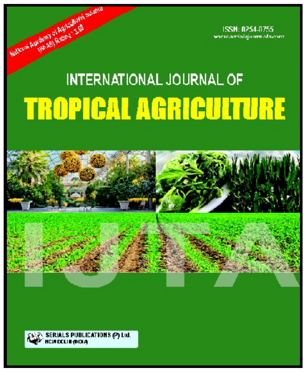

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Heterotic and Combi]ning Ability Estimates Using Seed Yield and its Components for Assessing Potential Crosses to Develop F_1 Hybrids in Castor Over Ennvironment

P.B. Dave[1*], A.L. Patel[2], N.A. Patel[3] and B.N. Patel[4]

[1] *Research Associate (Regional Research Station, AAU, Anand, Gujarat 388 110)*
[2] *Assistant Research Scientist (University Bhavan, AAU, Anand, Gujarat 388 110)*
[3] *Assistant Research Scientist (Main Vegetable Research Station, AAU, Anand, Gujarat 388 110)*
[4] *Associate Research Scientist (Agricultural Research Station, AAU, Sansoli, Gujarat 387 130)*
[*] *Corresponding Author. E-mail: pbdsl.259@gmail.com*

Abstract: Heterosis and combining ability estimates are very useful genetic parameters for identification of potential crosses to develop castor hybrid. The crosses were attempted in a line × tester mating design, which involved four female and ten tester parents, thus 40 F_1 hybrids were developed. The experiment was carried out in a randomized complete block design with three replications. The mean squares due to general combining ability (GCA) of lines and testers and specific combining ability (SCA) of lines × tester interactions were significant. The significance of GCA and SCA variances suggested non-additive gene action for controlling all the characters. The high but parallel expression of SCA and heterosis determines the involvement of dominant genes and suitability of F_1 crosses for development of hybrid in castor. Two F_1 hybrid; JP-65 × JI-398 and SKP-84 × ANDCI-10-4 manifested higher magnitude of SCA effects for seed yield, length of primary raceme, number of effective branches per plant, number of capsules on primary raceme and 100 seed weight. Almost this two F_1 hybrids also demonstrated higher heterobeltiotic effects for above same traits. The positive association between SCA and heterobeltiotic effects further determined the reliability of these two genetic parameters to identify potential F_1 hybrids.

Key words: Combining ability, heterobeltiosis, seed yield and attributing components traits.

INTRODUCTION

Castor (*Ricinus communis* L.) with $2n = 20$, belongs to the family *Euphorbiaceae* and it is indigenous to eastern Africa and most probably originated in Ethiopia. The crop is grown as an important industrial non-edible oil seed crop. India is the world's largest producer of castor with ranks first both in area and production and its derivatives contributing to almost 65 per cent share. Gujarat, Rajasthan and Andhra Pradesh are the major castor growing states in India. In India, castor occupied about 11.05 lakh ha area in 2014-15 and production was about 17.33 lakh tones with 1568 kg/ha productivity, respectively (Anon, 2015).

The genetic improvement of a new castor hybrids with high seed yield has been the unique target of all castor breeders. Heterosis is the performance of F_1 hybrids in relation to mid and better parents. It is useful in determining the most appropriate parents for improving specific traits. For utilization of heterosis, parents should be selected from the available germplasm that had ability to produce the best hybrids for most important characters over wide range of environments. The term heterotic pattern refers to a group of related or unrelated genotypes from the same or different populations, which display superior combining ability and heterotic response when crossed with genotypes from other genetically distinct germplasm groups (Melchinger and Gumber, 1998[1]). In hybrid research studies, a large number of crosses involving parental lines are used for assessing heterotic effects. Utilization of heterosis depends on genetic diversity existing between the parents, magnitude of dominance at loci which influence yield and the genetic distance between the chosen parental genotypes. It is possible to maximize heterosis by enhancing genetic distance between two chosen parental populations. For achieving a high degree of heterotic response, it is essential to have better knowledge about the performance of desirable parents in terms of hybrid combination; the heterotic studies are helpful in creating such information.

Selection of parents on the basis of phenotypic performance alone is not an effective approach because phenotypically superior parents may perform poor in cross combinations. It is therefore imperative to choose the parents on the basis of combining ability, particularly specific combing ability of parents in hybrid combination. Hence combining ability analysis via mating designs is the most widely used biometrical technique for identifying prospective parents and helps in formulating effective breeding strategy. The objectives of present investigation therefore were to estimate heterosis and specific combining ability of F_1 hybrids for the exploitation of hybrid vigour in seed yield and its components over environmental conditions.

MATERIALS AND METHODS

An experiment was conducted at the Agricultural Research Station, Anand Agriculture University, Anand (Gujarat), during *kharif* 2013-14 and 2014-15. The breeding material consisted of 4 parental lines as female's *viz.,* VP-1, SKP-84, JP-65 and JP-98 and 10 parental lines as testers/males such as SH-72, SKI-215, JI-96, JC-22, JI-398, ANDCI-9, ANDCI-8, Andci-10-4, JC-20 and ANDCM-2 with their 40 F_1 hybrids and GCH-7 as standard check hybrid. The seeds of 40 F_1 hybrids were developed by line × tester mating design. The seeds of parents and their F_1 hybrids were sown in a randomized complete block design with three replications. Distance between row to row and plant to plant was kept at 120 and 60 cm, respectively. Randomly five plants were tagged from each genotype excluding border plants for recording the data. The cultural practices like dry hoeing, weeding and inter-culturing were carried out as and when required.

