The present review is an attempt made for bringing together some of the research based findings on the heterosis, combining ability and gene action in castor. The review of literature cited by different investigators is presented as under:

2.1 HETEROSIS

Heterosis or hybrid vigour indicates the superiority of hybrid over its parents. It was first reported in plants by Koelreuter (1763) and noted that vigour in crosses increased with the increase in dissimilarity of parents. Exploitation of heterosis was first achieved in maize, which was followed subsequently in many crops like bajra, cotton, sorghum and others. East (1908) and Shull (1908) studied the effects of cross and self fertilization in maize and finally Shull (1914) coined the term “heterosis”, which represents percentage increase or decrease in the mean value of F₁ hybrid over its mid-parental value. Stebbins (1959) defined heterosis for crop plants as greater adaptedness to human needs which has been obtained in a particular environment through artificial selection followed by hybridization. Subsequently, many workers advanced several explanations for heterosis like dominance (Davenport, 1908), over dominance (East, 1908 and Shull, 1908) and epistasis (Jones, 1917 and Jinks and Jones, 1958). Later on, Bitzer et al. (1968) and Fonseca and Patterson (1968) coined a new term “heterobeltiosis” to describe improvement of heterozygotes in relation to better parent. However, in many studies, especially where commercial hybrids / varieties are under cultivation, increase or decrease in the mean value of F₁ hybrid over standard hybrid or variety has been considered as the manifestation of heterosis, known as standard heterosis.

In their study of 22 single crosses of castor, Zimmerman and Van Horn (1953) reported 87 to 132 per cent heterosis for seed yield per plant over their respective better parent.

Anubhava (1958) studied hybrid vigour in castor and reported 2.70 to 277.00 per cent heterosis for seed yield over their better parent.
In a study of heterosis in castor, Stein (1958) observed 106.00 per cent higher yield of F₁ hybrid over high yielding parent derived from two pure lines. Marked increase was also observed in other characters viz., vegetative vigour, number of seeds per raceme, number of racemes per plant and 100 seed weight.

While studying the heterosis for seed yield per plant through 8 x 8 diallel analysis in castor, Ankineedu and Kulkarni (1965) found that all the hybrids yielded more than their respective better parents and standard variety, HC 6. The highest heterosis for seed yield per plant (56.68%) was observed in cross between indigenous and exotic lines.

During their study of heterosis in six hybrids of castor, Satyabalan et al. (1965) observed significant positive heterosis for number of racemes per plant (68.70%), seed weight (66.04%) and seed yield (76.62%). However, heterosis was not observed for plant height, length of raceme, days to maturity and oil content.

While studying heterosis in castor, Ankineedu and Kulkarni (1967) found marked heterosis for seed yield per plant, plant height, number of nodes and length of main spike.

While studying hybrid vigour through 54 hybrids of castor involving nine pistillate lines and six indigenous and exotic monoecious lines, Gopani et al. (1968) observed positive heterosis over better parents for seed yield per pant (253.00%), number of effective branches per plant (16.67%), plant height (100.86%), number of capsules on main spike (73.24%) and oil content (3.99%). Negative heterosis was observed over better parent for 100 seed weight. Significantly higher yield was observed for hybrid TSP 10R x JI 15 (GCH 3) as compared to all other hybrids and inbreds and the hybrid was released for general cultivation in Gujarat as GCH 3. They suggested to exploit hybrid vigour in castor through the development of hybrids for commercial cultivation.

Varisai et al. (1969) studied hybrid vigour through top crosses in castor using six Egyptian inbreds and TMV 1 as tester and observed positive heterosis over better parents for number of branches per plant (33.30%), length of pistillate region of raceme (37.30%), length of raceme (50.90%), number of capsules per plant (56.50%) and seed yield per plant (62.30%). Negative heterosis was also observed for days to first flowering and days to maturity. The heterosis was not observed for number of nodes on main stem, oil content and 1000 seed weight.
In a study of heterosis through 13 hybrids of castor derived through top crosses of five Russian and eight indigenous inbreds and TMV 1 as tester, Varisai et al. (1970) reported positive heterosis in nine hybrids for seed yield per plant ranging from 9.00 to 84.90 per cent. Significant positive heterosis over better parents was reported in three hybrids for total number of capsules per plant ranging from 28.70 to 66.40 per cent. Significant heterosis was also noticed for number of racemes per plant in four hybrids ranging from 21.80 to 84.40 per cent. Heterosis was not observed for plant height, number of nodes up to main raceme, oil content and 1000 seed weight.

Hooks et al. (1971) studied heterosis in 21 hybrids derived through 7 x 7 diallel of castor and observed 9.30 to 235.10 per cent heterosis for seed yield.

Kabaria and Gopani (1971) studied the performance of the parents and the F1 and F2 generations of castor hybrid, GCH 3 (TSP 10R x JI 15) and observed significant heterosis in F1 over mid-parent for number of capsules on main spike (24.50 %), percentage of pistillate flowers (24.50 %) and seed yield per plant (42.90 %).

Gopani et al. (1972) studied hybrid vigour in five hybrids of castor in comparison with open pollinated variety, S 20 for two years at six locations and recorded 30.00 to 50.00 per cent higher yield of hybrids than the variety, S 20. However, none of the hybrids had higher oil content than the variety.

In a study of heterosis through 6 x 6 diallel of castor, Giriraj et al. (1973a) observed low magnitude of heterosis for length of primary raceme and seed yield per plant. However, heterosis was not observed for 100 seed weight and oil content.

Yadava et al. (1978) studied heterosis using 8 x 8 diallel of castor and reported that out of 28 crosses, seven crosses exhibited high and positive heterosis for seed yield per plant over mid-parent as well as better parent. The high heterosis was observed in crosses involving genetically diverse parents.

While studying heterosis in castor, Patel (1979) reported that the heterosis ranged from -73.07 to 140.30 per cent for seed yield, -28.60 to 51.95 per cent for number of nodes, -48.88 to 16.84 per cent for length of main spike, -63.97 to 73.92 per cent for number of capsules on main spike, -61.92 to 77.54 per cent for effective branches per plant, -65.44 to 66.10 per cent for number of capsules per plant, -32.26 to 22.90 per cent for 100 seed weight and -13.91 to 9.46 per cent for oil content.

Rao and Rao (1980) compared the performances of hybrids with varieties of castor and reported that all the hybrids except one out yielded the varieties. Hybrids
were also found genetically superior with respect to seed weight and length of pistillate region of raceme.

Kaul and Prasad (1983) studied heterosis through crosses between dwarf and tall inbreds of castor and found heterosis over their respective better parent for seed yield per plant ranging from 80.00 to 194.00 per cent. Heterosis observed for seed yield was due to the heterosis of main spike length and capsules on primary spike.

While studying heterosis through line x tester analysis of castor, Patel (1985) observed considerable heterosis over their respective better parent ranging from -36.44 to 123.84 per cent for number of effective branches per plant, -51.48 to 17.90 per cent for length of main spike, -66.78 to 55.36 per cent for number of capsules per main spike and -26.94 to 110.27 per cent for seed yield per plant.

Patel et al. (1986) studied the magnitude of heterosis in castor and found -25.10 to 64.30 per cent heterosis for seed yield per plant over their better parent. The considerable amount of heterosis was observed for other yield contributing characters.

In a study on heterosis and genetic architecture of oil content through 11 x 11 diallel analysis of castor (excluding reciprocals), Pathak et al. (1986) observed 13 and 11 crosses exhibited significant heterosis over better parent and mid-parent, respectively.

While studying the magnitude of heterosis in castor under low as well as high fertility conditions, Bhuva (1987) observed high heterosis for seed yield per plant and length of primary raceme; moderate heterosis for plant height up to main spike, number of effective branches, number of capsules on primary spike and 100 seed weight; and low heterosis for days to flowering, number of nodes up to primary spike, oil content and days to maturity under low as well as high fertility conditions.

Dangaria et al. (1987) studied the magnitude of heterosis for seed yield and yield attributes in 32 hybrids developed through line x tester mating design involving four pistillate lines and eight pollen parents and observed heterosis over their better parents ranging from 13.30 to 88.57 per cent for seed yield, -38.96 to 58.93 per cent for spike length, -35.85 to 97.50 per cent for number of capsules per plant, -27.27 to 9.26 per cent for 100 seed weight, -18.12 to 29.85 per cent for nodes up to main spike and -6.90 to 175.18 per cent for plant height.

While studying the magnitude of heterosis in castor, Thakkar (1987) reported high heterosis for seed yield per plant, number of capsules per plant and effective branches per plant; moderate heterosis for days to 50 per cent flowering, days to
maturity, plant height, number of nodes up to main raceme, number of capsules on main raceme and harvest index; and low heterosis for 100 seed weight and oil content. The results also revealed that crosses showing heterosis for seed yield per plant also exhibited heterosis for important yield components.

Pathak et al. (1988) studied heterosis through generation mean analysis for 11 traits in three crosses of castor using four inbred lines and observed significant positive heterosis for seed yield per plant, plant height, 100 seed weight and number of capsules on main spike. The other remaining traits exhibited either negative or negligible positive heterosis.

Dobaria et al. (1989) studied heterosis through partial diallel analysis involving 12 diverse castor genotypes and reported positive heterosis and heterobeltiosis for oil content ranging from 2.38 to 7.83 per cent and 1.95 to 5.91 per cent, respectively.

While studying heterosis in 20 castor hybrids under high and low fertility levels, Patel (1989a) observed moderate to high heterobeltiosis for most of the crosses under both the fertility levels for seed yield per plant, number of capsules per raceme, number of effective branches per plant, effective length of main raceme and plant height. The negative heterobeltiosis was observed for most of the crosses under both the fertility levels for days to flowering, days to maturity, number of nodes up to main spike and 100 seed weight.

Patel (1989b) studied heterosis through line x tester analysis in castor and observed marked degree of positive heterosis in individual crosses for different traits. The magnitude of heterosis was high for seed yield per plant, length of pistillate region of main spike, number of capsules on main spike; moderate for 100 seed weight and number of effective branches per plant; and low for days to 50 per cent flowering.

While studying the heterosis through line x tester analysis involving 3 females and 16 males of castor, Rabadia (1989) observed significant positive heterosis over better parents for length of main spike, seed weight, oil content, capsules on main spike, seed yield per plant and number of effective branches per plant. The significant negative and desirable heterosis over better parent was observed for plant height, number of nodes up to main spike, days to flowering and days to maturity.

Mehta et al. (1991a) studied heterosis through 10 x 10 diallel (excluding reciprocals) analysis for seed yield and ten yield related characters in castor.
relative heterosis and heterobeltiosis for seed yield per plant ranged from -50.75 to 104.57 and -60.02 to 66.58 per cent, respectively. The magnitude of heterosis was high for seed yield per plant, capsules on main spike and effective branches per plant; moderate for days to 50 per cent flowering and 100 seed weight; and low for days to maturity, nodes up to main spike, plant height, length of main spike and length of pistillate region of main spike.

While studying heterosis over better parent in 45 hybrids derived through 10 x 10 diallel (excluding reciprocals) of castor, Patel (1991a) observed relatively higher magnitude of heterosis over better parents for seed yield per plant, number of capsules per plant, effective branches per plant, harvest index and total number of branches per plant; moderate heterosis for number of capsules per main spike, plant height and 100 seed weight; and low heterosis for days to flowering, effective length of main spike, number of nodes up to main spike and oil content.

