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**Research Article**

# Heterosis for seed yield and yield components over environments in castor (*Ricinus communis* L.)

**K.N. Chaudhari[1]*, R.F. Chaudhary[2], D.K. Patel[3], Ashish Kanwal[4], H.N. Patel[5], H.C. Pathak[6] and B.H. Prajapari[7]**

[1] Department of Genetics and Plant Breeding, Navsari Agricultural University, Navsari
[2] Department of Plant Pathology, S.D. Agricultural University, Sardarkrushinagar
[3] Main Castor-Mustard Research station, S.D. Agricultural University, Sardarkrushinagar
[4] TCM, Monsanto India Limited, Vadodara
[5] Agricultural Research Station, S.D. Agricultural University, Ladol
[6] Director of Research, Navsari Agricultural University, Navsari
[7] Department of Agricultural Statistics, S.D. Agricultural University, Sardarkrushinagar
*Email: knc970@yahoo.co.in

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**Abstract:**
Investigation with 10 diverse inbreds, their 45 hybrids (generated by diallel mating design excluding reciprocals) along with two standard checks *viz*; GCH-4 and GCH-5 was taken up over four environments (two fertility levels and two sowing dates) to determine the extent of heterosis of seed yield and eight component traits. The heterobeltiosis and standard heterosis over GCH-4 and GCH-5 for seed yield/plant across the environments ranged from -13.71% to 47.89%, -25.08% to 22.77% and -31.62% to 12.04% respectively. SKI-280 x SH-41, SKI-280 x SKI-288, SH-41 x SKI-285, SKI-280 x SKI-215, SKI-288 x SH-41, SKI-288 x SKI-232, SKI-218 x SKI-232, SKI-215 x SH-41, SKI-288 x SKI-285, SKI-215 x SKI-285, SKI-232 x DCS-9 and SKI-215 x SKI-232 had significantly out yielded their better parent while SKI-232 x DCS-9 was significantly superior over GCH-4. Across the locations, the cross SKI-232 x DCS-9 produced the highest 182.28g of seed/plant and registered 30.49%, 22.77% and 12.04% superiority over better parent, GCH-4 and GCH-5 respectively. Magnitudes of heterosis vary from character to character and cross to cross. In general, for seed yield/plant across the locations magnitude of desirable heterosis was high over batter parent but low over standard checks. 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.

**Key words:** Castor, diallel, heterosis, *Ricinus communis* L.

## Introduction:

Castor, *Ricinus communis* L; is the only oilseed crop of India which earns about thousands of crore rupees of foreign exchange to the country every year. Though crop has wider adaptability and well responsive to irrigation and nutrients, its cultivation is mostly confined to arid and semi-arid regions of the country. The phenomenon of heterosis has proved to be the most important genetic tool in enhancing yield of often cross pollinated and cross pollinated crops in general and castor in particular. The exploitation of heterosis on commercial scale in castor is the major breakthrough in the enhancing its productivity. For genetic improvement, selection of superior parents is one of the important step for development of better hybrids. Though *per se* performance is taken as selection criterion, proper information on magnitude of heterosis, combining ability and gene action for seed yield and component traits involved in the inheritance in different parents and their crosses would be more helpful in selecting appropriate parents and desirable cross combinations for commercial exploitation of hybrid vigour (Dangaria *et al*; 1987). The present study was therefore undertaken, to determine the extent and mechanism of heterosis under different fertility levels in castor and ultimately, to isolate inbreds which can be more responsive to fertilizer.

## Material and methods

The experiment material consisted of 45 hybrids, generated by crossing 10 diverse inbreds (SKI-280, SKI-215, VI-9, SKI-288, SKI-218, SKI-271, SKI-232, SH-41, DCS-9 and SKI-285) in half diallel fashion and GCH-4 and GCH-5, the most successful hybrids as standard checks. The parents selected were elite genotype of the crop developed by pedigree breeding at Main Castor Mustard Research Station, S.D. Agricultural University, Sardarkrushinagar and at Directorate of Oilseeds Research, Hyderabad (Table 1). The resulting hybrids along with parents and standard checks were evaluated at Agronomy Instructional Farm, C.P. College of Agriculture, S.D. Agricultural University, Sardarkrushinagar in Randomized Block Design under three replications over four environments. The crop is well responsive to fertilizer and it has the potential for successful cultivating in pre-rabi season too. Therefore to study the response of the crop at varying levels of fertility and sowing time, environments were created by two different doses of fertility levels, (120-50-0 kg NPK/ha and 75-50-0 kg NPK/ha) and two different sowing dates ($14^{th}$ August and $13^{th}$ September). Thus investigation was taken up in four environments *viz;* **$E_1$**: Environment 1: Sowing date $14^{th}$ August, Fertility: 120-50-0 kg NPK/ha; **$E_2$**: Environment 2: Sowing date $14^{th}$ August, Fertility: 75-50-0 kg NPK/ha; **$E_3$**: Environment 3: Sowing date $13^{th}$ September, Fertility: 120-50-0 kg NPK/ha; **$E_4$**: Environment 4: Sowing date $13^{th}$ September, Fertility: 75-50-0 kg NPK/ha. Fertilizers were applied as per recommendation with three splits *i.e.* half dose of nitrogen was applied as a basal dose and remaining nitrogen was applied in two equal splits at 40 and 100 days after sowing. Each genotype was sown in a single row of fifteen dibbles. Parents, hybrids and standard checks were randomized separately in each replication and environment too. The distance between two rows was 90 cm, while between two plants within a row was 60cm. Fertilizer $P_2O_5$ was applied at the recommended rate of 50 kg/ha as a basal dose. The crop was raised under irrigated condition and all the agronomic practices and plant protection measures were adopted for raising a normal crop. Five competitive plants from each treatment in each replication and environment were, selected randomly and tagged, used for recording observations on seed yield per plant (g), day to 50 % flowering, days to maturity, plant height (cm), no. of nodes upto main spike, total no. of branches/plant, no. of effective branches/plant, length of main spike, no. of capsules on main spike and 100-seed weight. The analysis of variance for each trait was calculated as per Panse and Sukhatme (1978). The superiority of hybrids was estimated over better parents as heterobeltiosis and as standard heterosis over check GCH-4 and GCH-5 according to the method of Fonseca and Patterson (1968).