Observations were recorded on the length of primary raceme (cm), number of capsules on primary raceme, number of effective branches per plant, 100-seed weight (g), shelling out turn (%) and seed yield (g/plant). The data recorded on the material generated as per Line × Tester model of Kempthorne (1957[2]) was subjected to analysis of variance as per the Line × Tester model given by Singh and Chaudhary (1977[3]).

RESULTS AND DISCUSSION

The parents and their F_1s were evaluated for analysis of variance, mean performance, heterotic effects, general combining ability (GCA) and specific combining ability (SCA) effects. Significant differences among the genotypes, F_1s, genotypes × environments and hybrids × environments for attributing component characters *viz.,* length of primary raceme, number of capsules on primary raceme, effective number of branches per plant, 100 seed weight and shelling out turn were recorded on pooled basis; whereas, non-significant difference were recorded among genotypes × environments and hybrids × environments for particularly seed yield per plant (Table 1).

The mean squares due to genotypes were further partitioned into parental lines *viz.,* lines, testers and lines × testers and mean squares due to genotypes × environments were partitioned into lines × environments, testers × environments and lines *vs.* testers × environments which also showed significant differences in majority of the characters, but again in case of seed yield per plant, the above partitioned mean squares were recorded non-significant differences, respectively. This suggesting the differential response of genotypes and hybrids in varying environments for majority of the traits. These results thereby suggesting possibility of entire data was worth for estimating heterotic effects, general combining ability (GCA) and specific combining ability (SCA) effects.

The mean squares due to general combining ability (GCA) and specific combining ability (SCA) were highly significant for all the characters studied. Similar to present results, Punewar *et. al.* (2017[4])

Table 1

Pooled mean squares from line × tester analysis for seed yield and its components in castor

Source of Variation	*df*	*Length of primary raceme*	*Number of capsules on primary raceme*	*Number of effective branches per plant*	*100 seed weight*	*Shelling out turn*	*Seed yield per plant*
Environment	3	1377.83**	789.33**	70.66**	75.83**	126.00**	4357.33**
Replication within Envt.	2(8)	185.01**	149.09*	4.90**	0.57	16.00**	721.19
Genotype	55	525.22**	1302.80**	35.36**	102.90**	205.51**	23175.56**
F_1 hybrids	39	592.41**	1498.23**	36.02**	120.74**	229.96**	27801.03**
Lines (L)	3	228.18**	150.11	8.79**	21.32**	143.82**	3098.43**
Testers (T)	9	346.73**	264.66**	27.07**	60.57**	147.49**	3493.90**
Lines × Testers	1	823.88**	2557.55**	74.01**	29.12**	29.56*	40177.38**
Genotypes × Envt.	165	84.77**	108.79**	5.37**	10.69**	58.54**	351.07
F_1 hybrids × Envt.	117	92.94**	115.59**	5.70**	11.32**	64.86**	399.41
Lines × Envt.	9	165.80**	105.06	3.24*	16.05**	43.44**	116.47
Testers × Envt.	27	37.72	103.92*	4.90**	8.57**	43.87**	312.78
Lines *vs.* Testers × Envt.	3	3.78	64.15	15.56**	4.88**	63.75**	109.79
Error (Pooled)	440	50.13	66.75	1.61	0.94	5.76	386.16

*,**Significant at P = 0.05 and P = 0.01 levels of probability, respectively.

estimated significant general and specific combining ability effects for seed yield, length of primary raceme, number of capsules on primary raceme, number of effective branches per plant and 100 seed weight. The mean squares due to lines and testers parents both determined general combining ability (GCA) variances and males × females which pertained to specific combining ability (SCA) variances were significant for all of the characters. The variance ratio indicated the predominant role of non-additive gene action for all the characters. Thus, suggesting the importance of heterosis breeding for the improvement of hybrids in castor.

Since the main emphasis of this research work was to determine the relationship of heterosis, specially high parent heterosis (heterobeltiosis) with SCA effects so as to identify potential crosses for hybrid crop development, hence other data set like mean performance of parents, hybrid performance *per se* and GCA effects were less important for this study.

The Heterotic Effects and Specific Combining Ability Estimates

Heterosis is the superiority of F_1 hybrids over their better parents and standard check. Heterosis will to be useful when F_1 hybrid performance exceeds to that of better parent commonly known as heterobeltiosis (Patil *et. al.,* 2011[5]). The occurrence of heterosis is common in plant species, but the level of expression is highly variable. It is generally believed that F_1 hybrids which express positive heterosis are those with dominant genes whereas the ones which exhibit negative heterosis possess recessive genes. Specific combining ability (SCA) is defined as the performance of two parents in the specific crosses. As such, the phenomenon of hybrid vigour is a result of the specific combining ability of two parents. Aher *et. al.* (2015[6]) found greater portion of SCA variances over the GCA for seed yield traits in castor, thus stated that such traits could be improved through heterosis breeding.

