18.84	15.65	-3.37	6.32	-3.38	-50.00**	-43.42**	-34.85*
$L_{12} \times T_2$	-35.65**	-18.71**	9.71**	-7.66**	-7.13**	-8.02**	-15.82	-13.45	-15.76	-29.33	-25.06	-34.79	-20.83	-16.48	15.15
$L_{12} \times T_3$	6.29**	28.47**	81.29**	-1.31	0.79	-2.80**	70.99**	95.14**	115.02**	83.84**	100.62**	80.50**	81.39**	124.46**	136.36**
$L_{12} \times T_4$	-48.94**	-37.26**	-12.94**	-2.28**	1.48	-3.76**	26.46*	38.35**	44.50**	49.36**	67.13**	55.09**	46.51**	46.51**	90.91**
$L_{12} \times T_5$	-2.77**	-1.94*	65.75**	-0.17	0.87	0.39	-2.45	9.98	-7.69	6.62	31.17	-12.83	-67.00**	-64.52**	-50.00**

Crosses	Codeine (%)			Thebaine (%)			Papervine (%)			Nosacapine (%)		
	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)
$L_1 \times T_1$	-62.96**	-48.72**	-62.96**	0.00	5.26	0.00	-81.54**	-78.76**	-75.00**	-10.13	12.99	52.14**
$L_1 \times T_2$	-3.68	18.06	-32.22**	-26.32	-19.42	-20.00	-66.92**	-61.26**	-55.21**	-59.07**	-51.13**	-30.71**
$L_1 \times T_3$	-13.41	16.39	-21.11**	-4.76	13.21	-14.29	66.15**	116.00**	125.00**	9.70	65.61**	85.71**
$L_1 \times T_4$	-25.7**	-5.45	-42.22**	79.36**	89.92**	61.43**	-64.62**	-59.29**	-52.08**	-69.20**	-65.24**	-47.86**
$L_1 \times T_5$	-34.18**	-4.85	-23.70**	-30.3	-28.68	-34.29	-35.38**	-16.00	-12.50	-46.41**	-44.42**	-9.29
$L_2 \times T_1$	-45.77**	-39.31**	-31.11**	-69.93**	-52.02**	18.57	-58.33**	-46.31*	-58.33**	-26.43*	-9.25	-26.43*
$L_2 \times T_2$	-16.62**	7.32	5.93	-81.88**	-71.59**	-28.57	-20.65	0.69	-23.96	-4.38	23.89	9.29
$L_2 \times T_3$	-64.14**	-58.23**	-54.44**	-94.20**	-89.97**	-77.14**	-42.85*	-34.96	-58.33**	18.39	25.61	-26.43*
$L_2 \times T_4$	-26.24**	-8.49	-6.29	-91.66**	-86.14**	-67.14**	35.42*	74.49**	35.42*	-21.86**	5.93	2.14
$L_2 \times T_5$	-22.45**	-18.90**	-1.48	-85.51**	-76.61**	-42.86*	34.28	52.85*	-2.08	-9.09	30.29**	42.86**
$L_3 \times T_1$	-20**	-4.64	-20.00*	-57.14**	-46.90	-57.14**	-31.25*	10.92	-31.25*	-21.43*	34.97	-21.43*
$L_3 \times T_2$	42.11**	44.77**	0.00	-78.95**	-73.10**	-77.14**	-17.39	32.17	-20.83	-1.88	71.58**	12.14
