

HETEROSIS AND INBREEDING DEPRESSION FOR SEED YIELD AND ITS COMPONENT TRAITS IN CASTOR (*Ricinus communis* L.)

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ABSTRACT

The present investigation was undertaken with a view to generate genetic information on heterosis and inbreeding depression for seed yield and its component traits. The heterosis over better parent was significant and positive in all four crosses for days to flowering of primary raceme and days to maturity of primary raceme, indicates delay in flowering and maturity in hybrid combinations. The heterosis over better parent was significant and negative for dwarf stature in cross SKP 84 x JI 437. The heterosis over better parent was significant and positive for longer length of primary raceme in crosses JP 104 x JI 433 and SKP 84 x JI 441, for effective length of primary raceme in cross JP 104 x JI 433, for shelling out turn in cross SKP 84 x JI 437, for test weight in SKP 84 x JI 441, and for oil content in JP 104 x JI 433 and SKP 84 x JI 433. The heterobeltiosis was significant and negative in crosses JP 104 x JI 433, SKP 84 x JI 433 and SKP 84 x JI 441 for seed yield per plant. Moderate inbreeding depression was observed in the present study as a whole. The observed and the expected estimates for heterosis over mid parent, over better parent and inbreeding depression were in close agreement with one another for days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, 100 seed weight and oil content in all four crosses.

KEY WORDS: *Castor, Heterosis, Heterobeltiosis, Inbreeding depression, gene model*

INTRODUCTION

Castor (*Ricinus communis* L., $2n = 2x = 20$) is an industrially an important non-edible oilseed crop widely cultivated in the arid and semi-arid regions of the world. Castor is a sexually polymorphic species with different sex forms viz., monoecious, pistillate, hermaphrodite and pistillate with interspersed staminate flowers (ISF).

The phenomenon of heterosis has proved to be the most important genetic tool in enhancing the yield of cross pollinated

species in general and castor in particular. Heterosis breeding is an important crop improvement method adopted in many crops all over the world. On the other hand, the inbreeding depression reflects through the reduction in vigour. It is a quick and convenient way of combining desirable characters which has assumed greater significance in the production of F_1 hybrids. Therefore, estimation of heterosis and inbreeding depression is of immense importance for development of hybrids in

castor. The study of nature and magnitude of heterosis is useful in identifying superior cross combinations and its exploitation to get better transgressive segregates. Moreover, the study of heterosis *vis-a-vis* analysis of genetic effects provides understanding of genetic basis of observed heterosis.

MATERIALS AND METHODS

The basic set of twelve generations viz., P_1 , P_2 , F_1 , F_2 , B_1 ($F_1 \times P_1$), B_2 ($F_1 \times P_2$), B_{1S} (B_1 selfed), B_{11} ($B_1 \times P_1$), B_{12} ($B_1 \times P_2$), B_{2S} (B_2 selfed), B_{21} ($B_2 \times P_1$) and B_{22} ($B_2 \times P_2$) derived in four castor crosses namely JP 104 $\times$ JI 433 (cross 1), SKP84 $\times$ JI 433 (cross 2), SKP 84 $\times$ JI 437 (cross 3) and SKP84 $\times$ JI441 (cross 4) were sown in compact family block design with three replications at Sagdividi Farm, Department of Seed Science and Technology, Junagadh Agricultural University, Junagadh during *kharif* 2017-18. The plots of various generations contained different number of rows i.e., parents and F_1 in single row; B_1 and B_2 in three rows and F_2 , B_{1S} , B_{11} , B_{12} , B_{2S} , B_{21} and B_{22} in five rows. Each row was of 6.0 m in length with 120 cm and 45 cm inter and intra row spacing, respectively. All the recommended agronomical practices and necessary plant protection measures were followed timely to raise a good crop. Observations were recorded on individual plant basis in each replication on randomly selected five plants from P_1 , P_2 and F_1 ; fifteen plants from first backcross (B_1 and B_2) and twenty five plants of F_2 , B_{1S} , B_{11} , B_{12} , B_{2S} , B_{21} , B_{22} generations for twelve traits including seed yield per plant. The heterotic effects in term of superiority of F_1 over better parent (heterobeltiosis) as per Fonseca and Patterson (1968); over mid parent value (relative heterosis) as per Brigg (1963); and inbreeding depression was worked out as loss in vigour due to inbreeding and difference between mean of F_1 and F_2 . The expected heterosis and

inbreeding depression for different characters were calculated as under. All notations were used as per Mather and Jink (1977).