High length of primary raceme regarded as desirable raceme in castor because of it can produce more number of capsules on raceme. Among forty F_1 hybrids, nine hybrids exhibited significantly positive SCA effects while twelve hybrids gave significantly negative SCA effects for length of primary raceme (Table 3). The best three hybrids with significant desired SCA effects were JP-65 × JI-398 (12.17), SKP-84 × ANDCI-10-4 (9.64) and JP-98 × ANDCM-2 (9.50). Hence these three hybrids were preferable for primary raceme length. The heterotic effects for length of primary raceme were summarized in Table 2 which revealed that nine F_1 hybrids expressed significant and positive heterobeltiosis ranging from 9.19 to 22.23, while significant and negative heterobeltiosis varied from –8.86 to –22.67. The moderate, but positive heterobeltiosis may be desirable for raceme length and the hybrids JP-98 × SH-72 (22.23%), followed by SKP-84 × ANDCI-10-4 (21.93%) and VP-1 × ANDCI-8 (21.86%) were regarded as suitable ones for this trait.

From line × tester crosses, sixteen hybrids demonstrated significantly positive SCA effects, nonetheless thirteen crosses gave significantly negative SCA effects for number of effective branches per plant (Table 3). However, highest three SCA scoring F_1 hybrids were; JP-65 × JI-398 (3.81), SKP-84 × ANDCI-10-4 (2.68) and VP-1 × ANDCI-8 (2.09) for this trait. The results of heterotic effects of F_1 hybrids revealed that heterosis over better parent ranged between –30.37 to 31.45% whereas standard heterosis varied from -35.20 to 10.57% in number of effective branches per plant (Table 2). The highest increase over better parent (31.45%) was recorded by cross JP-65 × JI-398 and hybrid SKP-84 × ANDCI-10-4 (10.57%) exhibited maximum standard heterosis, nevertheless JP-98 × JC-20 and JP-65 × JI-398 ranked next higher scoring for better parent and standard heterosis with an increase of 25.25 and 8.61%. The less difference of F_1 hybrids (JP-65 × JI-398) in SCA and heterobeltiosis estimates

Table 2
Pooled mean square for combining ability, estimates of components of variance and their ratios seed yield and its components in castor

Source of Variation	*df*	*Length of primary raceme*	*Number of capsules on primary raceme*	*Number of effective branches per plant*	*100 seed weight*	*Shelling out turn*	*Seed yield per plant*
Environments	3	836.59**	542.06**	52.91**	53.53**	129.54**	2600.16**
Replication	8	208.82**	204.19**	5.36**	0.84	16.78**	813.67*
Female	3	486.72**	1758.86**	83.64**	188.78**	91.90**	31332.24**
Male	9	956.57**	2263.74**	24.79**	189.62**	301.13**	28760.11**
Female × Male	27	482.77**	1214.10**	34.47**	90.23**	221.59**	27088.96**
Female × Envt.	9	73.73	113.95	8.29**	17.12**	110.98**	140.57
Male × Envt.	27	70.86	123.01*	7.01**	10.92**	54.16**	467.64
F × M × Envt.	81	102.43**	113.29**	4.98**	10.82**	63.31**	405.52
σ^2 gca		3.20	9.43	0.20	1.14	-0.53	36.41
σ^2 sca		126.78	366.94	9.84	26.47	52.76	8894.49
σ^2 gca/σ^2 sca		0.03	0.03	0.02	0.04	–	0.00
Pooled Error	312	47.20	75.89	1.74	1.06	6.18	363.65

Note: –Note calculated due to –ve variance'.

*,**significant at $P = 0.05$ and $P = 0.01$ levels of probability, respectively.

indicated that SCA effects of hybrids is necessarily expected to be observed in hybrid vigour also, especially for effective branches per plant. Though one higher ranking hybrids did perform similar for SCA and heterosis, suggested that the hybrid performed in similar direction.

In castor plant, as the number of capsules on primary raceme increase, the seed yield also increases. Thus, there is close but positive association between capsules on primary raceme and seed yield. Twelve hybrids expressed significantly desired SCA effects for capsules per plant (Table 3), nonetheless the highest SCA effect of 24.90 was manifested by JP-65 × JI-398 followed by SKP-84 × ANDCI-10-4 (21.60). Similarly, twelve and four hybrids manifested significant and positive heterobeltiotic and standard heterotic effects for number of capsules on primary raceme (Table 2). The maximum heterosis of 43.77 and 14.60 % however were manifested by SKP-84 × ANNDCI-10-4 over its better patent and standard check, respectively followed by the cross JP-65 × JI-398 which exhibited heterobeltiosis of 40.22% over better parent and 12.06 % over standard check. These results suggested very close proximity between heterobeltiosis and SCA effects exists (Table 3). Sapovadiya *et. al.* (2015[7]) also reported highest heterobeltiosis (38.61%) and Standard heterosis (24.71%) for number of capsules on primary raceme.