## Results and discussion

Analysis Of Variance: The analysis of variance for experimental design (Table 2) revealed considerable genetic variation among the parents and hybrids for all the traits evaluated in individual as well as pooled over environments. This indicated that the experimental material selected and hybrids generated possessed sufficient genetic diversity. Comparison of mean squares due to parents vs. hybrids across the environments was found to be highly significant for all the traits which suggested that parental group as a whole was quite different from their $F_1$'s thus revealing the presence of heterosis for all the traits under investigation. Highly significant mean sum of squares due to genotypes x environments and hybrids x environments revealed that genotypes as well as hybrids were highly influenced by changing environments for all the traits while significance of mean sum of square of parent x environments suggested that parents were unstable for the traits like number of total and effective branches per plant, spike length 100-seed weight and seed yield per plant. The non-significance of comparison between parents vs. hybrids x environments for all the traits except days to 50 per cent flowering revealed that difference between the average performance of hybrids and parents were consistent for all the characters except days to 50 per cent flowering over varying environments.

Heterobeltiosis**:**An examination of performance of hybrids with respect to heterosis over better parent for seed yield/plant (Table 3) revealed that among 50 hybrids, SKI-280 x SKI-215, SKI-280 x SH-41, SKI-288 x SKI-285, SH-41 x SKI-285, SKI-232 x DCS-9, SH-41 x DCS-9, SKI-215 x SKI-285, SKI-215 x SH-41, SKI-288 x SKI-232, SKI-288 x SH-41, SKI-280 x SKI-288, DCS-9 x SKI-285 in $E_1$; SKI-215 x SKI-232, SKI-215 x SKI-285, SKI-232 x DCS-9, SKI-218 x SKI-232, SKI-288 x SKI-232, SH-41 x SKI-285, SKI-280 x SH-41, SKI-280 x SKI-215, SKI-280 x SKI-288, SKI-271 x DCS-9, SKI-215 x SH-41 in $E_2$; SKI-280 x SKI-215, SKI-280 x SH-41, SKI-215 x SKI-285, SKI-280 x SKI-288, SKI-288 x SKI-285, SH-41 x SKI-285, SKI-215 x SKI-232, SKI-232 x DCS-9, SKI-288 x SH-41, SKI-215 x SH-41, SKI-215 x SKI-218, SKI-215 x SKI-288, SKI-288 x SKI-271, SH-41 x DCS-9, SKI-288 x SKI-232, SKI-218 x SKI-232, SKI-280 x SKI-271, SKI-271 x SH-41, SKI-215 x SKI-271 in $E_3$ while SKI-288 x SH-41, SKI-280 x SH-41, SKI-215 x SH-41, SKI-232 x SH-41, SH-41 x SKI-285, SKI-288 x SKI-232, SKI-215 x SKI-232, SKI-218 x SKI-232, SKI-288 x SKI-285, SKI-232 x SKI-285, SKI-280 x SKI-215 in $E_4$ registered significant superiority over their respective better parent. Range of heterosis was -16.66% to 50.37%, -23.63% to 34.93%, -15.48% to 45.91 % and -18.42% to 47.72 % in $E_1$, $E_2$, $E_3$ and $E_4$ respectively. Across the four locations, heterobeltiosis ranged between -13.71% to 47.89% with 12 hybrids significantly out yielding their respective better parent. The highest heterobeltiosis was observed to the extent of 47.89% (SKI-280 x SH-41) followed by 42.40% (SKI-280 x SKI-288) and 41.89% (SH-41 x SKI-285). Over environments, heterobeltiosis for days to 50% flowering ranged between (-15.60% to