Patel (1991b) studied heterosis over better parent using line x tester analysis involving 18 females and 5 males of castor. High heterobeltiosis was observed for seed yield per plant, number of capsules per plant and number of effective branches per plant; moderate heterobeltiosis for 100 seed weight and days to maturity; and low heterobeltiosis for total length of main spike, days to 50 per cent flowering, number of nodes up to main spike and plant height. It was observed that most heterotic crosses for yield and its components also depicted high per se performance.

While studying heterosis in four separate crosses of castor based on generation mean analysis, Patel (1992) observed significant and desirable heterosis and heterobeltiosis for seed yield and its components, suggested the feasibility of the exploitation of hybrid vigour on commercial scale.

While studying the heterosis through line x tester analysis involving four females and nine males of castor, Gadhesariya (1994) observed that the magnitude of heterobeltiosis for seed yield per plant was comparatively high; moderate for effective length of main spike, number of capsules on main spike and number of total and effective branches per plant and relatively low for 100 seed weight and days to 50 per cent flowering. Cross, VP 1 x JI 96 and SKP 93 x 48-1 depicted the highest heterotic effects for seed yield.

Patel (1994a) studied the extent of heterosis in four environments for seed yield per plant and other yield contributing characters utilizing line x tester mating design involving four diverse female parents and fourteen male parents and observed
significant heterosis on pooled basis over standard check hybrid in desired direction for days to 50 per cent flowering, days to 50 per cent maturity, plant height, number of nodes up to main raceme, length of main raceme, number of capsules on main raceme, number of effective branches per plant, total number of branches per plant, seed yield per plant, 100 seed weight and oil content. Significant heterobeltiosis was observed in desired direction for all the characters studied except number of nodes up to main raceme.

In a study of heterosis through line x tester analysis involving five pistillate lines and fourteen male parents of castor, Patel (1994b) reported that seed yield per plant was found to be the most heterotic component followed by seed yield per main raceme and number of capsules on main raceme. Out of 21 crosses showing positive heterosis over their corresponding better parent for seed yield per plant, 15 crosses manifested economic hybrid vigour over GCH 4. The hybrid SKP 25 x JH 128 exhibited the highest heterosis for seed yield per plant among all the hybrids tested. Similarly, for seed yield per main raceme, hybrid SKP 82 x SH 66 exhibited the highest heterosis.

In a study of heterosis through line x tester analysis involving four females and fourteen pollinators of castor, Patel (1994c) reported that hybrids exhibited high heterosis and per se performance for seed yield per plant also manifested high heterosis and per se performance for important yield contributing traits like length of main raceme, number of capsules on main raceme, number of effective branches per plant and 100 seed weight.

While studying the heterosis in 11 separate crosses of castor based on generation mean analysis, Bhand (1996) observed that two hybrids viz., Aruna x SKI 12 and VP 1 x Aruna expressing significant positive heterosis and heterobeltiosis for seed yield, length of main raceme, number of capsules on main raceme, number of total and effective branches per plant and 100 seed weight. The cross Aruna x SKI 12 showed the highest relative heterosis (58.96 %) and heterobeltiosis (53.20 %) with the maximum seed yield per plant (269.44 g) followed by hybrid VP 1 x Aruna with heterosis (45.54 %), heterobeltiosis (21.94 %) and seed yield per plant (208.76 g).

Patel (1996) studied the magnitude of heterosis in five crosses viz., VP 1 x 48-1, Geeta x SH 41, Geeta x 2-73-11. SKP 25 x JM 6 and SKP 25 x SPS 43-3 through generation mean analysis and observed significant and desirable
heterobeltiosis for yield and majority of yield components. In view of high heterosis in crosses, VP 1 x 48-1 and Geeta x SH 41, suggested the feasibility of the exploitation of hybrid vigour on commercial scale.

Chakrabarty (1997) estimated heterosis in 20 crosses of castor derived from four lines and five testers by crossing them in line x tester mating design. Significant heterosis was found for days to flowering of primary spike and number of nodes up to main spike. Two hybrids viz., DCH 159 and DCH 171 were superior over their respective better parent for number of effective spikes per plant and oil content. The high heterosis for seed yield was associated with number of effective spikes per plant.

Saiyed et al. (1997) studied heterosis for seed yield and yield components in castor using diallel crosses involving ten parents. Considerable amount of heterobeltiosis was observed for seed yield per plant, number of capsules per plant, number of effective branches per plant and oil content. Lower amount of heterobeltiosis was observed for shelling out turn, kernel content, 100 seed weight and effective length of main spike. The cross Aruna x SKI 6 recorded the highest heterobeltiosis (41.08 %) for seed yield per plant.

Patel (1998a) studied heterosis in castor using diallel analysis (excluding reciprocals) involving seven elite lines of castor and reported high magnitude of heterobeltiosis and standard heterosis for effective length of main spike, number of capsules per main spike, number of capsules per plant, seed yield per plant, harvest index and 100 seed weight.

While studying the heterosis for seed yield, oil content, density and iodine value of oil and six other yields contributing traits following diallel analysis in 36 F₁s and 36 F₂s under irrigated and rainfed conditions, Patel (1998b) reported positive and highly significant heterosis for seed yield and its attributes. Among all the traits, capsules on main spike exhibited the maximum heterosis in cross, SKI 72 x TMV 5 (52.99%) under irrigated condition and heterobeltiosis in cross, TMV 5 x SKI 119 (44.59%) over both the environments. The best performing crosses for yield per se performance, SKI 22 x TMV 5, 48-1 x SKI 119 and SKI 107 x SPS 43-3 under irrigated condition and SKI 22 x SPS 43-3, SKI 22 x TMV 5 and SKI 22 x SKI 119 under rainfed condition exhibited high heterosis.

Manivel et al. (1999) evaluated 60 hybrids of castor produced by line x tester mating design (4 pistillate lines and 15 inbreds) over environments (two locations and two seasons) to determine the extent of heterosis for seed yield and seven yield related
traits. Considerable amount of heterosis over better parent and best parent was observed for seed yield per plant. The heterosis for seed yield appeared to be due to high manifestation of heterosis for length of primary raceme, number of racemes per plant, number of capsules per plant and 100 seed weight. Desirable heterosis was also recorded for days to 50 per cent flowering, plant height up to primary raceme and number of nodes up to primary raceme.

With a view to develop early maturing varieties and hybrids of castor suitable for Andhra Pradesh, an attempt was made by Thatikunta et al. (2000) to estimate heterotic potential of elite parents through 8 x 8, line x tester mating design. The lines as well as testers exhibited good gca effects for seed yield. The data indicated that for realization of heterosis, at least one parent must have higher gca for yield components. High heterosis for crosses made between poor parents was also observed. These results suggested that, additive as well as non-additive components can be exploited for the development of potential varieties and hybrids.

Joshi et al. (2002a) studied heterosis over better parent (BP) and standard hybrid (SH) in castor over four environments using 112 crosses developed by line x tester (4 x 28) mating design. The results showed that three cross combinations namely SKP 93 x J 1, SKP 93 x 6-219-22 and VP 1 x HO exhibited significant and high positive heterosis over better parent and standard hybrid for seed yield per plant. These crosses also had significant and positive heterosis for number of capsules per plant, number of capsules per main spike and seed yield per main spike. Considerable amount of significant and desirable heterosis over better parent and standard hybrid was also recorded for days to flowering, days to maturity of main spike, plant height, number of nodes up to main spike, length of main spike, number of effective branches per plant and 100 seed weight, while low heterosis was observed for oil content.

Lavanya and Chandramohan (2003) evaluated 27 crosses of castor developed by line x tester (3 x 9) mating design for estimating the heterosis over better parent and standard check for seed yield and yield components. Significant and desirable heterosis was observed for seed yield per plant, number of effective spikes per plant, 100 seed weight, oil content and days to 50 per cent flowering.

Tank et al. (2003) studied heterosis for seed yield per plant and other important yield attributes in a 10 x 10 diallel crosses and observed moderate magnitude of heterosis for seed yield per plant, number of effective branches per plant and total number of branches per plant, and low magnitude of heterosis for number of
capsules on main raceme, effective length of main raceme, 100 seed weight and oil content.

Golakia et al. (2004) carried out generation mean analysis for seed yield and yield contributing traits in six basic generations (P₁, P₂, F₁, F₂, BC₁ and BC₂) of three crosses in castor. The highest heterosis over better parent (84.00 %) was shown by SKP 4 x JI 269. Same cross also exhibited significant heterobeltiosis for plant height and number of capsules on primary raceme. The cross SKP 4 x JI 266 also exhibited significant and positive heterosis for plant height, number of nodes, length of primary spike, number of capsules on primary raceme and 100 seed weight.

Patel (2005) carried out generation mean analysis using four crosses of castor under three environments and reported high magnitude of heterosis, heterobeltiosis and economic heterosis for seed yield per plant; low heterosis for days to flowering; number of nodes up to main raceme, 100 seed weight and oil content; and moderate heterosis for length of main raceme, effective branches per plant over mid parent and standard check.

Ramana et al. (2005) crossed three pistillate lines (DPC 9, DPC 10 and DPC 13) and 9 wilt resistant testers (PCS 1, PCS 121, JI 220, JI 225, JI 240, JI 260, SKI 229, SKI 232 and SKI 233) in a line x tester mating design in rabi 2000-01. The 27 hybrids along with their 12 parents and 2 standards controls (DCH 32 and GCH 4) were evaluated under rainfed condition during kharif 2001-02. Observations were recorded for seed yield (90, 120 and 150 days after sowing), and its components (number of nodes up to primary spike, plant height up to primary spike, effective spikes per plant, 100 seed weight and oil content. Highly significant differences in parents vs. hybrids indicated the presence of heterosis for all the characters. The crosses, DPC 10 x SKI 229, DPC 10 x JI 240, DPC 10 x PCS 121, DPC 10 x JI 225 and DPC 10 x JI 220 exhibited high per se performance and high percentage of heterosis, heterobeltiosis and standard heterosis for seed yield.

Thakkar et al. (2005) studied heterobeltiosis and standard heterosis for seed yield and its attributes in 75 castor hybrids developed through line x tester mating design. Significant and positive heterosis over better parent and standard heterosis was observed for seed yield ranged from 5.57 to 128.46 per cent and 3.58 to 28.98 per cent, respectively. The cross combinations SKP 49 x SPS 43-3, Geeta x SKI 147 and SKP 49 x SH 72 exhibited significant and positive heterosis over check hybrid (GCH 4) for seed yield per plant.
Lavanya et al. (2006) evaluated 25 castor hybrids generated by 5 x 5, line x tester mating design along with parents and standards checks, DCH 32 and GCH 4 for heterosis. The results showed that standard heterosis for seed yield ranged from -31.9 per cent to 105.5 per cent over both the standard checks (DCH 32 and GCH 4). Seven hybrids exhibited more than 50 per cent standard heterosis, which could be used for commercial purpose. The hybrids DPC 10 x RG 297 and DPC 10 x RG 2178 exhibited high standard heterosis along with low wilt incidence in castor.