1) Heterosis over better parent

$$(i) F_1 - \bar{P}_1 = [h] - [d]$$

$$(ii) F_1 - \bar{P}_2 = [h] - [-d]$$

2) Heterosis over mid parent = $[h]$

3) Inbreeding depression = $[h]/2$

For the characters where the digenic interaction model was found adequate, the expected heterosis and inbreeding depression were determined using the parameters of best fitting model. For example, the expectation of heterosis and inbreeding depression measured on a six parameters scale had the following form,

1) Heterosis over better parent

$$(i) \bar{F}_1 - \bar{P}_1 = ([h] + [1]) - ([d] + [i])$$

$$(ii) \bar{F}_1 - \bar{P}_2 = ([h] + [1]) - (-[d] + [i])$$

2) Heterosis over mid parent = $([h] + [1]) - [i]$

3) Inbreeding depression = $(1/2)[h] + (3/4)[1]$

For the characters where the trigenic interaction model was found adequate, the expected heterosis and inbreeding depression were calculated as under:

1) Heterosis over better parent

$$(i) \bar{F}_1 - \bar{P}_1 = ([h] + [1] + [z]) - ([d] + [i] + [w])$$

$$(ii) \bar{F}_1 - \bar{P}_2 = ([h] + [1] + [z]) - (-[d] + [i] - [w])$$

2) Heterosis over mid parent = $([h] + [1] + [z]) - [i]$

3) Inbreeding depression = $(1/2)[h] + (3/4)[1] + (7/8)[z]$

Where, (d) = Additive gene effect, (h) = Dominance gene effect, (i) = Additive x additive gene effect, (j) = Additive x dominance gene effect, (l) = Dominance x dominance gene effect, (w) = Additive x additive x additive gene effect, (x) = Additive x additive x dominance gene effect, (y) = Additive x dominance x dominance gene effect and (z) = Dominance x dominance x dominance gene effect.

RESULTS AND DISCUSSION

The perusal of results presented in Table 1 indicated that the extent of heterosis over mid-parent and better parent was

pronounced for various characters recorded in four crosses. For the characters like days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme and number of nodes up to primary raceme, the low scoring parent was taken as better parent. The heterosis over better parent was significant and positive in all four crosses viz., JP 104 x JI 433, SKP 84 x JI 433, SKP 84 x JI 437 and SKP 84 x JI 441 for days to flowering of primary raceme and days to maturity of primary raceme, indicates delay in flowering and maturity in hybrid combinations. The heterosis over better parent was significant and positive for tall plant height in one cross, JP 104 x JI 433 and significant and negative for dwarf stature in cross SKP 84 x JI 437. Similarly, for more number of nodes up to primary raceme, crosses SKP 84 x JI 437 and SKP 84 x JI 441 manifested significant and positive heterobeltiosis. The heterosis over better parent was significant and positive for longer length of primary raceme in crosses JP 104 x JI 433 and SKP 84 x JI 441, while it was noted significant and negative for shorter length of primary raceme in cross SKP 84 x JI 433 and SKP 84 x JI 437. Similar results were reported for effective length of primary raceme, except cross SKP 84 x JI 441, which was non-significant. The heterosis over better parent was noted significant and negative for number of effective branches per plant in cross SKP 84 x JI 437 and for number of capsules on primary raceme in cross SKP 84 x JI 441. The heterosis over better parent was significant and positive for higher shelling out turn in cross SKP 84 x JI 437, while it was noted significant and negative for lower shelling out turn in all the remaining three crosses. The heterosis over better parent was noted significant and positive for higher test weight in cross SKP 84 x JI 441. The heterobeltiosis was significant and negative in crosses JP 104 x

JI 433, SKP 84 x JI 433 and SKP 84 x JI 441 for seed yield per plant, while it was noted significant and positive in crosses JP 104 x JI 433 and SKP 84 x JI 433 for high oil content and significant and negative in crosses SKP 84 x JI 437 and SKP 84 x JI 441 for low oil content.