46.58%), for days to maturity it ranged between (-15.00% to 23.23%), for number of nodes it ranged between (-8.18% to 28.14%) and for plant height it ranged between (-16.16% to 61.65%). Across the locations, SKI-215 x SKI-285, SKI-215 x SKI-232, SKI-215 x SKI-288, SKI-215 x SKI-271, SKI-215 x DCS-9, SKI-280 x SH-41, SH-41 x DCS-9, DCS-9 x SKI-285, SH-41 x SKI-285, SKI-232 x DCS-9, SKI-280 x SKI-271, SKI-232 x SKI-285 for days to 50% flowering; SKI-288 x DCS-9, SKI-288 x SKI-285, SKI-288 x SKI-232, SKI-288 x SH-41, SKI-215 x DCS-9, SH-41 x SKI-285, SH-41 x DCS-9, SKI-280 x SKI-285, SKI-215 x SKI-232, SKI-215 x SKI-285, SKI-232 x SKI-285, SKI-232 x SH-41, SKI-280 x SH-41, SKI-280 x SKI-288, DCS-9 x SKI-285, SKI-215 x SKI-288, SKI-232 x DCS-9, SKI-280 x SKI-271, SKI-271 x SKI-285, SKI-288 x SKI-271, SKI-271 x SH-41, SKI-271 x DCS-9 for days to maturity; SKI-288 x SKI-232, DCS-9 x SKI-285, SH-41 x DCS-9, SKI-215 x SKI-232, SH-41 x SKI-285, SKI-232 x SKI-285, SKI-215 x SH-41, SKI-288 x DCS-9, SKI-280 x SKI-285, SKI-232 x DCS-9, SKI-280 x SKI-288 for no. of nodes up to main spike and SKI-280 x SKI-285, SKI-271 x DCS-9 and SKI-215 x DCS-9 for plant height were significantly superior over their better parents. Range of heterobeltiosis over environments was -14.50% to 31.37% for total no. of branches/plant, -11.17% to 33.08% for no. of effective branches/plant, -11.51% to 39.43% for length of main spike, -12.75% to 57.35% for no. of capsules on main spike and -7.42 % to 6.22% for 100 seed weight. Over the environments, SH-41 x SKI-285, SKI-232 x SH-41, SKI-232 x SKI-285, SKI-271 x SH-41, SKI-232 x DCS-9, DCS-9 x SKI-285, SH-41 x DCS-9, SKI-271 x SKI-232, SKI-271 x SKI-285, VI-9 x SKI-288, SKI-271 x DCS-9 for total no. of branches/plant; SH-41 x SKI-285, SKI-232 x DCS-9, SKI-232 x SH-41, SKI-271 x SH-41, SKI-288 x SKI-285, SKI-288 x SH-41, SH-41 x DCS-9, SKI-288 x SKI-232, SKI-232 x SKI-285, SKI-271 x SKI-285, SKI-271 x SKI-232, DCS-9 x SKI-285, SKI-271 x DCS-9, SKI-280 x SH-41, VI-9 x SKI-288 for no. of effective branches/plant; SKI-280 x SH-41, SKI-280 x SKI-215, SKI-288 x SH-41, SKI-232 x DCS-9, SKI-280 x SKI-288, SH-41 x SKI-285, SKI-218 x SKI-232, SKI-218 x DCS-9, SKI-215 x SKI-232, SH-41 x DCS-9, SKI-288 x SKI-232, SKI-215 x SH-41, SKI-280 x SKI-232, SKI-218 x SH-41, SKI-280 x DCS-9 for length of main spike; SKI-280 x SH-41, SKI-280 x SKI-215, SKI-288 x SH-41, SH-41 x SKI-285, SKI-232 x DCS-9, SKI-280 x SKI-288, SKI-215 x SH-41, SKI-288 x SKI-285, SKI-215 x SKI-232, SKI-288 x SKI-232, SKI-218 x DCS-9, SKI-215 x SKI-285, SKI-218 x SKI-232 for no. of capsules on main spike and SKI-232 x DCS-9, SH-41 x DCS-9, SKI-280 x SH-41, DCS-9 x SKI-285, SKI-280 x DCS-9, SKI-288 x DCS-9, SKI-232 x SKI-285, SKI-280 x SKI-215, SKI-232 x SH-41 for 100-seed weight recorded significant superiority over their respective better parent. It was observed that majority of hybrids showing high heterobeltiosis for seed yield per plant, in general, also manifested desirable heterotic effects for many of their important yield contributing traits *e.g.* cross SKI-280 x SH-41, having highest heterobeltiosis for seed yield/plant also registered significant desirable heterobeltiosis for yield components like days to 50% flowering, days to maturity, no. of effective branches/plant, length of main spike and no. of capsules/spike (Table 4); while cross SKI-280 x SKI-288 depicted significant heterobeltiosis for yield components like days to maturity, no. of nodes/plant, length of main spike and no. of capsules/spike. This suggested that heterosis for seed yield/plant resulted due to desirable heterosis for some of important component traits. Similar findings were recorded by Kaul and Prasad (1983), Thakkar (1987), Mehta *et al.* (1991), Joshi (1993), Patel and Pathak (2006) and Tank *et al.* (2003).

