Half Diallel Analysis for Estimation of Heterosis for Phonological Traits in Linseed (*Linum usitatissimum* L.)

Divya Mahto, P. K Singh and Shailesh Marker

1Department of Genetics & Plant Breeding, Sam Higginbottom University of Agriculture, Technology and Sciences, Allahabad - 211007 (U.P.), India
2Department of Plant Breeding and Genetics, Bihar Agricultural University Sabour, Bhagalpur (Bihar), India

*Corresponding author

**Abstract**

The research consisted of eight parents of linseed which were crossed as per half diallel analysis (Griffing 1956 Model 1 and Method 2) in Rabi 2010-11 to generate 28 crosses (excluding reciprocals). These 28 crosses were assessing along with eight parents and three checks viz: T-397, Neelum and Allahabad Local in RBD having three replications during 2011-12 at the Field Experimentation Centre of Department of Genetics and Plant Breeding, Sam Higginbottom University of Agriculture, Technology and Sciences, Allahabad. The data were recorded on ten characters to study the heterosis. The significant mean sum of squares for all the ten characters indicated the presence of a considerable amount of variability. **Per se** performance for seed yield and its components depicted that cross M-42(169) × POLF-19(1765) was found to be best. Estimate of heterosis (ha) showed that the highest average Heterosis, heterobeltiosis and economic heterosis for seed yield plant was observed by cross PbD2-42(2789) X GS-129(1018).

**Keywords**

Heterosis, Combining ability, Seed Yield and Linseed (*Linum usitatissimum*L.)

**Introduction**

Linseed (*Linum usitatissimum* L.) is an annual self-pollinated diploid (2x=2n=30) oilseed crop belonging to *Linaceae* family and it as an earliest domesticated and economically important industrial non edible oilseed crop which is being cultivated for seed and its fiber since centuries. It is also known as ‘Alsi’ or ‘Tisi’, and mainly cultivated for fibre (Flax fibre) and seed oil (Linseed) or both (dual purpose linseed), essential poly unsaturated fatty acids such as alpha-linolenic acid and rich supply of soluble dietary fiber. Flaxseed oil is used as an industrial drying oil due to its high linolenic acid content Omega-3 fatty.
acids lower levels of triglycerides in the blood, thereby reducing heart disease, and also show promise in the fighting against Inflammatory diseases such as rheumatoid arthritis. The average seed yield of linseed in India is 403 Kg/ha which is comparably very low in comparison with world average seed yield that is 943 Kg/h.

In India, linseed occupied 3.59 lakh hectare area with 1.46 lakh tonnes production and productivity of 408kg/ha in 2011-12 (FAOSTAT, 2012). The low seed yield is chiefly due to limited resources available to poor farmers along with non-availability of high-yielding cultivars.

So, the development of high-yielding varieties/lines is needed to compete with other linseed growing countries. Such lines/varieties can easily be developed through suitable hybridization and selection programmes to isolate superior segregants.

Combining ability provides an important tool for selection of desirable parents and to get required information regarding the nature of gene action controlling desirable trait degree of heterosis provides a basis for genetic diversity and guideline to the choice of desirable parents for developing superior F1 hybrids so as to exploit hybrid vigor and for building gene pool for exploitation in population improvement.

Exploitation of heterosis in linseed in the form of hybrid varieties is a breakthrough in the field of linseed improvement (Pali and Mehta, 2014). Development of better hybrids using stable high yielding lines shall increase the yield of this crop.

In order to achieve high yielding cross combination, it is essential to evaluate available promising diverse lines in their hybrid combinations for yield and its components. Keeping the above facts in mind, the present investigation was carried out to study the extent of heterosis in 28 F1 hybrid over better-parent and standard variety in a half diallel cross set of 8 diverse parents.

This study reveals good scope for isolating suitable parents for hybrid development and to select potent transgressive segregants which can be further evaluated to increase the yield potential.

**Materials and Methods**

The details of the materials and methods adopted in the present study entitled “Half diallel analysis for estimation of heterosis for phenological traits in linseed (Linum usitatissimum L.)” was carried out to derived informations on heterosis in linseed during Rabi 2011-12 at the Field Experimentation Centre of the Deptt. of Genetics and Plant Breeding, Allahabad School of Agriculture, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS) formerly Allahabad Agricultural Institute Allahabad (U.P)

The experimental materials consisted of 8 parents which were crossed as per diallel analysis (Griffing 1956 Model 1 and Method 2) in Rabi 2010-11 to generate 28 crosses (excluding reciprocals). These 28 crosses were evaluated along with 8 parents and 3 checks viz: T-397, Neelum and Allahabad Local so, total experimental material consisted of 39 entries (8 parents + 28 crosses + 3 checks), planted in a Randomized Block design and Observations for the ten characters were recorded on five randomly selected plants for all the traits except for days to 50% flowering and days to maturity, where the observations were recorded on plot basis. The estimation of heterosis, heterobeltiosis and standard heterosis are presented under following heads:
**Estimation of Heterosis**

Heterosis is expressed as percent deviation from the mid parent. In the present experiment heterosis was estimated for 18 hybrids for the 10 characters studies, (Turner 1953).

\[
\text{ha} \ (% \) = \left( \frac{F_1 - MP}{MP} \right) \times 100
\]

Testing the significance, critical difference

\[C.\ D.\ (\text{heterosis}) = (F_1 - MP) \times t_{0.05}\]

Where,

- \( F_1 \) = mean of F1
- \( MP \) = mean of parents of respective F1
- \( (F_1 - MP) = \sqrt{(2MS_e / r)} \)

