Original Research Article

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Heterosis and Heterobeltiosis for Seed Yield and its Components in Indian Mustard (Brassica juncea L. Czern & Coss) under Normal (E1) and Moisture Stress (E2) Environments

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A B S T R A C T

A set of 10 x 10 diallel crosses excluding reciprocals of Indian mustard along with their parents were evaluated in randomized block design with three replications in two set of environments i.e. normal (E1) and moisture stress (E2) in RBD design with three replications during Rabi 2015-16. Observation were recorded on various quantitative characters viz., Observations were recorded on days to flowering, days to maturity, plant height (cm), primary branches per plant, length of main raceme (cm), number of siliqua on main raceme, number of seeds per siliqua, 1000-seed weight (g), seed yield per plant (g) and oil content (%). Heterosis and heterobeltiosis of higher magnitude was expressed for seed yield per plant, number of siliqua on main raceme and number of seeds per siliqua. The crosses Vardan x RH-30 and Bio-902 x NRCDR-2 were identified as the superior crosses under both the environments which can be utilized for high yield and moisture stress genotypes.

Keywords
Indian mustard, Heterosis, Heterobeltiosis and Brassica juncea.

Introduction

Indian mustard [Brassica juncea (L.) Czern & Coss] is an important oilseed crop belongs to family Brassicaceae (Cruciferae) and genus Brassica. It is a natural amphidiploid having 36 chromosomes (2n). It is largely self-pollinated but certain amount of cross pollination (2-15%) may take place due to honeybees (Vaghela et al., 2011). Mustard was originated in China and from there; it was introduced to India (Vaughan, 1977).

Rapeseed and Mustard are the major Rabi oilseed crops of India. Oil content in mustard seed varies from 37 to 49 per cent. The oil obtained is the main cooking medium in Northern India and cannot be easily replaced by any other edible oil. The seed and oil of mustard have a peculiar pungency due to presence of glucosinolate and its hydrolysis products such as allyl-isothio-cynate making it suitable to be used as condiment in the preparation of pickles and for flavoring
curries and vegetables. The oil is utilized for human consumption throughout Northern India in cooking and frying purposes.

Moisture stress is major limiting factor in productivity of rapeseed-mustard. Majority of the cultivation is still dependent on rainfall and conserved moisture. Brassica species are mostly grown on light texture soil using conserved moisture from monsoon rains. Crop inevitably suffers from drought stress during the reproductive period of growth after depletion of stored water (Kumar, 2001). Hence development of drought tolerant/resistant varieties of Indian mustard is essential to increase the production.

In the present scenario of changing agroclimatic conditions where there is depleting underground water and increased terminal temperature, the plant breeders have two challenges in the oilseed production, first the yield potential should further be increased in traditional area of mustard cultivation and second, short duration and drought tolerant oilseed varieties should be developed to maintain the production in the state and serve as an alternative to wheat in nontraditional areas.

Grafius (1959) suggested that there might not be any specific genes for yield per se. Since, heterosis has an important role in all plant breeding programmes; it would be very helpful to know the relationship between heterosis for seed yield and its components (Azizinia, 2011). Selection of desirable heterotic crosses at an early stage is very important in developing high-yielding genotypes. Effective utilization of heterosis to develop high-yielding hybrids, therefore, has been the major objective of Brassica oilseed breeding in recent years (Wang, 2005). The main objective of the present study, therefore, was to isolate superior cross combination(s) by estimating heterosis (mid parent heterosis) and heterobeltiosis in F₁ crosses under normal (E₁) and moisture stress (E₂) environments in Indian mustard [Brassica juncea (L.) Czerń & Coss].

Materials and Methods

The experimental material comprised ten genetically diverse parents of Indian mustard viz.; CS-52, GM-3, PBR-357, Vardan, RH-30, Bio-902, Kranti, NRCDR-2, RGN-229 and RN-393. The parents were crossed in diallel fashion (excluding reciprocal) to develop the hybrid seeds of 45 crosses. All the crosses were grown in randomized block design with three replications under two environments namely, normal (E₁) and moisture stress (E₂) at Agronomy farm S.K.N. College of Agriculture, Jobner, Jaipur. In both the environments pre-sowing irrigation was given to facilitate germination of seeds. In normal environment (E₁) and moisture stress environment (E₂), one irrigation was given at 45 days after sowing i.e. at about initiation of flowering. Moisture stress environment was created by stopping further irrigation in E₂ i.e. no irrigation was given after 45 days in E₂. In normal environment, the second and last irrigation was given at 70 days after sowing. Observations were recorded on days to flowering, days to maturity, plant height (cm), primary branches per plant, length of main raceme (cm), number of siliqua on main raceme, number of seeds per siliqua, 1000-seed weight (g), seed yield per plant (g) and oil content (%). The data obtained were subjected to analysis of variance as per standard procedures.

Results and Discussion

Analysis of variance in individual environment (Table 1) revealed highly significant differences among genotypes for all the characters in both the environments consequently established the circumstances...
that the characters manifested the presence of ample genetic diversity among the genotypes. This is in conformity with the findings obtained by Arrifullah et al., (2013), Kumar et al., (2014), Synrem et al., (2014) and Akabari et al., (2016).

Mean squares due to Parents vs. generations were found significant for all the characters in all the environments except for days to 50% flowering in E2 and plant height in E1 indicated the presence of heterosis. Similar findings were obtained by Sheoran et al., (2000) and Tuncturk and Ciftci (2007) also reported significant differences between genotypes for seed yield and its attributes.

Mean squares due to F1 vs. F2 were found significant for all the characters in both the environments except for days to maturity in E1, number of primary branches per plant in E2, number of seeds per silique in E1 and E2 and 1000-seed weight in E2. Similar findings were obtained by Vaghela et al., (2011) and Arifullah et al., (2013).

Short and medium plant stature less vulnerable to lodging due to heavy winds is also preferred in Brassica. Early maturity is useful in most plant species especially Brassica where delayed maturity cause losses in yield and quality of oil due to high temperature (Turi et al., 2006). Similarly, initiation of branches near the base of plant is also desirable for profuse branching with vigorous stature. Negative heterosis, therefore, is useful regarding days to flowering, days to maturity and plant height. Early maturing genotypes suffer lower losses due to shattering, tolerate or seeding the next crop. Similarly, shorter plants with greater numbers of branches are desirable due to their ability to withstand winds. In the present study, negative heterotic values for these traits were noted for many of the crosses (Table 2). Crosses showing significant negative values suggested that these crosses could be used to develop new early maturing varieties. Pourdad and Sachan (2003) also reported significant negative heterosis for days to 50% flowering and maturity and high negative heterosis for plant height in Brassica napus. Similarly, Nassimi et al., (2006) also obtained significant negative better-parent heterosis for maturity and plant height. Engqvist and Becker (1991) found that rapeseed hybrids with earlier flowering and higher yields were slightly late maturing. The crosses CS-52 x Bio-902 and GM-3 x Vardan significant positive heterosis and heterobeltiosis under both the environments. In Brassica, positive heterosis for number of primary branches is desirable, because plants with vigorous stature containing more branches provide opportunity for higher yields. For length of main raceme; the crosses RH-30 x NRCDR-2 and NRCDR-2 x RN-393, for silique on main raceme; the crosses PBR-357 x RH-30 and CS-52 x RN-393, for number of seeds per silique; the crosses RH-30 x Bio-902, for seed yield per plant; the crosses PBR-357 x Kranti, Vardan x RH-30 and Vardan x RN-393 significant positive heterosis and heterobeltiosis under both the environments. Results of high heterosis and heterobeltiosis for seed yield per plant and contributing traits were also reported by Ghosh et al., (2002). The level of heterosis observed in these crosses justifies the development of commercial hybrids in Indian mustard. Commercial exploitation of hybrid in Brassica juncea has been reported by many mustard workers like Meena et al., (2014, 15) and Akbar et al., (2007) also reported that these crosses with positive heterosis and heterobeltiosis may be utilized for hybrid seed production by CMS and restorer lines. Heterotic crosses showing substantial and significant SCA effects for seed yield over mid-parent and better parent are indicated (Table 3).
Table 1 ANOVA for various characters in normal (E1) and moisture stress environment (E2) in mustard