It is assumed that as 100 seed weight increases, the yield correspondingly increases if the number of seed was kept constant. With respect to seed weight, from among forty crosses, eighteen hybrids gave significantly positive SCA effects (Table 3). However, top three rankers for SCA effects were; JP-65 × JI-398 (5.03), SKP-84 × ANDCI-10-4 (3.89) and VP-1 × ANDCM-2 (3.37). Very similar to SCA effects, 18 F_1 hybrids also exhibited significant and positive heterobeltiosis ranging from 3.41% to 23.45% (Table 2).

Table 3
Pooled Heterosis and heterobeltiotic effects of F_1 hybrids for seed yield and its components

	Length of primary raceme (cm)		*Number of capsules on primary raceme*		*Number of effective branchesper plant*	
F_1 hybrids	*HB*	*SH*	*HB*	*SH*	*HB*	*SH*
VP-1 × SH–72	8.55	–12.63**	19.93**	–16.32**	18.43**	–14.76**
VP-1 × SKI-215	3.76	–8.89**	33.85**	–3.33	13.96**	–13.02**
VP-1 × JI-96	–6.29	–13.05**	5.42	–23.83**	2.43	–26.61**
VP-1 × JC-22	–10.43*	–27.91**	–12.79**	–27.63**	0.78	–15.31**
VP-1 × JI-398	–15.47**	–17.91**	–6.22	–25.05**	–14.34**	–29.22**
VP-1 × ANDCI-9	–13.02**	–18.26**	3.85	–19.35**	–5.85	–23.03**
VP-1 × ANDCI-8	21.86**	8.40**	38.58**	8.14*	21.61**	6.44**
VP-1 × ANDCI-10-4	8.95	–6.28*	–4.23	–23.66**	–7.70*	–7.48**
VP-1 × JC-20	–5.89	–19.75**	–23.13**	–32.95**	11.87*	–20.09**
VP-1 × ANDCM-2	–14.33**	–17.54**	–12.34**	–30.24**	6.30	–17.48**
SKP-84 × SH–72	–1.63	–11.40**	26.40**	–11.80**	12.31**	–12.70**
SKP-84 × SKI-215	9.19*	–1.65	33.51**	–3.58	22.94**	–4.44**
SKP-84 × JI-96	–14.57**	–20.73**	5.26	–23.94**	6.57	–17.16**
SKP-84 × JC-22	–7.18	–16.40**	–17.44**	–31.49**	10.61**	–7.05**
SKP-84 × JI-398	–15.64**	–18.07**	–15.85**	–32.75**	8.42*	–10.42**
SKP-84 × ANDCI-9	–7.72	–13.28**	–4.41	–25.76**	–5.05	–22.37**
SKP-84 × ANDCI-8	18.47**	6.70*	38.58**	8.14*	18.88**	4.04**
SKP-84 × ANDCI-10-4	21.93**	9.82**	43.77**	14.60**	10.30**	10.57**
SKP-84 × JC-20	2.97	–7.26*	–1.47	–14.06**	–11.47**	–31.18**
SKP-84 × ANDCM-2	–18.34**	–21.40**	–4.47	–23.98**	13.29**	–11.94**
JP–65 × SH–72	19.20**	–5.84*	3.87	–23.77**	11.63*	–19.66**
JP–65 × SKI-215	10.12*	–3.30	20.15**	–11.82**	20.94**	–7.70**
JP–65 × JI-96	–1.80	–8.89**	8.64	–20.27**	15.02**	–17.59**
JP–65 × JC-22	10.33*	–14.56**	–16.15**	–30.41**	–16.95**	–30.20**
JP–65 × JI-398	12.46**	9.21**	40.22**	12.06**	31.45**	8.61**
JP–65 × ANDCI-9	–1.46	–7.40**	–1.84	–23.77**	6.25	–13.13**
JP–65 × ANDCI-8	0.05	–11.00**	17.27**	–8.49*	–16.65**	–27.05**
JP–65 × ANDCI-10-4	6.52	–8.37**	6.35	–15.23**	–30.37**	–30.20**
JP–65 × JC-20	–15.36**	–27.82**	–14.37**	–25.31**	18.43**	–21.07**
JP–65 × ANDCM-2	–22.67**	–25.56**	13.31**	–9.83**	–16.53**	–35.20**
JP-98 × SH-72	22.23**	–3.44	31.26**	–8.42*	15.26**	–17.05**
JP-98 × SKI-215	–2.04	–13.98**	5.03	–24.15**	–12.39**	–33.14**
JP-98 × JI-96	–13.31**	–19.56**	–4.56	–31.03**	11.08*	–20.42**

Contd. Table 3

	Length of primary raceme (cm)		*Number of capsules on primary raceme*		*Number of effective branchesper plant*	
F_1 hybrids	*HB*	*SH*	*HB*	*SH*	*HB*	*SH*
JP-98 × JC-22	4.44	–19.56**	–5.83	–21.85**	–1.94	–17.59**
JP-98 × JI-398	–8.86*	–11.49**	–11.66*	–29.40**	–9.61*	–25.31**
JP-98 × ANDCI-9	–4.93	–10.65**	2.37	–20.50**	–13.83**	–29.55**
JP-98 × ANDCI-8	–6.41	–16.75**	3.45	–19.27**	–4.97	–16.83**
JP-98 × ANDCI-10-4	–8.00	–20.87**	–13.13**	–30.75**	–28.42**	–28.25**
JP-98 × JC-20	–18.33**	–30.36**	–15.53**	–26.33**	25.25**	–18.03**
JP-98 × ANDCM-2	–4.71	–8.28**	–10.69*	–28.93**	–3.50	–25.09**
S. E. ±	2.86		3.33		0.52	
No. of significant crosses	21	37	23	38	30	40

BP and SH were better parent and standard check hybrid, respectively.
*,**significant at $P = 0.05$ and $P = 0.01$ levels of probability, respectively.