**Estimation of heterobeltiosis**

Heterobeltiosis is expressed as percent deviation towards desirable side i.e may be increase or decrease in performance over better parents.

\[
\text{hb} \ (% \) = \left( \frac{F_1 - BP}{BP} \right) \times 100
\]

Its significance was tested using critical difference i.e. C. D.

\[\text{CD (BP)} = SE \left( F_1 - BP \right) \times t_{0.05}\]

Where,

- \( BP \) = mean of the desirable better parent
- \( SE \left( F_1 - BP \right) = \sqrt{(2MS_e / r)} \)

**Estimation of standard heterosis**

Standard heterosis was expressed as percentage increase or decrease towards desirable side observed in F1 over standard check.

\[
\text{hc} \ (% \) = \left( \frac{F_1 - SC}{SC} \right) \times 100
\]

Critical difference was applied for testing is significance

\[\text{CD (SH= SE)} \left( F_1 - SC \right) \times t_{0.05}\]

Where,

- \( SC \) = mean of high yielding standard check
- \( SE \left( F_1 - SC \right) = \sqrt{(2MS_e / r)} \)

**Results and Discussion**

The mean value for ten characters of F1 hybrid and parents were compared. Magnitude of heterosis, heterobeltiosis and economic heterosis for different quantitative traits expressed as percentage increase or decrease are presented in Table -1 and Table -2 and described character wise as under:

**Analysis of variance**

The mean sum of squares for 10 characters is presented in Table 1.1. The mean sum of squares due to treatments, parents, hybrids and parents V/s hybrids were significant for all the characters except for days to 50% flowering due to parents V/s hybrids. The analysis of variance revealed the presence of significance amount of variability among parents, their crosses (F1) and among parents V/s crosses (F1) for all the characters studied.
This suggested that the parental lines selected were quite variable, considerable amount of variability existed among the hybrids and presence of overall heterosis for most of the characters under study was present.

Similar trends for variance and its components were also reported by Rai and Das (1974), Govind and Murty (1979), Kumar et al., (1980), Patil and Chopde (1983), Singh and Sindhu(1986), Thakur et al., (1986), Dakhore et al., (1987), Singh et al., (1987), Goray et al., (1990), Mishra and Rai (1993), Saraswat et al., (1993), Verma et al., (1993), Pillai et al., (1995), Mishra and Rai (1996), Verma and Mahta (1996), Yadav (1997), Bhateria et al., (2001), Kumar et al., (2002), Ratnaparkhi et al., (2004), Sharma et al., (2005), Bhateria et al., (2006), Sood et al., (2006), Pant et al., (2007) and Pant et al., (2008) in linseed.

Mean performance of parents and their hybrids

The mean values, range, grand mean (GM), standard error of mean (SEm), critical difference (CD) of parents and their crosses in F1 generation along with check for all the characters are presented in Table 4.2.

Days to 50 percent flowering (Table 1.2)

The days to 50 per cent flowering varied among hybrids from 82.00 days (FRW-6(973) × PbD2-42(2789)) to 98.67 days (FRW-6(973) × FRW-6(973)) in linseed.

Days to maturity (Table 1.2)

The data revealed that days to maturity ranged among hybrids from 140.00 days (FRW-6(973) × PbD2-42(2789)) to 151.0 days (M-42(169) × FRW-6(973)), among parents 133.00 days (POLF-19(1765)) to 148.00 days (C91538(456)) and among checks 128.33 days (T-397) to 135.0 days (Neelum).

The hybrid FRW-6(973) × PbD2-42(2789) (140) was found statistically at par with M-42(169) × POLF-19(1765) (141.0), M-42(169) × PbD2-42(2789) (140.66), FRW-6(973) × C91538(456) (142.0), FRW-6(973) × POLF19(1765) (141.67), FRW-6(973) × PbD2-42(2789) (140), FRW-6(973) × GS-234(1703) (142.33) and FRW-6(973) × GS-129(1018) (140).

Plant height (cm) (Table 1.2)

The plant height ranged among hybrids from 59.33 cm (GS-234(1703) × GS-129(1018)) to 81.77 cm (M-42(169) × GS-129(1018)), among parents from 63.97 (POLF-17(1704)) to 76.33 cm (M-42(169)) and among checks from 57.30 (Allahabad local) to 76.16 cm (T-397).

The hybrid GS-234(1703) × GS-129(1018) (59.33) was found statistically at par with FRW-6(973) × POLF17(1704) (61.13) and POLF-19(1765)× POLF-17(1704) (58.66).

Number of primary branches per plant (Table 1.2)

The number of primary branches per plant varied among hybrids from 3.66 (M-42(169) × GS-129(1018)) to 9.16 (C91538(456) × POLF19(1765)), among parents from 4.20 (GS-234(1703)) to 6.33 (C91538(456)) and among checks from 4.67 (Neelum) to 13.0 (T-397).
The hybrid C91538(456) × POLF19(1765) (9.16) was found statistically at par with FRW-6(973) × PbD2-42(2789) (7.16), C91538(456) × POLF19(1765) (9.16), C91538(456) × PbD2-42(2789) (8.16), C91538(456) × GS-234(1703) (7.16), POLF19(1765) × POLF-17(1704) (8.16), and POLF-17(1704) × GS-234(1703) (8.9).

**Number of capsule per plant (Table 1.2)**

The data revealed that number of capsule per plant ranged among hybrids from 52.4 (FRW-6(973) × GS-129(1018)) to 265.7 (FRW-6(973) × C91538(456)), among parents from 47.33 (PbD2-42(2789)) to 153.67 (FRW-6(973)) and among checks from 110.36 (Neelum) to 387.00 (T-397).