| Source of Variation | Characters Env. | Days to 50% flowering | Days to maturity | Plant height (cm) | Number of primary branches per plant | Length of main raceme (cm) |
|---------------------|----------------|------------------------|-----------------|------------------|--------------------------------------|--------------------------|
| Replications        | E1             | 43.77***               | 9.16*           | 705.87**         | 2.80**                               | 33.41                    |
|                     | E2             | 4.34                   | 75.14***        | 1407.73**        | 0.14                                 | 232.41**                 |
| Genotypes (G)       | E1             | 9.25**                 | 26.38**         | 301.92**         | 0.26**                               | 164.03**                 |
|                     | E2             | 5.89**                 | 35.77**         | 112.68**         | 0.35**                               | 94.16**                  |
| Parents (P)         | E1             | 10.16**                | 17.68**         | 177.40**         | 0.17**                               | 166.27**                 |
|                     | E2             | 3.54                   | 21.34**         | 83.73*           | 0.36**                               | 4.66                     |
| Generation          | E1             | 8.36**                 | 24.88**         | 317.78**         | 0.24**                               | 160.44**                 |
|                     | E2             | 6.17**                 | 36.68**         | 106.44**         | 0.34**                               | 93.41**                  |
| F1                  | E1             | 10.32**                | 16.60**         | 180.36**         | 0.29**                               | 121.94**                 |
|                     | E2             | 4.90*                  | 29.65**         | 123.77**         | 0.28**                               | 53.98**                  |
| F2                  | E1             | 4.25**                 | 33.47**         | 268.83**         | 0.18**                               | 78.63**                  |
|                     | E2             | 7.11**                 | 32.38**         | 79.938**         | 0.42**                               | 92.71**                  |
| F1 vs F2            | E1             | 103.29**               | 10.80           | 8517.5**         | 0.31*                                | 5453.82**                |
|                     | E2             | 20.28*                 | 534.81**        | 510.19**         | 0.03                                 | 1859.20**                |
| Parents vs Generation | E1         | 80.08**                | 238.22**        | 11.82            | 3.47**                               | 463.33**                 |
|                     | E2             | 2.61                   | 85.33**         | 928.30**         | 0.49**                               | 966.24**                 |
| Error               | E1             | 2.36                   | 2.85            | 29.68            | 0.06                                 | 19.71                    |
|                     | E2             | 3.23                   | 2.28            | 37.082           | 0.06                                 | 22.93                    |

*, ** Significant at 5 per cent & 1 per cent levels of significance, respectively
| Source of Variation | Characters | Env.  | df  | Number of siliqua on main raceme | Number of seeds per siliqua | 1000 seed weight (g) | Seed yield per plant (g) | Oil content (%) |
|---------------------|------------|-------|-----|----------------------------------|----------------------------|----------------------|-------------------------|-----------------|
| Replications        |            | E₁    | 2   | 51.10                            | 0.29                       | 0.68**               | 1.97                    | 28.70**         |
|                     |            | E₂    | 2   | 436.51**                         | 2.44                       | 2.51**               | 5.94**                  | 6.70**          |
| Genotypes (G)       |            | E₁    | 99  | 63.69**                          | 2.67**                     | 0.20**               | 18.78**                 | 1.26**          |
|                     |            | E₂    | 99  | 70.96**                          | 2.34**                     | 0.15*                | 16.92**                 | 1.95**          |
| Parents (P)         |            | E₁    | 9   | 24.53                            | 1.83                       | 0.26**               | 0.64                    | 1.72*           |
|                     |            | E₂    | 9   | 12.20                            | 1.85                       | 0.17                 | 0.94                    | 2.07*           |
| Generation          |            | E₁    | 89  | 54.36**                          | 2.53**                     | 0.18**               | 19.52**                 | 1.11**          |
|                     |            | E₂    | 89  | 72.35**                          | 2.20**                     | 0.15*                | 17.64**                 | 1.91**          |
| F1                  |            | E₁    | 44  | 38.91**                          | 2.17**                     | 0.12*                | 10.93**                 | 0.52            |
|                     |            | E₂    | 44  | 42.74**                          | 1.65*                      | 0.14                 | 8.49**                  | 1.35*           |
| F2                  |            | E₁    | 44  | 50.91**                          | 2.94**                     | 0.19**               | 5.78**                  | 0.91            |
|                     |            | E₂    | 44  | 30.97**                          | 2.76**                     | 0.16*                | 7.85**                  | 1.27*           |
| F1 vs F2            |            | E₁    | 1   | 886.57**                         | 0.32                       | 2.53**               | 1002.02**               | 36.24**         |
|                     |            | E₂    | 1   | 3195.48**                        | 1.86                       | 0.18                 | 851.30**                | 54.10**         |
| Parents vs Generation|          | E₁    | 1   | 1246.40**                        | 22.75**                    | 0.83**               | 115.71**                | 10.46**         |
|                     |            | E₂    | 1   | 475.93**                         | 18.79**                    | 0.44*                | 96.63**                 | 5.06*           |
| Error               |            | E₁    | 198 | 17.40                            | 1.20                       | 0.08                 | 1.12                    | 0.69            |
|                     |            | E₂    | 198 | 12.65                            | 1.05                       | 0.10                 | 1.04                    | 0.86            |

*, ** Significant at 5 per cent & 1 per cent levels of significance, respectively.
### Table 2

Estimates of heterosis and heterobeltiosis for days to 50% flowering under normal (E1) and moisture stress (E2) environments.

| S. No. | Crosses                     | Heterosis (%) | Heterobeltiosis (%) |
|--------|-----------------------------|---------------|---------------------|
|        |                             | $E_1$         | $E_2$               | $E_1$         | $E_2$               |
| 1.     | CS-52 X GM-3                | -2.05         | 1.32                | -3.05         | 0.66                |
| 2.     | CS-52 X PBR-357             | -0.25         | 2.58                | -0.51         | 0.63                |
| 3.     | CS-52 X Vardan              | -2.77         | -0.32               | -3.50         | -2.52               |
| 4.     | CS-52 X RH-30               | -1.56         | -1.65               | -4.06         | -1.97               |
| 5.     | CS-52 X Bio-902             | 3.11          | 1.96                | 1.02          | 1.30                |
| 6.     | CS-52 X Kranti              | -1.82         | 1.94                | -4.06         | 0.00                |
| 7.     | CS-52 X NRCDR-2             | -3.65*        | 1.95                | -6.09**       | 0.64                |
| 8.     | CS-52 X RGN-229             | 0.52          | -3.25               | 2.54          | -4.49               |
| 9.     | GM-3 X PBR-357              | -1.29         | -3.25               | -2.04         | -5.70*              |
| 10.    | GM-3 X Bio-902              | -2.09         | -2.63               | -3.11         | -3.90               |
| 11.    | GM-3 X Vardan               | 0.26          | -1.30               | -3.25         | -4.30               |
| 12.    | GM-3 X RH-30                | 3.16          | 3.27                | 4.66*         | 1.28                |
| 13.    | GM-3 X RGN-229              | 2.39          | 3.90                | 0.00          | 0.63*               |
| 14.    | PBR-357 X Vardan            | -4.55*        | -3.47               | -5.50**       | -3.77               |
| 15.    | PBR-357 X RH-30             | 2.35          | -3.25               | 2.54          | -3.50               |
| 16.    | PBR-357 X Bio-902           | 0.25          | -1.28               | -1.53         | -2.53               |
| 17.    | PBR-357 X Bio-902           | -3.65*        | -7.59**             | -5.61**       | -7.59**             |
| 18.    | PBR-357 X GM-3              | 2.35          | -0.64               | 2.53          | -0.64               |
| 19.    | PBR-357 X RGN-229           | 1.84          | -4.46               | 3.25          | -4.43               |
| 20.    | PBR-357 X NH-393            | 1.58          | -4.43               | 1.30          | -1.20               |
| 21.    | PBR-357 X RGN-229           | 1.58          | -4.43               | 1.30          | -1.20               |
| 22.    | Vardan X RH-30              | -1.29         | -3.87               | -4.50*        | -6.29*              |
| 23.    | Vardan X Bio-902            | 5.40**        | -1.6                | 6.29*         | -3.49               |
| 24.    | Vardan X Kranti             | 2.58          | -6.62**             | 5.00**        | -6.92*              |
| 25.    | Vardan X NH-393             | 1.81          | -0.32               | -1.50         | -1.26               |
| 26.    | Vardan X RGN-229            | 0.78          | -3.49               | -3.00         | -4.40               |
| 27.    | Vardan X RGN-229            | 0.78          | -3.49               | -3.00         | -4.40               |
| 28.    | Vardan X RH-30              | -3.65*        | -3.25               | -8.00**       | -0.63               |
| 29.    | RH-30 X Bio-902             | -2.13         | 4.26                | -2.65         | 3.25                |
| 30.    | RH-30 X Vardan              | -1.33         | -1.62               | -1.60         | -3.80               |
| 31.    | RH-30 X RGN-229             | 0.53          | -0.33               | 0.53          | -1.92               |
| 32.    | RH-30 X NH-393              | -1.61         | 1.63                | -2.14         | 0.00                |
| 33.    | NH-393 X RGN-229            | -0.81         | 2.27                | -1.60         | 0.00                |
| 34.    | NH-393 X Vardan             | -1.33         | -1.92               | -1.59         | -3.16               |
| 35.    | NH-393 X Bio-902            | -2.66         | -3.87               | -3.17         | -4.49               |
| 36.    | NH-393 X RGN-229            | -3.74*        | 0.00                | -4.76*        | -0.64               |
| 37.    | NH-393 X Bio-902            | -3.74*        | 0.00                | -4.76*        | -0.64               |
| 38.    | NH-393 X RGN-229            | -1.88         | -1.92               | -3.17         | -3.16               |
| 39.    | NH-393 X Vardan             | -4.00*        | -3.25               | -4.26         | 1.27                |
| 40.    | NH-393 X Bio-902            | -0.53*        | 0.00                | -5.32*        | -0.63               |
| 41.    | NH-393 X RGN-229            | -1.61         | -0.63               | -2.66         | -0.63               |
| 42.    | NH-393 X Vardan             | -3.61         | 5.13*               | -3.74         | -5.13               |
| 43.    | NH-393 X Bio-902            | -6.20**       | -2.55               | -0.95**       | -3.16               |
| 44.    | NH-393 X RGN-229            | -1.36         | -5.10*              | -1.62         | -5.70*              |
| 45.    | SED                         | 1.156         | 1.236               | 1.334         | 1.428               |
| CD (5%) | 2.329                       | 2.492         | 2.690               | 2.878         |
| CD (1%) | 3.031                       | 3.243         | 3.500               | 3.744         |
Table 2: Estimates of heterosis and heterobeltiosis for days to maturity under normal (E1) and moisture stress (E2) environments