	100 seed weight (g)		*Shelling out turn (%)*		*Seed yield per plant (g)*	
F_1 hybrids	*HB*	*SH*	*HB*	*SH*	*HB*	*SH*
VP-1 × SH-72	–11.37**	–23.04**	–7.00**	–15.73**	12.17*	–26.44**
VP-1 × SKI-215	10.80**	–9.68**	5.04**	–5.04**	21.28**	–10.79
VP-1 × JI-96	–9.53**	–16.35**	–14.27**	–16.34**	–3.78	–32.34**
VP-1 × JC-22	7.11**	–8.69**	–6.82**	–8.40**	–9.44	–39.08**
VP-1 × JI-398	–4.05**	–17.27**	5.24**	–4.85**	–39.66**	–61.21**
VP-1 × ANDCI-9	–4.40**	–22.07**	8.34**	–2.05*	13.56**	–20.28*
VP-1 × ANDCI-8	18.81**	5.13**	–6.84**	–4.92**	30.15**	7.61
VP-1 × ANDCI-10-4	–27.62**	–25.82**	7.65**	–1.09	–31.40**	–41.91**
VP-1 × JC-20	–12.39**	–18.20**	5.23**	–2.01*	–24.09**	–44.17**
VP-1 × ANDCM-2	4.21**	–7.60**	–8.17**	–9.95**	–8.98	–38.48**
SKP-84 × SH-72	–8.05**	–16.23**	–2.21	–8.55**	41.37**	–4.39
SKP-84 × SKI-215	7.18**	–2.36**	3.96*	–2.77**	33.03**	–2.15
SKP-84 × JI-96	6.34**	–1.67**	–5.97**	–8.23**	15.46**	–18.81*
SKP-84 × JC-22	0.63	–8.33**	–15.80**	–17.23**	–5.31	–35.96**
SKP-84 × JI-398	–9.41**	–17.47**	–8.76**	–14.68**	–36.07**	–56.76**
SKP-84 × ANDCI-9	–9.26**	–17.34**	–8.50**	–14.43**	–2.69	–31.69**
SKP-84 × ANDCI-8	19.61**	8.96**	1.51	3.60**	28.98**	6.64
SKP-84 × ANDCI-10-4	7.86**	10.53**	7.52**	0.55	31.03**	10.96
SKP-84 × JC-20	–5.40**	–11.66**	–7.86**	–13.83**	2.17	–24.86**
SKP-84 × ANDCM-2	–5.69**	–14.09**	–18.82**	–20.39**	14.75**	–22.40**

Contd. Table 3

	100 seed weight (g)		*Shelling out turn (%)*		*Seed yield per plant (g)*	
F_1 hybrids	*HB*	*SH*	*HB*	*SH*	*HB*	*SH*
JP–65 × SH-72	–13.38**	–24.77**	2.78	1.21	42.34**	–6.65
JP–65 × SKI-215	21.03**	2.63**	0.08	–1.45	35.08**	–0.64
JP–65 × JI-96	–8.52**	–15.42**	–9.02**	–10.42**	24.76**	–12.27
JP–65 × JC-22	–1.53	–16.06**	–14.58**	–15.89**	6.57	–28.32**
JP–65 × JI-398	23.45**	6.45**	4.49**	2.88**	71.01**	9.92
JP–65 × ANDCI-9	3.41*	–12.31**	–4.06**	–5.53**	3.67	–27.21**
JP–65 × ANDCI-8	1.16	–10.49**	–10.85**	–9.02**	–16.18**	–30.70**
JP–65 × ANDCI-10-4	–2.52*	–0.10	–16.24**	–17.53**	–56.04**	–62.77**
JP–65 × JC-20	4.32**	–2.59**	–4.11**	–5.59**	–29.92**	–48.46**
JP–65 × ANDCM-2	2.38	–9.22**	–21.82**	–23.01**	–9.11	–38.57**
JP-98 × SH-72	0.62	–12.62**	–4.71**	–13.65**	18.61**	–22.21**
JP-98 × SKI-215	6.46**	–9.74**	10.71**	–1.50	–27.14**	–46.41**
JP-98 × JI-96	6.57**	–1.46**	–13.38**	–15.47**	–19.44**	–43.35**
JP-98 × JC-22	17.64**	0.28	–3.15*	–4.79**	–41.16**	–60.42**
JP-98 × JI-398	5.42**	–9.10**	13.79**	–2.89**	4.63	–32.74**
JP-98 × ANDCI-9	1.67	–13.81**	–9.65**	–18.54**	9.27*	–23.29**
JP-98 × ANDCI-8	12.74**	–0.24	–17.71**	–16.01**	–13.79**	–28.72**
JP-98 × ANDCI-10-4	0.63	3.13**	3.83*	–4.61**	–6.10	–20.49*
JP-98 × JC-20	9.04**	1.82**	–7.74**	–14.09**	1.99	–24.99**
JP-98 × ANDCM-2	–7.60**	–18.08**	–8.64**	–10.41**	18.09**	–20.19*
S. E. ±	0.39		0.97		8.14	
No. of significant crosses	33	37	36	35	28	30

BP and SH were better parent and standard check hybrid, respectively.
*,**significant at $P = 0.05$ and $P = 0.01$ levels of probability, respectively.