Patel and Pathak (2006b) evaluated 50 hybrids developed through line x tester mating design using five lines and ten testers to study heterosis for seed yield in castor. The results revealed high heterotic effect for seed yield per plant, plant height, number of effective branches per plant and total number of branches per plant. Geeta x SKI 107, Geeta x VI 9 and SKP 5 x SKI 73 were the most heterotic hybrids showing the highest significant and positive standard heterosis, whereas SKP 72 x SKI 80, VP 1 x SKI 80 and SKP 72 x SH 72 exhibited highest significant and positive heterobeltiosis for seed yield per plant.

Maheshwari (2007) studied the heterosis in castor using diallel analysis involving ten elite lines of castor and reported high heterosis, heterobeltiosis and standard heterosis for seed yield per plant, plant height, length of main raceme, number of capsules on main spike and number of effective branches per plant; moderate heterosis for days to 50 per cent flowering, days to maturity, number of nodes up to main raceme and 100 seed weight; and low heterosis for oil content.

Golakia et al. (2008) evaluated 44 castor hybrids developed by line x tester mating design (4 pistillate lines and 11 male parents) along with 15 parents and standard check for heterosis of yield determinant traits. The significant and desired heterosis and standard heterosis for seed yield per plant was ranged from 18.70 to 39.60 per cent and 17.0 to 32.8 per cent, respectively. The crosses JP 88 x DCS 89, JP 65 x DCS 89, JP 88 x PCS 124, JP 88 x JI 274 and JP 65 x JI 309 were found promising hybrids over standard check GCH 6.

Barad et al. (2009a) studied heterobeltiosis and standard heterosis for seed yield and its attributes in 40 castor hybrids developed through line x tester mating design. Significant and positive heterosis over better parent and standard heterosis was observed for seed yield, which ranged from -49.22 per cent to 141.32 per cent and -55.27 per cent to 17.10 per cent, respectively. The cross combinations
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ACP 1 x JI 35 (17.10 %) and JP 65 x VI 9 (13.82 %) exhibited significant and positive standard heterosis over GCH 4 for seed yield per plant.

Patel et al. (2009) evaluated a set of 45 hybrids derived through a 10 x 10 diallel mating design excluding reciprocals along with ten parents to identify the most promising heterotic crosses in castor. The results indicated that three crosses i.e., SKI 205 x SH 21, SKI 205 x SKI 226 and SKI 294 x SKI 304 were identified as promising for most of the desirable traits, which could be considered for exploitation of hybrid vigour in castor. The top high yielding cross SKI 205 x SKI 226 possessed high level of heterosis over better parent (32.33%) and standard check (48.78%) for seed yield per plant.

Sridhar et al. (2009) evaluated 75 castor hybrids generated through line x tester design along with their parents for heterosis, heterobeltiosis and standard heterosis for seed yield per plant and its related traits in castor and reported that heterosis observed for seed yield per plant might be due to manifestation of high heterosis for yield components viz., length of primary spike, length of effective spike, number of capsules per primary spike and 100 seed weight. The magnitude of heterosis over mid parent, better parent and standard check for seed yield per plant ranged from 39.69 per cent to 74.42 per cent, 57.61 per cent to 59.01 per cent and 20.33 per cent to 66.37 per cent, respectively. The cross combinations LRES 17 x RG 1713, VP 1 x RG 224 and LRES 17 x RG 224 exhibited significant and positive heterosis over standard check for seed yield per plant.

Monpara (2010) computed heterosis in six castor crosses and reported that cross Geeta x JI 263 exhibited the highest standard heterosis followed by JP 90 x JI 258 and JP 86 x JI 273 for seed yield per plant under pre-rabi season, while in case of rabi season, the maximum standard heterosis was displayed by hybrid SKP 42 x SKI 215 followed by Geeta x JI 263.

Sodavadiya (2010) studied heterosis for seed yield per plant in a 10 x 10 diallel cross of castor. The results revealed that among 45 hybrids, DCS 89 x PCS 124, JI 353 x PCS 124 and Geeta x PCS 124 recorded the significant and positive heterosis over GCH 6 for seed yield per plant. The cross SKP 42 x JI 371 followed by DCS 89 x PCS 124 and SKP 42 x JI 338 recorded the highest heterobeltiosis for seed yield per plant. The high heterosis in these hybrids was mainly due to high heterosis in one or more of their component traits.
Chaudhari et al. (2011) evaluated ten diverse inbreds, their 45 hybrids (generated by diallel mating design excluding reciprocals) along with two standard checks viz., GCH 4 and GCH 5 to determine the extent of heterosis for seed yield and eight component traits. The heterobeltiosis and standard heterosis over GCH 4 and GCH 5 for seed yield per plant across the environments ranged from -13.71 per cent to 47.89 per cent, -25.08 per cent to 22.77 per cent and -31.62 per cent to 12.04 per cent, respectively. Hybrids SKI 280 × SH 41, SKI 280 × SKI 288, SH 41 × SKI 285, SKI 280 × SKI 215, SKI 288 × SH 41, SKI 288 × SKI 232, SKI 218 × SKI 232, SKI 215 × SH 41, SKI 288 × SKI 285, SKI 215 × SKI 285, SKI 232 × DCS 9 and SKI 215 × SKI 232 significantly out yielded their better parents, while SKI 232 × DCS 9 was significantly superior over GCH 4. Across the locations, the cross SKI 232 × DCS 9 produced the highest 182.28 g of seed yield per plant and registered 30.49, 22.77 and 12.04 per cent superiority over better parent, GCH 4 and GCH 5, respectively.

Patel et al. (2013a) evaluated four pistillate lines and 12 inbred lines with their 48 hybrids and one check hybrid (GCH 7) under semi rabi condition of middle Gujarat for estimation of heterosis in castor. The heterobeltiosis was negative for days to 50 per cent flowering, days to 50 per cent maturity of primary spike, plant height up to primary spike, number of nodes up to primary spike, 100 seed weight and oil content, whereas the estimates of heterobeltiosis were positive for seed yield per plant and number of capsules per plant. The characters length of primary spike, number of secondary spikes, number of tertiary spikes, number of effective branches per plant and number of capsules per primary spike depicted heterotic effect in both the directions. The crosses VP 1 x DCS 47, Geeta x SH 41, SKP 84 x DCS 47, Geeta x SKI 270 and SKP 24 x DCS 47 were found promising hybrids for seed yield.

Singh et al. (2013) studied P1, P2, F1, F2, B1 (F1 x P1), B2 (F1 x P2), B1S (B1 selfed), B11 (B1 x P1), B12 (B1 x P2), B2S (B2 selfed), B21 (B2 x P1) and B22 (B2 x P2) generations derived from three castor crosses (JP 96 x JI 368, JP 96 x JI 372 and JP 101 x SKI 215) for seed yield and its contributing characters in castor. The heterosis over better parent was found significant in desirable direction for number of capsules on main raceme in JP 96 x JI 368; for length of main raceme, effective length of main raceme and number of capsules on main raceme in cross JP 96 x JI 372; and for oil content in cross JP 101 x SKI 215.
Chaudhari and Patel (2014) evaluated 12 genotypes of castor (*Ricinus communis* L.) consisting four lines and eight testers along with their 32 hybrids developed through line × tester mating design. In general, for yield and yield attributing traits, the promising hybrids with high heterosis (over better parent as well as standard hybrid) were VP 1 x ANDCM 2 and SKP 84 x ANDCM 2 with high mean. These cross combinations could be utilized for further use in breeding programme for improvement in yield of castor.

Makani *et al.* (2015) evaluated 56 genotypes including 10 parents, 45 hybrids (develop by diallel mating design excluding reciprocals) and 1 standard check GCH 7 to determine the extent of heterosis for seed yield, its components and wilt resistance over environments. The data on heterobeltiosis revealed that crosses SKI 341 x GC 3 and SKI 341 x SPS 43-3 gave consistence performance for seed yield per plant in all the environments. The crosses MCI 108 x SKI 341 and SKI 341 x SPS 43-3 exhibited significant positive standard heterosis in all the environments for seed yield per plant. The crosses which found significant for seed yield per plant were also found resistance to wilt. Magnitudes of heterosis vary from character to character and cross to cross. In general, for seed yield per plant across the locations, magnitude of desirable heterosis was high over better parent, but low over standard check. For developing high yielding and earlier maturing genotypes, selection of crosses on the basis of *per se* performance with considerable per cent heterobeltiosis and standard heterosis would be more desirable.

Patel *et al.* (2015) studied heterosis for yield and its component traits in castor through line x tester mating design using five lines and ten testers. Analysis of variance revealed highly significant difference among the parents for all the traits under study. The crosses ACP 1-06-07-2 x SKI 299, ANDCP 06-07 x SKI 270 and JP 65 x JI 321 exhibited significant positive SCA effects for seed yield per plant and its component traits, The promising hybrids with high heterosis and mean performance for yield and its component traits were ACP 1-06-07-2 x SKI 299, SKP 84 x DCS 47, ANDCP 06-07 x SKI 215, ACP 1-06-07-2 x SKI 215 and ANDCP 06-07 x SKI 270 and were at par with check.

Sapovadiya *et al.* (2015) assessed the extent of heterosis over environments in castor for 12 quantitative traits including seed yield per plant. Four pistillate lines and 13 monoecious testers were crossed in a line x tester fashion to develop 52 F₁ hybrids. The pooled analysis of variance over environments showed significant differences
among the environments (sowing dates) for all the characters except number of capsules on primary raceme indicating wide variation in environmental conditions or differential expression of traits under different sowing dates. The mean squares due to parents, hybrids and parents \( vs. \) hybrids were also found significant for all the characters, indicating the presence of sufficient amount of genetic diversity in the material for the traits studied. Significant and desired heterobeltiosis and standard heterosis ranged from -37.14 to 75.95 per cent and -61.77 to 18.64 per cent for seed yield per plant, respectively. However, magnitude of heterosis was vary substantially from cross to cross and character to character. The crosses JP 89 x PCS 124, JP 89 x RG 2826, SKP 84 x 48-1, SKP 106 x 48-1 and SKP 106 x PCS 124 were the best heterotic combinations for seed yield per plant, which recorded 75.95, 70.45, 61.11, 60.45 and 58.57 per cent heterobeltiosis, respectively. The heterosis for seed yield per plant was associated with the heterosis expressed by its component characters.