The heterosis over mid-parent was significant and positive for days to flowering in three crosses JP 104 x JI 433, SKP 84 x JI 433 and SKP 84 x JI 437 and for days to maturity in all four crosses JP 104 x JI 433, SKP 84 x JI 433, SKP 84 x JI 437 and SKP 84 x JI 441, which indicates the lateness in flowering and maturity. The heterosis over mid parent was significant and positive for tall plant height in cross JP 104 x JI 433 and significant and negative for shorter plant height in cross SKP 84 x JI 437. The relative heterosis was noted significant and positive in crosses SKP 84 x JI 437 and SKP 84 x JI 441 for number of nodes up to primary raceme. The heterosis over mid-parent was significant and positive for longer effective length of primary raceme in crosses JP 104 x JI 433 and SKP 84 x JI 441, while it was noted significant and negative for shorter effective length of primary raceme in cross SKP 84 x JI 433 and SKP 84 x JI 437. Similar results were reported for length of primary raceme, except cross SKP 84 x JI 433, which was non-significant. The heterosis over mid-parent was noted significant and negative for number of effective branches per plant in cross SKP 84 x JI 437. The heterosis over mid-parent was noted significant and negative for number of capsules on primary raceme in cross SKP 84 x JI 441, while it was significant and positive in SKP 84 x JI 437. The heterosis over mid-parent was significant and positive for higher shelling out turn in cross SKP 84 x JI 437, while it was noted significant and negative for lower shelling out turn in SKP 84 x JI 433 and SKP 84 x JI 441. The heterosis over mid-

parent was noted significant and positive for higher test weight in cross SKP 84 x JI 441. The relative heterosis was noted significant and negative for seed yield per plant in cross SKP 84 x JI 433 and significant and positive in JP 104 x JI 433 and SKP 84 x JI 441, while it was noted significant and positive in crosses JP 104 x JI 433 and SKP 84 x JI 433 for high oil content and significant and negative in crosses SKP 84 x JI 437 and SKP 84 x JI 441 for low oil content.

The estimates of calculated heterosis over mid-parent and better parent either significant or non-significant showed that, a close agreement was noted between observed and expected heterobeltiosis for days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, 100 seed weight and oil content in all four crosses; for length of primary raceme in cross JP 104 x JI 433; for effective length of primary raceme in crosses JP 104 x JI 433 and SKP 84 x JI 441; for number of effective branches per plant in crosses SKP 84 x JI 437 and SKP 84 x JI 441; for number of capsules on primary raceme in crosses JP 104 x JI 433, SKP 84 x JI 437 and SKP 84 x JI 441; and for shelling out turn in cross SKP 84 x JI 441. Similarly, a close agreement was found between observed and expected mid-parent heterosis for days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, 100 seed weight and oil content in all four crosses; for number of nodes up to primary raceme in cross JP 104 x JI 433, SKP 84 x JI 433 and SKP 84 x JI 441; for length of primary raceme and effective length of primary raceme in crosses JP 104 x JI 433 and SKP 84 x JI 441; for number of effective branches per plant in crosses SKP 84 x JI 437 and SKP 84 x JI 441; for number of capsules on primary raceme in crosses JP 104 x JI 433, SKP 84 x JI 437 and SKP 84 x