| S. No. | Crosses                      | Heterosis (%) | Heterobeltiosis (%) |
|--------|------------------------------|---------------|---------------------|
|        |                              | $E_1$         | $E_2$               |
| 1.     | CS-52 X GM-3                 | 1.04          | 4.79*               |
| 2.     | CS-52 X PBR-357              | 1.29          | -2.05*              |
| 3.     | CS-52 X Vardan               | 1.01          | 3.40**              |
| 4.     | CS-52 X RH-30                | -2.20*        | 0.29                |
| 5.     | CS-52 X Bio-902              | -3.80**       | 6.39**              |
| 6.     | CS-52 X Kranti               | -1.28         | 8.08**              |
| 7.     | CS-52 X NRCDR-2              | 0.00          | 1.49                |
| 8.     | CS-52 X RGN-229              | -2.58**       | 0.30                |
| 9.     | CS-52 X RN-393               | -2.69**       | 5.97**              |
| 10.    | GM-3 X PBR-357               | -0.26         | 2.70**              |
| 11.    | GM-3 X Vardan                | -1.28         | 1.72                |
| 12.    | GM-3 X RH-30                 | -0.66         | -2.70**             |
| 13.    | GM-3 X Bio-902               | -2.30*        | 1.44                |
| 14.    | GM-3 X Kranti                | 0.26          | 6.53**              |
| 15.    | GM-3 X NRCDR-2               | 1.03          | 4.78**              |
| 16.    | GM-3 X RGN-229               | 0.52          | 3.60**              |
| 17.    | GM-3 X RN-393                | -0.13         | 4.24**              |
| 18.    | PBR-357 X Vardan             | -1.02         | 1.30                |
| 19.    | PBR-357 X RH-30              | -2.20*        | 2.29*               |
| 20.    | PBR-357 X Bio-902            | -3.05**       | 4.50**              |
| 21.    | PBR-357 X Kranti             | 0.00          | 3.80**              |
| 22.    | PBR-357 X NRCDR-2            | -2.04*        | 0.00                |
| 23.    | PBR-357 X RGN-229            | 0.52          | 2.03*               |
| 24.    | PBR-357 X RN-393             | -1.67         | -2.13*              |
| 25.    | Vardan X RH-30               | -4.73**       | 2.16*               |
| 26.    | Vardan X Bio-902             | -5.24**       | 3.52**              |
| 27.    | Vardan X Kranti              | -5.79**       | 0.44                |
| 28.    | Vardan X NRCDR-2             | -5.76**       | -1.91               |
| 29.    | Vardan X RGN-229             | -3.05**       | -1.32               |
| 30.    | Vardan X RN-393              | -4.67**       | -1.72               |
| 31.    | RH-30 X Bio-902              | -3.4**        | 0.44                |
| 32.    | RH-30 X Kranti               | 2.45*         | 4.97**              |
| 33.    | RH-30 X NRCDR-2              | -1.93*        | 5.54**              |
| 34.    | RH-30 X RGN-229              | -4.04**       | 2.90**              |
| 35.    | RH-30 X RN-393               | -2.84**       | -2.42*              |
| 36.    | Bio-902 X Kranti             | -5.54**       | 7.58**              |
| 37.    | Bio-902 X NRCDR-2            | -6.02         | 7.26**              |
| 38.    | Bio-902 X RGN-229            | -2.29*        | 4.57**              |
| 39.    | Bio-902 X RN-393             | -2.65**       | 3.47**              |
| 40.    | Kranti X NRCDR-2             | -5.57**       | 2.99**              |
| 41.    | Kranti X RGN-229             | -0.26         | 4.15**              |
| 42.    | Kranti X RN-393              | -1.91*        | 3.64**              |
| 43.    | NRCDR-2 X RGN-229            | -2.81**       | 8.58**              |
| 44.    | NRCDR-2 X RN-393             | -2.15*        | 4.79**              |
| 45.    | RGN-229 X RN-393             | -5.28**       | 3.61**              |

| SED   | 1.212                      |
| CD (5%) | 2.444                      |
| CD (1%) | 3.179                      |
Table 2: Estimates of heterosis and heterobeltiosis for plant height under normal (E1) and moisture stress (E2) environments

| S. No. | Crosses                  | Heterosis (%) | Heterobeltiosis (%) |
|--------|--------------------------|---------------|---------------------|
|        |                          | E₁     | E₂     | E₁    | E₂    |
| 1      | CS-52 X GM-3             | -3.12  | -2.98  | -9.28** | -4.67  |
| 2      | CS-52 X PBR-357          | 2.01   | 4.56   | -4.66  | 1.71   |
| 3      | CS-52 X Vardan           | 5.25*  | 4.8    | -0.27  | 2.92   |
| 4      | CS-52 X RH-30            | 11.27** | 8.23** | 3.87   | 7.09*  |
| 5      | CS-52 X Bio-902          | 5.57*  | 3.83   | 0.81   | 1.15   |
| 6      | CS-52 X Kranti           | 13.36** | 941**  | 9.95** | 8.81*  |
| 7      | CS-52 X NRCDR-2          | 14.94** | 8.34** | 11.40** | 5.49  |
| 8      | CS-52 X RGN-229          | 1.61   | -0.06  | -4.69  | -9.33** |
| 9      | CS-52 X RN-393           | 4.60   | 9.31** | -0.68  | 9.13** |
| 10     | GM-3 X PBR-357           | -1.76  | 0.13   | -1.96  | -0.88  |
| 11     | GM-3 X Vardan            | 9.71**  | 11.40** | 8.35** | 11.35** |
| 12     | GM-3 X RH-30             | 2.98   | 4.57   | 2.63   | 3.82   |
| 13     | GM-3 X Bio-902           | 3.55   | -4.45  | 1.44   | -5.28  |
| 14     | GM-3 X Kranti            | 3.87   | 6.81*  | 0.16   | 4.37   |
| 15     | GM-3 X NRCDR-2           | 0.17   | -3.07  | -3.32  | -3.95  |
| 16     | GM-3 X RGN-229           | -6.92** | -3.69  | -7.08** | -7.42* |
| 17     | GM-3 X RN-393            | -3.47  | 1.37   | -4.87  | -0.24  |
| 18     | PBR-357 X Vardan         | -1.57  | 5.85*  | -2.99  | 4.82   |
| 19     | PBR-357 X RH-30          | 1.55   | 9.62** | 1.42   | 7.75*  |
| 20     | PBR-357 X Bio-902        | 4.56*  | 1.59   | 2.22   | 1.44   |
| 21     | PBR-357 X Kranti         | 2.55   | -0.23  | -1.31  | -3.47  |
| 22     | PBR-357 X NRCDR-2        | 3.54   | 2.38   | -0.27  | 2.28   |
| 23     | PBR-357 X RGN-229        | 3.79   | 7.49** | 3.39   | 4.34   |
| 24     | PBR-357 X RN-393         | 2.28   | 6.65*  | 0.59   | 3.91   |
| 25     | Vardan X RH-30           | -0.06  | 10.43** | -1.63  | 9.60** |
| 26     | Vardan X Bio-902         | 1.37   | 4.32   | 0.54   | 3.46   |
| 27     | Vardan X Kranti          | 4.74*  | 7.96** | 2.24   | 5.46   |
| 28     | Vardan X NRCDR-2         | 6.02   | 7.21*  | 3.57   | 6.28   |
| 29     | Vardan X RGN-229         | 0.68   | 6.35*  | -0.40  | 2.27   |
| 30     | Vardan X RN-393          | 1.96   | 8.98** | 1.73   | 7.20*  |
| 31     | RH-30 X Bio-902          | 5.54*  | 0.60   | 3.06   | -0.98  |
| 32     | RH-30 X Kranti           | 9.01**  | 14.16** | 4.79   | 12.35** |
| 33     | RH-30 X NRCDR-2          | 8.67** | 2.04   | 4.55   | 0.39   |
| 34     | RH-30 X RGN-229          | 6.69** | -0.21  | 6.15*  | -4.74  |
| 35     | RH-30 X RN-393           | 6.74** | 5.23   | 4.84   | 4.30   |
| 36     | Bio-902 X Kranti         | 10.78** | 11.35** | 9.01** | 7.89*  |
| 37     | Bio-902 X NRCDR-2        | 7.83** | -1.89  | 6.20*  | -1.94  |
| 38     | Bio-902 X RGN-229        | 4.34   | 4.75   | 2.39   | 1.54   |
| 39     | Bio-902 X RN-393         | 3.49   | 14.84** | 2.87   | 12.06** |
| 40     | Kranti X NRCDR-2         | 12.72** | 11.78** | 12.62** | 8.26*  |
| 41     | Kranti X RGN-229         | -3.43  | 5.70   | -6.7** | -3.62  |
| 42     | Kranti X RN-393          | -0.10  | 13.53** | -2.28  | 12.72** |
| 43     | NRCDR-2 X RGN-229        | 6.74** | 2.90   | 3.19   | -0.21  |
| 44     | NRCDR-2 X RN-393         | 2.92   | 7.59*  | 0.77   | 4.93   |
| 45     | RGN-229 X RN-393         | -9.90** | 7.50** | -11.06** | 1.76  |
| SED  |                          | 3.931  | 4.074  | 4.543  | 4.704  |
| CD (5%)|                         | 7.929  | 8.211  | 9.156  | 9.481  |
| CD (1%)|                         | 10.316 | 10.683 | 11.912 | 12.336 |
Table 2 Estimates of heterosis and heterobeltiosis for Number of primary branches per plant under normal (E1) and moisture stress (E2) environments