Patted \textit{et al.} (2016) studied the heterobeltosis and standard heterosis for seed yield and its attributes in 80 hybrids developed through line x tester mating design (ten lines and eight testers). The significant positive heterosis for seed yield over better parent ranged from -35.15 per cent to 111.34 per cent and standard heterosis over checks DCH 177 and DCH 519 for seed yield ranged from 46.89 per cent to 48.14 per cent and -27.72 per cent to 101.63 per cent, respectively. The cross combination DCS 94 x K 11-1166-11 exhibited the significant positive better parent heterosis and significant positive standard heterosis over both the checks DCH 177 and DCH 519 for seed yield per plant. Comparison of top five crosses for yield \textit{per se} performance (DCS 94 x K 11-1166-1, DCS 78 x K 11-1174-1, DCS 94 x 48-1, DCS 17 x K 11-1135-1 and DCS 94 x K 11-1135-1), heterosis over better parent and standard heterosis indicated that most superior hybrids were accompanied by significant and positive heterosis for yield attributing traits like primary spike length, effective spike length, secondary spike length, number of capsules on primary spike and effective number of spikes per plant advocating that the high heterosis for seed yield resulted through contribution of these component traits. Hybrid vigour of superior crosses can be exploited commercially in future through further evaluation for stability performances across the environments over years.
2.2 COMBINING ABILITY AND GENE ACTION

One of the important practical problems encountered by plant breeders is the choice of appropriate parents which nick well in hybridization and produce superior off-springs. The usual approach is to choose the parents on the basis of *per se* performance. However, it does not provide always a good indication of the superiority of hybrids. It is of common experience that certain combinations nick well to produce superior hybrids, whereas other involving equally promising parents produced poor hybrids. Therefore, it is always essential to study the combining ability of parents before they are utilized in actual breeding programme. Combining ability has been defined as the ability of a line to transmit its characteristics to the progenies; therefore, much of the success rests upon the combining ability of parents, as the criterion for the selection of parents.

The concept of combining ability has become very popular in the discipline of plant breeding since Davis (1927) suggested the use of inbred variety cross (top cross) as a method of evaluating inbred lines of maize. Later on Sprague and Tatum (1942) elaborated it by proposing the concept of general and specific combining ability. The general combining ability (gca) is defined as the average performance of a line in a series of crosses and is considered as a measure of additive gene action, whereas specific combining ability is the deviation in performance of a cross combination predicted on the basis of the general combining ability effects of the parents involved in the cross. It is considered as a measure of non-additive gene action, which includes the portion arising from dominance and epistatic deviations.

Federer and Sprague (1947) suggested that single tester provides the most efficient means of testing specific combining ability, whereas more than one tester is necessary for estimation of general combining ability.

Green (1948) reported that combining ability was an inherited trait and suggested that segregants with relatively high proportion of favourable genes would occur more than often in the progenies of crosses of high combining ability inbreds than in the progenies of crosses where one or both the parents had lower combining ability.

Henderson (1952) defined specific combining ability in terms of interactions that were due to the consequences of intra-allelic gene interactions (dominance) and also due to inter-allelic (epistasis) gene interactions.

Kempthorne (1957) discussed the general and specific combining ability
variances in terms of covariance of half and full sibs in a random mating population.

Where,

\[ \sigma^2_{gca} = \text{Cov. (H. S.)}, \]  
\[ \sigma^2_{sca} = \text{Cov. (F. S.)} - 2 \text{Cov. (H. S.)} \]

With the advancements in biometrical genetics, several methods have been developed to assess the general and specific combining ability of different genetic materials, *viz.*, inbred x variety or a top cross technique (Jenkins and Brunson, 1932), poly cross (Tysdal *et al.*, 1942), modification of North Carolina Design-II (Comstock and Robinson, 1948), diallel analysis (Griffing, 1956a and 1956b), line x tester analysis (Kempthorne, 1957), partial diallel analysis (Kempthorne and Curnow, 1961), triallel analysis (Rawlings and Cocherham, 1962) and modified line x tester (Murty *et al.*, 1967). For selecting genotypes for hybridization on the basis of combining ability, line x tester analysis has been found to be more advantageous than other methods, as there is always uncertainty about the randomness of pollination in poly cross techniques, whereas the numbers of crosses involved in diallel method are too high.

Murty *et al.* (1967) extended line x tester analysis to calculate variances due to gca and sca including the parental lines in a bid to obtain single degree of freedom for parent vs. hybrid comparison. The significance of this contrast was taken to indicate the presence of heterosis. This analysis is known as modified line x tester (MLT).

Chandra *et al.* (1969) reported that line x tester is not only useful for practical screening work, but is also more comprehensive than other techniques like diallel, which are generally based on fewer parents.

Arunachalam (1974) compared the line x tester and modified line x tester design and suggested the use of ‘t’ test to judge the superiority of hybrids. It was also suggested that parents and hybrids should be sown separately in each replication.

Bhapkar and Cruz (1967) studied the inheritance of oil content in a cross of two parents and revealed that F₁ mean oil content was higher than those of the parents. The F₂ population showed continuous variation with mean being more towards the F₁ showing involvement of large number of genes with epistatic effects indicating possibilities of selecting lines with higher oil content.

Hooks *et al.* (1971) studied the magnitude of genetic variances in castor through 7 x 7 diallel analysis and observed significant general and specific combining ability effects for days to flowering, number of racemes per plant and oil content.
Giriraj (1973) studied combining ability in a diallel set of six varieties of castor and reported dominance and over dominance for yield and partial dominance for length of primary raceme, number of capsules on primary raceme, 100 seed weight and oil content.

While studying combining ability in a diallel set of crosses of six varieties of castor, Giriraj et al. (1973b) observed highly significant general and specific combining ability variances for seed yield per plant, length of primary raceme, number of capsules on primary raceme, 100 seed weight and oil content. Preponderance of additive type of gene action was observed for length of primary raceme, 100 seed weight, oil content and seed yield per plant. Aruna was found to be good general combiner for oil content, whereas TMV 1 and Gujarat monospike were the good combiners for seed yield, length of primary raceme and number of capsules on primary raceme.

Ramaswamy and Menon (1973) carried out genetic analysis of 4 x 4 diallel set of crosses and observed predominance of additive genetic variance for seed yield and yield contributing characters.

In a study of combining ability through line x tester analysis using 12 female parents and 2 pollen parents of castor, Kandaswami (1977) observed the importance of non-additive genetic variance for number of branches, number of racemes, length of raceme, length of pistillate region of raceme and total number of capsules, whereas predominance of additive genetic variance was found to be important for seed yield per plant. The results also revealed that a large part of total genetic variation for seed yield and its components was associated with a significant general combining ability effects, while specific combining ability had small effects on yield.

In their combining ability study of 8 x 8 diallel cross (excluding reciprocals) in castor, Yadava et al. (1978) observed predominance of non-additive genetic variance for the expression of seed yield per plant. High magnitude of specific combining ability variance was observed than general combining ability variance and perfect correspondence between the specific combining ability effects of a cross and its heterotic value. Parent Rc 1377 was found to be the best general combiner, whereas CH 1 x JI 44, Rc 1377 x Rs 7, Aruna x VHB 144 and Rc 1379 x Rs 7 had higher specific combining ability effects for seed yield per plant.

Singh and Yadava (1981) studied combining ability through 8 x 8 half diallel in castor and observed significant general and specific combining ability variances for
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days to flowering, days to maturity and seed yield per plant. Higher magnitude of specific combining ability variances was observed for days to maturity and seed yield per plant. Parents, Rc 1377, Rs 7 and Rc 1379 were the best general combiners for early flowering, early maturity and seed yield, respectively. Pc No. 1 x CH 1, Pc No. 2 x Rc 1377 and CH 1 x JI 44 had the highest specific combining ability effects for days to flowering, days to maturity and seed yield per plant, respectively. It was also found that higher specific combining ability effects were generally observed for crosses having parents from genetically divergent groups.

Singh and Srivastava (1982) evaluated six yield related traits in 30 hybrids obtained by crossing 15 lines (11 from USA, 3 from India and 1 from USSR) with testers Tarai 4 and Type 3 and observed that dominance effects were predominant for number of effective branches per plant, days to flowering, length of main spike, length of pistillate region of main raceme, number of capsules per plant and seed yield per plant.

Singh and Yadav (1982) carried out genetic analysis of plant height through 8 x 8 half diallel involving dwarf, medium and tall inbreds of castor and observed that plant height was under the control of both additive as well as non-additive genetic variances. However, additive genetic variance was predominant.

While studying inheritance of seed yield per plant through 5 x 5 diallel of castor, Alba and Greco (1983) observed that both additive as well as non-additive gene effects were involved in the inheritance of seed yield per plant.

Bhatt and Reddy (1983) studied combining ability through 8 x 8 diallel crosses of castor and found that both general and specific combining ability variances were significant for days to flowering, number of capsules on main raceme and seed yield per plant. It was further observed that both additive and non-additive components were equally important for days to flowering, while non-additive component was predominantly involved in the expression of capsules on main raceme and seed yield per plant. Parents HO and HC 8 were found to be good general combiners for seed yield per plant, whereas 279 and VI 9 were good general combiners for early flowering and HO and T 3 were good general combiners for number of capsules per main raceme. The cross, T 3 x 157-B was the best specific combination to exploit non-fixable components. It was advocated the use of biparental mating with reciprocal recurrent selection for exploitation of both fixable and non-fixable components for further improvement in seed yield.
In their studies on combining ability for seed yield per plant and five other yield contributing characters through line x tester analysis involving five exotic females and four indigenous males, Kandaswami et al. (1983) observed that general combining ability effects were more important than specific combining ability effects for seed yield per plant. Parents Rc 913 (male) and Rc 1092 (female) had significant positive general combining ability effects for seed yield. Parents, Rc 1079 and Rc 1179/2 (females) and hybrids Rc 1075 x Rc 1079, Rc 1075 x Rc 1092 and Rc 913 x Rc 1179/2 were suggested to be exploited for high genetic gain.

While studying combining ability for days to flowering, number of nodes and plant height up to main spike through line x tester analysis involving three pistillate lines and 18 pollen parents of castor, Patel et al. (1984) observed preponderance of additive type of gene action for days to flowering and number of nodes. Females 240 and VP 1, and males 279, 1379 and Aruna were good general combiners for all the traits. It was suggested that parents with lower mean value for nodes up to main spike should be selected to exploit earliness in castor hybrids.

Swarn Lata et al. (1984) studied combining ability of seed yield per plant and five other related characters in a set of diallel crosses involving 17 diverse varieties of castor and observed that both general and specific combining ability variances were highly significant for number of nodes up to main raceme, number of capsules per primary raceme, 100 seed weight and seed yield per plant. General combining ability variances were significant for plant height and length of primary raceme. Predominance of additive type of gene action was observed for plant height, number of nodes up to main raceme, length of primary raceme and 100 seed weight, whereas non-additive type of gene action was predominantly involved in the expression of number of capsules on primary raceme and seed yield per plant. Parents PB 1, HC 8, T 4, Aruna, Sowbhagya and I-21 were found to be good general combiners for seed yield per plant. It was suggested that the hybridization between dwarf and tall parents for improvement in seed yield, as they were higher yielders with longer primary raceme and more number of capsules per primary raceme.

Narkhede et al. (1985) studied the combining ability of seed yield per plant and seven related characters through 4 x 4 diallel crosses in castor and observed significant general and specific combining ability variances for number of capsules on main spike. However, additive type of gene action was predominantly involved in the expression of nodes up to main spike, effective spikes per plant and 100 seed weight.
While studying combining ability in castor, Patel (1985) observed importance of non-additive type of gene action for days to 50 per cent flowering, days to maturity, plant height, number of nodes up to main spike, number of effective branches per plant, length of main spike, capsules per main spike, 100 seed weight, harvest index, oil content and seed yield per plant. Parents SKP 25, SKI 18, VI 9, VH 52, HO and JM 4 were good general combiners for seed yield and yield contributing characters.