JI 441; and for seed yield per plant in cross SKP 84 x JI 433. These results indicated that the estimation of genetic parameters, on which the expected heterosis was based, has been carried out using most suitable model. Discrepancy observed between calculated and expected relative heterosis and heterobeltiosis for the remaining crosses with respect to specific traits might be due to involvement of higher order interaction and/or presence of linkage. According to Mather and Jinks (1971), if heterosis is measured on which an additive-dominance model is adequate, the positive and negative heterosis can occur only when $\pm [h]$ is greater than $[d]$. For this $[h]$ must be greater than $[d]$ for some or all genes, that is there must be super dominance or over dominance at some or all the loci. Secondly, there must be dispersion of completely or incompletely dominant genes. Unfortunately neither degree of dominance nor degree of association can be estimated from generation means. The distinction between these two causes of heterosis cannot be made without recourse to second degree statistics viz., variance and covariance.

If the heterosis is measured either on digenic or trigenic interaction model, its specification becomes more complex and there are many ways in which heterosis could arise. Nevertheless, it is more likely to arise with a greater magnitude when $[h]$, $[l]$ and $[z]$ have the same sign, that is, interaction is predominantly of a complementary kind as well as the interacting pairs of genes are dispersed so that their contribution to the degree of association is either very small or zero and hence, their contribution to $[d]$, $[i]$ and $[w]$ is negligible. In the present study, the presence of duplicate type of epistasis, was found in the experiment as a whole, support the magnitude of observed heterosis for many of the characters recorded in all four crosses. Though linkage does not affect the

specification of the parental and F_1 means, it bias the estimates of three of the four components of heterosis viz., [h], [i] and [l] for digenic interaction and five of the six components of heterosis viz., [h], [i], [l], [w] and [z]. So if linkage is present, it will distort the relative magnitude of these components and affect the interpretation of the causes of heterosis. The evidence of linkage, however, was not possible to obtain in the present study. The observed heterosis was found to have resulted either due to the action of dominance component only or due to the combinations with either digenic or trigenic types of epistasis for different characters in four crosses of castor. In most of the cases, the observed heterosis was either due to dominance [h], dominance x dominance [l] interaction and dominance x dominance x dominance [z] interaction or only due to dominance [h] effect and dominance x dominance [l] interactions.

It is also noticed that crosses JP 104 x JI 433 and SKP 84 x JI 441 manifested high and significant mid-parental heterosis for seed yield per plant, of which JP 104 x JI 433 also noted significant and positive mid-parent heterosis for length of primary raceme, effective length of primary raceme and oil content, and SKP 84 x JI 441 for length of primary raceme, effective length of primary raceme and 100 seed weight. The varied degree of heterosis for seed yield and its components in castor has been reported earlier by Kabaria and Gopani (1971), Yadava *et al.* (1978), Pathak *et al.* (1986), Pathak *et al.* (1988), Dobaria *et al.* (1989), Mehta *et al.* (1991), Manivel *et al.* (1999), Golakia *et al.* (2004), Golakia *et al.* (2008), Sridhar *et al.* (2009), Bindu Priya *et al.* (2018) and Patel *et al.* (2018). The character like days to flowering of primary raceme, plant height up to primary raceme and number of nodes up to primary raceme are not directly related to seed yield per plant, but they are important in determining the

maturity period. Usually, dwarf lines with less number of nodes, mature earlier than the taller lines with higher number of nodes. Thus, from the viewpoint of developing early maturing and dwarf varieties/hybrids, the trend of negative heterosis for plant height up to primary raceme and number of nodes up to primary raceme is most desirable and essential feature, which should be exploited in term of negative heterosis. In the present study, cross SKP 84 x JI 437 possessed significant and negative mid-parent as well as better parent heterosis for plant height up to primary raceme, could be exploited for the development of dwarf stature hybrids.