$L_3 \times T_3$	-41.66**	-34.73**	-48.15**	-30.23	-30.23	-57.14**	-34.28	-1.08	-52.08**	-5.19	46.00	-47.86**
$L_3 \times T_4$	-28.57**	-23.66*	-44.44**	-35.71	-27.27	-48.57*	-41.66**	-5.88	-41.67**	-16.39*	48.54**	9.29
$L_3 \times T_5$	-16.13*	4.84	-3.70	0.00	21.10	-5.71	57.14**	136.56**	14.58	-48.64**	-6.99	-19.29
$L_4 \times T_1$	-18.52*	-12.00	-18.52*	0.00	16.67	0.00	-20.83	-4.40	-20.83	-36.43**	-35.74**	-36.43**
$L_4 \times T_2$	14.35	25.24**	-2.59	-30.26	-15.87	-24.29	-45.65**	-35.48	-47.92**	-33.13**	-27.95**	-23.57*
$L_4 \times T_3$	-17.47*	-14.71	-24.81**	-10.71	35.48	-10.00	-5.71	-0.75	-31.25*	-48.91**	-34.58*	-50.00**
$L_4 \times T_4$	-49.56**	-47.27**	-57.04**	26.00	-5.66	-28.57	-55.21**	-45.91*	-55.21**	0.00	14.38	30.71**
$L_4 \times T_5$	15.97*	33.70**	34.44**	6.06	20.69	0.00	175.71**	190.23**	101.04**	13.64*	40.06**	78.57**
$L_5 \times T_1$	-54.44**	-36.92**	-54.44**	-84.91**	-81.82**	-77.14**	45.83**	64.71**	45.83**	-40.71**	-27.83*	-40.71**
$L_5 \times T_2$	106.84**	153.55**	45.56**	-43.39**	-34.07*	-14.29	44.56**	60.24**	38.54**	-1.88	25.60*	12.14
$L_5 \times T_3$	-26.83**	-1.64	-33.33**	-37.74**	-11.41	-5.71	43.24*	47.22*	10.42	3.33	11.38	-33.57**
$L_5 \times T_4$	-3.33	23.03	-24.81**	-62.26**	-50.62**	-42.86	-31.25*	-22.35	-31.25*	-52.46**	-36.26**	-37.86**
$L_5 \times T_5$	-28.75**	3.00	-17.41*	-52.83**	-41.86*	-28.57	25.67	29.17	-3.125	-30.45**	-1.29	9.29
$L_6 \times T_1$	-17.41*	32.74**	-17.41*	-62.85**	-52.73*	-62.86**	10.42	35.03	10.42	-19.29	18.95	-19.29
$L_6 \times T_2$	-3.68	42.97**	-32.22**	114.47**	181.03**	132.86**	178.26**	234.64**	166.67**	26.88**	93.33**	45.00**
$L_6 \times T_3$	-29.67**	10.89	-35.93**	651.16**	678.31**	361.43**	85.71**	98.47**	35.42*	90.90**	131.50**	5.00
$L_6 \times T_4$	-4.76	44.93**	-25.93**	553.57**	662.5**	422.86**	14.58	40.13*	14.58	-57.92**	-33.91*	-45.00**
$L_6 \times T_5$	-24.6**	24.54*	-12.59	96.96**	145.28**	85.71**	4.28	11.45	-23.96	-24.09**	23.70*	19.29