| S. No. | Crosses                        | Heterosis (%) | Heterobeltiosis (%) |
|-------|--------------------------------|---------------|---------------------|
|       |                                | E<sub>1</sub> | E<sub>2</sub> | E<sub>1</sub> | E<sub>2</sub> |
| 1.    | CS-52 X GM-3                   | 13.62**       | 7.02   | 11.45*     | -1.61    |
| 2.    | CS-52 X PBR-357                | 4.25          | 5.65   | 3.05       | 5.65     |
| 3.    | CS-52 X Vardan                 | 3.79          | 2.2    | 3.01       | -6.45    |
| 4.    | CS-52 X RH-30                  | -2.14         | -0.39  | -8.02*     | -3.76    |
| 5.    | CS-52 X Bio-902                | 27.84**       | 20.16**| 24.43**    | 17.74**  |
| 6.    | CS-52 X Kranti                 | 16.60**       | 6.03   | 15.27**    | -0.81    |
| 7.    | CS-52 X NRCDR-2                | 11.79**       | 6.22   | 11.36*     | 3.23     |
| 8.    | CS-52 X RGN-229                | 1.90          | -6.14  | 1.52       | -13.71** |
| 9.    | CS-52 X RN-393                 | 15.56**       | 7.32   | 12.23**    | 6.45     |
| 10.   | GM-3 X PBR-357                 | 9.45*         | 14.04**| 8.59       | 4.84     |
| 11.   | GM-3 X Vardan                  | 11.97**       | 22.71**| 9.02*      | 22.12**  |
| 12.   | GM-3 X RH-30                   | 6.18          | -8.86  | -2.01      | -18.80** |
| 13.   | GM-3 X Bio-902                 | 12.80**       | 1.35   | 11.90*     | -5.04    |
| 14.   | GM-3 X Kranti                  | 5.51          | 9.43   | 4.69       | 7.41     |
| 15.   | GM-3 X NRCDR-2                 | 20.93**       | 14.93**| 18.18**    | 8.55     |
| 16.   | GM-3 X RGN-229                 | 20.93**       | 25.00**| 18.18**    | 25.00**  |
| 17.   | GM-3 X RN-393                  | 7.17          | 1.77   | 2.16       | -5.74    |
| 18.   | PBR-357 X Vardan               | -2.68         | 3.96   | -4.51      | -4.84    |
| 19.   | PBR-357 X RH-30                | -2.53         | -2.72  | -9.40*     | -6.02    |
| 20.   | PBR-357 X Bio-902              | 12.70**       | -7.82  | 10.94*     | -9.68    |
| 21.   | PBR-357 X Kranti               | 15.63**       | 0.86   | 15.63**    | -5.65    |
| 22.   | PBR-357 X NRCDR-2              | 3.85          | -4.56  | 2.27       | -7.26    |
| 23.   | PBR-357 X RGN-229              | 30.00**       | 3.51   | 28.03**    | -4.84    |
| 24.   | PBR-357 X RN-393               | -0.37         | -7.32  | -4.32      | -8.06    |
| 25.   | Vardan X RH-30                 | 7.80*         | -1.69  | 2.01       | -12.78** |
| 26.   | Vardan X Bio-902               | 9.73*         | 20.72**| 6.02       | 12.61*   |
| 27.   | Vardan X Kranti                | 13.41**       | 18.48**| 11.28*     | 15.74**  |
| 28.   | Vardan X NRCDR-2               | 7.17          | 5.45   | 6.77       | -0.85    |
| 29.   | Vardan X RGN-229               | -0.38         | 24.64**| -0.75      | 24.04**  |
| 30.   | Vardan X RN-393                | -0.515        | 3.11   | -7.19      | -4.92    |
| 31.   | RH-30 X Bio-902                | 14.29**       | 1.59   | 4.70       | -3.76    |
| 32.   | RH-30 X Kranti                 | 4.69          | -0.41  | -2.68      | -9.77**  |
| 33.   | RH-30 X NRCDR-2                | -0.36         | -4.80  | -6.04      | -10.53*  |
| 34.   | RH-30 X RGN-229                | -3.91         | -6.33  | -9.40*     | -16.54** |
| 35.   | RH-30 X RN-393                 | 0.69          | -10.59*| -2.68      | -14.29** |
| 36.   | Bio-902 X Kranti               | 11.11**       | 0.44   | 9.37*      | -4.20    |
| 37.   | Bio-902 X NRCDR-2              | 7.81          | -13.56**| 4.55       | -14.29** |
| 38.   | Bio-902 X RGN-229              | 14.06**       | 21.97**| 10.61*     | 14.29**  |
| 39.   | Bio-902 X RN-393               | 3.42          | -0.41  | -2.16      | -1.64    |
| 40.   | Kranti X NRCDR-2               | 9.23*         | 12.00  | 7.58       | 7.69     |
| 41.   | Kranti X RGN-229               | 8.46*         | 19.81**| 6.82       | 17.59**  |
| 42.   | Kranti X RN-393                | 11.61**       | -5.22  | 7.19       | -10.66*  |
| 43.   | NRCDR-2 X RGN-229              | 21.21**       | -7.69  | 21.21**    | -12.82*  |
| 44.   | NRCDR-2 X RN-393               | 17.34**       | -7.95  | 14.39**    | -9.84    |
| 45.   | RGN-229 X RN-393               | 9.96**        | 2.65   | 7.19       | -4.92    |
| **SED**|                            | 0.166         | 0.181  | 0.191      | 0.209    |
| **CD (5%)**|                         | 0.334         | 0.365  | 0.386      | 0.422    |
| **CD (1%)**|                        | 0.435         | 0.475  | 0.503      | 0.549    |
Table 2: Estimates of heterosis and heterobeltiosis for length of main raceme under normal (E1) and moisture stress (E2) environments