Several crosses as discussed/listed in this chapter previously manifested significant and desirable heterosis as well as heterobeltiosis for different traits in different crosses. As observed in the present study, several research worker have also reported heterosis in desired direction for plant height up to primary raceme by Golakia *et al.* (2004), Patel and Pathak (2006), Patel *et al.* (2013) and Punewar *et al.* (2017); for number of nodes up to primary raceme by Manivel *et al.* (1999), Thakkar *et al.* (2005) and Punewar *et al.* (2017); for length of primary raceme by Mehta *et al.* (1991), Saiyed *et al.* (1997), Manivel *et al.* (1999), Golakia *et al.* (2004), Sridhar *et al.* (2009), Patel *et al.* (2013), Singh *et al.*, (2013), Patted *et al.* (2016) and Punewar *et al.* (2017); for number of capsules on primary raceme by Mehta *et al.* (1991), Manivel *et al.* (1999), Sridhar *et al.* (2009), Patted *et al.* (2016) and Punewar *et al.* (2017); for shelling out turn by Saiyed *et al.* (1997); for 100 seed weight by Manivel *et al.* (1999), Lavanya and Chandramohan (2003), Golakia *et al.* (2004), Sridhar *et al.* (2009), Patel *et al.* (2013) and Punewar *et al.* (2017); for seed yield per plant by Manivel *et al.* (1999), Lavanya and Chandramohan (2003), Golakia *et al.* (2004), Thakkar *et al.*

(2005), Patel and Pathak (2006), Sridhar *et al.* (2009), Chaudhari and Patel (2014), Sapovadiya *et al.* (2015); Patted *et al.* (2016), Punewar *et al.* (2017), Bindu Priya *et al.* (2018), Delvadiya *et al.* (2018) and Patel *et al.* (2018); and for oil content by Patel *et al.* (2013) and Punewar *et al.* (2017).

The estimates for inbreeding depression were found significant and negative for seed yield per plant in crosses SKP 84 x JI 433, SKP 84 x JI 437 and SKP 84 x JI 441; for days to flowering of primary raceme in cross JP 104 x JI 433; for days to maturity of primary raceme in cross SKP 84 x JI 433; for effective length of primary raceme and number of effective branches per plant in cross SKP 84 x JI 437; for number of capsules on primary raceme and oil content in cross SKP 84 x JI 441; and for shelling out turn percentage in crosses JP 104 x JI 433 and SKP 84 x JI 433.

Significant and positive inbreeding depression was observed for days to flowering of primary raceme in crosses SKP 84 x JI 433 and SKP 84 x JI 441; for plant height up to primary raceme in JP 104 x JI 433; for number of nodes up to primary raceme and 100 seed weight in SKP 84 x JI 437; for length of primary raceme and effective length of primary raceme in cross, SKP 84 x JI 441; for number of effective branches per plant in crosses JP 104 x JI 433 and SKP 84 x JI 441; for shelling outturn in crosses SKP 84 x JI 437 and SKP 84 x JI 441; and for oil content in cross SKP 84 x JI 433. The significant and positive inbreeding depression was reported by Pathak *et al.* (1988) for 100 seed weight and seed yield per plant; by Golakiya *et al.* (2004) for total length of primary raceme, effective length of primary raceme, number of capsules on primary raceme, 100-seed weight and seed yield per plant; by Singh *et al.* (2013) for shelling outturn, seed yield per plant, 100-seed weight, length and effective

length of main raceme, number of capsules per plant, oil content, days to maturity, plant height and number of nodes; and by Virani *et al.* (2014) for seed yield and majority of its component traits in castor, which supports the results obtained in the present study. It is desirable to have high, significant and positive heterosis with low inbreeding depression for characters like seed yield and its components. This is equally applicable to developmental traits.