Contd…

Crosses	Codeine (%)			Thebaine (%)			Papervine (%)			Nosacapine (%)		
	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)	BP (%)	MP (%)	EP (%)
$L_7 \times T_1$	-30.07**	-29.30**	-28.52**	-14.28	29.03	-14.26	-23.95	-17.98	-23.96	-6.99	-6.01	-5.00
$L_7 \times T_2$	-9.42	7.29	-7.41	-60.53**	-39.39	-57.14**	-17.39	-12.64	-20.83	-10.63	-5.61	2.14
$L_7 \times T_3$	-39.85**	-36.39**	-38.52**	-53.48	-39.39	-71.43**	-31.71	-26.32	-41.67**	16.78	51.82**	19.29
$L_7 \times T_4$	59.42**	81.07**	62.96**	-41.07	-16.46	-52.86**	17.71	26.97	17.71	14.75	28.83**	50.00**
$L_7 \times T_5$	-53.35**	-50.42**	-45.93**	-54.55*	-32.58	-57.14**	9.75	18.42	-6.25	-45.45**	-33.88**	-14.29
$L_8 \times T_1$	-39.63**	-35.57**	-39.63**	132.85**	132.86**	132.86**	7.29	29.56	7.29	21.43*	64.25**	21.43*
$L_8 \times T_2$	22.88**	36.15**	7.41	-34.21	-31.51	-28.57	-20.65	-5.81	-23.96	54.38**	117.62**	76.43**
$L_8 \times T_3$	-14.63	-12.86	-22.22**	104.28**	153.09**	104.29**	47.14*	54.89*	7.29	146.75**	163.89**	35.71**
$L_8 \times T_4$	-30.93**	-26.91**	-39.63**	-81.43**	-79.37**	-81.43**	-62.50**	-54.72**	-62.50**	-63.39**	-46.40**	-52.14**
$L_8 \times T_5$	-55.27**	-48.99**	-48.15**	-14.28	-11.76	-14.29	-67.14**	-65.41**	-76.04**	-33.18**	2.44	5.00
$L_9 \times T_1$	-69.25**	-60.76**	-69.26**	-52.85**	-37.74	-52.86**	45.83**	141.38**	45.83**	14.29	52.38**	14.29
$L_9 \times T_2$	33.15**	47.52**	-6.29	-69.74**	-58.93*	-67.14**	73.91**	185.71**	66.67**	-56.25**	-39.13**	-50.00**
$L_9 \times T_3$	-4.06	18.29	-12.59	-46.51	-41.77	-67.14**	8.57	68.89*	-20.83	-9.09	-4.76	-50.00**
$L_9 \times T_4$	52.38**	76.31**	18.52*	7.14	30.43	-14.29**	-6.25	55.17*	-6.25	-36.07**	-7.51	-16.43
$L_9 \times T_5$	-28.75**	-4.29	-17.41*	112.12**	174.51**	100.00**	4.28	62.22*	-23.96	-15.00*	28.97**	33.57**
$L_{10} \times T_1$	-40.29**	-39.96**	-39.63**	-34.28	-23.33	-34.29	-45.83**	-23.53	-45.83**	-33.57**	-29.28*	-33.57**
$L_{10} \times T_2$	-23.07**	-9.29	-22.22**	131.57**	179.37**	151.43**	113.04**	196.97*	104.17**	73.13**	95.76**	97.86**
$L_0 \times T_3$	-54.95**	-52.60**	-54.44**	120.00**	136.56**	57.14**	-42.85*	-27.27	-58.33**	-48.78**	-37.00*	-55.00**
$L_{10} \times T_4$	23.07**	39.13**	24.44**	-28.57	-24.53	-42.86*	69.79**	139.71*	69.79**	7.65	28.76**	40.71**

$L_{10} \times T_5$	-34.18**	-29.69**	-23.70**	203.03**	244.83**	185.71**	280.00**	383.64*	177.08**	-48.64**	-34.11**	-19.29
$L_{11} \times T_1$	-22.22**	-0.71	-22.22**	-67.14**	-63.49**	-67.14**	-41.66**	-34.88*	-41.67**	3.59	12.70	23.57*
$L_{11} \times T_2$	-36.84**	-30.03*	-55.56**	-78.95**	-75.76**	-77.14**	-28.26	-21.43	-31.25*	-53.89**	-52.91**	-45.00**
$L_{11} \times T_3$	-63.41**	-54.89**	-66.67**	-23.21	-13.13	-38.57	-55.26**	-53.42**	-64.58**	-10.18	22.95	7.14
$L_{11} \times T_4$	-17.62	-4.68	-35.93**	35.71	35.71	8.57	0.00	11.63	0.00	-14.21	-10.29	12.14
$L_{11} \times T_5$	-57.51**	-42.92**	-50.74**	166.66**	188.52**	151.43**	-25.00	-21.92	-40.63**	-69.55**	-65.37**	-52.14**
$L_{12} \times T_1$	-70.37**	-61.54**	-70.37**	-28.57	-28.57	-28.57	-34.37*	-34.03*	-34.38*	-60.78**	-59.04**	-57.14**
$L_{12} \times T_2$	-10.53	1.19	-37.04**	-7.89	-4.11	0.00	-20.00	-18.72	-20.83	-35.63**	-34.19**	-26.43*
$L_{12} \times T_3$	47.56**	85.20**	34.44**	542.85**	696.46**	542.86**	478.95**	566.67**	472.92**	74.51**	132.17**	90.71**
$L_{12} \times T_4$	53.81**	81.46**	19.63**	471.43**	534.92**	471.43**	281.25**	283.25**	281.25**	31.15**	42.86**	71.43**
$L_{12} \times T_5$	-53.35**	-36.38**	-45.93**	-24.28	-22.06	-24.286	-48.42**	-40.60*	-48.96**	-16.82*	-1.88	30.71**

Where, * = $p < 0.05\%$; ** = $p < 0.001\%$; S.E.M. = Standard Error of Mean, (BP) = Better Parent; (EP) =Economic Parent; (MP) = Mid/average parent and **(-)** = No heterosis except for the trait days to 50% flowering and plant height

Table 3: Expression of the best heterosis over economic parent (c.v. CIMAP Ajay) among all the crosses in relation with the fourteen traits.