The hybrid FRW-6(973) × C91538(456) (265.7) was found statistically at par with FRW-6(973) × C91538(456) (265.7).

**Number of seeds per capsule (Table 1.2)**

The mean values for number of seeds per capsule varied among hybrids from 5.00 (FRW-6(973) × C91538(456)) to 9.3 (M-42(169) × C91538(456)), among parents from 8.2 (GS-234(1703)) to 9.6 (M-42(169)) and among checks from 4.53 (Neelum) to 9.1 (Allahabad local).

The hybrid M-42(169) × C91538(456) (9.3) was found statistically at par with M-42(169) × FRW-6(973) (9.6), FRW-6(973) × GS-234(1703) (8.3), C91538(456) × POLF17(1704) (8.2), C91538(456) × GS-234(1703) (9.2), and POLF-17(1704) × GS-234(1703) (8.7).

**1000-grain weight (g) (Table 1.2)**

The 1000-grain weight ranged among hybrids from 4.9g (M-42(169) × POLF-17(1704)) to 8.8g (FRW-6(973) × POLF17(1704)), among parents from 6.22g (M-42(169)) to 7.47g (GS-234(1703)) and among checks from 7.2g (T-397) to 7.7g (Allahabad local).

The hybrid M-42(169) × POLF-17(1704) (8.8) was found statistically at par with M-42(169) × PbD2-42(2789) (7.25), FRW-6(973) × C91538(456), FRW-6(973) × POLF19(1765) (7.6), FRW-6(973) × POLF17(1704) (7.4) and PbD2-42(2789) × GS-234(1703) (7.5).

**Biological yield per plant (g) (Table 1.2)**

The mean values for biological yield per plant ranged among hybrids from 9.09g (M-42(169) × PbD2-42(2789)) to 29.22g (FRW-6(973) × C91538(456)), among parents from 11.66g (GS-129(1018)) to 15.26g (M-42(169)) and among checks from 14.39g (Neelum) to 27.57 g (T-397).

Hybrid FRW-6(973) × C91538(456) (29.22) was found statistically at par with FRW-6(973) × GS-234(1703) (31.18).

**Harvest index (%) (Table 1.2)**

The harvest index varied among hybrids from 17.18% (C91538(456) × GS-234(1703)) to 41.50% (POLF-17(1704) × GS-234(1703)), among parents from 20.97 % (GS-234(1703)) to 33.38% (FRW-6(973)) and among checks from 22.34% (Neelum) to 32.37% (Allahabad local).

The hybrid POLF-17(1704) × GS-234(1703) (41.5%) was found statistically at par with M-42(169) × FRW-6(973) (39.38).

**Seed yield per plant (g) (Table 1.2)**

The data revealed that seed yield per plant ranged among hybrids from 2.96g (M-42(169) × POLF-17(1704)) to 7.9g (M-42(169) × POLF-19(1765)), among parents...
from 2.86g (PbD2-42(2789)) to 4.25g (M-42(169)) and among checks from 3.21g (Neelum) to 8.35g (T-397).

The hybrid M-42(169) × POLF-19(1765) (7.9) was found statistically at par with M-42(169) × FRW-6(973) (5.25), M-42(169) × POLF-19(1765) (7.90), FRW-6(973) × POLF19(1765) (7.19), FRW-6(973) × GS-234(1703) (6.28), FRW-6(973) × GS-129(1018) (6.28) and POLF-19(1765)× POLF-17(1704) (6.51).

The Per se performance was advocated by Genter and Alexander (1962) as one of the useful methods in evaluating parents for heterosis breeding in cross pollinated crop like maize.

A perusal of mean value of yield and yield contributing characters revealed that among parents genotype M-42(169) (4.25g/plant) and POLF-19(1765) (3.97g/plant) exhibited maximum value of seed yield per plant along with other contributing traits viz: number of seeds per capsule (9.6 and 8.7), number of capsules per plant (85.33 and 60.0), number of primary branches per plant (5.7 and 5.2), days to 50% flowering (89.0 and 86.0) and days to maturity (147.0 and 133.0).

Among the hybrids cross M-42(169) × POLF-19(1765) exhibited maximum value of seed yield per plant (7.9g) along with number of capsules per plant (61.6) and 1000-grain weight (6.56), whereas the hybrid FRW-6(973) × C91538(456) exhibited next higher value for seed yield per plant (7.86g) along with number of seeds per capsule (5.0) and primary branches per plant (5.96).

On the basis of Per se performance for seed yield per plant, five best high yielding identified hybrids are, M-42(169)×POLF-19(1765), FRW-6(973)×C91538(456), PbD2-42(2789)×GS-129(1018), FRW-6(973)×POLF-19(1765) and FRW-6(973)×GS-234(1703). (Table 4.3)

The recent trend in breeding linseed has been to evolve varieties with early flowering and early maturity because in late maturity types oil synthesis get adversely affected by temperature and time and later developed capsules do not bear well developed seeds.

Further the late maturing linseed does not fit well in multiple cropping system. Therefore, an attempt was made in present investigation to identity early maturing linseed genotypes.

Genotypes shows early maturity thus can be on immense use in the future breeding programme. These findings are in conformity with the findings of Singh and Singh(1979), Kumar et al., (1980), Singh et al., (1987), Saraswat et al., (1993), Verma et al., (1993), Mishra and Rai (1996), Patel et al., (1998), Ratnaparkhi et al., (1998), Kumar et al., (2000), Yadav and Srivastava (2002), Swarnakar et al., (2003), Ratnaparkhi et al., (2004), Sharma et al., (2005), Bhateria et al., (2006) Sood et al., (2006), Pant et al., (2007) and Pant et al., (2008).