| S. No. | Crosses                        | Heterosis (%) | Heterobeltiosis (%) |
|-------|--------------------------------|---------------|---------------------|
|       |                                | E1            | E2                  | E1                | E2          |
| 1     | CS-52 X GM-3                   | 55.07**       | 22.95*              | 44.38**           | 19.79       |
| 2     | CS-52 X PBR-357                | 43.31**       | 51.69**             | 36.12**           | 49.62**     |
| 3     | CS-52 X Vardan                 | 23.05**       | 11.52               | 13.47*            | 8           |
| 4     | CS-52 X RH-30                  | 23.27**       | 44.96**             | 11.52             | 44.86**     |
| 5     | CS-52 X Bio-902                | 31.26**       | 39.03**             | 22.20**           | 32.42**     |
| 6     | CS-52 X Kranti                 | 24.60**       | 37.83**             | 1.01              | 32.44**     |
| 7     | CS-52 X NRCDR-2                | 27.35**       | 29.96**             | 12.54*            | 26.13**     |
| 8     | CS-52 X RGN-229                | 27.95**       | 24.93**             | 18.32*            | 20.99*      |
| 9     | CS-52 X RN-393                 | 52.92**       | 36.62**             | 32.63*            | 30.70**     |
| 10    | GM-3 X PBR-357                 | 23.85**       | 31.33**             | 21.27**           | 29.69**     |
| 11    | GM-3 X Vardan                  | 33.52**       | 19.77*              | 32.13**           | 19.03       |
| 12    | GM-3 X RH-30                   | 14.57**       | 26.78**             | 11.06             | 23.44*      |
| 13    | GM-3 X Bio-902                 | 35.30**       | 19.48*              | 35.29**           | 16.73       |
| 14    | GM-3 X Kranti                  | -6.87         | 32.36**             | -19.87**          | 30.49**     |
| 15    | GM-3 X NRCDR-2                 | 7.23          | 14.15               | 1.34              | 13.70       |
| 16    | GM-3 X RGN-229                 | 24.76**       | 28.96**             | 23.84**           | 28.17**     |
| 17    | GM-3 X RN-393                 | 10.04**       | 34.91**             | 7.46              | 32.41**     |
| 18    | PBR-357 X Vardan               | 41.38**       | 4.66                | 37.02**           | 2.73        |
| 19    | PBR-357 X RH-30                | 19.29**       | 31.20**             | 13.30*            | 29.33**     |
| 20    | PBR-357 X Bio-902              | 20.98**       | 5.33                | 18.45**           | 1.67        |
| 21    | PBR-357 X Kranti               | 5.77          | 16.90               | -10.59*           | 13.85       |
| 22    | PBR-357 X NRCDR-2              | 11.75*        | 26.76**             | 3.53              | 24.70*      |
| 23    | PBR-357 X RGN-229              | 20.93**       | 35.82**             | 17.55**           | 33.33**     |
| 24    | PBR-357 X RN-393               | 11.23*        | 2.94                | 1.03              | -0.20       |
| 25    | Vardan X RH-30                 | 8.43          | 33.02**             | 6.19              | 28.74**     |
| 26    | Vardan X Bio-902               | 12.65*        | 23.10**             | 11.49             | 21.01*      |
| 27    | Vardan X Kranti                | -13.78**      | 5.55                | -25.16**          | 4.70        |
| 28    | Vardan X NRCDR-2               | 0.69          | 5.95                | -3.89             | 5.71        |
| 29    | Vardan X RGN-229               | 4.32          | 18.06*              | 4.00              | 18.05       |
| 30    | Vardan X RN-393               | 5.89          | 14.51              | -0.98             | 13.07       |
| 31    | RH-30 X Bio-902                | 7.93          | 12.51              | 4.63              | 7.10        |
| 32    | RH-30 X Kranti                 | -7.42         | 33.45**             | -18.17**          | 28.15**     |
| 33    | RH-30 X NRCDR-2                | 44.58**       | 31.43**             | 40.83**           | 27.48**     |
| 34    | RH-30 X RGN-229                | 29.25**       | 26.68**             | 26.19**           | 21.64*      |
| 35    | RH-30 X RN-393                | 8.93          | 17.83*              | 3.91              | 12.66       |
| 36    | Bio-902 X Kranti               | -0.43         | 34.04**             | -14.33**          | 32.82**     |
| 37    | Bio-902 X NRCDR-2              | 5.87          | 34.18**             | 0.06              | 31.60**     |
| 38    | Bio-902 X RGN-229             | 11.30         | 17.77*              | 10.49             | 15.76       |
| 39    | Bio-902 X RN-393             | 4.00          | 36.98**             | -3.69             | 36.36**     |
| 40    | Kranti X NRCDR-2              | -1.32         | 13.33              | -10.71*           | 12.16       |
| 41    | Kranti X RGN-229              | 8.40          | -1.36              | -6.15             | -2.15       |
| 42    | Kranti X RN-393               | -6.21         | 9.26              | -13.44**          | 8.76        |
| 43    | NRCDR-2 X RGN-229             | 20.19**       | 20.64*              | 14.38*            | 20.37*      |
| 44    | NRCDR-2 X RN-393             | 20.11**       | 44.46**             | 17.55**           | 42.33**     |
| 45    | RGN-229 X RN-393             | -4.61         | 26.79**             | -11.05            | 25.20**     |

SED
CD (5%)  5.986  6.157  6.912  7.109
CD (1%)  7.788  8.01  8.993  9.249
Table 2. Estimates of heterosis and heterobeltiosis for siliqua on main raceme under normal (E1) and moisture stress (E2) environments

| S. No. | Crosses                      | Heterosis (%) | Heterobeltiosis (%) |
|--------|------------------------------|---------------|---------------------|
|        |                              | $E_1$         | $E_2$               | $E_1$   | $E_2$   |
| 1.     | CS-52 X GM-3                 | 22.96**       | 36.33**             | 17.47   | 32.82** |
| 2.     | CS-52 X PBR-357              | 32.02**       | 50.97**             | 30.74** | 48.39** |
| 3.     | CS-52 X Vardan               | 36.50**       | 7.79                | 30.64** | 3.08    |
| 4.     | CS-52 X RH-30                | 29.72**       | 50.71**             | 29.59** | 44.89** |
| 5.     | CS-52 X Bio-902              | 23.08**       | 40.95**             | 17.86   | 31.69** |
| 6.     | CS-52 X Kranti               | 24.79**       | 43.17**             | 17.98*  | 35.18** |
| 7.     | CS-52 X NRCDR-2              | 37.15**       | 34.70**             | 33.78** | 26.79** |
| 8.     | CS-52 X RGN-229              | 12.85         | 31.73**             | 1.02    | 29.18** |
| 9.     | CS-52 X RN-393               | 50.69**       | 42.87**             | 48.31** | 35.08** |
| 10.    | GM-3 X PBR-357               | 31.99**       | 35.12**             | 24.93** | 33.91** |
| 11.    | GM-3 X Vardan                | 18.54*        | 22.11*              | 18.31*  | 19.80*  |
| 12.    | GM-3 X RH-30                 | 16.68*        | 30.73**             | 11.58   | 22.58*  |
| 13.    | GM-3 X Bio-902               | 21.18**       | 18.75*              | 20.88*  | 13.75   |
| 14.    | GM-3 X Kranti                | 25.54**       | 29.27**             | 24.18** | 25.17** |
| 15.    | GM-3 X NRCDR-2               | 9.97          | 18.14*              | 7.64    | 14.04   |
| 16.    | GM-3 X RGN-229               | 13.82         | 31.96**             | 6.29    | 31.09** |
| 17.    | GM-3 X RN-393                | 47.96**       | 26.34**             | 43.54** | 22.51** |
| 18.    | PBR-357 X Vardan             | 29.47**       | -0.54               | 22.76*  | -3.28   |
| 19.    | PBR-357 X RH-30              | 43.49**       | 38.10**             | 41.95** | 30.59** |
| 20.    | PBR-357 X Bio-902            | 35.52**       | 5.93                | 28.56** | 0.61    |
| 21.    | PBR-357 X Kranti             | 30.38**       | 14.18               | 22.14*  | 9.60    |
| 22.    | PBR-357 X NRCDR-2            | 19.94*        | 25.40**             | 15.88   | 20.00** |
| 23.    | PBR-357 X RGN-229            | 13.34         | 44.37**             | 0.57    | 44.03** |
| 24.    | PBR-357 X RN-393             | 35.29**       | 5.87                | 31.87** | 1.77    |
| 25.    | Vardan X RH-30               | 23.24**       | 39.22**             | 18.06*  | 28.23** |
| 26.    | Vardan X Bio-902             | 12.68         | 23.07**             | 12.62   | 20.10*  |
| 27.    | Vardan X Kranti              | 18.44*        | 5.44                | 16.93   | 4.04    |
| 28.    | Vardan X NRCDR-2             | 23.36**       | 7.76                | 20.98*  | 5.98    |
| 29.    | Vardan X RGN-229             | 7.26          | 19.05*              | -0.01   | 16.04   |
| 30.    | Vardan X RN-393              | 11.18         | 9.90                | 8.06    | 8.59    |
| 31.    | RH-30 X Bio-902              | 11.01         | 17.25               | 6.40    | 5.62    |
| 32.    | RH-30 X Kranti               | 30.96**       | 45.61**             | 23.94** | 32.48** |
| 33.    | RH-30 X NRCDR-2              | 59.58**       | 28.20**             | 55.82** | 16.31   |
| 34.    | RH-30 X RGN-229              | 15.11*        | 29.02**             | 3.13    | 21.73*  |
| 35.    | RH-30 X RN-393               | 13.64         | 25.56**             | 11.96   | 14.39   |
| 36.    | Bio-902 X Kranti             | 17.13*        | 35.93**             | 15.58   | 34.43** |
| 37.    | Bio-902 X NRCDR-2            | 32.52**       | 29.35**             | 30.03** | 28.33** |
| 38.    | Bio-902 X RGN-229            | 0.26          | 12.88               | -6.58   | 7.45    |
| 39.    | Bio-902 X RN-393             | 23.99**       | 35.81**             | 20.58*  | 34.11** |
| 40.    | Kranti X NRCDR-2             | 29.45**       | 13.49               | 25.37** | 13.12   |
| 41.    | Kranti X RGN-229             | 16.28**       | 1.38                | 9.71    | -2.03   |
| 42.    | Kranti X RN-393              | 22.69**       | 10.04               | 17.78*  | 9.88    |
| 43.    | NRCDR-2 X RGN-229            | 1.69          | 10.15               | -6.90   | 5.65    |
| 44.    | NRCDR-2 X RN-393             | 29.67**       | 38.48**             | 28.50** | 37.83** |
| 45.    | RGN-229 X RN-393             | 1.83          | 28.48**             | -7.54   | 23.78** |