In the present study the magnitude of heterobeltiosis for seed yield/plant and no. of capsules on main spike was moderate to high. Similar finding was earlier reported by Ankineedu and Kulkarni, 1967; Varisai *et al.*, 1969; Patel, 1994a; Patel, 1998a and Joshi *et al.*, 2001. Most of the yield components like days to 50% flowering, days to maturity, no. of total and effective branches/plant and length of main spike manifested moderate heterosis. Similar trends of heterobeltiosis were reported by Ankineedu and Kulkarni, 1967; Varisai *et al.*, 1969; Kaul and Prasad, 1983; Patel, 1989; Patel, 1994a; Tank *et al.*, 2003 and Patel and Pathak, 2006. Present outcome of low heterobeltiosis for no. of nodes up to main spike and 100 seed weight was in agreement with earlier findings of Thakkar, 1987; Saiyed, 1993; Patel, 1994a, Tank *et al.*, 2003 and Patel and Pathak, 2006.

Standard Heterosis: On commercial point of view, the superiority of newly developed hybrids should be judged by comparing their performance with the best cultivated hybrid/s or variety. Therefore the popular hybrids *viz;* GCH-4 and GCH-5 of the region were used as standard checks. For seed yield/plant, range of standard heterosis was -24.01% to 33.23% , -34.00% to 28.63%, -29.28% to 27.38% and -41.42% to 35.54% over GCH-4 in $E_1$, $E_2$, $E_3$ and $E_4$ respectively while over GCH-5 standard heterosis ranged between -30.39% to 22.05%, -38.83% to 19.20%, -34.98% to 17.10%, -48.09% to 20.10% in $E_1$, $E_2$, $E_3$ and $E_4$ respectively (Table 3). Moreover, SKI-232 x DCS-9, SH-41 x DCS-9, SKI-288 x SKI-232, SKI-288 x SKI-285 in $E_1$; SKI- 232 x DCS-9 and SKI-271 x DCS-9 in $E_2$, SKI-280 x SH-41, SKI- 232 x

DCS-9, SKI-280 x SKI-215, SKI-280 x SKI-288 and SH-41 x DCS-9 in $E_3$ and SKI-218 x SKI-232 and SKI-280 x SH-41 in $E_4$ exhibited significant superiority over GCH-4 while SKI-232 x DCS-9 and SH-41 x DCS-9 in $E_1$; SKI-232 x DCS-9 in $E_2$; SKI-280 x SH-41, SKI-232 x DCS-9, SKI-280 x SKI-215 and SKI-280 x SKI-288 in $E_3$ and SKI-232 x DCS-9 in $E_4$ had significantly out yielded GCH-5. Over the four environments, SKI-232 x DCS-9 had significantly out yielded the GCH-4 while none of the hybrids was significantly superior over GCH-5. The highest yielding hybrid 'SKI-232 x DCS-9' (182.28 g) revealed the highest standard heterosis of 22.77 per cent and 12.04 per cent across the environments over the standard checks, GCH-4 and GCH-5, respectively (Table 4).

For days to 50% flowering, heterosis over GCH-4 and GCH-5 ranged between -16.31% to 17.40% and -17.85% to 15.23%, respectively, across the locations, while it was -5.32% to 24.42% and -10.55% to 17.54% for days to maturity, -1.83% to 28.79% and -12.89% to 14.29% for no. of nodes up to main spike, -30.49% to 41.74% and -45.00% to 12.16% for plant height, -8.40% to 28.47% and -6.59% to 31.01% for total no. of branches/plant, -7.77% to 32.61% and -7.48% to 33.04% for no. of effective branches/plant, -10.68% to 40.61% and -20.48% to 25.19% for length of main spike, -16.31% to 45.82% and -32.61% to 17.42% for no. of capsules on main spike and -10.44% to 3.27% and -11.92% to 1.56% for 100 seed weight over GCH-4 and GCH-5, respectively (Table 3).

It will be of considerable interest to know the cause of heterosis for seed yield in castor. Top ten (10) hybrids with respect to mean seed yield over four environments along with their values of heterobeltiosis, standard heterosis over check GCH-4 and GCH-5, *sca* effects as well as component traits showing significant and desirable heterosis over standard checks GCH-4 and GCH-5 are listed in Table 4. The result indicated that among top ten (10) hybrids, eights hybrids registered highly significant and desirable heterobeltiosis over their respective better parent for seed yield. All the top ten hybrids also recorded highly significant and desirable (positive) *sca* effects for seed yield per plant. This emphasized that heterosis breeding in castor is rewarding.

The highest yielding hybrid SKI-232 x DCS-9 manifested significant and desirable heterosis over standard check GCH-4 for most of all the important yield contributing characters *viz.,* effective branches per plant, length of main spike, number of capsules on main spike, 100-seed weight; while it failed to record significant and desirable heterosis over GCH-5 for number of capsules on main spike and 100-seed weight, which were most important yield attributes. This emphasized that high degree of standard heterosis for seed yield/plant might be due to the desirable heterosis observed for their important component traits. High association of heterosis between seed yield components and seed yield/plant in castor have also been earlier reported by Kaul and Prasad (1983), Patel *et al*; (1986), Thakkar (1987), Mehta *et al.* (1991), Patel (1991), Joshi (1993), Patel (1994b), Bhand (1996), Patel (1996), Patel (1998b), Manivel *et al.* (2000), Joshi *et al.* (2001) and Patel and Pathak (2006). Earlier Whitehouse *et al;* (1958) and Grafius (1959) suggested that there can not be any gene system special for seed yield *per se*, as yield is an end product of multiplicative interaction of several yield components.