**Heterosis, heterobeltiosis and economic heterosis**

In the present study, the magnitude of estimates of relative heterosis (MP), heterobeltiosis (BP) and standard heterosis (economic heterosis) have been expressed as percent increases in hybrid performance in relation to mid parent, better parent and best standard check, respectively.

The character wise heterosis, heterobeltiosis and economic heterosis are presented in table 2.2. The character wise results are summarized as under.
**Table 1.1** Analysis of variance for ten yield attributing traits in Linseed

| S.No. | Characters                          | Mean | Sum of Squares |
|-------|------------------------------------|------|----------------|
|       |                                    | Replications | Treatments | Parents | Hybrids | P vs Hy | Error | Total |
| 2     |                                    | 2    | 35           | 7       | 27      | 1       | 70    | 107   |
| 1     | Days to 50% flowering              | 1.23 | 43.94**      | 32.95** | 44.48** | 106.35** | 0.88  | 14.97 |
| 2     | Days to Maturity                   | 0.19 | 55.89**      | 120.38**| 24.81** | 443.63** | 1.65  | 19.36 |
| 3     | Plant height                       | 0.13 | 88.53**      | 50.34** | 100.36**| 36.66**  | 0.13  | 29.04 |
| 4     | Number of Primary branches per plant| 0.19 | 5.10**       | 1.13**  | 6.13**  | 5.09**   | 0.10  | 1.74  |
| 5     | Number of Capsules per plants      | 0.35 | 11101.44**   | 3512.47**| 11065.58**| 65192.55**| 0.18  | 3631.13|
| 6     | Number of Seeds per capsule        | 0.08 | 3.92**       | 0.47**  | 4.38**  | 15.79**  | 0.03  | 1.31  |
| 7     | 1000 grain weight                  | 0.02 | 1.59**       | 0.60**  | 1.86**  | 1.02**   | 0.01  | 0.53  |
| 8     | Biological yield per plant         | 0.25 | 100.39**     | 6.50**  | 119.98**| 228.89** | 0.19  | 32.96 |
| 9     | Harvest index                      | 1.84 | 98.73**      | 67.14** | 107.07**| 94.84**  | 1.85  | 33.54 |
| 10    | Seed yield per plant               | 0.04 | 6.74**       | 0.93**  | 7.56**  | 25.09**  | 0.02  | 2.22  |

**significant at 1% level of significance respectively**
### Table 1.2 Mean performances of parents and hybrids for different characters in linseed