SED         2.920   2.563   3.371   2.96
CD (5%)     5.885   5.166   6.795   5.965
CD (1%)     7.656   6.721   8.841   7.761

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Table 2 Estimates of heterosis and heterobeltiosis for number of seeds per siliqua under normal (E1) and moisture stress (E2) environments

| S. No. | Crosses                      | Heterosis (%) | Heterobeltiosis (%) |
|-------|------------------------------|---------------|---------------------|
|       |                              | E₁  | E₂                  | E₁  | E₂              |
| 1.    | CS-52 X GM-3                 | 4.65 | 14.07*              | -1.72 | 7.99          |
| 2.    | CS-52 X PBR-357              | 3.00 | 8.02               | 2.67  | 7.21          |
| 3.    | CS-52 X Vardan               | 3.18 | 10.36              | 2.54  | 6.68          |
| 4.    | CS-52 X RH-30                | 9.41 | 17.14**            | 4.01  | 16.27*        |
| 5.    | CS-52 X Bio-902              | -0.88 | 6.67               | -4.16 | 5.78          |
| 6.    | CS-52 X Kranti               | 5.06 | 5.36               | 3.95  | -0.23         |
| 7.    | CS-52 X NRCDR-2              | 6.91 | 2.49               | 2.67  | -2.69         |
| 8.    | CS-52 X RGN-229              | 16.19* | 14.63*              | 13.36 | 14.29         |
| 9.    | GM-3 X PBR-357               | 7.02 | 12.17              | 0.80  | 6.94          |
| 10.   | GM-3 X Vardan                | 11.24 | 12.43              | 5.07  | 3.08          |
| 11.   | GM-3 X RH-30                 | 1.04 | -1.94              | -0.26 | -6.51         |
| 12.   | GM-3 X Bio-902               | 10.95 | 18.12**            | 7.65  | 12.72         |
| 13.   | GM-3 X Kranti                | 9.74 | 12.49              | 2.04  | 1.16          |
| 14.   | GM-3 X NRCDR-2               | 0.17 | -2.35              | -9.42 | -11.96        |
| 15.   | GM-3 X RGN-229               | 22.49** | 23.97**              | 17.77* | 17.03*        |
| 16.   | GM-3 X RN-393                | 11.70 | 17.26*            | 5.69  | 10.40         |
| 17.   | PBR-357 X Vardan             | 9.59 | 7.42               | 9.26  | 3.08          |
| 18.   | PBR-357 X RH-30              | 10.10 | 6.92               | 4.99  | 6.92          |
| 19.   | PBR-357 X Bio-902            | 8.92 | 10.01              | 5.64  | 10.91         |
| 20.   | PBR-357 X Kranti             | -1.26 | -7.17             | -2.62 | -12.72        |
| 21.   | PBR-357 X NRCDR-2            | -0.12 | 2.84              | -4.38 | -3.05         |
| 22.   | PBR-357 X RGN-229            | 10.17 | 3.59               | 7.84  | 2.51          |
| 23.   | PBR-357 X RN-393             | 7.37 | 9.75               | 6.85  | 8.30          |
| 24.   | Vardan X RH-30               | 5.25 | 5.52               | 0.65  | 1.26          |
| 25.   | Vardan X Bio-902             | 9.23 | 12.04              | 6.25  | 7.43          |
| 26.   | Vardan X Kranti              | -8.80 | -9.19            | -10.31 | -11.10       |
| 27.   | Vardan X NRCDR-2             | 0.86 | 2.92               | -3.72 | 1.03          |
| 28.   | Vardan X RGN-229             | 11.84 | 1.77              | 9.78  | -1.34         |
| 29.   | Vardan X RN-393              | 4.64 | 8.77               | 4.45  | 5.74          |
| 30.   | RH-30 X Bio-902              | 25.97** | 19.13**            | 23.78** | 19.03*       |
| 31.   | RH-30 X Kranti               | 2.75 | 1.95               | -3.30 | -4.14         |
| 32.   | RH-30 X NRCDR-2              | 11.26 | 11.69              | 1.80  | 5.30          |
| 33.   | RH-30 X RGN-229              | 2.07 | -0.56              | -0.62 | -1.60         |
| 34.   | RH-30 X RN-393               | 12.10 | 9.63               | 7.39  | 8.18          |
| 35.   | Bio-902 X Kranti             | 11.75 | 3.95               | 6.94  | -2.34         |
| 36.   | Bio-902 X NRCDR-2            | 10.34 | -3.20              | 2.60  | -8.81         |
| 37.   | Bio-902 X RGN-229            | 1.65 | 1.31               | 0.70  | 0.17          |
| 38.   | Bio-902 X RN-393             | -0.08 | 4.11               | -2.64 | 2.64          |
| 39.   | Kranti X NRCDR-2             | -9.25 | -11.93*           | -11.95 | -12.18       |
| 40.   | Kranti X RGN-229             | 7.80 | 9.69               | 4.10  | 4.16          |
| 41.   | Kranti X RN-393              | 16.12** | 5.59              | 13.99* | 0.54          |
| 42.   | NRCDR-2 X RGN-229            | 5.93 | 11.23              | -0.64 | 5.92          |
| 43.   | NRCDR-2 X RN-393             | -1.73 | -3.46            | -6.34 | -7.83         |
| 44.   | RGN-229 X RN-393             | 25.03** | 11.31            | 22.96** | 10.99       |

| SED  | 0.781 | 0.733 | 0.902 | 0.846 |
| CD (5%) | 1.575 | 1.478 | 1.818 | 1.706 |
| CD (1%) | 2.049 | 1.923 | 2.366 | 2.22  |
Table 2 Estimates of heterosis and heterobeltiosis for 1000-seed weight under normal (E1) and moisture stress (E2) environments