However, the highest heterobeltiotic estimate of 23.45% was exhibited by cross JP-65 × JI-398 which also gave positive (6.45%) standard heterosis and the highest standard heterosis of 10.53% was exhibited by cross SKP-84 × ANDCI-10-4 which also gave positive (7.86%) heterobeltiosis. Though, the first ranking hybrid (JP-65 × JI-398) with maximum SCA (5.03) effect also ranked similar for heterobeltiosis which indicated the supremacy of hybrid JP-65 × JI-398, suggested that SCA effects of hybrids must be taken as granted for expecting similar vigour in seed weight also.

Seventeen hybrids manifested significantly positive SCA effects and seventeen hybrids also recorded significant negative SCA effects for shelling out turn. However, SKP-84 × ANDCI-8 (6.90) followed by JP-65 × SH-72 (6.30) and JP-98 × JC-22 (5.14) scored maximum significant desired SCA effects (Table 3). Results depicted in Table 2 indicated that F_1 hybrids expressed low to medium positive heterobeltiosis (0.08 to 13.79%) and positive standard heterosis (0.55 to 3.60%). The highest significant positive heterobeltiosis of 13.79% was manifested by JP-98 × JI-398, whereas hybrid JP-98 × SKI-215

Table 4
Pooled specific combining ability (SCA) estimates from line × tester analysis for seed yield and its components in castor

F_1 hybrids	Length of primary raceme	Number of capsules on primary raceme	Number of effective branches per plant	100 seed weight	Shelling out turn	Seed yield per plant
VP-1 × SH-72	–2.20	–0.20	0.02	0.54**	–5.24**	–17.76**
VP-1 × SKI-215	–0.50	7.44**	0.06	0.20	–2.60**	21.13**
VP-1 × JI-96	2.68	1.73	–1.12**	–0.71**	–3.46**	–3.25
VP-1 × JC-22	–5.07**	1.09	0.17	1.66**	0.88	15.32**
VP-1 × JI-398	–5.10**	–4.65**	–2.49**	–0.81**	–1.10*	–53.62**
VP-1 × ANDCI-9	–3.32	3.55*	–0.33	–0.07	3.97**	23.93**
VP-1 × ANDCI-8	9.17**	10.65**	2.09**	3.25**	–0.07	57.46**
VP-1 × ANDCI-10-4	0.99	–7.87**	0.80**	–5.75**	1.76**	–22.32**
VP-1 × JC-20	1.99	–6.44**	0.21	–1.68**	3.20**	–10.42**
VP-1 × ANDCM-2	1.35	–5.30**	0.58*	3.37**	2.65**	–10.47**
SKP-84 × SH-72	–4.19**	–0.60	–0.55*	0.34	0.89	5.18
SKP-84 × SKI-215	1.81	2.83	0.49	0.17	0.44	10.92**
SKP-84 × JI-96	–5.70**	–2.76	–0.56*	1.71**	3.25**	–1.36
SKP-84 × JC-22	0.31	–6.72**	0.55*	–0.68**	–3.07**	–8.53*
SKP-84 × JI-398	–8.09**	–15.86**	–0.50	–3.34**	–5.67**	–74.19**
SKP-84 × ANDCI-9	–2.63	–6.52**	–1.12**	–0.95**	–2.21**	–35.87**
SKP-84 × ANDCI-8	5.07**	6.26**	0.84**	2.07**	6.90**	23.49**
SKP-84 × ANDCI-10-4	9.64**	21.62**	2.68**	3.89**	4.41**	76.87**
SKP-84 × JC-20	8.07**	5.90**	–2.38**	–1.97**	–2.62**	5.76
SKP-84 × ANDCM-2	–4.29**	–4.15*	0.55*	–1.25**	–2.31**	–2.28
JP–65 × SH-72	0.50	–10.11**	–0.23	–2.10**	6.30**	15.99**
JP–65 × SKI-215	1.33	–3.39	1.38**	2.24**	0.54	31.03**
JP–65 × JI-96	3.49*	1.57	0.76**	–2.46**	1.14*	31.20**
JP–65 × JC-22	2.33	–4.69**	–1.62**	–2.85**	–2.95**	26.76**
JP–65 × JI-398	12.17**	24.90**	3.81**	5.03**	4.65**	107.12**
JP–65 × ANDCI-9	2.30	–3.67*	1.69**	1.13**	2.66**	–8.43*
JP–65 × ANDCI-8	–6.90**	–7.39**	–2.54**	–4.00**	–1.77**	–52.46**
JP–65 × ANDCI-10-4	–2.68	–3.71*	–2.18**	0.76**	–7.70**	–89.11**
JP–65 × JC-20	–5.96**	–2.99	0.56*	1.46**	1.83**	–36.23**
JP–65 × ANDCM-2	–6.57**	9.47**	–1.63**	0.78**	–4.69**	–25.89**
JP-98 × SH-72	5.90**	10.91**	0.76**	1.22**	–1.95**	–3.42
JP-98 × SKI-215	–2.64	–6.88**	–1.94**	–2.61**	1.62**	–63.08**
JP-98 × JI-96	–0.47	–0.54	0.91**	1.46**	–0.93	–26.60**
JP-98 × JC-22	2.43	10.32**	0.90**	1.86**	5.14**	–33.56**