| S.No | Genotype                  | Days to 50% flowering | Days to maturity | Plant height (cm.) | primary branches per plant | Capsules per plant | Seeds per capsule | Biological yield per plant (gm.) | Economic yield per plant (gm.) | 1000 grain weight (gm.) | Harvest index (%) |
|------|---------------------------|------------------------|------------------|--------------------|---------------------------|-------------------|------------------|----------------------------------|-------------------------------|----------------------|-------------------|
| 1.   | M-42(169)                 | 89.00                  | 147.00           | 76.333             | 5.7000                    | 85.3333           | 9.6000           | 15.2667                          | 4.2533                        | 6.2233               | 27.8560           |
| 2.   | M-42(169)xFRW-6(973)      | 85.00                  | 151.66           | 75.3667            | 3.9000                    | 145.6000          | 9.1667           | 13.3300                          | 5.2500                        | 5.9500               | 39.3800           |
| 3.   | M-42(169)xC91538(456)     | 83.00                  | 145.33           | 64.8000            | 5.6333                    | 145.0667          | 9.3000           | 9.0967                           | 3.1267                        | 6.3600               | 34.3667           |
| 4.   | M-42(169)xPOLF-19(1765)   | 86.00                  | 141.00           | 66.8000            | 5.2000                    | 61.6000           | 8.8000           | 26.0400                          | 7.9033                        | 6.5600               | 30.3467           |
| 5.   | M-42(169)xPOLF-17(1704)   | 84.00                  | 147.00           | 81.2000            | 4.2000                    | 97.2000           | 8.8000           | 18.7500                          | 3.9967                        | 4.9667               | 21.3133           |
| 6.   | M-42(169)xPbD2-42(2789)   | 85.00                  | 140.66           | 68.6667            | 4.1667                    | 93.8000           | 9.1333           | 9.0967                           | 2.9567                        | 7.2567               | 32.5033           |
| 7.   | M-42(169)xGS-234(1703)    | 86.00                  | 144.00           | 75.9667            | 3.6667                    | 56.0667           | 7.8000           | 8.2933                           | 3.0067                        | 5.7500               | 36.2700           |
| 8.   | M-42(169)xGS-129(1018)    | 87.00                  | 145.00           | 81.7667            | 4.6667                    | 60.0000           | 8.6000           | 12.5333                          | 3.3300                        | 6.4333               | 26.5667           |
| 9.   | FRW-6(973)                | 86.66                  | 134.00           | 73.6333            | 5.6667                    | 153.6667          | 9.1000           | 11.8133                          | 3.9433                        | 6.2300               | 33.3800           |
| 10.  | FRW-6(973)xC91538(456)    | 94.00                  | 142.00           | 72.7667            | 5.9667                    | 265.7000          | 5.0000           | 29.2233                          | 7.8667                        | 7.6000               | 26.9133           |
| 11.  | FRW-6(973)xPOLF-19(1765)  | 95.00                  | 141.66           | 69.0667            | 5.2000                    | 172.6667          | 6.0667           | 25.0000                          | 7.1900                        | 7.4667               | 28.8067           |
| 12.  | FRW-6(973)xPOLF-17(1704)  | 98.66                  | 144.00           | 61.1333            | 6.3000                    | 253.6000          | 6.6000           | 17.6333                          | 4.7400                        | 8.8000               | 26.8767           |
| 13.  | FRW-6(973)xPbD2-42(2789)  | 93.00                  | 140.00           | 67.0667            | 7.1667                    | 165.2000          | 6.7000           | 15.7133                          | 4.9333                        | 7.1233               | 31.3933           |
| 14.  | FRW-6(973)xGS-234(1703)   | 92.00                  | 142.33           | 70.0000            | 5.6333                    | 156.8000          | 8.3000           | 31.1867                          | 6.2867                        | 8.0333               | 20.1533           |
| 15.  | FRW-6(973)xGS-129(1018)   | 82.00                  | 140.33           | 65.6667            | 5.3333                    | 52.4000           | 9.0000           | 16.6600                          | 6.2800                        | 6.8200               | 37.6897           |
| 16.  | C91538(456)               | 87.00                  | 148.00           | 68.0667            | 6.3333                    | 102.6667          | 9.0667           | 14.0400                          | 3.2333                        | 6.5800               | 23.0233           |
| 17.  | C91538(456)xPOLF-19(1765) | 85.00                  | 146.33           | 73.7667            | 9.1667                    | 232.0667          | 8.8000           | 16.2400                          | 4.1333                        | 6.5567               | 25.4533           |
| 18.  | C91538(456)xPOLF-17(1704) | 87.00                  | 146.00           | 65.6667            | 5.8667                    | 211.3333          | 8.2333           | 13.7500                          | 3.2667                        | 7.1200               | 23.7600           |
| 19.  | C91538(456)xPbD2-42(2789) | 89.00                  | 145.00           | 62.3333            | 8.1667                    | 150.0667          | 9.0667           | 10.0000                          | 3.3733                        | 6.7467               | 33.9300           |
| 20.  | C91538(456)xGS-234(1703)  | 88.00                  | 143.66           | 72.6667            | 7.1667                    | 232.0667          | 6.2000           | 25.0000                          | 4.2867                        | 6.6000               | 17.1867           |
| 21.  | C91538(456)xGS-129(1018)  | 84.66                  | 144.00           | 67.6667            | 6.3333                    | 100.7667          | 9.2000           | 11.0367                          | 3.0500                        | 6.3500               | 27.6313           |
| 22.  | POLF-19(1765)             | 86.00                  | 133.00           | 69.1667            | 5.2000                    | 60.0000           | 8.7000           | 12.0133                          | 3.9700                        | 6.5600               | 33.0400           |
| 23.  | POLF-19(1765)xPOLF-17(1704)| 85.33                  | 146.00           | 58.6667            | 8.1667                    | 152.6667          | 8.6000           | 20.0000                          | 6.5133                        | 7.4600               | 32.6200           |
| S.No | Genotype | Days to 50% flowering | Days to maturity | Plant height (cm.) | primary branches per plant | Capsules per plant | Seeds per capsule | Biological yield per plant (gm.) | Economic yield per plant (gm.) | 1000 grain weight (gm.) | Harvest index (%) |
|------|----------|-----------------------|------------------|-------------------|---------------------------|-------------------|------------------|-------------------------------|-----------------------------|----------------------|------------------|
| 24. | POLF-19(1765)×PbD2-42(2789) | 90.00 | 148.00 | 67.0667 | 6.3333 | 156.6667 | 6.0667 | 14.2633 | 3.8700 | 5.7800 | 27.1300 |
| 25. | POLF-19(1765)×GS-234(1703) | 88.00 | 142.66 | 67.2000 | 5.6000 | 111.0000 | 9.1333 | 13.6200 | 4.4633 | 7.7000 | 32.7667 |
| 26. | POLF-19(1765)×GS-129(1018) | 86.00 | 144.00 | 70.8000 | 5.6333 | 191.6667 | 6.7000 | 17.7700 | 3.9900 | 7.2833 | 22.4467 |
| 27. | POLF-17(1704) | 84.66 | 134.33 | 63.9667 | 5.1667 | 97.6667 | 8.7667 | 15.1767 | 3.9333 | 7.1867 | 25.9367 |
| 28. | POLF-17(1704)×PbD2-42(2789) | 86.00 | 144.00 | 68.2000 | 6.2000 | 112.5667 | 7.7000 | 16.3000 | 3.9067 | 7.0700 | 23.9600 |
| 29. | POLF-17(1704)×GS-234(1703) | 87.66 | 148.66 | 62.3333 | 8.9000 | 184.2000 | 8.7667 | 9.6667 | 4.0033 | 7.4633 | 41.5067 |
| 30. | POLF-17(1704)×GS-129(1018) | 85.33 | 145.00 | 66.0667 | 5.9667 | 144.0667 | 8.3333 | 13.0000 | 3.0867 | 7.7033 | 23.8600 |
| 31. | PbD2-42(2789) | 87.00 | 145.00 | 66.0667 | 5.6333 | 47.3333 | 9.0667 | 13.0433 | 2.8567 | 6.9600 | 21.8967 |
| 32. | PbD2-42(2789)×GS-234(1703) | 85.00 | 140.00 | 74.6000 | 6.1667 | 55.2000 | 9.2000 | 15.6833 | 3.5667 | 7.5133 | 22.7167 |
| 33. | PbD2-42(2789)×GS-129(1018) | 86.00 | 146.00 | 68.2000 | 4.6333 | 167.3333 | 7.6333 | 24.1677 | 4.1667 | 7.2333 | 27.8633 |
| 34. | GS-234(1703) | 78.66 | 135.33 | 72.3333 | 4.2000 | 53.9000 | 8.2333 | 14.1167 | 2.9600 | 7.4700 | 20.9667 |
| 35. | GS-234(1703)×GS-129(1018) | 86.66 | 140.00 | 59.3333 | 4.6000 | 134.0667 | 8.0667 | 18.0000 | 5.0033 | 7.0067 | 27.8633 |
| 36. | GS-129(1018) | 82.00 | 137.00 | 71.6000 | 5.3333 | 87.0667 | 9.1000 | 11.6600 | 3.0167 | 6.5200 | 25.7967 |
| 37. | T-397(c) | 85.00 | 128.33 | 76.1667 | 12.7667 | 387.3333 | 8.5333 | 27.6667 | 8.3600 | 7.2000 | 30.3200 |
| 38. | Allahabad local(c) | 78.00 | 131.00 | 57.3000 | 11.9667 | 344.0000 | 9.1000 | 21.9967 | 7.0667 | 7.7000 | 32.3767 |
| 39. | Neem(c) | 88.00 | 135.00 | 65.8667 | 4.7000 | 110.3667 | 4.5333 | 14.3933 | 3.2167 | 7.5767 | 22.3433 |
| Mean | 86.72 | 142.11 | 68.8547 | 6.1179 | 143.3530 | 8.1735 | 16.5177 | 4.5603 | 6.9439 | 28.2483 |