| S. No. | Crosses       | Heterosis (%) | Heterobeltiosis (%) |
|-------|---------------|---------------|---------------------|
|       | E₁  | E₂  | E₁  | E₂  |
| 1.    | CS-52 X GM-3 | 9.19 | 6.46 | 7.35 | 4.47 |
| 2.    | CS-52 X PBR-357 | -0.17 | -0.29 | -7.06 | -6.09 |
| 3.    | CS-52 X Vardan | 6.87 | 4.1  | 6.15 | 3.03 |
| 4.    | CS-52 X RH-30 | 4.59 | 9.82 | 1.93 | 9.19 |
| 5.    | CS-52 X Bio-902 | 0.96 | 1.87 | -7.38 | -4.9 |
| 6.    | CS-52 X Kranti | 7.53 | 5.85 | 3.99 | 3.88 |
| 7.    | CS-52 X NRC DR-2 | 8.48 | 13.76* | 6.65 | 12.01 |
| 8.    | CS-52 X RGN-229 | 5.62 | 7.28 | 1.33 | 3.07 |
| 9.    | GM-3 X PBR-357 | -0.23 | 2.78 | -5.62 | -1.44 |
| 10.   | GM-3 X RN-393 | 1.27 | 4.80 | -4.08 | -1.30 |
| 11.   | GM-3 X Vardan | 13.48** | 12.67* | 12.32* | 11.71 |
| 12.   | GM-3 X RH-30 | 8.61 | 10.39 | 7.63 | 8.95 |
| 13.   | GM-3 X Bio-902 | 5.29 | 3.46 | -1.88 | -1.68 |
| 14.   | GM-3 X Kranti | 3.48 | 2.54 | 1.76 | 2.54 |
| 15.   | GM-3 X NRC DR-2 | 2.66 | -6.17 | 2.66 | -6.49 |
| 16.   | GM-3 X RGN-229 | 5.39 | -4.67 | 2.80 | -6.71 |
| 17.   | GM-3 X RN-393 | 0.77 | 1.14 | -2.98 | -3.01 |
| 18.   | PBR-357 X Vardan | 3.53 | -8.24 | -3.00 | -12.73* |
| 19.   | PBR-357 X RH-30 | 4.62 | -6.83 | -0.19 | -11.77 |
| 20.   | PBR-357 X Bio-902 | -4.12 | -14.10** | -5.63 | -14.91* |
| 21.   | PBR-357 X Kranti | -1.62 | 2.43 | -5.43 | -1.78 |
| 22.   | PBR-357 X NRC DR-2 | -3.60 | -5.91 | -8.81 | -10.06 |
| 23.   | PBR-357 X RGN-229 | -2.80 | -4.89 | -5.81 | -6.84 |
| 24.   | PBR-357 X RN-393 | 3.65 | -2.53 | 1.69 | -2.53 |
| 25.   | Vardan X RH-30 | 11.88* | 6.78 | 9.77 | 6.30 |
| 26.   | Vardan X Bio-902 | 4.52 | -0.53 | -3.51 | -6.25 |
| 27.   | Vardan X Kranti | 11.89* | 6.36 | 8.94 | 5.44 |
| 28.   | Vardan X NRC DR-2 | 13.83** | 10.72 | 12.68* | 10.14 |
| 29.   | Vardan X RGN-229 | 9.00 | 5.55 | 5.26 | 2.43 |
| 30.   | Vardan X RN-393 | 8.43 | 3.13 | 3.37 | -1.92 |
| 31.   | RH-30 X Bio-902 | -0.29 | -3.61 | -6.29 | -9.54 |
| 32.   | RH-30 X Kranti | 13.14** | 10.54 | 12.25* | 9.10 |
| 33.   | RH-30 X NRC DR-2 | 12.91** | 12.36* | 11.90* | 11.26 |
| 34.   | RH-30 X RGN-229 | 11.03* | -0.63 | 9.25 | -4.00 |
| 35.   | RH-30 X RN-393 | 2.70 | -3.36 | -0.26 | -8.49 |
| 36.   | Bio-902 X Kranti | 5.88 | 4.31 | 0.24 | -0.87 |
| 37.   | Bio-902 X NRC DR-2 | 10.16* | 6.49 | 2.66 | 0.87 |
| 38.   | Bio-902 X RGN-229 | 6.88 | 4.43 | 2.00 | 1.34 |
| 39.   | Bio-902 X RN-393 | 0.75 | -3.46 | -2.60 | -4.37 |
| 40.   | Kranti X NRC DR-2 | 12.98** | 5.42 | 11.10* | 5.07 |
| 41.   | Kranti X RGN-229 | 8.83 | 3.06 | 7.92 | 0.86 |
| 42.   | Kranti X RN-393 | 7.81 | 3.93 | 5.51 | -0.34 |
| 43.   | NRC DR-2 X RGN-229 | 9.97* | 3.84 | 7.26 | 1.28 |
| 44.   | NRC DR-2 X RN-393 | 6.70 | 1.04 | 2.72 | -3.42 |
| 45.   | RGN-229 X RN-393 | 0.03 | -6.15 | -1.30 | -8.08 |
|       | SED | 0.222 | 0.249 | 0.256 | 0.288 |
|       | CD (5%) | 0.447 | 0.503 | 0.516 | 0.581 |
|       | CD (1%) | 0.582 | 0.654 | 0.672 | 0.756 |
Table. 2 Estimates of heterosis and heterobeltiosis for seed yield per plant under normal (E1) and moisture stress (E2) environments

| S. No. | Crosses                  | Heterosis (%) | Heterobeltiosis (%) |
|--------|--------------------------|---------------|---------------------|
|        |                          | E1    | E2    | E1    | E2    |
| 1.     | CS-52 X GM-3             | 42.61**| 49.25**| 35.11**| 37.47**|
| 2.     | CS-52 X PBR-357          | 27.83**| 48.72**| 27.08* | 47.97**|
| 3.     | CS-52 X Vardan           | 39.61**| 45.51**| 33.76**| 36.81**|
| 4.     | CS-52 X RH-30            | 37.37**| 41.04**| 33.36**| 41.00**|
| 5.     | CS-52 X Bio-902          | 28.77**| 35.73**| 24.68* | 27.64* |
| 6.     | CS-52 X Kranti           | 25.99**| 29.41* | 21.89* | 20.54* |
| 7.     | CS-52 X NRCDR-2          | 39.63**| 61.80**| 32.53**| 48.63**|
| 8.     | CS-52 X RGN-229          | 68.81**| 70.30**| 59.91**| 55.36**|
| 9.     | GM-3 X PBR-357           | 12.77  | 21.21  | 7.44   | 11.13  |
| 10.    | GM-3 X Vardan            | 48.94**| 4.26   | 47.20**| 2.00   |
| 11.    | GM-3 X RH-30             | 14.37  | -1.13  | 5.37   | -8.91  |
| 12.    | GM-3 X Bio-902           | 58.10**| 40.69**| 54.60**| 37.61**|
| 13.    | GM-3 X Kranti            | 15.92  | 16.11  | 13.44  | 14.72  |
| 14.    | GM-3 X NRCDR-2           | 7.56   | 22.35* | 7.36   | 22.00  |
| 15.    | GM-3 X RGN-229           | 45.03**| 64.24**| 45.01**| 62.53**|
| 16.    | GM-3 X RN-393            | 68.47**| 72.04**| 63.95**| 71.92**|
| 17.    | PBR-357 X Vardan         | 51.48**| 75.97**| 45.94**| 64.67**|
| 18.    | PBR-357 X RH-30          | 36.07**| 62.96**| 31.36**| 62.11**|
| 19.    | PBR-357 X Bio-902        | 17.31  | 37.56**| 14.22  | 28.76* |
| 20.    | PBR-357 X Kranti         | 85.20**| 97.50**| 80.19**| 83.10**|
| 21.    | PBR-357 X NRCDR-2        | 61.61**| 68.85**| 54.24**| 54.41**|
| 22.    | PBR-357 X RGN-229        | 40.73**| 41.81**| 34.05**| 28.79* |
| 23.    | PBR-357 X RN-393         | 42.65**| 56.31**| 39.56**| 43.22**|
| 24.    | Vardan X RH-30           | 92.78**| 72.49**| 79.55**| 62.22**|
| 25.    | Vardan X Bio-902         | 78.82**| 73.94**| 76.89**| 73.90**|
| 26.    | Vardan X Kranti          | 27.57**| 32.45**| 26.30* | 31.12* |
| 27.    | Vardan X NRCDR-2         | 46.59**| 50.42**| 45.16**| 46.74**|
| 28.    | Vardan X RGN-229         | 42.79**| 64.80**| 41.10**| 59.57**|
| 29.    | Vardan X RN-393          | 83.05**| 88.49**| 80.20**| 84.28**|
| 30.    | RH-30 X Bio-902          | 41.91**| 60.95**| 33.52**| 51.39**|
| 31.    | RH-30 X Kranti           | 46.67**| 53.52**| 37.90**| 43.03**|
| 32.    | RH-30 X NRCDR-2          | 67.69**| 50.34**| 54.77**| 38.14**|
| 33.    | RH-30 X RGN-229          | 41.93**| 62.74**| 30.74**| 48.50**|
| 34.    | RH-30 X RN-393           | 31.15**| 35.35**| 23.97* | 24.62* |
| 35.    | Bio-902 X Kranti         | 30.04**| 27.98**| 29.93**| 26.67**|
| 36.    | Bio-902 X NRCDR-2        | 86.96**| 79.20**| 83.15**| 74.78**|
| 37.    | Bio-902 X RGN-229        | 65.87**| 80.31**| 62.16**| 74.55**|
| 38.    | Bio-902 X RN-393         | 72.60**| 90.03**| 71.75**| 85.74**|
| 39.    | Kranti X NRCDR-2         | 65.63**| 61.56**| 62.38**| 59.17**|
| 40.    | Kranti X RGN-229         | 54.73**| 56.62**| 51.39**| 53.15**|
| 41.    | Kranti X RN-393          | 48.12**| 27.70**| 47.27**| 26.09* |
| 42.    | NRCDR-2 X RGN-229        | 30.30**| 47.36**| 30.03**| 46.24**|
| 43.    | NRCDR-2 X RN-393         | 75.06**| 57.27**| 70.67**| 56.92**|
| 44.    | RGN-229 X RN-393         | 24.77**| 26.73**| 21.40**| 25.49**|
|        | SED                      | 0.764 | 0.766 | 0.882 | 0.896 |
|        | CD (5%)                  | 1.540 | 1.565 | 1.778 | 1.807 |
|        | CD (1%)                  | 2.004 | 2.036 | 2.314 | 2.351 |
Table 2 Estimates of heterosis and heterobeltiosis for oil content under normal (E1) and moisture stress (E2) environments