Patel et al. (1985) studied combining ability in 44 entries involving 32 hybrids and their 12 parents and observed additive type of gene action for seed yield and number of capsules per plant and non-additive type of gene action for 100 seed weight, plant height up to main raceme, effective branches per plant and days to flowering in castor.

Bhatt and Reddy (1986) studied six crosses of castor for seven yield components and reported significant epistatic interactions for days to flower, number of nodes up to main raceme, plant height up to main raceme, number of racemes and seed yield. However, predominance of fixable gene effects for most of the characters suggested the utilization of bulk population and mass pedigree methods for enhancing seed yield, whereas biparental mating with reciprocal recurrent selection could be used for the exploitation of both fixable and non-fixable genetic components of yield and its attributes in castor.

Patel et al. (1986) studied combining ability through line x tester analysis using 4 pistillate lines and 15 monoecious pollen parents of castor and reported the preponderance of non-additive type of gene action for seed yield per plant and number of capsules on main spike and predominance of additive type of gene action for nodes up to main spike, effective spikes per plant and 100 seed weight. Female VP 1 and male VI 4 were good general combiners for seed yield. It was suggested that high yielding parents were good general combiners and thus, selection of parents for hybridization can be done on the basis of per se performance.

Pathak et al. (1986) studied the genetic architecture of oil content through 11 x 11 half diallel in castor and found predominance of non-additive type of gene action for oil content. Parents 2-73-11, T 4, I 21 and Masalio were good general combiners. Several crosses possessed higher mean values, significant heterosis and higher and significant positive specific combining ability effects for oil content, which can be
exploited for developing varieties with higher oil content in castor through further breeding.

Dangaria *et al.* (1987) studied combining ability through line x tester analysis involving 4 pistillate lines and 8 pollen parents of castor for seed yield and its attributes and found predominance of non-additive type of gene action for seed yield per plant, number of capsules per plant and effective branches per plant and preponderance of additive type of gene action for length of main spike and 100 seed weight. Females SKP 4 and VP 1 were the best general combiners of 100 seed weight and effective branches per plant, respectively, while SKP 3 was the best general combiner for length of main spike and number of capsules per main spike. Male JI 35 was the best general combiner for yield and important yield traits. It was observed that parents having high *per se* performance were also good general combiners.

Fatteh *et al.* (1987) carried out line x tester analysis using four pistillate lines and eight pollen parents in castor for length of seed, width of seed, thickness of seed, 100 seed weight, endosperm percentage and oil content and observed predominance of additive gene action for all the traits related to oil content. Female SKP 3 was good general combiner for seed width, seed length and oil content and SKP 4 was good general combiner for seed width, 100 seed weight and thickness of seed. Among males, SPS 43-3 was the best general combiner for seed length, thickness of seed and 100 seed weight. It was also reported that parents showing higher mean performance generally proved to be good general combiners.

Study of gene effects for some quantitative characters in castor revealed predominance of additive gene effects for plant height and length of spike; dominance gene effects for number of effective spikes, number of primary and secondary racemes and yield per plant; and epistatic gene effects for number of nodes up to main raceme and capsule number per main raceme (Narkhede *et al.*, 1987).

Pathak and Dangaria (1987) studied combining ability through 11 x 11 diallel analysis of castor and observed highly significant general and specific combining ability variances for days to flowering, days to maturity, number of nodes up to main spike, length of main spike, capsules on main spike, effective branches per plant, 100 seed weight and seed yield per plant. The predominance of additive type of gene action was observed for all the traits except seed yield per plant, which was controlled by non-additive type of gene action. Parents Masalio, HO, HC 8 and VI 9 were good general combiners for seed yield per plant, plant height and length of main spike,
while Aruna x Masalio, 279 x 2-73-11, HC 8 x 411-JI, 413-A x 2-73-11 and T 4 x VI 9 were good combinations for seed yield and its contributing characters.

Thakkar (1987) studied combining ability through diallel analysis involving six varieties of castor and reported the importance of both additive and non-additive types of gene action in the expression of days to 50 per cent flowering, days to maturity, plant height, nodes up to main raceme, number of capsules on main raceme, 100 seed weight, harvest index and seed yield per plant. The variance ratio of general to specific combining ability indicated the predominance of non-additive genetic variance for all the characters except number of nodes up to main raceme, plant height and 100 seed weight. It was also found that the ranking of parents based on general combining ability effects and per se performance was almost similar.

Fatteh et al. (1988) studied combining ability through line x tester analysis involving three females and eight males of castor for seven characters and reported the importance of non-additive type of gene action in the expression of seed yield per plant, capsules per main spike and effective branches per plant. However, additive type of gene action was found to be important in the expression of days to 50 per cent flowering, nodes up to main spike and plant height. Female, SKP 4 was good general combiner for days to 50 per cent flowering and 100 seed weight and VP 1 for plant height and effective branches per plant. Males SPS 43, JI 69 and VI 9 were good general combiners for seed yield.

Pathak et al. (1988) studied gene effects through generation mean analysis using four inbred lines, their three F1’s, F2’s and back crosses in castor and found that additive, additive x additive and dominance x dominance effects were more important for seed yield, whereas dominance x dominance for days to flowering, only additive effects for total and effective branches and all types of gene effects were found important for plant height up to main raceme, length of main spike and 100 seed weight.

While studying combining ability and gene action for oil content in castor involving 12 genotypes and their F1 hybrids, Dobaria et al. (1989) reported that additive as well as non-additive types of gene action were involved in the inheritance of oil content with non-additive being predominant. Parents TMV 5, JM 3 and 240 had higher general combining ability effects for oil content, while 2-73-11 x SH 38 and SH 15 x 2-73-11 had higher specific combining ability effects for oil content.
Diallel analysis of 10 diverse genotypes of castor was used for studying combining ability for seed yield and its attributing characters by Mehta (1989). Both general and specific combining ability variances were observed to be highly significant for seed yield per plant, length of main raceme, length of pistillate region of main raceme, number of effective branches per plant, number of capsules on main raceme, 100 seed weight and seed yield per main raceme indicating the importance of additive and non-additive types of gene action in the expression of these traits, with additive type of gene action being predominant.

While studying combining ability through line x tester analysis in castor for seed yield per plant, days to flowering, number of nodes up to main raceme, length of main raceme, effective length of main raceme, plant height, days to maturity of main raceme, number of capsules on main raceme, number of effective branches per plant, days to maturity of whole plant, 100 seed weight and oil content, Patel (1989a) observed predominance of non-additive type of gene action for all the traits studied except 100 seed weight for which additive type of gene action was more important. None of the parents had good general combining ability for all the traits. However, on the basis of trait wise performance, JI 35-15 was good general combiner for seed yield per plant, while JP 65 and 48-1 were good combiners for seed weight and oil content. Parents SKP 23 and SKP 4 were good combiners for days to flowering. It was reported that the mean performance of parents was good index of its general combining ability.

Patel (1989b) used line x tester analysis in castor to study the combining ability for yield and its component characters. The results revealed that high performing parents also exhibited high general combining ability effects. It was observed that specific combining ability effects for days to 50 per cent flowering, days to maturity of main spike, plant height, number of effective branches per plant, number of capsules on main spike, 100 seed weight, length of pistillate region of main spike and seed yield per plant were highly significant. The crosses showing high specific combining ability effects for yield also depicted high specific combining ability effects for its related traits viz., length of pistillate region of main spike, number of capsules on main spike and number of effective branches per plant. Parents VP 1, SKP 93, SKI 14, 48-1 and VI 9 were found to be good general combiners for yield and some of its related traits.
Pathak et al. (1989) carried out line x tester analysis for seed yield and its components in castor and reported that VP 1 was the best female parent for seed yield, total as well as effective branches per plant and 100 seed weight. Amongst testers, VH 28/2, JI 16 and JI 21 had high gca effects for yield and yield components. EC 103745 and 1379 had high gca effects for earliness and dwarfness, respectively. The crosses CNES 1 x VH 282, CNES 1 x 201, JP 58 x GAUCH 1, JP 58 x 2-73-11, JP 58 x JI 16 and VP 1 x EC 103745 with good sca effects, were identified as potential crosses for developing superior genotypes in castor through further breeding efforts.

Mehta et al. (1991b) analyzed a set of 10 x 10 diallel cross for combining ability in four earliness related characters in castor and observed that additive gene action was predominant for days to 50 per cent flowering of main spike, days to maturity of main spike, plant height up to main spike and nodes up to main spike. The GCA effects for all the four traits indicated more or less similar trend in per se performance. Parents having lower mean performance for nodes up to main spike could be selected for exploiting earliness in castor, as it bears primary spike earlier.

Patel (1991a) noted that the additive and non-additive gene actions were involved in the inheritance of days to 50 per cent flowering, number of capsules per main spike, length of main spike, number of nodes up to main spike, plant height, total branches per plant, effective branches per plant, oil content, seed yield per plant, 100 seed weight and harvest index. It was suggested that direct selection could be effective in exploring the additive gene action in the initial stage of breeding. However, in long run reciprocal recurrent selection could be more effective.

While studying combining ability using line x tester analysis involving 18 females and 5 males of castor, Patel (1991b) noted importance of non-additive type of gene action in the expression of days to 50 per cent flowering, days to maturity, plant height, total length of main spike, number of capsules on main spike, 100 seed weight and seed yield per plant and additive type of gene action for number of nodes up to primary raceme.

Dhapke et al. (1992) evaluated 35 entries of castor to judge the genetic diversity among them for various characters. The results revealed that number of branches, number of capsules on main raceme, length of pistillate region of main raceme and seed yield per plant were mainly influenced by additive gene action.
Dobaria et al. (1992) carried out combining ability analysis for seed yield and its components in castor based on 12 x 12 diallel crosses and reported importance of both additive and non-additive gene actions for all the characters studied. Relative importance of GCA and SCA revealed the major role of non-additive gene action in the control of seed yield and additive gene action for length of main spike, effective length of main spike, effective branches per plant, number of capsules per main spike, number of capsules per plant and 100 seed weight. Parents HC 8, JM 3 and 48-1 were good general combiners for seed yield and its components. Majority of the superior cross combinations involved either low x low or high x low general combiners.

Narkhede et al. (1992) found preponderance of additive gene action for days to maturity of main raceme, number of capsules per main raceme, number of effective branches per plant, number of capsules per plant, 100 seed weight and seed yield per plant and non-additive gene effects for length of main raceme, pistillate region of main raceme, plant height and oil content.

While evaluating the crosses derived through generation mean analysis involving five diverse parents of castor, Patel (1992) reported both additive as well as non-additive gene effects for days to flowering, plant height, number of total and effective branches per plant, number of capsules on main raceme and seed yield in different crosses. It was suggested to explore the possibility of commercial hybrids or alternatively to follow cyclic method of breeding to evolve desirable ideotypes of castor suitable for specific farming conditions.

Dangaria et al. (1993) studied line x tester analysis involving 3 pistillate lines and 18 pollen parents in castor and found the involvement of non-additive type of gene action in the expression of characters viz., seed yield, number of effective branches per plant and capsules per main spike. Hence, the development of superior hybrids for commercial cultivation was suggested for further improvement of yield potentiality in castor.

Goyani et al. (1993) studied inheritance of oil content, hull content and seed yield through 6 x 6 diallel set in castor and reported the predominant role of additive genetic variance in the inheritance of oil content and seed yield.