| C.V. | 1.039 | 0.8702 | 0.5130 | 5.0889 | 0.3079 | 2.3027 | 2.5185 | 3.1388 | 1.6864 | 4.6237 |
| F ratio | 57.908 | 53.90 | 778.39 | 116.7147 | 95254.7734 | 134.1050 | 609.4277 | 392.2313 | 113.0714 | 55.9087 |
| F Prob. | 0.000 | 0.00 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| S.E. | 0.520 | 0.714 | 0.203 | 0.1797 | 0.2549 | 0.1087 | 0.2402 | 0.0826 | 0.0676 | 0.7541 |
| C.D. 5% | 1.465 | 2.011 | 2.574 | 2.5063 | 2.7178 | 1.3061 | 2.6765 | 2.2328 | 1.1904 | 2.1240 |
| C.D. 1% | 1.944 | 2.66 | 2.762 | 2.6716 | 2.9522 | 1.4060 | 2.8974 | 2.3088 | 1.2526 | 2.8176 |
| Range Lowest | 78.00 | 128.33 | 57.3000 | 3.6667 | 47.3333 | 4.5333 | 8.2933 | 2.8567 | 4.9667 | 17.1867 |
| Range Highest | 98.66 | 151.66 | 81.7667 | 12.7667 | 387.3333 | 9.6000 | 31.1867 | 8.3600 | 8.8000 | 41.5067 |
**Table.2.2 (a) Heterosis(Ha), Heterobeltiosis(Hb)and Economic Heterosis(Hc) for days to 50% flowering and days to maturity in linseed**

| S. No | Genotypes                        | Days to 50% flowering | Days to maturity |
|-------|----------------------------------|------------------------|------------------|
|       |                                  | Ha         | Hb          | Hc         | Ha         | Hb          | Hc         |
| 1     | M-42(169) × FRW-6(973)           | -3.23**    | -4.49**     | -3.41**    | 7.95**     | 3.17**      | 12.35**    |
| 2     | M-42(169) × C91538(456)          | -5.68**    | -6.74**     | -5.68**    | -1.47*     | -1.80*      | 7.65**     |
| 3     | M-42(169) × POLF-19(1765)        | -1.71*     | -3.37**     | -2.27*     | 0.71       | -4.08**     | 4.44**     |
| 4     | M-42(169) × POLF-17(1704)        | -3.26**    | -5.62**     | -4.55**    | 4.50**     | 0.00        | 8.89**     |
| 5     | M-42(169) × PbD2-42(2789)        | -3.41**    | -4.49**     | -3.41**    | -3.65**    | -4.31**     | 4.20**     |
| 6     | M-42(169) × GS-234(1703)         | 2.58**     | -3.37**     | -2.27*     | 2.01**     | -2.04**     | 6.67**     |
| 7     | M-42(169) × GS-129(1018)         | 1.75*      | -2.25*      | -1.14      | 2.11**     | -1.36       | 7.41**     |
| 8     | FRW-6(973) × C91538(456)         | 8.25**     | 8.05**      | 6.82**     | 0.71       | -4.05**     | 5.19**     |
| 9     | FRW-6(973) × POLF-19(1765)       | 10.04**    | 9.62**      | 7.95**     | 6.12**     | 5.72**      | 4.94**     |
| 10    | FRW-6(973) × POLF-17(1704)       | 15.18**    | 13.85**     | 12.12**    | 7.33**     | 7.20**      | 6.67**     |
| 11    | FRW-6(973) × PbD2-42(2789)       | 7.10**     | 6.90**      | 5.68**     | 0.36       | -3.45**     | 3.70**     |
| 12    | FRW-6(973) × GS-234(1703)        | 11.29**    | 6.15**      | 4.55**     | 5.69**     | 5.17**      | 5.43**     |
| 13    | FRW-6(973) × GS-129(1018)        | -2.77**    | -5.38**     | -6.82**    | 3.57**     | 2.43**      | 3.95**     |
| 14    | C91538(456) × POLF-19(1765)      | -1.73*     | -2.30*      | -3.41**    | 4.15**     | -1.13       | 8.40**     |
| 15    | C91538(456) × POLF-17(1704)      | 1.36       | 0.00        | -1.14      | 3.42**     | -1.35       | 8.15**     |
| 16    | C91538(456) × PbD2-42(2789)      | 2.30**     | 2.30*       | 1.14       | -1.02      | -2.03**     | 7.41**     |
| 17    | C91538(456) × GS-234(1703)       | 6.24**     | 1.15        | 0.00       | 1.41*      | -2.93**     | 6.42**     |
| 18    | C91538(456) × GS-129(1018)       | 0.20       | -2.68**     | -3.79**    | 1.05       | -2.70**     | 6.67**     |
| 19    | POLF-19(1765) × POLF-17(1704)    | 0.00       | -0.78       | -3.03**    | 9.23**     | 8.68**      | 8.15**     |
| 20    | POLF-19(1765) × PbD2-42(2789)    | 4.05**     | 3.45**      | 2.27*      | 6.47**     | 2.07**      | 9.63**     |
| 21    | POLF-19(1765) × GS-234(1703)     | 6.88**     | 2.33*       | 0.00       | 6.34**     | 5.42**      | 5.68**     |
| 22    | POLF-19(1765) × GS-129(1018)     | 2.38**     | 0.00        | -2.27*     | 6.67**     | 5.11**      | 6.67**     |
| 23    | POLF-17(1704) × PbD2-42(2789)    | 0.19       | -1.15       | -2.27*     | 3.10**     | -0.69       | 6.67**     |
| 24    | POLF-17(1704) × GS-234(1703)     | 7.35**     | 3.54**      | -0.38      | 10.26**    | 9.85**      | 10.12**    |
| 25    | POLF-17(1704) × GS-129(1018)     | 2.40**     | 0.79        | -3.03**    | 6.88**     | 5.84**      | 7.41**     |
| 26    | PbD2-42(2789) × GS-234(1703)     | 2.62**     | -2.30*      | -3.41**    | -0.12      | -3.45**     | 3.70**     |
| 27    | PbD2-42(2789) × GS-129(1018)     | 1.78*      | -1.15       | -2.27*     | 3.55**     | 0.69        | 8.15**     |
| 28    | GS-234(1703) × GS-129(1018)      | 7.88**     | 5.69**      | -1.52      | 2.82**     | 2.19**      | 3.70**     |