Traits	Crosses									
X_1	$L_4 \times T_4$	-	-	-	-	-	-	-	-	-
X_2	$L_4 \times T_4$	-	-	$L_9 \times T_1$	-	-	-	-	-	-
X_3	$L_4 \times T_4$	-	-	-	-	$L_{10} \times T_4$	-	-	-	-
X_4	$L_4 \times T_4$	$L_4 \times T_1$	-		-	-	-	-	-	-
X_5	$L_4 \times T_4$	$L_4 \times T_1$	$L_6 \times T_1$	-	-	-	$L_{10} \times T_2$	$L_{10} \times T_5$	$L_{12} \times T_3$	$L_{12} \times T_4$
X_6	-	$L_4 \times T_1$	$L_6 \times T_1$	$L_9 \times T_1$	-	$L_{10} \times T_4$	$L_{10} \times T_2$	$L_{10} \times T_5$	$L_{12} \times T_3$	-
X_7	-	-	-	-	-	$L_{10} \times T_4$	-	-	-	-
X_8	$L_4 \times T_4$	-	$L_6 \times T_1$	$L_9 \times T_1$	-	-	$L_{10} \times T_2$	$L_{10} \times T_5$	$L_{12} \times T_3$	$L_{12} \times T_4$
X_9	$L_4 \times T_4$	$L_4 \times T_1$	-	$L_9 \times T_1$	-	-	$L_{10} \times T_2$	$L_{10} \times T_5$	$L_{12} \times T_3$	$L_{12} \times T_4$
X_{10}	-	-	$L_6 \times T_1$	-	-	-	$L_{10} \times T_2$	$L_{10} \times T_5$	$L_{12} \times T_3$	$L_{12} \times T_4$
X_{11}	-	-	-	-	$L_4 \times T_5$	$L_{10} \times T_4$	-	-	$L_{12} \times T_3$	$L_{12} \times T_4$
X_{12}	-	-	-	-	-	-	$L_{10} \times T_2$	$L_{10} \times T_5$	$L_{12} \times T_3$	$L_{12} \times T_4$
X_{13}	-	-	-	$L_9 \times T_1$	-	$L_{10} \times T_4$	$L_{10} \times T_2$	$L_{10} \times T_5$	$L_{12} \times T_3$	$L_{12} \times T_4$
X_{14}	$L_4 \times T_4$	-	-	-	$L_4 \times T_5$	$L_{10} \times T_4$	$L_{10} \times T_2$	-	$L_{12} \times T_3$	$L_{12} \times T_4$
Total=	8	4	4	5	2	6	8	7	9	8

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 (g/plant); X_9= Dry husk capsule (g/plant); X_{10} = Morphine (%); X_{11}= Codeine(%); X_{12} = Thebaine(%); X_{13} = Papervine(%); X_{14} = Nosacapine (%).