| S. No. | Crosses                          | Heterosis (%) | Heterobeltiosis (%) |
|-------|---------------------------------|--------------|--------------------|
|       |                                 | E1           | E2                 | E1         | E2         |
| 1.    | CS-52 X GM-3                    | 0.96         | -0.33              | 0.01       | -2.61      |
| 2.    | CS-52 X PBR-357                 | -1.57        | -0.11              | 3.73**     | 3.28      |
| 3.    | CS-52 X Vardan                  | 1.66         | 3.24               | 0.72       | 2.07       |
| 4.    | CS-52 X RH-30                   | -1.11        | 0.14               | 4.41*      | -2.01     |
| 5.    | CS-52 X Bio-902                 | 1.11         | 0.36               | 0.16       | -0.93     |
| 6.    | CS-52 X Kranti                  | 1.12         | 2.63               | 0.13       | 2.51       |
| 7.    | CS-52 X NRCDR-2                 | -0.07        | 0.26               | -2.31      | -1.61     |
| 8.    | CS-52 X RGN-229                 | -0.61        | 0.71               | -2.71      | -0.29     |
| 9.    | CS-52 X RN-393                  | 0.66         | 1.07               | -0.80      | -0.15     |
| 10.   | GM-3 X PBR-357                  | -3.20*       | -3.63*             | 4.43*      | 4.52*      |
| 11.   | GM-3 X Vardan                   | 2.90         | -1.15              | 2.89       | 2.32      |
| 12.   | GM-3 X RH-30                    | -2.10        | 0.12               | 4.49*      | -0.02     |
| 13.   | GM-3 X Bio-902                  | 1.23         | -1.52              | 0.91       | -2.54     |
| 14.   | GM-3 X Kranti                   | -0.11        | 2.65               | 0.14       | 0.18      |
| 15.   | GM-3 X NRCDR-2                  | -0.97        | -2.33              | 2.27       | -2.76     |
| 16.   | GM-3 X RGN-229                  | -1.30        | -1.21              | -2.48      | -2.51     |
| 17.   | GM-3 X RN-393                   | -0.04        | 0.56               | -0.55      | -0.55     |
| 18.   | PBR-357 X Vardan                | 1.08         | 2.18               | -0.22      | 0.05      |
| 19.   | PBR-357 X RH-30                 | -3.41*       | -1.25              | 4.57**     | -2.31     |
| 20.   | PBR-357 X Bio-902               | -0.88        | -2.03              | -1.83      | 3.93*     |
| 21.   | PBR-357 X Kranti                | -0.87        | 3.17               | -2.10      | -0.22     |
| 22.   | PBR-357 X NRCDR-2               | -2.48        | -0.74              | -2.53      | -2.08     |
| 23.   | PBR-357 X RGN-229               | -2.44        | -2.47              | -2.52      | 4.64*     |
| 24.   | PBR-357 X RN-393                | -0.48        | -3.69*             | 1.24       | 5.63**    |
| 25.   | Vardan X RH-30                  | -3.25*       | 1.84               | 5.62**     | 0.78      |
| 26.   | Vardan X Bio-902                | 0.42         | -0.68              | 0.08       | -0.83     |
| 27.   | Vardan X Kranti                 | 0.22         | -1.55              | 0.17       | -2.78     |
| 28.   | Vardan X NRCDR-2                | -0.86        | -0.56              | -2.19      | -1.30     |
| 29.   | Vardan X RGN-229                | -0.06        | -0.42              | -1.27      | -0.56     |
| 30.   | Vardan X RN-393                 | -0.43        | -3.07              | -0.96      | -3.15     |
| 31.   | RH-30 X Bio-902                 | -4.41**      | -1.57              | 6.45**     | 2.44      |
| 32.   | RH-30 X Kranti                  | -1.48        | 1.88               | 3.86*      | -0.42     |
| 33.   | RH-30 X NRCDR-2                 | -1.36        | 0.79               | -2.50      | 0.50      |
| 34.   | RH-30 X RGN-229                 | -319*        | 3.64*              | -4.42*     | 2.42      |
| 35.   | RH-30 X RN-393                  | -2.50        | 0.45               | -4.40**    | -0.51     |
| 36.   | Bio-902 X Kranti                | 1.82         | 1.34               | 1.52       | -0.08     |
| 37.   | Bio-902 X NRCDR-2               | 1.52         | 0.03               | 0.50       | -0.56     |
| 38.   | Bio-902 X RGN-229               | -1.07        | 1.69               | 1.94       | 1.39      |
| 39.   | Bio-902 X RN-393                | -0.44        | -2.94              | -0.63      | -3.02     |
| 40.   | Kranti X NRCDR-2                | -1.00        | 0.21               | -2.27      | -1.78     |
| 41.   | Kranti X RGN-229                | -0.59        | 1.24               | 1.75       | 0.11      |
| 42.   | Kranti X RN-393                 | 0.05         | 1.58               | -0.43      | 0.23      |
| 43.   | NRCDR-2 X RGN-229               | -1.97        | -0.35              | -2.10      | -1.24     |
| 44.   | NRCDR-2 X RN-393                | 1.56         | 0.77               | 0.73       | 0.09      |
| 45.   | RGN-229 X RN-393                | -1.17        | 1.20               | -1.85      | 0.98      |

**SED**: 0.604 0.657 0.697 0.758
**CD (5%)**: 1.218 1.324 1.406 1.529
**CD (1%)**: 1.584 1.723 1.830 1.989
**Table 3** Best three heterotic and heterobeltiotic crosses (F1) for seed yield/plant along with their SCA effects and per se performance in normal (E1) and moisture stress (E2) environments

| Environments | Heterotic Crosses   | Heterosis   | SCA effect | per se performance (g) | Heterobeltiotic Crosses | Heterobeltiosis | SCA effect | per se performance |
|--------------|---------------------|-------------|------------|-------------------------|--------------------------|------------------|------------|-------------------|
| **E1**       | Vardan x RH-30      | 92.78**     | 3.86**     | 15.57                   | Bio-902 x NRCDR-2        | 83.15**          | 3.42**     | 16.19             |
|              | Bio-902 x NRCDR-2   | 86.96**     | 3.42**     | 16.19                   | Vardan x RN-393          | 80.20**          | 2.61**     | 15.62             |
|              | PBR-357 x Kranti    | 85.20**     | 4.37**     | 15.31                   | PBR-357 x Kranti         | 80.19**          | 4.37**     | 15.31             |
| **E2**       | PBR-357 x Kranti    | 97.50**     | 3.87**     | 13.43                   | Bio-902 x RN-393         | 85.74**          | 2.81**     | 13.98             |
|              | Bio-902 x RN-393    | 90.03**     | 2.81**     | 13.98                   | Vardan x RN-393          | 84.28**          | 2.85**     | 13.87             |
|              | Vardan x RN-393     | 88.49**     | 2.85**     | 13.87                   | PBR-357 x Kranti         | 83.10**          | 3.87**     | 13.43             |
Dixit et al., (2005) reported that these crosses showing heterosis and heterobeltiosis for seed yield per plant possessed significant and positive SCA effects. Similar results of significant correlation between heterosis for seed yield and mean performance of the crosses were reported by Ramech (2012) and Aher et al., (2009) found that the promising hybrid also had high per se performance and significant desirable SCA effects for various characters. The crosses PBR-357 x Kranti showed high heterotic and heterobeltiotic crosses under both the environments.

From data of heterosis and heterobeltiosis, it was observed that crosses with high magnitude of heterosis had higher magnitude of SCA effects and better per se performance. Hence selection of superior crosses for development of hybrids should necessarily base not only on the magnitude of heterosis, but also high mean performance and high SCA effects.

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