** and *significant at 1% and 5% level of significance respectively
**Table 2.2 (b) Heterosis (H_a), Heterobeltiosis (H_b) and Economic Heterosis (H_c) for plant height and primary branches per plant in linseed**

| S.No | Genotypes | Plant height(cm) |  |  |  |  |
|------|------------|------------------|---|---|---|---|
|      |            | Ha   | Hb   | H_c | Ha   | H_b | H_c |
| 1    | M-42(169) × FRW-6(973) | 0.51 | -1.27** | 14.42** | -31.38** | -31.58** | -17.02** |
| 2    | M-42(169) × C91538(456) | -10.25** | -15.11** | -1.62** | -6.37 | -11.05** | 19.86** |
| 3    | M-42(169) × POLF-19(1765) | -8.18** | -12.49** | 1.42** | -4.59 | -8.77 | 10.64 |
| 4    | M-42(169) × POLF-17(1704) | 15.75** | 6.38** | 23.28** | -22.70** | -26.32** | -10.64 |
| 5    | M-42(169) × PbD2-42(2789) | -3.56** | -10.04** | 4.25** | -26.47** | -26.90** | -11.35 |
| 6    | M-42(169) × GS-234(1703) | 2.20** | -0.48 | 15.33** | -25.93** | -35.67** | -21.99** |
| 7    | M-42(169) × GS-129(1018) | 10.55** | 7.12** | 24.14** | -15.41** | -18.13** | -0.71 |
| 8    | FRW-6(973) × C91538(456) | 2.71** | -1.18** | 10.48** | -0.56 | -5.79 | 26.95** |
| 9    | FRW-6(973) × POLF-19(1765) | -3.27** | -6.20** | 4.86** | -4.29 | -8.24 | 10.64 |
| 10   | FRW-6(973) × POLF-17(1704) | -11.14** | -16.98** | -7.19** | 16.31** | 11.18** | 34.04** |
| 11   | FRW-6(973) × PbD2-42(2789) | -3.98** | -8.92** | 1.82** | 26.84** | 26.47** | 52.48** |
| 12   | FRW-6(973) × GS-234(1703) | -4.09** | -4.93** | 6.28** | 14.19** | -0.59 | 19.86** |
| 13   | FRW-6(973) × GS-129(1018) | -9.57** | -10.82** | -0.30 | -0.30 | -5.88 | 13.48** |
| 14   | C91538(456) × POLF-19(1765) | 7.51** | 6.65** | 11.99** | 58.96** | 44.74** | 95.04** |
| 15   | C91538(456) × POLF-17(1704) | -0.53 | -3.53** | -0.30 | 2.03 | -7.37 | 24.82** |
| 16   | C91538(456) × PbD2-42(2789) | -7.06** | -8.42** | -5.36** | 36.49** | 28.95** | 73.76** |
| 17   | C91538(456) × GS-234(1703) | 3.51** | 0.46 | 10.32** | 36.08** | 13.16** | 52.48** |
| 18   | C91538(456) × GS-129(1018) | -3.10** | -5.49** | 2.73** | 8.57** | 0.00 | 34.75** |
| 19   | POLF-19(1765) × POLF-17(1704) | -11.87** | -15.18** | -10.93** | 57.56** | 57.05** | 73.76** |
| 20   | POLF-19(1765) × PbD2-42(2789) | -0.81* | -3.04** | 1.82** | 16.92** | 12.43** | 34.75** |
| 21   | POLF-19(1765) × GS-234(1703) | -5.02** | -7.10** | 2.02** | 19.15** | 7.69 | 19.15** |
| 22   | POLF-19(1765) × GS-129(1018) | 0.59 | -1.12** | 7.49** | 6.96 | 5.62 | 19.86** |
| 23   | POLF-17(1704) × PbD2-42(2789) | 4.90** | 3.23** | 3.54** | 14.81** | 10.06* | 31.91** |
| 24   | POLF-17(1704) × GS-234(1703) | -8.54** | -13.82** | -5.36** | 90.04** | 72.26** | 89.36** |
| 25   | POLF-17(1704) × GS-129(1018) | -2.53** | -7.73** | 0.30 | 13.65** | 11.87* | 26.95** |
| 26   | PbD2-42(2789) × GS-234(1703) | 7.80** | 3.13** | 13.26** | 25.42** | 9.47 | 31.21** |
| 27   | PbD2-42(2789) × GS-129(1018) | -0.92* | -4.75** | 3.54** | -15.50v | -17.75** | -1.42 |
| 28   | GS-234(1703) × GS-129(1018) | -17.55** | -17.97** | -9.92** | -3.50 | -13.75** | -2.13 |