CONCLUSION

The heterosis over better parent was significant and positive in all four crosses for days to flowering of primary raceme and days to maturity of primary raceme, indicates delay in flowering and maturity in hybrid combinations. The heterosis over better parent was significant and negative for dwarf stature in cross SKP 84 x JI 437. The heterosis over better parent was significant and positive for longer length of primary raceme in crosses JP 104 x JI 433 and SKP 84 x JI 441, for effective length of primary raceme in cross JP 104 x JI 433, for shelling out turn in cross SKP 84 x JI 437, for test weight in SKP 84 x JI 441, and for oil content in JP 104 x JI 433 and SKP 84 x JI 433. The heterobeltiosis was significant and negative in crosses JP 104 x JI 433, SKP 84 x JI 433 and SKP 84 x JI 441 for seed yield per plant. Moderate inbreeding depression was observed in the present study as a whole. The observed and the expected estimates for heterosis over mid parent, over better parent and inbreeding depression were in close agreement with one another for days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, 100 seed weight and oil content in all four crosses.

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Table 1: Estimates of observed and expected heterosis and inbreeding depression for twelve characters in four castor crosses

Heterosis/ Inbreeding depression	Observed/ Expected values	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of nodes up to primary raceme	Length of primary raceme (cm)	Effective length of primary raceme (cm)	Number of effective branches per plant	Number of capsules on primary raceme	Shelling out turn (%)	100 seed weight (g)	Seed yield per plant (g)	Oil content (%)
JP 104 x JI 433 (cross 1)													
Mid parent	Observed	1.30* ± 0.49	1.60** ± 0.51	7.35** ± 1.75	-0.90 ± 0.50	6.39** ± 1.22	5.16** ± 1.19	-0.30 ± 0.98	-6.03 ± 7.81	0.36 ± 1.74	0.55 ± 1.17	19.07** ± 6.75	1.63** ± 0.20
	Expected	0.93	2.79	7.34	-0.98	6.08	5.25	0.96	-5.58	-5.26	-0.43	13.57	1.85
Better parent	Observed	1.33** ± 0.47	3.47** ± 3.14	8.76** ± 3.10	-0.07 ± 0.67	4.45* ± 1.79	4.58** ± 1.33	-2.47 ± 1.45	-10.27 ± 9.57	-9.72** ± 2.01	-1.15 ± 1.35	-56.15** ± 8.08	1.52** ± 0.29
	Expected	1.47	4.53	9.38	-0.37	3.95	4.62	0.45	-11.02	-12.88	-2.57	77.20	1.53
Inbreeding depression	Observed	-0.77* ± 0.33	-0.47 ± 0.55	16.21** ± 1.52	-0.28 ± 0.49	4.88 ± 0.97	-0.33 ± 1.37	3.85** ± 0.69	-3.88 ± 6.58	- 24.97** ± 1.80	1.15 ± 1.02	-4.22 ± 6.59	-0.06 ± 0.13
	Expected	-0.20	0.52	14.96	-0.29	4.15	-0.32	3.37	-1.15	-34.71	-1.02	2.51	-0.17
SKP 84 x JI 433 (cross 2)													
Mid parent	Observed	4.83** ± 0.70	2.03* ± 0.82	1.18 ± 2.03	-1.00 ± 0.74	-4.57 ± 2.57	-9.82** ± 3.22	1.07 ± 1.10	-5.23 ± 8.13	-6.07* ± 2.72	-0.46 ± 0.61	-39.43** ± 5.96	1.50** ± 0.28
	Expected	4.27	1.82	2.58	-0.62	-2.41	-5.21	2.44	-10.05	-10.02	-0.19	-37.65	0.89
Better parent	Observed	8.40** ± 0.82	5.40** ± 0.86	2.03 ± 2.40	0.33 ± 0.98	-16.73** ± 3.34	-19.20** ± 3.97	0.01 ± 1.14	-7.07 ± 8.13	-7.52* ± 3.37	-0.87 ± 0.57	-84.24** ± 7.43	0.90** ± 0.28
	Expected	7.76	5.28	3.19	0.11	-12.89	-14.15	1.26	-12.69	-12.89	-0.21	-97.17	0.55
Inbreeding depression	Observed	2.33** ± 0.69	-1.92* ± 0.85	3.22 ± 1.87	-1.11 ± 0.73	-0.03 ± 2.35	-2.79 ± 3.06	1.52 ± 1.10	-10.73 ± 8.53	-9.95** ± 2.39	-0.66 ± 0.85	-172.17** ± 6.20	0.87** ± 1.79
	Expected	1.66	-2.27	3.87	-0.36	2.14	2.83	2.95	-14.84	-20.01	-1.09	-140.15	0.08

Table 1: Contd...