3.1 Days to 50% flowering

Since, early flowering is a desirable character in *Papaver somniferum* L. crop therefore; crosses towards significant negative heterosis were selected. Crosses $L_1 \times T_4$, $L_1 \times T_5$, $L_2 \times T_3$, $L_2 \times T_4$, $L_2 \times T_5$, $L_3 \times T_1$, $L_4 \times T_4$, $L_6 \times T_1$, $L_6 \times T_2$, $L_6 \times T_3$, $L_6 \times T_4$, $L_6 \times T_5$, $L_7 \times T_5$, $L_9 \times T_2$, $L_9 \times T_3$, $L_9 \times T_4$, $L_9 \times T_5$, $L_{10} \times T_5$, $L_{11} \times T_1$, $L_{11} \times T_2$ and $L_{11} \times T_3$ were highly significant showing negative heterosis over better parent. On the other hand, crosses $L_1 \times T_2$, $L_1 \times T_4$, $L_1 \times T_5$, $L_2 \times T_3$, $L_2 \times T_4$, $L_2 \times T_5$, $L_3 \times T_1$, $L_3 \times T_2$, $L_4 \times T_4$, $L_4 \times T_5$, $L_5 \times T_5$, $L_6 \times T_1$, $L_6 \times T_2$, $L_6 \times T_3$, $L_6 \times T_4$, $L_6 \times T_5$, $L_7 \times T_5$, $L_9 \times T_2$, $L_9 \times T_3$, $L_9 \times T_4$, $L_9 \times T_5$, $L_{10} \times T_5$, $L_{11} \times T_1$, $L_{11} \times T_2$, $L_{11} \times T_3$, $L_{11} \times T_4$, $L_{11} \times T_5$, $L_{12} \times T_4$ and $L_{12} \times T_5$ exhibited negative heterosis over the mid parent. Whereas, only one hybrid namely $L_4 \times T_4$ which demonstrated negative heterosis over the economic parent and favoured the early flowering.

3.2 Plant height (cm)

For plant height (cm) medium height plant are desirable to avoid lodging problems in opium poppy. Therefore, from the overall crosses it was found that the hybrids $L_1 \times T_2$, $L_2 \times T_2$, $L_3 \times T_1$, $L_3 \times T_2$, $L_3 \times T_3$, $L_3 \times T_4$, $L_4 \times T_2$, $L_5 \times T_2$, $L_6 \times T_2$, $L_6 \times T_3$, $L_8 \times T_2$, $L_9 \times T_1$, $L_9 \times T_2$, $L_{10} \times T_1$, $L_{11} \times T_1$, $L_{11} \times T_2$ and $L_{12} \times T_2$ exhibited significantly negative heterosis over the better parent and considered desirable for the trait plant height. The crosses showed significant negative hetrosis $L_3 \times T_1$, $L_3 \times T_2$, $L_3 \times T_3$, $L_9 \times T_1$ and $L_{11} \times T_2$ over the mid parent. While, significant negative hetrosis were exhibited by hybrids namely, $L_3 \times T_1$, $L_3 \times T_3$, $L_9 \times T_1$ and $L_{11} \times T_1$ over the economic parent and counted desirable for plant height. Consonance, results of negative heterosis for the traits days to 50% flowering and plant height were also reported by (Dodiya *et al.*, 2005; Dubey *et al.*, 2007; Singh & Pandey, 2011 and Khatik *et al.*, 2017) [2, 3, 16,12]. Whereas, the crosses towards positive heterosis over better parent, mid parent as well as economic parent for plant height estimated was undesirable.

3.3 No. of leaves/plant

From the overall study of crosses it was observed that hybrids, namely $L_5 \times T_2$, $L_8 \times T_2$ and $L_{11} \times T_2$ exhibited significantly positive heterosis over better parent. The hybrids $L_4 \times T_2$, $L_5 \times T_2$, $L_7 \times T_2$, $L_8 \times T_1$, $L_8 \times T_2$ and $L_{11} \times T_2$ were positively significant over the mid parent and hybrids namely $L_4 \times T_2$, $L_4 \times T_4$, $L_{10} \times T_4$ and $L_{11} \times T_2$ exhibited significantly positive heterosis over the economic parent for no. of leaves/plant and found desirable. Although, hybrids exhibited towards negative heterosis over better parent, mid parent and over economic parent were considered undesirable.

3.4 Pedicel length

Hybrids $L_1 \times T_2$, $L_2 \times T_1$ and $L_2 \times T_3$ were highly positive significant over better parent. Whereas, hybrids namely $L_1 \times T_1$, $L_1 \times T_2$, $L_2 \times T_1$, $L_2 \times T_3$ and $L_8 \times T_1$were positively significant over mid parent. On the other hand crosses namely, $L_1 \times T_1$, $L_1 \times T_2$, $L_2 \times T_1$, $L_2 \times T_3$, $L_4 \times T_1$, $L_4 \times T_4$ and $L_8 \times T_4$ were positively significant over the economic parent and considered desirable.