Thus present investigation manifested that high magnitude of heterosis for seed yield/plant in castor is associated with high degree of heterosis in yield component traits. Number of capsules on main spike and 100 seed weight have significant influence on seed yield/plant followed by spike length and effective branches/plant.

Future Strategy: Besides SKI-232 x DCS-9, the hybrids *viz;* SKI-280 x SH-41, SKI-280 x SKI-288, SH-41 x SKI-285, SKI- 280 x SKI-215, SKI-288 x SH-41, SKI-288 x SKI-232, SKI-218 x SKI-232, SKI-215 x SH-41, SKI-288 x SKI-285 and SKI-215 x SKI-285 registered significant and high magnitude of heterobeltiosis over the environments thus providing the best chances to isolate high yielding and earlier maturing genotype/s in later segregating generations. Biparental mating design between superior plants in segregating generations of these crosses will be fruitful to evolve high yielding genotypes having short stature, compact nodes, long spikes with more number of capsules and bolder seeds.

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**Table1: Pedigree and source of the parental lines used in diallel mating design**

| Parents | Pedigree | Source |
|---|---|---|
| SKI-280 | (SKP-93 x TMV-5) x (SKP-35 x JM-6) | S.K.Nagar, Gujarat |
| SKI-215 | (SKI-8A x SA-2) $F_{10}$ | S.K.Nagar, Gujarat |
| VI-9 | Selection from S 20 | S.K.Nagar, Gujarat |
| SKI-288 | (VP-1 x TMV-5) $F_6$ | S.K.Nagar, Gujarat |
| SKI-218 | (SH-41 x JM-6) x SH-41 | S.K.Nagar, Gujarat |
| SKI-271 | Selection from Geeta, 50 Kr | S.K.Nagar, Gujarat |
| SKI-232 | SKI-18 x JM-6 | S.K.Nagar, Gujarat |
| SH-41 | (CO-1 x 279) x 413 A 15.4 | S.K.Nagar,Gujarat |
| DCS-9 | Selection from 240 x Bhagya | DOR, Hyderabad |
| SKI-285 | (SKP-72 x SKI-13) $F_6$ | S.K.Nagar, Gujarat |

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**Table 2 : Analysis of variance for seed yield and its components over environments**

| Source of variation | DF | Days to 50 % flowering | Days to maturity | No. of nodes up to main spike | Plant height (cm) | Total no. of branches/plant | No. of Effective branches /plant | Length of main spike (cm) | No. of capsules on main spike | 100-Seed weight (g) | Seed yield/plant (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Environments (E) | 3 | 257.57** | 566.78** | 86.52** | 5387.75** | 39.35** | 32.70** | 5280.74** | 7412.54** | 87.03** | 45635.80** |
| Genotypes (G) | 54 | 266.99** | 756.04** | 16.38** | 2973.06** | 1.40** | 1.31** | 307.42** | 520.20** | 20.76** | 3558.25** |
| Parents (P) | 9 | 487.27** | 1092.98** | 31.89** | 5442.57** | 0.76** | 0.52** | 177.08** | 343.22** | 27.73** | 3017.57** |
| Hybrids (H) | 44 | 225.54** | 665.57** | 13.40** | 2514.72** | 1.26** | 1.03** | 234.87** | 426.61** | 18.60** | 2567.74** |
| P *vs.* H | 1 | 108.63** | 1704.55** | 7.65** | 914.72** | 13.27** | 20.99** | 4672.55** | 6231.09** | 52.97** | 52006.58** |
| G x E | 162 | 0.81** | 1.13** | 0.42** | 6.05** | 0.71** | 0.61** | 91.69** | 123.18** | 1.29** | 828.26 ** |
| P x E | 27 | 0.50 | 0.34 | 0.19 | 4.62 | 0.25** | 0.28** | 28.18** | 50.34 | 0.70** | 516.74 ** |
| H x E | 132 | 0.86** | 1.30** | 0.47** | 5.70** | 0.82** | 0.69** | 106.52** | 138.80** | 1.44** | 896.30 ** |
| P *vs.* H x E | 3 | 1.14* | 0.58 | 0.19 | 33.96 | 0.06 | 0.04 | 10.90 | 91.54 | 0.25 | 638.09 |
| Error | 432 | 0.41 | 0.82 | 0.13 | 24.54 | 0.10 | 0.09 | 15.46 | 38.09 | 0.28 | 274.52 |