Heterosis/ Inbreeding depression	Observed/ Expected values	Days to flowering of primary raceme	Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of nodes up to primary raceme	Length of primary raceme (cm)	Effective length of primary raceme (cm)	Number of effective branches per plant	Number of capsules on primary raceme	Shelling out turn (%)	100 seed weight (g)	Seed yield per plant (g)	Oil content (%)
SKP 84 x JI 437 (cross 3)													
Mid parent	Observed	0.80 ± 0.50	4.00** ± 0.63	-17.94** ± 3.78	3.57** ± 0.53	-12.10** ± 2.74	-16.79** ± 2.60	-2.20** ± 0.72	23.00** ± 4.80	20.03** ± 3.49	-0.92 ± 0.77	-7.54 ± 6.66	-1.22** ± 0.17
	Expected	0.86	3.27	-17.19	-3.47	-5.55	-7.82	-2.00	23.09	61.99	-1.13	97.80	-1.19
Better parent	Observed	1.60** ± 0.47	10.27** ± 0.71	-16.37** ± 0.06	4.53** ± 0.57	-12.80** ± 3.07	-22.38** ± 3.22	-3.13** ± 0.78	6.60 ± 5.86	17.24** ± 3.85	-1.25 ± 1.05	-11.80 ± 7.23	-1.59** ± 0.21
	Expected	1.87	9.55	-17.06	4.29	-6.47	-9.30	-3.03	6.61	56.83	-1.68	95.40	-1.60
Inbreeding depression	Observed	0.65 ± 0.50	-1.05 ± 0.67	-0.14 ± 3.28	2.16** ± 0.56	-1.92 ± 1.91	-11.08** ± 1.80	-1.57* ± 0.77	2.40 ± 4.77	16.14** ± 3.24	1.65* ± 0.63	-204.02** ± 6.71	-0.15 ± 0.17
	Expected	0.80	-1.80	2.92	2.02	-6.56	-12.11	-1.48	2.57	68.85	1.72	-102.13	-0.08
SKP 84 x JI 441 (cross 4)													
Mid parent	Observed	3.10** ± 0.72	4.03** ± 0.61	-3.29 ± 3.67	1.70* ± 0.61	9.21** ± 3.12	6.11* ± 2.95	1.17 ± 1.11	-13.63** ± 2.58	-5.99** ± 2.10	6.20** ± 1.28	26.22** ± 6.69	-2.43** ± 0.23
	Expected	3.76	3.72	-4.18	1.62	7.23	4.73	1.51	-14.08	1.66	7.22	163.23	-2.90
Better parent	Observed	3.13** ± 0.81	6.67** ± 0.64	-3.14 ± 4.62	2.20** ± 0.71	8.60** ± 3.01	4.75 ± 3.11	0.13 ± 1.15	-15.80** ± 3.27	-9.67** ± 1.98	5.83** ± 1.41	-19.61* ± 7.13	-2.69** ± 0.23
	Expected	3.99	6.30	-2.18	2.13	4.72	3.02	0.47	-16.12	-10.29	7.04	127.77	-3.23
Inbreeding depression	Observed	2.41** ± 0.72	1.13 ± 0.63	-3.32 ± 3.23	0.48 ± 0.56	16.85** ± 2.21	20.04** ± 1.92	2.95** ± 1.10	-9.45** ± 2.98	6.79** ± 1.78	1.17 ± 1.32	-64.80** ± 6.85	-1.50** ± 0.22
	Expected	3.60	0.83	-3.28	0.23	14.69	18.65	3.32	-10.14	-32.28	2.60	64.07	-2.06

[MS received : March 05 , 2019]

[MS accepted :March 18, 2019]