3.5 No. of capsule/plant

From all over the crosses it was observed that hybrids namely $L_1 \times T_4$, $L_4 \times T_1$, $L_4 \times T_4$, $L_6 \times T_1$, $L_7 \times T_1$, $L_8 \times T_5$, $L_{10} \times T_2$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ were found highly positive significant over better, mid and economic parent. Whereas, hybrids namely

$L_1 \times T_5$, $L_3 \times T_3$, $L_4 \times T_2$, $L_5 \times T_4$, $L_5 \times T_5$ and $L_{12} \times T_1$ over economic parent and $L_2 \times T_2$, $L_8 \times T_1$ and $L_{11} \times T_1$ over both mid as well as economic parent were obtained significant positive heterosis and desirable for no. of capsule/plant.

3.6 Capsule index
The hybrids namely $L_3 \times T_2$, $L_3 \times T_4$, $L_4 \times T_1$, $L_4 \times T_3$, $L_5 \times T_1$, $L_5 \times T_2$, $L_6 \times T_1$, $L_6 \times T_4$, $L_9 \times T_1$, $L_9 \times T_2$, $L_9 \times T_3$, $L_{10} \times T_2$, $L_{10} \times T_4$, $L_{11} \times T_2$ and $L_{12} \times T_3$ were found high positive significant heterosis over better, mid and economic parent. Whereas, hybrid $L_7 \times T_2$ over mid parent; hybrids $L_1 \times T_2$, $L_3 \times T_5$, $L_{10} \times T_3$, $L_{10} \times T_5$, $L_{11} \times T_4$, $L_{11} \times T_5$, $L_{12} \times T_1$, $L_{12} \times T_2$ and $L_{12} \times T_5$ over economic parent and hybrids namely $L_5 \times T_3$, $L_6 \times T_2$, $L_7 \times T_4$, $L_8 \times T_5$ and $L_9 \times T_5$ heterosis over mid as well as over economic parent were found positively significant for capsule index.

3.7 Days to maturity (days)
As the late maturity is a desirable character for *P. somniferum* L. so the hybrids toward positive direction were estimated over better parent *viz*. $L_1 \times T_4$, $L_3 \times T_3$, $L_3 \times T_4$ and $L_8 \times T_4$. Similarly, hybrids $L_1 \times T_4$, $L_1 \times T_5$, $L_2 \times T_4$, $L_3 \times T_3$, $L_3 \times T_4$, $L_3 \times T_5$, $L_4 \times T_4$, $L_8 \times T_4$ and $L_9 \times T_3$ were obtained significant positive heterosis over mid parent. Alike, excluding few non-significant negative crosses namely $L_1 \times T_5$, $L_2 \times T_4$, $L_3 \times T_4$, $L_3 \times T_5$, $L_4 \times T_5$, $L_9 \times T_3$ and $L_{12} \times T_5$ all were highly negative significant over economic parent for days to maturity but, the maximum negative and significant heterosis was observed in $L_{10} \times T_4$ (-8.81**) and non-significant positive hybrid was found for $L_{12} \times T_5$ (0.39).

3.8 Seed yield (g/plant)
The hybrids $L_2 \times T_5$, $L_4 \times T_5$, $L_6 \times T_1$, $L_{10} \times T_1$, $L_{10} \times T_2$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ were highly positive significant over better parent. Whereas, hybrids $L_1 \times T_4$, $L_1 \times T_5$, $L_2 \times T_5$, $L_4 \times T_1$, $L_4 \times T_4$, $L_4 \times T_5$, $L_6 \times T_1$, $L_7 \times T_1$, $L_8 \times T_5$, $L_{10} \times T_1$, $L_{10} \times T_2$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ exhibited positive and highly significant heterosis over the mid parent. However, highly significant positive heterosis was exhibited by the hybrids $L_1 \times T_4$, $L_4 \times T_4$, $L_4 \times T_5$, $L_6 \times T_1$, $L_8 \times T_1$, $L_8 \times T_5$, $L_9 \times T_1$, $L_{10} \times T_1$, $L_{10} \times T_2$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ over the economic parent moreover, the heterosis towards negative direction were undesirable for seed yield (g/plant).