Contd. Table 4

F_1 hybrids	Length of primary raceme	Number of capsules on primary raceme	Number of effective branches per plant	100 seed weight	Shelling out turn	Seed yield per plant
JP-98 × JI-398	1.02	–4.39*	–0.81**	–0.88**	2.12**	20.68**
JP-98 × ANDCI-9	3.65**	6.65**	–0.24	–0.10	–4.42**	20.37**
JP-98 × ANDCI-8	–7.34**	–9.52**	–0.39	–1.32**	–5.06**	–28.49**
JP-98 × ANDCI-10-4	–7.95**	–10.04**	–1.30**	1.10**	1.54**	34.56**
JP-98 × JC-20	–4.10**	3.53*	1.61**	2.19**	–2.41**	40.89**
JP-98 × ANDCM-2	9.50**	–0.03	0.50	–2.90**	4.35**	38.65**
S. E. ±	1.40	1.78	0.27	0.21	0.51	3.89

*,**Significant at $P = 0.05$ and $P = 0.01$ levels of probability, respectively.

manifested next higher heterobeltiosis (10.71%) among the F_1 hybrids for shelling out turn. The discrepancy in the hybrid performance was observed in top scoring for SCA and heterobeltiosis which suggested that if the objective of breeding is to develop potential hybrids for shelling out turn, both SCA and heterosis may not necessarily favors the same hybrids. Thus better hybrids may be selected to improve this trait in castor.

Seed yield per plant had a unique importance among many plant characters because it plays an important role in strengthening the economy of the growers and the country. The SCA results of forty hybrids for seed yield revealed that 17 F_1 hybrids manifested significantly positive SCA effects and 17 hybrids gave significantly negative SCA effects, whereas remaining 6 hybrids had either only positive or negative SCA effects (Table 3). However, hybrids JP-65 × JI-398 (107.12), SKP-84 × ANDCI-10-4 (76.87) and VP-1 × ANDCI-8 (57.46), were three top scorers in expressing SCA effects. Contrary to SCA results, among these 17 F_1 hybrids, 12 hybrids showed significantly positive heterobeltiosis, whereas remaining 5 hybrids had either positive or negative heterobeltiosis for seed yield per plant (Table 2 and Fig 1). The heterobeltiosis of that 12 hybrids ranged from 9.27% (JP-98 × ANDCI-9) to 71.01% (JP-65 × JI-398) and the top three scoring F_1 hybrids were; JP-65 × JI-398, JP-65 × SH-72 and JP-65 × SKI-215 and their Figure 1 relationship between heterosis and SCA effects for seed yield increase over better parents were; 71.01, 42.34 and 35.08%, respectively. It is very interesting to note that only one out of three hybrids was same which exhibited high SCA effects (107.12) also manifested greater heterobeltiosis (71.01) for seed yield. The positive correlation between SCA effects and heterobeltiosis also support the idea that hybrids which are good specific combiners for seed yield may be those which reliably exhibit high vigour in productivity also (Table 3). Ramesh *et. al.* (2013[8]) while estimating GCA and SCA observed that hybrid JP -87 × RG-1740/A exhibited reasonably high SCA effect for seed yield, length of primary raceme and number of capsules on primary raceme which indicated that the progenies of this cross may be used for improving yield and yield components.

Similar kind of results were in accordance with Punewar *et. al.* (2017[4]). They found higher SCA than GCA suggesting that dominant genes controlling length of primary raceme, number of capsules on primary raceme, 100 seed weight and seed yield per plant. F_1 hybrid Geeta × JI-379 performed well in SCA determination, outstanding mean performance *per se* and heterosis over both better patent and standard check. They stated that higher SCA effects associated with useful heterosis were more pronounced for seed yield traits and above hybrid could prove useful for hybrid crop development.