**Note:-** ***** and ****** denotes significant at P= 0.05 and P=0.01 levels, respectively.

**Table 3. Range of heterosis, no. of significant and desirable hybrids and best heterotic hybrids with significant superiority over Batter Parent (BP), GCH-4 and GCH-5 in individual and pooled over environments**

| Characters | E | Range of Heterosis over | | | No. of significant & desirable hybrids over | | | Best heterotic hybrid/s with significant superiority over | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | BP | GCH-4 | GCH-5 | BP | GCH-4 | GCH-5 | BP | GCH-4 | GCH-5 |
| Seed yield/plant (g) | $E_1$ | -16.66 to 50.37 | -24.01 to 33.23 | -30.39 to 22.05 | 12 | 4 | 2 | SKI-280 x SKI-215 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| | $E_2$ | -23.63 to 34.93 | -34.00 to 28.63 | -38.83 to 19.20 | 11 | 2 | 1 | SKI-215 x SKI-232 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| | $E_3$ | -15.48 to 45.91 | -29.28 to 27.38 | -34.98 to 17.10 | 19 | 5 | 4 | SKI-280 x SH-41 | SKI-280 x SH-41 | SKI-280 x SH-41 |
| | $E_4$ | -18.42 to 47.72 | -41.42 to 35.54 | -48.09 to 20.10 | 11 | 2 | 1 | SKI-288 x SH-41 | SKI-218 x SKI-232 | SKI-218 x SKI-232 |
| | Pld | -13.71 to 47.89 | -25.08 to 22.77 | -31.62 to 12.04 | 12 | 1 | - | SKI-280 x SH-41 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| Days to 50% flowering | $E_1$ | -16.77 to 34.71 | -16.36 to 17.60 | -18.41 to 14.72 | 13 | 21 | 25 | SKI-215 x SKI-285 | SKI-215 x SKI-232 | SKI-215 x SKI-232 |
| | $E_2$ | -15.48 to 47.47 | -18.36 to 15.82 | -20.37 to 12.96 | 14 | 21 | 28 | SKI-215 x SKI-285 | SKI-215 x SKI-232 | SKI-215 x SKI-232 |
| | $E_3$ | -10.33 to 47.59 | -14.72 to 18.41 | -14.72 to 18.41 | 13 | 20 | 20 | SKI-215 x SKI-285 | SKI-215 x SKI-232 | SKI-215 x SKI-232 |
| | $E_4$ | -15.62 to 43.33 | -15.83 to 18.38 | -17.90 to 15.43 | 13 | 23 | 23 | SKI-215 x SKI-285 | SKI-215 x SKI-232 | SKI-215 x SKI-232 |
| | Pld | -15.60 to 46.58 | -16.31 to 17.40 | -17.85 to 15.23 | 12 | 21 | 24 | SKI-215 x SKI-285 | SKI-215 x SKI-232 | SKI-215 x SKI-232 |
| Days to maturity | $E_1$ | -14.75 to 23.47 | -5.52 to 23.61 | -10.20 to 17.49 | 21 | 3 | 11 | SKI-288 x SKI-285 | SKI-288 x DCS-9 | SKI-288 x DCS-9 |
| | $E_2$ | -14.69 to 24.31 | -5.92 to 22.74 | -11.44 to 15.54 | 20 | 3 | 14 | SKI-288 x DCS-9 | SKI-288 x DCS-9 | SKI-288 x DCS-9 |
| | $E_3$ | -14.63 to 22.18 | -3.38 to 26.38 | -9.48 to 18.39 | 23 | 2 | 11 | SKI-288 x DCS-9 | SKI-288 x DCS-9 | SKI-288 x DCS-9 |
| | $E_4$ | -16.02 to 22.97 | -6.46 to 24.93 | -11.11 to 18.71 | 22 | 3 | 13 | SKI-288 x DCS-9 | SKI-288 x DCS-9 | SKI-288 x DCS-9 |
| | Pld | -15.00 to 23.23 | -5.32 to 24.42 | -10.55 to 17.54 | 22 | 2 | 11 | SKI-288 x DCS-9 | SKI-288 x DCS-9 | SKI-288 x DCS-9 |
| No. of nodes up to main spike | $E_1$ | -10.53 to 27.39 | -3.36 to 26.51 | -12.75 to 14.21 | 11 | - | 23 | SH-41 x SKI-285 | - | VI-9 x SKI-288 |
| | $E_2$ | -10.83 to 26.67 | -3.90 to 26.84 | -14.30 to 13.10 | 14 | 1 | 32 | DCS-9 x SKI-285 | VI-9 x SKI-288 | DCS-9 x SKI-285 |
| | $E_3$ | -10.78 to 33.98 | 2.05 to 34.41 | -11.83 to 16.13 | 14 | - | 23 | SH-41 x DCS-9 | - | VI-9 x SKI-285 |
| | $E_4$ | -9.32 to 23.81 | -2.11 to 27.85 | -12.76 to 13.93 | 9 | - | 23 | SKI-280 x SKI-285 | - | VI-9 x SKI-288 |
| | Pld | -8.18 to 28.14 | -1.83 to 28.79 | -12.89 to 14.29 | 11 | - | 14 | SKI-288 x SKI-232 | - | VI-9 x SKI-288 |
| Plant height (cm) | $E_1$ | -16.25 to 62.27 | -29.21 to 44.81 | -47.46 to 7.49 | 2 | 23 | 39 | SKI-280 x SKI-285 | VI-9 x SKI-288 | VI-9 x SKI-288 |
| | $E_2$ | -15.31 to 71.66 | -33.66 to 36.08 | -46.34 to 10.08 | 2 | 31 | 38 | SKI-280 x SKI-285 | VI-9 x SKI-288 | VI-9 x SKI-288 |
| | $E_3$ | -14.73 to 59.30 | -27.40 to 42.42 | -40.87 to 16.01 | 5 | 25 | 37 | SKI-280 x SKI-285 | VI-9 x SKI-288 | VI-9 x SKI-288 |
| | $E_4$ | -18.39 to 60.82 | -27.29 to 46.95 | -41.68 to 17.87 | 6 | 25 | 36 | SKI-280 x SKI-285 | VI-9 x SKI-288 | VI-9 x SKI-288 |
| | Pld | -16.16 to 61.65 | -30.49 to 41.74 | -45.00 to 12.16 | 3 | 27 | 38 | SKI-280 x SKI-285 | VI-9 x SKI-288 | VI-9 x SKI-288 |