Natarajan et al. (1993) studied the nature of combining ability and gene action for yield and its components through 5 x 5 partial diallel analysis and observed that both additive and non-additive gene actions were responsible for seed yield, length of main raceme and pistillate region.
Patel et al. (1993) studied combining ability using a set of 9 x 9 diallel crosses in castor and found that only non-additive type of gene action was involved in the inheritance of seed yield per plant, whereas both additive and non-additive types of gene actions were equally important for the expression of length of main spike. The days to 50 per cent flowering, nodes up to main spike and 100 seed weight were predominantly governed by additive type of gene action.

Saiyed (1993) studied combining ability through a 10 x 10 diallel of castor and reported that non-additive type of gene action was predominantly involved in the expression of seed yield per plant, effective branches per plant, kernel content and number of capsules per plant. The additive type of gene action was primarily involved in the expression of days to flowering, number of nodes up to main spike, capsules on main spike and 100 seed weight. The estimates of general combining ability effects revealed that parent, SH 21, 48-1, SH 16 and SH 62 were good general combiners for seed yield and some of its attributes, while 1379, SKP 6 and VH 25 were good general combiners for earliness. The hybrid SH 21 x 48-1 was the best specific combination for seed yield, as it ranked first in specific combining ability effect, heterosis over better parent and per se performance.

Patel (1994a) studied a set of line x tester crosses involving 4 lines and 14 testers in castor over environments and reported the preponderance of non-additive type of gene action in the expression of days to 50 per cent flowering, days to maturity, number of nodes up to main raceme, plant height, number of total and effective branches per plant, length of main raceme, number of capsules on main raceme, seed yield per plant, 100 seed weight and oil content.

Patel (1994b) studied the combining ability through a line x tester analysis involving five lines and 14 testers and reported that per se performance of parents was closely associated with gca effects for seed yield per plant and other related characters. It was also observed that there is strong association between hybrid mean performance and sca effects. Days to 50 per cent flowering of main raceme, days to maturity of main raceme and number of nodes up to main raceme were governed by additive type of gene action. In case of plant height, length of main raceme, 100 seed weight and seed yield per main raceme, both additive and non-additive types of gene actions were important, while for seed yield per plant, number of capsules on main raceme, number of effective branches and oil content, non-additive gene action was preponderant. The parents SKP 82, SKP 93, SH 41, Aruna and SPS 35-9B were found
to be good general combiners for seed yield and some of its components. The line, Aruna recorded the highest number of branches per plant with high seed yield per plant, whereas 1379 and EC 103745 were good general combiners for days to 50 per cent flowering and days to maturity with dwarf plant type.

While studying the combining ability through a line x tester analysis involving four females and fourteen pollinators of castor, Patel (1994c) reported the preponderance of non-additive gene action in the expression of days to 50 per cent flowering, days to maturity, number of nodes up to main raceme, plant height, number of effective branches per plant, total number of branches per plant, length of main raceme, number of capsules on main raceme and seed yield per plant.

Sudhakar et al. (1995) studied combining ability effects in castor for plant height, number of nodes up to primary spike, number of effective spikes per plant, length of primary spike, length of female column in primary spike, number of capsules on primary spike and seed yield per plant. TMV 2 was the best general combiner for seed yield, while high SCA effects were recorded in seven hybrid combinations. GCA effects of the parents were found in accordance with per se performance of the parents for seed yield per plant.

Vindhyavarman and Ganesan (1995) evaluated 24 hybrids developed by crossing between three pistillate lines and eight pollen parents using line x tester mating design along with 11 parents and reported preponderance of non-additive gene action for number of effective spikes per plant, length of main spike, effective length of main spike, number of capsules and seed yield, whereas importance of both, additive and non-additive gene actions was observed for nodes up to main spike.

While studying the combining ability in 11 crosses of castor based on generation mean analysis, Bhand (1996) reported that different gene effects were responsible for the inheritance of the different characters in the same cross and for the same character in different crosses, indicating specific handling of individual cross in segregating generations would be advantageous for the improvement of these characters. In general, the characters controlled by additive gene effect can best be improved by adopting different types of selections. The characters controlled by non-additive gene effect or both additive and non-additive gene effects can successfully be improved by utilizing hybrid vigour or following cyclic method of breeding i.e., recurrent selection.
While studying the gene effects in five crosses, VP 1 x 48-1, Geeta x SH 41, Geeta x 2-73-11, SKP 25 x JM 6 and SKP 25 x SPS 43-3 through generation mean analysis, Patel (1996) reported that both additive as well as non-additive gene effects were involved in the expression of seed yield and most of the yield components, but overall, different gene effects were responsible for the inheritance of the same characters in different crosses and for different characters in the same cross.

Chakrabarty (1997) studied combining ability analysis by line x tester mating design and observed that additive gene action was predominant for number of nodes up to primary raceme, height up to primary raceme, total and effective length of primary raceme, number of capsules on primary raceme, number of effective spikes per plant and 100 seed weight. Preponderance of non-additive gene action was evidenced for seed yield per plant and oil content.

Patel (1998a) studied the combining ability of seven elite parents of castor using diallel analysis excluding reciprocals and observed that 2-73-11, SPS 43-3, SKI 80 and SKI 119 were good general combiners for seed yield per plant and some of the yield components. Parents DCS 9, SKI 73, SKI 119 and SKI 80 were found good general combiners for earliness, number of nodes up to main spike and plant height. The per se performance of parents for various characters was, in general, related to their high gca effects. Estimates of variances due to gca and sca along with D and H components revealed that additive as well as non-additive gene actions were involved in the inheritance of all the characters under study with predominant role of non-additive gene action for most of the traits.

While studying the combining ability in respect of seed yield, oil content, density and iodine value of oil and six other yield contributing traits following diallel analysis involving nine castor inbreds, their 36 F₁ hybrids and 36 F₂s under irrigated and rainfed conditions, Patel (1998b) reported that parents SPS 43-3, SKI 22 and 48-1 under irrigated and VI 9, SKI 119 and 48-1 under rainfed conditions were good general combiners for yield and its components. Per se performance of a cross was also related to sca effect. Estimates of KD/KR ratios along with D and H components revealed that additive as well as non-additive gene actions were involved in the inheritance of most of the traits with predominant role of non-additive gene action under both the environments.

Mehta (2000) observed that both GCA and SCA variances were highly significant for seed yield and its contributing characters. However, the former was
higher than latter indicating the preponderance of additive gene action in the expression of all these traits. The parent VI 9 was good general cominers for seed yield per plant, seed yield per main raceme and number of capsules on main raceme and SKI 8A for seed yield per plant, length of main raceme, length of pistillate region of main raceme and number of capsules on main raceme, while JI 25, 48-1 and EC 103745 had high GCA effects and high per se performance for number of capsules on main raceme, number of effective branches per plant and 100 seed weight, respectively.

Solanki and Joshi (2000) studied 8 x 8 half diallel crosses in six environments over two seasons. The results indicated that both gca and sca were influenced by environment and observed higher sensitiveness of non additive gene effects to the environmental changes. The ratio of additive to total genotypic variance revealed the preponderance of additive gene effects for the inheritance of nodes up to primary raceme, effective and total length of primary raceme, capsules on primary raceme, capsules per plant and 100 seed weight, while seed yield per plant and spikes per plant were mainly governed by non-additive gene effects.

With a view to develop early maturing varieties and hybrids of castor suitable for Andhra Pradesh, an attempt was made by Thatikunta et al. (2000) to estimate heterotic potential of elite parents through 8 x 8 line x tester mating design. The lines as well as testers exhibited good gca effects for seed yield. The data indicated that for realization of heterosis, at least one parent must have higher gca for yield components. High heterosis for crosses made between poor parents was also observed. These results suggest that, additive as well as non-additive components can be exploited for the development of potential varieties and hybrids.

Gondaliya et al. (2001) carried out generation mean analysis for three crosses to study the genetic architecture of seed yield and related traits in castor. Additive and non-additive gene effects were significant for seed yield and majority of the traits. However, majority of dominance and epistatic components were higher than that of additive component. Duplicate type of epistatic effect was observed in most of the cases. Higher magnitude of dominance and dominance x dominance gene effects were observed for seed yield per plant. Thus, heterosis breeding, synthetic varieties and population improvement adopting inter se mating among promising divergent genotypes and affecting simultaneous selection for seed yield, its components and oil content is an ideal breeding approach for castor improvement.
Joshi et al. (2001) studied line x tester analysis for combining ability under four environments (sowing in the 1st fortnight of July as rainfed crop and with supplementary irrigation; sowing in the 1st week of August and September as irrigated crop). Preponderance of non-additive gene action was observed for days to flowering, days to maturity, plant height up to main spike and number of nodes up to main spike. Mean squares due to females x environments interaction was significant only for days to maturity, while females x males x environments interaction was significant for all the traits except days to flowering.

Kavani et al. (2001) studied combining ability for nine attributes using line x tester mating design involving five lines and seven testers in castor and observed higher SCA variances than GCA variances for days to 50 per cent maturity of primary spike, 100 seed weight, number of capsules on primary spike, number of nodes up to main spike, total and effective length of main spike, plant height, number of effective spikes per plant and seed yield per plant, indicating preponderance of non-additive type of gene action in the inheritance of these traits.

Joshi et al. (2002b) attempted line x tester analysis over four environments involving four pistillate lines and twenty eight male parents in castor and recorded higher magnitude of SCA variances than GCA variances for number of capsules per main spike, seed yield per main spike, number of effective branches per plant, number of capsules per plant, seed yield per plant and 100 seed weight, indicating preponderance of non-additive type of gene action in the inheritance of these traits. On the other hand, additive gene action was predominant in the expression of length of main spike and oil content. GCA variances of females and SCA variance of hybrids were more sensitive to environmental fluctuations for all the traits, while GCA variance due to males was sensitive to environmental fluctuations only for length of main spike. The parental performance was significantly and positively correlated with GCA effects for number of capsules per main spike, seed yield per main spike, 100 seed weight and oil content, while association between SCA effects and per se performance of crosses was significant and positive for all the traits.

Ramu et al. (2002) studied combining ability analysis and observed that SCA variances were higher in magnitude than GCA variances for all the traits, indicated predominance of non-additive gene action for days to 50 per cent flowering, plant height up to main spike, number of nodes up to main spike, effective length of main
spike, total number of main spike, total number of capsules on main spike, 100 seed weight, seed yield per plant, oil content and oil yield per plant.

Lavanya and Chandramohan (2003) reported that non-additive gene action was predominant for days to 50 per cent flowering, number of nodes up to primary spike, plant height, seed yield in first, second and third picking and total seed yield, whereas additive gene action was predominant for effective spikes per plant, 100 seed weight and oil content. Female line M 619 for plant height, 100 seed weight, seed yield in all the three pickings and total seed yield, while M 584 for effective spikes per plant and yield at first picking and oil content was good combiners. Among the males, JI 240 for seed yield in all the three pickings, total seed yield and oil content, JI 220 for seed yield in second and third picking, SKI 233 for effective spikes per plant and SKI 229 and JI 225 for 100 seed weight were good general combiners.