3.9 Dry husk capsule (g/plant)
Hybrids $L_1 \times T_5$, $L_2 \times T_5$, $L_3 \times T_5$, $L_4 \times T_5$, $L_8 \times T_1$, $L_8 \times T_5$, $L_{10} \times T_1$, $L_{10} \times T_2$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ expressed highly significant positive heterosis over the better parent. Whereas, hybrids $L_1 \times T_4$, $L_1 \times T_5$, $L_2 \times T_5$, $L_3 \times T_5$, $L_4 \times T_1$, $L_4 \times T_4$, $L_4 \times T_5$, $L_6 \times T_1$, $L_8 \times T_1$, $L_8 \times T_5$, $L_{10} \times T_1$, $L_{10} \times T_2$, $L_{10} \times T_5$, $L_{11} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ exhibited highly significant positive heterosis over the mid parent for the character dry husk capsule yield/plant. However, among all the hybrids the crosses namely, $L_4 \times T_4$, $L_8 \times T_1$, $L_9 \times T_1$, $L_{10} \times T_1$, $L_{10} \times T_2$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ showed highly significant positive heterosis over the economic parent.

3.10 Morphine (%)
Among all the hybrids, crosses $L_1 \times T_3$, $L_1 \times T_4$, $L_6 \times T_1$, $L_8 \times T_1$, $L_{12} \times T_3$, $L_{12} \times T_4$ and $L_{10} \times T_5$ exhibited significant positive heterosis over better parent. Hybrids $L_1 \times T_4$, $L_6 \times T_1$, $L_8 \times T_1$, $L_8 \times T_2$, $L_8 \times T_5$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ were found positive significant over the mid parent. Likewise, hybrids namely $L_1 \times T_4$, $L_6 \times T_1$, $L_8 \times T_1$, $L_8 \times T_2$, $L_8 \times T_5$, $L_{10} \times T_2$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ were recorded positive and highly significant over the economic parent and found desirable for the trait morphine alkaloid content in percent.

3.11 Codeine (%)
The hybrids namely, $L_3 \times T_2$, $L_4 \times T_5$, $L_5 \times T_2$, $L_7 \times T_4$, $L_8 \times T_2$, $L_9 \times T_2$, $L_9 \times T_4$, $L_{10} \times T_4$, $L_{12} \times T_3$ and $L_{12} \times T_4$ were found positive and high significant over the better parent. Similarly, hybrids $L_3 \times T_2$, $L_4 \times T_2$, $L_4 \times T_5$, $L_5 \times T_2$, $L_6 \times T_1$, $L_6 \times T_2$, $L_6 \times T_4$, $L_6 \times T_5$, $L_7 \times T_4$, $L_8 \times T_2$, $L_9 \times T_2$, $L_9 \times T_4$, $L_{10} \times T_4$, $L_{12} \times T_3$ and $L_{12} \times T_4$ were found positively and highly significant over the mid parent. Although, hybrids $L_4 \times T_5$, $L_5 \times T_2$, $L_7 \times T_4$, $L_9 \times T_4$, $L_{10} \times T_4$, $L_{12} \times T_3$ and $L_{12} \times T_4$ were found positively and highly significant over the economic parent and considered desirable for the trait codeine content (%).

3.12 Thebaine (%)
Hybrids $L_1 \times T_4$, $L_6 \times T_2$, $L_6 \times T_3$, $L_6 \times T_4$, $L_6 \times T_5$, $L_8 \times T_1$, $L_8 \times T_3$, $L_9 \times T_5$, $L_{10} \times T_2$, $L_{10} \times T_3$, $L_{10} \times T_5$, $L_{11} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ were found positively and highly significant over better parent, mid parent as well as over economic parent for thebaine content.

3.13 Papervine (%)
All the hybrids, namely $L_1 \times T_3$, $L_2 \times T_4$, $L_4 \times T_5$, $L_5 \times T_1$, $L_5 \times T_2$, $L_6 \times T_2$, $L_6 \times T_3$, $L_9 \times T_1$, $L_9 \times T_2$, $L_{10} \times T_2$, $L_{10} \times T_4$, $L_{10} \times T_5$, $L_{12} \times T_3$ and $L_{12} \times T_4$ were found positive and significant heterosis over better, mid and economic parent. Moreover, hybrids namely $L_3 \times T_5$, $L_5 \times T_3$ and $L_8 \times T_3$ was found highly and positively significant over better and mid parent for heterosis. Whereas, $L_2 \times T_5$, $L_6 \times T_4$, $L_9 \times T_3$, $L_9 \times T_4$ and $L_9 \times T_5$ were found positive and high significant over mid parent for papervine alkaloid content (%).