E=Environments; $E_1$: Environment 1; $E_2$: Environment 2; $E_3$: Environment 3; $E_4$: Environment 4; Pld= Pooled over environments

**Table 3. (Contd…)**

| Characters | E | Range of Heterosis over | | | No. of significant & desirable hybrids over | | | Best heterotic hybrid/s with significant superiority over | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | BP | GCH-4 | GCH-5 | BP | GCH-4 | GCH-5 | BP | GCH-4 | GCH-5 |
| Total no. of branches/ plant | $E_1$ | -30.43 to 43.63 | -22.48 to 55.04 | -21.05 to 57.89 | 11 | 22 | 24 | SH-41 x SKI-285 | DCS-9 x SKI-285 | DCS-9 x SKI-285 |
| | $E_2$ | -17.77 to 45.09 | -18.53 to 27.78 | -15.48 to 32.56 | 8 | 8 | 14 | DCS-9 x SKI-285 | DCS-9 x SKI-285 | DCS-9 x SKI-285 |
| | $E_3$ | -16.87 to 43.54 | -9.25 to 48.14 | -9.25 to 48.14 | 14 | 28 | 28 | SKI-271x SKI-285 | VI-9 x SKI-288 | VI-9 x SKI-288 |
| | $E_4$ | -25.50 to 44.07 | -25.50 to 23.53 | -23.93 to 26.13 | 14 | 9 | 11 | SKI-288 x SH-41 | SKI-218 x DCS-9 | SKI-218 x DCS-9 |
| | Pld | -14.50 to 31.37 | -8.40 to 28.47 | -6.59 to 31.01 | 11 | 13 | 19 | SH-41 x SKI-285 | VI-9 x SKI-288 | VI-9 x SKI-288 |
| No. of Effective branches /plant | $E_1$ | -29.06 to 52.94 | -18.02 to 64.26 | -18.02 to 64.26 | 15 | 24 | 24 | SKI-232 x DCS-9 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| | $E_2$ | -16.66 to 47.88 | -17.49 to 41.14 | -19.07 to 38.43 | 13 | 12 | 10 | DCS-9 x SKI-285 | DCS-9 x SKI-285 | DCS-9 x SKI-285 |
| | $E_3$ | -19.29 to 40.58 | -10.41 to 45.84 | -8.40 to 49.11 | 16 | 25 | 25 | SKI-271x SKI-285 | SH-41 x DCS-9 | SH-41 x DCS-9 |
| | $E_4$ | -26.16 to 60.59 | -22.63 to 29.69 | -21.01 to 32.40 | 19 | 14 | 18 | SKI-288 x SH-41 | SKI-215 x SKI-218<br>SKI-218 x DCS-9 | SKI-215 x SKI-218<br>SKI-218 x DCS-9 |
| | Pld | -11.17 to 33.08 | -7.77 to 32.61 | -7.48 to 33.04 | 15 | 20 | 20 | SH-41 x SKI-285 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| Length of main spike (cm) | $E_1$ | -21.92 to 37.48 | -21.04 to 30.12 | -27.22 to 19.94 | 21 | 15 | 6 | SKI-280 x SKI-215 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| | $E_2$ | -8.57 to 60.46 | -18.01 to 65.28 | -26.78 to 47.60 | 20 | 13 | 4 | SKI-232 x DCS-9 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| | $E_3$ | -27.66 to 63.60 | -24.14 to 47.35 | -30.90 to 34.23 | 12 | 10 | 7 | SKI-280 x SH-41 | SH-41 x DCS-9 | SH-41 x DCS-9 |
| | $E_4$ | -18.87 to 53.13 | -8.36 to 51.01 | -24.88 to 23.79 | 21 | 29 | 5 | SKI-280 x SH-41 | SKI-218 x SKI-232 | SKI-218 x SKI-232 |
| | Pld | -11.51 to 39.43 | -10.68 to 40.61 | -20.48 to 25.19 | 15 | 12 | 3 | SKI-280 x SKI-215 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| No. of capsules on main spike | $E_1$ | -26.92 to 54.50 | -23.50 to 47.36 | -37.10 to 21.16 | 10 | 2 | 2 | SKI-280 x SKI-215 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| | $E_2$ | -27.76 to 48.33 | -33.79 to 55.75 | -44.93 to 29.55 | 15 | 9 | 2 | SKI-232 x DCS-9 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| | $E_3$ | -28.01 to 73.68 | -18.39 to 67.95 | -42.80 to 22.01 | 12 | 19 | 3 | SKI-280 x SH-41 | SKI-280 x SH-41 | SKI-280 x SH-41 |
| | $E_4$ | -20.88 to 61.34 | -32.22 to 58.00 | -42.04 to 35.10 | 10 | 8 | 2 | SKI-288 x SH-41 | SKI-218 x SKI-232 | SKI-218 x SKI-232 |
| | Pld | -12.75 to 57.35 | -16.31 to 45.82 | -32.61 to 17.42 | 13 | 7 | - | SKI-280 x SKI-215 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| 100-Seed weight (g) | $E_1$ | -7.86 to 4.95 | -9.70 to 4.08 | -11.29 to 2.24 | 11 | 4 | 2 | SKI-232 x DCS-9 | SKI-232 x DCS-9 | SKI-232 x DCS-9 |
| | $E_2$ | -9.03 to 6.85 | -12.11 to 2.80 | -12.64 to 2.18 | 12 | 2 | 2 | SKI-271 x DCS-9<br>SKI-232 x DCS-9 | SKI-271 x DCS-9<br>SKI-232 x DCS-9 | SKI-271 x DCS-9<br>SKI-232 x DCS-9 |
| | $E_3$ | -7.39 to 16.58 | -10.04 to 4.94 | -11.06 to 3.74 | 7 | 4 | 4 | SKI-280 x SKI-215 | SKI-280 x SH-41 | SKI-280 x SH-41 |
| | $E_4$ | -9.57 to 7.19 | -11.45 to 6.16 | -14.22 to 2.84 | 9 | 1 | 1 | SKI-232 x DCS-9 | SKI-218 x SKI-232 | SKI-218 x SKI-232 |
| | Pld | -7.42 to 6.22 | -10.44 to 3.27 | -11.92 to 1.56 | 9 | 1 | - | SKI-232 x DCS-9 | SKI-232 x DCS-9 | - |