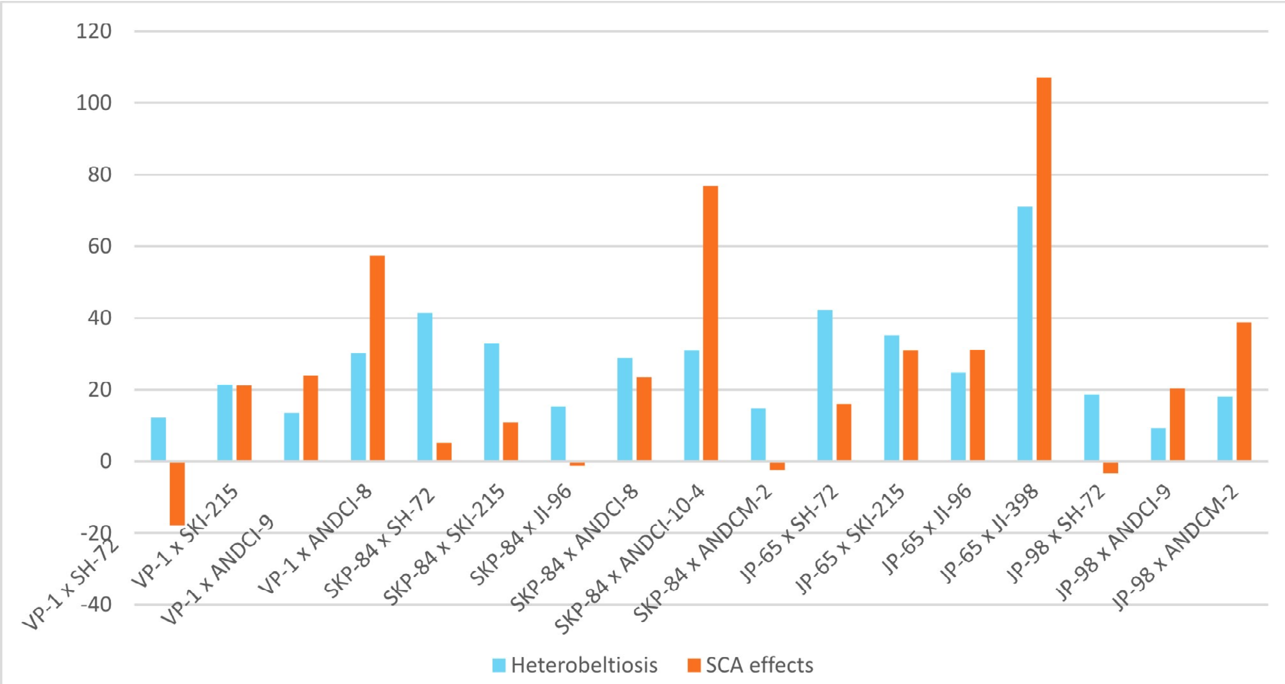

Figure 1: Pooled Relationship between Significant desirable heterobeltiosis and SCA effects for seed yield per plant

CONCLUSION

The variances ratio due to general combining ability (GCA) and specific combining ability (SCA) were significant suggesting the predominant role of non-additive gene action for all the characters under study. The high and parallel expression of SCA and heterosis effects of F_1 hybrids for important traits determine the suitability of F_1 crosses for hybrid development in castor. F_1 hybrid such as JP-65 × JI-398 and SKP-84 × ANDCI-10-4 manifested both higher SCA and heterobeltiotic effects indicating that seed yield, length of primary raceme, number of effective branches per plant, number of capsules on primary raceme and 100 seed weight can be considered for hybrid castor development either on the basis of their SCA or heterotic effects or both. The close and positive association between SCA and heterobeltiotic effects in this two F_1 hybrid was observed for above traits obviously indicated that both estimates were equally reliable to identify potential crosses for hybrid castor development.

REFERENCES

Aher, A. R.; Patel, K. V.; Patel M. P. and Patel, J. A. (2015), Genetic analysis of seed yield and component characters over environments in castor (*Ricinus communis* L.). *Electronic journal of plant breeding,* 6(1): 141-149.

Anonymous (2015), Area, production and yield per hectare of castor crop in India. (Director's Report, IIOR, Hyderabad).

Kempthorne, O., (1957), An Introduction to Genetic Statistics, *John Wiley and Sons,* New York.

Melchinger, A. E. and R. K. Gumber. (1998), Overview of heterosis and heterotic groups in agronomic crops. In: Lamkey K. R. and J. E. Staub. (ed.). Concepts and breeding of heterosis in crop plants. *CSSA, Madison, WI.* pp. 29-44.

Patil, S. A., M. R. Naik, A. B. Patil and G. R. Chaugule. (2011), Heterosis for seed cotton yield and its contributing characters in cotton (*Gossypium hirsutum* L.). Plant Archives, **11**(1): 461-465.

Punewar, A. A., Patil, A. S., Nandanwar, H. R., Pael, S. M. and Patel, B. N. (2017), Genetic dissection of heterosis and combining ability in castor (*Ricinus communis* L.) with line × tester analysis. *Journal of Experimental Biology and Agricultural Sciences,* **5**(1): 077-086.

Ramesh, M., Lavanya, C., Sujatha, M., Sivasankari, A., Aruna Kumari, J. and Meena, H. P. (2013), Heterosis and combining ability for yield and yield component characters of newly developed castor (*Ricinus communis* L.) hybrid. *The Bioscan,* **8**(4): 1421-1424.

Sapovadiya, M. H., Dobariya, K. L., Babariya, C. A., Mungra, K. S. and Vavdiya, P. A. (2015), Heterosis for seed yield and its components over environments in castor (*Ricinus communis* L.). *Electronic Journal of Plant Breeding,* **6**(4): 1118-1123.

Singh, R. K. and Choudhary, B. D. (1977), Biometrical methods in quantitative genetic analysis. *Kalyani Publishers, New Delhi,* India.