3.14 Nosacapine (%)
From all over the hybrids namely $L_4 \times T_5$, $L_6 \times T_2$, $L_8 \times T_1$, $L_8 \times T_2$, $L_8 \times T_3$, $L_{10} \times T_2$, $L_{12} \times T_3$ and $L_{12} \times T_4$ were found significant positive heterosis over better, mid and economic parent. Moreover, hybrid $L_6 \times T_3$ over both better as well as mid parent, hybrids $L_3 \times T_2$, $L_3 \times T_4$, $L_5 \times T_2$, $L_6 \times T_5$, $L_7 \times T_3$ and $L_9 \times T_1$ over mid parent, hybrids namely $L_1 \times T_1$, $L_4 \times T_4$, $L_{11} \times T_1$ and $L_{12} \times T_5$ over economic parent and crosses $L_1 \times T_3$, $L_2 \times T_5$, $L_7 \times T_4$, $L_9 \times T_5$ and $L_{10} \times T_4$ over both mid as well as economic parent were found significant positively heterosis and estimated desirable for nosacapine alkaloid content in percent.
From the overall study, it is clear that the hybrid $L_1 \times T_4$ exhibited best heterosis over BP in four traits – days to 50% flowering, no. of capsule, days to maturity and morphine alkaloid content (%). $L_6 \times T_3$ demonstrated best heterosis over better parent in traits – days to 50% flowering, plant height, thebaine, papervine and nosacapine alkaloid content (%). $L_{12} \times T_3$ and $L_{12} \times T_4$ showed best heterosis over better parent for capsule index, no of capsule/plant, seed yield (g/plant), dry husk capsule (g/plant), morphine, codeine, thebaine, papervine and nosascapine alkaloid content (%). Whereas, the hybrids $L_{10} \times T_2$ and $L_{10} \times T_5$ for no. of capsule/plant, seed yield (g/plant), dry husk yield (g/plant) and $L_{10} \times T_5$ for morphine while, $L_{10} \times T_2$ for thebaine, papervine and nosacapine alkaloid content in percent.
However, the hybrid $L_4 \times T_4$ exhibited the best heterosis over economic parent in traits, namely- days to 50% flowering, no. of leaves/plant, pedicel length, no. of capsule, seed yield, dry husk yield and nosacapine; while, $L_9 \times T_1$, exhibited the best heterosis over economic parent for plant height, capsule index, seed yield (g/plant), dry husk yield (g/plant) and papervine; $L_6 \times T_1$ for capsule index, no. of capsule, seed yield and morphine content (%); $L_{10} \times T_4$ for no. of leaves/plant, days

to maturity, capsule, index, codeine content (%), papervine and nosacapine content (%); however crosses $L_{10}\times T_2$, $L_{10}\times T_5$, $L_{12}\times T_3$ and $L_{12}\times T_4$ exhibited the best heterosis over economic parent for the traits, namely- no. of capsule, capsule index, seed yield (g/plant), dry husk yield (g/plant), morphine, thebaine, papervine and nosacapine alkaloid content (%) and consequently $L_{12}\times T_3$, $L_{12}\times T_4$ for codeine content (%) and $L_4\times T_5$ for codeine and nosacapine content (%) both (Table-3). Hence, it is clear from above result that these superior promising crosses can be recommended for exploitation of heterosis to obtain appropriate segregants for crop improvement program in opium poppy. Consequently, high heterosis for morphological traits and alkaloid content was also reported in *Papaver somniferum* by (Patidar, 1994; Dubey *et al*., 2007; Yadav *et al*., 2007; Kumar *et al*., 2008; Singh & Pandey, 2011; Khatik *et al*., 2017; Valizadeh *et al*., 2017; Dogramaci & Arslan, 2019; Nesara *et al*., 2020 and Yazıcı & Yılmaz, 2020) [15, 3, 32, 11, 16, 12, 28, 4, 13, 34].

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