E=Environments; $E_1$: Environment 1; $E_2$: Environment 2; $E_3$: Environment 3; $E_4$: Environment 4; Pld= Pooled over environments

**Table 4. Performance of top ten (10) high yielding hybrids for heterosis over Better Parent (BP), Standard check GCH-4 and GCH-5, their sca effects and component traits showing significant and desirable heterois over Better Parent (BP) and standard check GCH- 4 and GCH-5**

| Hybrid | Seed yield/Pl (g) | Heterosis over | | | SCA effect | Components showing significant and desirable heterosis over | | |
|---|---|---|---|---|---|---|---|---|
| | | BP | GCH-4 | GCH-5 | | BP | GCH-4 | GCH-5 |
| SKI-232 x DCS-9 | 182.28 | 30.49** | 22.77* | 12.04 | 30.04** | DF, DM, ND, TB, EB, Spk, Cap, TW, Oil | DF, Pht, TB, EB, Spk, Cap, TW, Oil | DF, ND, Pht, TB, EB, Spk |
| SKI-280 x SH-41 | 165.45 | 47.89** | 11.44 | 1.70 | 27.18** | DF, DM, EB, Spk, Cap, TW | DF, TB, EB, Spk, Cap, | DF, Pht, TB, EB |
| SKI-218 x SKI-232 | 165.41 | 33.51** | 11.41 | 1.67 | 24.05** | Spk, Cap, Oil | Spk, Cap, Oil | - |
| SKI-280 x SKI-288 | 163.23 | 42.40** | 9.94 | 0.33 | 25.63** | DM, ND, Spk, Cap, Oil | Pht, Spk | ND, Pht |
| SKI-288 x SKI-232 | 160.45 | 34.49** | 8.07 | -1.38 | 15.24** | DM, ND, EB, Spk, Cap, Oil | DF,Pht | DF, DM,, ND, Pht |
| SH-41 x DCS-9 | 159.99 | 14.53 | 7.76 | -1.66 | 12.32** | DF, DM, ND, TB, EB, Spk, TW, Oil | DF, TB, EB, Spk, Cap | DF, DM, ND, Pht, TB, EB, Spk |
| SKI-288 x SH-41 | 156.34 | 36.39** | 5.30 | -3.90 | 15.71** | DM, EB, Spk, Cap | Pht, Spk, Cap | DM, ND, Pht |
| SH-41 x SKI-285 | 156.17 | 41.89** | 5.18 | -4.01 | 19.53** | DF, DM, ND, TB, EB, Spk, Cap | DF, Pht, TB, EB, Spk | DF, ND, Pht, TB, EB |
| SKI-218 x DCS-9 | 155.56 | 11.36 | 4.78 | -4.38 | 12.40** | Spk, Cap, Oil | EB, Spk, Cap | TB, EB, Spk |
| SKI-280 x SKI-215 | 154.57 | 38.17** | 4.11 | -4.99 | 27.48** | Spk, Cap, TW, Oil | Pht, Spk, Cap | Pht |

**Note:-** * and ** indicates significant at P = 0.05 and P = 0.01 levels, respectively.
DF=Days to 50% flowering; DM= Days to maturity of main spike; ND=No. of nodes up to main spike; Pht= Plant height up to main spike (cm); TB=Total branches/plant; EB=Effective branches/plant; Spk= Length of main spike (cm); Cap= No. of capsules on main spike; TW= 100-Seed weight (g)