Solanki et al. (2003) studied gene effects through analysis of generation mean for eight characters in five crosses of castor. Results indicated the presence of additive, dominance and epistatic gene effects. Among non-allelic interaction dominance x dominance (‘l’) interaction was of greater magnitude than main gene effects for almost all the characters, indicating the importance of heterosis breeding to utilize non-additive gene effects. The additive gene effects (‘d’) also contributed significantly for different traits like capsules on primary, capsules on S₁T₁ raceme and effective length of primary raceme in VP 1 x RG 299 and RG 184 x RG 299 crosses, for capsules on S₁T₁ raceme and effective length of S₁T₁ raceme in cross MCP 2 x RG 125. Selection in segregating generations of these crosses will be effective for development of inbreds possessing longer spikes and higher number of capsules on primary and S₁T₁ raceme. However, to exploit the additive as well as non-additive gene effects reciprocal recurrent selection procedure may be utilized.

Tank et al. (2003) evaluated 45 hybrids derived through ten parental half diallel analysis to study the combining ability in castor and reported that non-additive gene action played a major role for all the characters except effective length of main raceme and number of capsules on main raceme. Parents 48-1, DCS 9 and JI 106 were good for seed yield, while SKI 80 x JI 226 showed high per se performance and this cross could be commercially exploited for genetic improvement in castor.

Golakia et al. (2004) evaluated three families of castor comprising of P₁, P₂, F₁, F₂, B₁ and B₂ for eight metric traits. The individual scaling tests and joint scaling test indicated that additive-dominance model was adequate in seven cases viz., plant
height, number of nodes and number of effective spikes per plant in SKP 4 x JI 266, number of capsules on primary raceme, number of effective spikes per plant and seed yield per plant in SKP 4 x JI 269 and 100 seed weight in JP 81 x JI 263. The results of the rest of the traits suggested the presence of additive, dominance and epistatic gene effects for the traits indicating the importance of both additive and non-additive gene actions. Duplicate type of epistasis was prevalent in most of the cases.

Solanki et al. (2004) crossed new castor pistillate line, MCP 1-1 along with the most popular pistillate line, VP 1 with 16 testers in line x tester design to study the combining ability. Variance due to GCA and SCA indicated the preponderance of non-additive gene action for seed yield per plant, days to 50 per cent maturity of primary raceme and effective length of primary raceme. The new pistillate line MCP 1-1 was a good general combiner for seed yield and 100 seed weight. Amongst testers, MP 17-01 was identified as a good combiner for seed yield, effective length of primary raceme and number of primary branches per plant.

Patel (2005) carried out generation mean analysis using four crosses of castor under three environments and reported that seed yield and its components viz., days to 50 per cent flowering, plant height, number of nodes up to main raceme, number of capsules on main raceme, number of effective branches per plant, 100 seed weight and oil content were governed by both additive and non-additive type of gene action.

Chandramohan et al. (2006) studied combining ability for seed yield and its component traits using line x tester mating design involving four lines and nine testers in castor. The components of GCA and SCA variances indicated the predominance of additive gene action for days to 50 per cent flowering, days to maturity, number of nodes, plant height, effective spike length, capsules on main raceme and 100 seed weight. The three lines namely DCS 5, DCS 7 and SH 72 and two testers viz., VP 1 and DPC 9 were identified as good general combiners for seed yield per plant.

Gadhesariya et al. (2006) carried out 4 x 9, line x tester analysis to determine the nature of combining ability of parents and hybrids of castor bean for yield and other yield attributing characters. Non-additive type of gene action was important in the inheritance of days to 50 per cent flowering, effective length of main spike, number of capsules on main spike, total number of branches per plant and seed yield per plant. Female parents JP 65 and SKP 23 and male parents 63-MO and JI 84 were good general combiners for seed yield. The estimated SCA effects revealed that the best combinations were SKP 93 x SH 16, JP 65 x JI 95 and SKP 93 x 48-1 for seed
yield per plant; SKP 93 x SH 41 for days to 50 per cent flowering; VP 1 x JI 84 for number of nodes up to main spike and total length of main spike; SKP 23 x JI 95 for effective length of main spike; SKP 23 x JI 84 for total number of branches per plant and JP 65 x JI 95 for number of effective branches per plant.

Kanwal et al. (2006) carried out line x tester analysis for seed yield and its components in castor by using five lines and ten testers. The results showed that non-additive gene action was predominantly involved in the expression of days to 50 per cent flowering, plant height, number of nodes up to main raceme, oil content and seed yield per plant. Female lines SKP 72 and SKP 6 and male lines SKI 217 and SKI 218 were good general combiners for seed yield per plant and length of main raceme. The crosses SKP 72 x 48-1, SKP 4 x SKI 218 and SKP 6 x JI 263 involving good x good, good x poor and good x poor general combiners, respectively for seed yield.

Patel and Pathak (2006a) studied combining ability over environments in castor for seed yield per plant and 10 other characters using line x tester analysis involving 5 pistillate lines and 10 male parents. The estimated components of gca and sca variances showed the preponderance of non-additive type of gene action for seed yield per plant and other yield attributing traits except plant height and 100 seed weight, where the additive type of gene action was more important. Among the parents, Geeta, SKP 5 and SKI 107 were found to be good general combiners and among the hybrids, SKP 5 x SKI 73, Geeta x VI 9 and VP 1 x SKI 168 were the three best specific combinations for seed yield per plant and some of the important yield components. It was observed that the high yielding parents were also the good general combiners for seed yield and some of the important yield components. The crosses exhibited high sca effects did not always involve the parents with high gca effects.

Maheshwari (2007) studied combining ability using a set of 10 x 10 diallel (excluding reciprocals) crosses of castor and observed that non-additive type of gene action was predominantly involved in the expression of seed yield per plant, days to 50 per cent flowering, days to maturity, length of main spike, number of nodes up to main spike, effective branches per plant, 100 seed weight and oil content. Results also revealed highly significant general combining ability effects for all characters except number of effective branches per plant and sca for all the characters except nodes number up to main raceme and number of effective branches per plant.

Madariya et al. (2008) studied the combining ability using line x tester mating design involving ten lines and four testers. The analysis of variance indicated
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preponderance of non-additive gene action in the expression of seed yield per plant, whereas for other traits, additive gene action was more important. The parents JP 88, JP 84, JI 306 and JI 285 were good general combiners for seed yield per plant and some yield contributing traits. The crosses JP 84 x JI 285, JP 88 x JI 285, JP 84 x JI 306 and SKP 106 x JI 257 were good specific combiners for seed yield per plant.

Patel et al. (2008a) carried out line x tester analysis to determine the nature of combining ability of 11 parents and 30 hybrids of castor. Non-additive type of gene action was important in the inheritance of days to 50 per cent flowering, days to maturity, effective length of main spike, number of capsules on main spike and seed yield per plant. Male parent SKI 268 was good general combiner for seed yield. The estimates of SCA effects revealed that the best combinations were JP 65 x SKI 268 and JP 65 x SKI 271 for seed yield per plant; JP 65 x SKI 271 for length of main raceme; and VP 1 x SKI 267 and JP 65 x SKI 266 for number of effective branches per plant.

Patel et al. (2008b) carried out 10 x 10 diallel cross analysis in castor to determine the nature of combining ability of seed yield and other characters. Non-additive type of gene action was predominant in the inheritance of all the traits except days to 50 per cent flowering and days to maturity. Male parents SKI 205, SKI 226 and SH 21 were good general combiners for seed yield. The estimated SCA effects revealed that the best combination was SKI 294 x SKI 304 for seed yield per plant.

Parmar (2008) carried out line x tester analysis using 14 males and 4 females to determine the nature of combining ability of different traits. Non-additive type of gene action was predominant in the inheritance of all the traits, except number of effective branches and 100 seed weight. A female parent SKP 106 was good general combiner for seed yield. The estimates of SCA effects revealed that the best combinations were SKP 106 x SKI 215, SKP 106 x SKI 299 and SKP 108 x SKI 215 for seed yield per plant.

Sridhar et al. (2008) studied combining ability using five lines and 15 testers in line x tester mating design. The results revealed that GCA variances were higher in magnitude than SCA variances for number of capsules per primary spike and 100 seed weight, which indicated preponderance of additive gene action for both the traits, whereas non-additive gene action was predominant for primary spike length, effective spike length, seed yield per plant and oil content. Among lines, DPC 9 and testers,
RG 224 and RG 2779 were found to be good general combiners for majority of the yield contributing characters.

Barad et al. (2009b) studied combining ability for seed yield and its components in 40 hybrids generated by 5 x 8, line x tester mating design in castor. The results revealed that GCA variances were significant for days to 50 per cent flowering, plant height, number of nodes up to primary raceme and 100 seed weight, whereas SCA variances were significant for all the characters, indicating the preponderance of non-additive gene action in the inheritance of these characters. The parents JP 65 and VP 1 among females and JI 35, I 21 and VI 9 among males were superior and consistent general combiners for seed yield and majority of yield contributing characters. Three parents viz., VP 1, GC 2 and EB 16 were found good general combiners for days to 50 per cent flowering, days to 50 per cent maturity of primary raceme, plant height and number of nodes up to primary raceme, while VP 1 and SKI 283 were good general combiners for oil content. The best three hybrids that recorded significant and positive SCA effects for seed yield were ACP 1 x SPS 44-1, VP 1 x GC 2 and SKP 4 x EC 38538.

Gouri Shankar et al. (2009) carried out combining ability analysis in castor using four elite pistillate lines and six diverse male parents. The comparison of relative magnitude of GCA and SCA variances indicated that additive gene action was predominant in the control of days to maturity, number of nodes up to primary spike and 100 seed weight, while non-additive gene action was predominant for days to 50 per cent flowering, plant height up to primary spike, primary spike length, seed yield per plant and oil content.

Solanki et al. (2009) carried out line x tester analysis using four females and ten males to estimate combining ability and nature of gene action in castor. The estimates of variance ratio (\(\sigma^2_{gca} / \sigma^2_{sca}\)) revealed the role of non-additive gene action in the expression of days to 50 per cent flowering, days to maturity, plant height, number of nodes up to main raceme, length of main raceme, number of capsules on main raceme, number of effective branches per plant, 100 seed weight, oil content and total seed yield per plant.

Yogitha et al. (2009) developed 36 hybrids through line x tester set by crossing three testers with twelve female lines in castor. The resultant 36 hybrids were evaluated for combining ability. The results revealed that variance component due to SCA was greater in magnitude than GCA, which indicated importance of non-additive
gene effects in the inheritance of all the characters i.e. days to 50 per cent flowering, days to maturity, plant height, number of nodes up to primary spike, effective spike length, number of spikes per plant, 100 seed weight, oil content, number of capsules per plant and seed yield per plant.

Sridhar et al. (2010) studied combining ability over environments using line x tester mating design involving five lines and fifteen testers to identify good parents and best cross combinations for earliness and its related traits in castor. The estimated components of gca and sca variances showed the preponderance of additive gene action for number of nodes up to primary spike and non-additive gene action for plant height, whereas the traits days to 50 per cent flowering and days to maturity were governed by both the types of gene action as the gca and sca variances were equal in magnitude. Parents Kranthi, RG 1471, RG 178, DCS 9 and RG 2724 were good general combiners for all the four traits. The crosses Kranthi × RG 1471, LRES 17 × RG 2724 and VP 1 × RG 1471 were the best specific combinations to exploit the non-fixable components for all the traits studied related to earliness. The study revealed that per se performance of crosses had significant and positive correlation with sca effects for most of the traits. The best performing hybrids were generally composed of good × good and good × poor combinations. The crosses with poor × poor combinations did not find place among the top performing hybrids for all the four traits related to earliness.

Patel et al. (2012) studied combining ability over environments in castor using 48 hybrids developed through line x tester mating design consisting 16 parents (four females and 12 males). The estimates of potency ratio and predictability ratio in respect to \( \sigma^2_{gca} \) and \( \sigma^2_{sca} \) revealed the preponderance of additive genetic variance for days to 50 per cent flowering, number of node up to primary spike, effective length of primary spike, total number of capsules per plant, seed yield per plant and 100 seed weight. Non-additive genetic variance was predominant for days to 50 per cent maturity of primary spike and shelling out turn, whereas for number of capsules on primary spike only additive genetic variance was significant. The estimates of additive genetic variance were more consistent over environments for all the characters; whereas non-additive genetic variances varied for all the characters except shelling out turn and oil content. The pistillate lines, Geeta and SKP 84 and male parents, SKI 270, DCS 47, SPS 44-1, EB 16 and SKI 147 were good general combiners for seed yield and important yield contributing characters. Crosses
SKP 24 x SKI 270, VP 1 x DCS 47 and SKP 84 x SKI 202 were good specific combiners for seed yield per plant.

Patel et al. (2013b) studied combining ability in castor for ten characters using 45 hybrids developed through diallel mating design without reciprocals along with ten parents. Combining ability analysis indicated that the mean squares due to GCA and SCA were highly significant for all the characters. The magnitude of GCA variances was higher than that of SCA variances for days to flowering, days to maturity, plant height, number of nodes on main stem, number of branches per plant and 100 seed weight, suggesting the importance of additive type of gene action in the inheritance of these traits. The mean squares due to SCA were also higher in case of effective raceme length, number of capsules on primary raceme, seed yield per plant and oil content, thereby suggesting the predominance of non-additive gene action. The parents PCS 124, SKI 291 and SKI 281 were good general combiners for seed yield as well as for yield attributing characters viz., effective raceme length, number of capsules on primary raceme, total number of effective branches per plant and 100 seed weight.

Ramesh et al. (2013) estimated the components of genetic variation in castor for 14 plant type related traits. The analysis for combining ability revealed significant mean sum of squares of both general combining ability (GCA) and specific combining ability (SCA) for all the characters, which indicated the presence of both additive and non-additive gene actions. The ratio of GCA variance and SCA variance revealed the predominance of non-additive gene action for all the traits except plant height up to primary spike, number of nodes up to primary spike, number of capsules per primary spike and total length of secondary spike. JP 87 was good general combiner for most of the characters including seed yield. The line DCS 106 was also a good general combiner for early flowering, days to maturity and number of capsules on secondary spike. Cross JP 87 × RG 1740/A was a good specific combiner for seed yield per plant and other yield components. The hybrid DPC 9 × RG 156 with good specific combining ability for days to maturity can be used for yield improvement in castor. In general, for yield and other yield attributing traits, the promising hybrids with high heterosis JP 87 × RG 1740/A, JP 87 × DCS 106, DPC 17 × RG 156, DPC 17 × DCS 106 and DPC 17 × DCS 107 were on par with the check.

Aher et al. (2014) evaluated 36 castor hybrids developed by half diallel mating design along with nine pistillate parents for combining ability effects. The genotypes,
parents and hybrids significantly differed among themselves for all the characters, except shelling out turn for parents and hybrids. Significance of both $\sigma^2_{gca}$ and $\sigma^2_{sca}$ for most of the characters suggested importance of both additive and non-additive genetic variances for their inheritance. The estimates of potency ratio and predictability ratio revealed preponderance of additive genetic variance for number of nodes up to primary raceme, plant height up to primary raceme, total length of primary raceme, effective length of primary raceme, number of secondary spikes per plant, 100 seed weight, volume weight and shelling out turn. The parents JP 65 and DPC 9 were good general combiners and SKP 84, ANDCP 06-07-1 and ANDCP 06-07 were average general combiners for seed yield and important yield contributing characters. Crosses SKP 84 x JP 65, ANDCP 06-07 x JP 65 and JP 65 x ANDCP 06-07-1 were good specific combiners for seed yield and good/average specific combiners for rest of the characters. The crosses which involved at least one good general combiner parent would produce transgressive segregants. However, for full exploitation of existing genetic variance in these crosses, intermating of elite plants in the early segregating generations would be profitable to build up elite population for early and dwarf pistillate lines with high seed yield.

Chaudhari and Patel (2014) evaluated 12 genotypes of castor (*Ricinus communis* L.) consisting four lines and eight testers along with their 32 hybrids developed through line x tester mating design. The analysis for combining ability revealed significant mean sum of squares of both general combining ability (GCA) and specific combining ability (SCA) for all the characters, which indicated the presence of both additive and non-additive gene actions. The ratio of GCA variance and SCA variance revealed the predominance of non-additive gene action for all the traits except for days to 50 per cent flowering, days to 50 per cent maturity and oil content. VP 1, SKP 84, ANDCM 2, ANDCI 9 and ANDCI 10-4 were good general combiners for most of the characters including seed yield. Cross JP 65 x JC 22 was a good specific combiner for seed yield per plant and other yield components.

Golakia *et al.* (2015) studied combining ability involving four females and eleven males using line x tester analysis in two years with two date of sowing. Sufficient genetic variability was observed for earliness and seed yield per plant. Environments played a significant role in the expression of these traits. The $sca/gca$ ratio indicated additive gene effects for days to flowering of primary raceme and seed
yield per plant. Preponderance of non-additive gene effects was observed for days to maturity of primary raceme and nodes up to primary raceme. Both additive and non-additive gene effects were equally important for the inheritance of plant height up to primary raceme. Based on per se performance and gca effects, female JP 82 and male JI 258 were found superior for earliness, while female JP 88 and male DCS 89 were good for seed yield per plant. The best per se yielding cross JP 88 x DCS 89 manifested significant desirable standard heterosis for seed yield per plant, but was undesirable for earliness. Reverse was true for the best specific combiner cross JP 82 x JI 258.

Patel et al. (2015) studied combining ability for yield and its component traits in castor through line x tester mating design using five line and ten testers. The analysis for combining ability revealed significant mean sum of squares of both general combining ability (GCA) and specific combining ability (SCA) for all the characters, which indicated the presence of both additive and non-additive gene actions. The ratio of GCA variance and SCA variance revealed the predominance of non-additive gene action for all the traits except number of nodes up to primary raceme, 100 seed weight and oil content. Among the parents, lines ACP 1-06-07-2, ANDCP 06-07 and SKP 84, and testers DCS 47, JI 321, SKI 215 and PCS 124 were found good general combiners for seed yield per plant and majority of yield contributing traits. Testers ANDCI 15 and ANDCI 8 were considered good general combiner for days to 50 per cent flowering and days to maturity.

Rajani et al. (2015) studied the combining ability for seed yield and its component traits in castor using line x tester mating design involving six diverse pistillate lines and eight inbred lines. The analysis of variance for combining ability revealed that the mean squares due to lines, testers and lines x testers were highly significant for all the characters except mean square due to lines x testers for oil content and indicated that both additive and non-additive gene actions played a vital role in the inheritance of all the traits. The estimates of gca effects for seed yield and its related traits indicated that three lines viz., SKI 346, JI 397 and JI 399 and one tester namely JP 96 were found good general combiner for seed yield per plant and some of its component traits. The estimation of sca effects of the crosses indicated the six hybrids manifested significant and positive sca effects for seed yield per plant. The best three specific combinations were SKP 106 x SKI 346, JP 96 x JI 397 and SKP 106 x JI 401, which resulted from average x good, good x good and average x
poor combiner parents, respectively. The *per se* performance of hybrids had significant and positive correlation with SCA effects for all the traits.

Kavani *et al.* (2016) evaluated 32 castor hybrids generated in line x tester (4 lines x 8 testers) mating design along with their parents to estimate the combining ability for ten characters in castor. The components of GCA and SCA from analysis of combining ability revealed that non-additive gene action was preponderance in the genetic control of all the characters studied except oil content, which was controlled by additive gene action, while 100 seed weight indicated negative estimates. Among female parents, JP 96 was good general combiner for plant height, number of effective spikes per plant, 100 seed weight and oil content, while SKP 84 and SKP 106 were found good general combiners for number of nodes up to main spike, number of capsules on primary raceme and number of effective spikes per plant. For earliness, JP 96 and SKP 84 were found to be good general combiners. Among male parents, PCS 124 and SKI 271 were identified as good general combiners for plant height, number of nodes up to main spike, number of capsules on primary raceme and oil content. Among the hybrids, JP 105 x SKI 271, JP 96 x SKI 294, JP 105 x SKI 291 and JP 96 x PCS 124 had high SCA effects for seed yield per plot and other yield traits, were also accompanied with high *per se* performance; hence *per se* performance of the hybrids would be a good indicator for predicting SCA effects. These hybrids could be exploited through heterosis breeding, as these hybrids are expected to give desirable transgressive segregants in the succeeding segregating generations.

Patel *et al.* (2016) worked out the estimates of the components of genetic variation using line x tester analysis in castor for ten plant type related traits. The analysis for combining ability revealed significant mean sum of squares for all the characters except seed yield and oil content of general combining ability (GCA), while for specific combining ability (SCA), significant mean sum of squares were observed for 100 seed weight, length of primary spike, number of node up to primary spike and number of capsules per plant. This indicated the presence of both additive and non-additive gene actions. The ratio of gca and sca variances revealed predominance of non-additive gene action for all the traits. Among the parental genotypes, line SKP 122 was good general combiner for most of the characters including seed yield, while the line SKP 42 was also a good general combiner for all the characters except seed yield and effective branches per plant. The cross
combinations JI 96 x SKI 350 and SKP 121 x SH 41 were good specific combiners for seed yield. The hybrid SKP 42 x SKI 342 had good specific combining ability for days to maturity can be used for early maturity in castor. In general, for yield and other yield attributing traits, the promising hybrids with high SCA effect were SKP 42 x SKI 350, SKP 84 x SKI 342, SKP 121 x SH 41, JP 96 x SKI 342 and JP 96 x SKI 350. These cross combinations could be utilized for further use in breeding programme for improvement in yield and other desirable characters of castor.

Pawar and Sakhare (2016) studied combining ability in castor (*Ricinus communis* L.) in three female and seven male parents crossed in line x tester fashion. The parent 48-1 among the females, whereas the parents EC 168554, SKI 1, Salem 91 and EC 284470 among the males displayed significant gca effects for seed yield and most of the yield contributing characters indicating the importance of these parents as good combiners for improvement in castor. The cross AKC 1 x EC 168554 recorded the highest significant positive sca effect followed by AKC 1 x Salem 91, 48-1 x EC 284470 and 48-1 x SKI 1 for seed yield and most of the characters and hence, these crosses can be further exploited in breeding programmes of castor.