**and *significant at 1% and 5% level of significance respectively**
Table 2.2 (c) Heterosis (Ha), Heterobeltiosis (Hb) and Economic Heterosis (Hc) for capsules per plant and seeds per capsule in linseed

| S.No | Genotypes | Capsules per plant | Seeds per capsules |
|------|------------|--------------------|--------------------|
|      |            | Ha                 | Hb                 | Hc     | Ha     | Hb     | Hc     |
| 1    | M-42(169) × FRW-6(973) | 21.84** | -5.25** | 31.92** | -1.96 | -4.51** | 102.21** |
| 2    | M-42(169) × C91538(456) | 54.33** | 41.30** | 31.44** | -0.36 | -3.13*  | 105.15** |
| 3    | M-42(169) × POLF-19(1765) | -15.23** | -27.81** | -44.19** | -3.83** | -8.33** | 94.12** |
| 4    | M-42(169) × POLF-17(104) | 6.23** | -0.48 | -11.93** | -4.17** | -8.33** | 94.12** |
| 5    | M-42(169) × PbD2-42(2789) | 41.41** | 9.92** | -15.01** | -2.14 | -4.86** | 101.47** |
| 6    | M-42(169) × GS-234(1703) | -19.46** | -34.30** | -49.20** | -12.52** | -18.75** | 72.06** |
| 7    | M-42(169) × GS-129(1018) | -30.39** | -31.09** | -45.64** | -8.02** | -10.42** | 89.71** |
| 8    | FRW-6(973) × C91538(456) | 107.31** | 72.91** | 140.74** | -44.95** | -45.05** | 10.29** |
| 9    | FRW-6(973) × POLF-19(1765) | 61.62** | 12.36** | 56.45** | -31.84** | -33.33** | 33.82** |
| 10   | FRW-6(973) × POLF-17(104) | 101.80** | 65.03** | 129.78** | -26.12** | -27.47** | 45.59** |
| 11   | FRW-6(973) × PbD2-42(2789) | 64.38** | 7.51** | 49.68** | -26.24** | -26.37** | 47.79** |
| 12   | FRW-6(973) × GS-234(1703) | 51.08** | 2.04** | 42.07** | -4.23** | -8.79** | 83.09** |
| 13   | FRW-6(973) × GS-129(1018) | -56.47** | -65.90** | -52.52** | -1.10 | -1.10 | 98.53** |
| 14   | C91538(456) × POLF-19(1765) | 185.33** | 1(126.04** | 110.27** | -0.94 | -2.94 | 94.12** |
| 15   | C91538(456) × POLF-17(104) | 110.98** | 105.84** | 91.48** | -7.66** | -9.19** | 81.62** |
| 16   | C91538(456) × PbD2-42(2789) | 100.09** | 46.17** | 35.97** | 0.00 | 0.00 | 100.00** |
| 17   | C91538(456) × GS-234(1703) | 196.44** | 126.04** | 110.27** | -28.32** | -31.62** | 36.76** |
| 18   | C91538(456) × GS-129(1018) | 6.22** | -1.85** | -8.70** | 1.28 | 1.10 | 102.94** |
| 19   | POLF-19(1765) × POLF-17(104) | 93.66** | 56.31** | 38.33** | -1.53 | -1.90 | 89.71** |
| 20   | POLF-19(1765) × PbD2-42(2789) | 191.93** | 161.11** | 41.95** | -31.71** | -33.09** | 33.82** |
| 21   | POLF-19(1765) × GS-234(1703) | 94.91** | 85.00** | 0.57 | 7.87** | 4.98** | 101.47** |
| 22   | POLF-19(1765) × GS-129(1018) | 160.65** | 120.14** | 73.66** | -24.72** | -26.37** | 47.79** |
| 23   | POLF-17(104) × PbD2-42(2789) | 55.26** | 15.26** | 1.99** | -13.64** | -15.07** | 69.85** |
| 24   | POLF-17(104) × GS-234(1703) | 143.06** | 88.60** | 66.90** | 3.14* | 0.00 | 93.38** |
| 25   | POLF-17(104) × GS-129(1018) | 55.97** | 47.51** | 30.53** | -6.72** | -8.42** | 83.82** |
| 26   | PbD2-42(2789) × GS-234(1703) | 9.05** | 2.41** | -49.98** | 6.36** | 1.47 | 102.94** |
| 27   | PbD2-42(2789) × GS-129(1018) | 149.01** | 92.19** | 51.62** | -15.96** | -16.12** | 68.38** |
| 28   | GS-234(1703) × GS-129(1018) | 90.21** | 53.98** | 21.47** | -6.92** | -11.36** | 77.94** |

** and *significant at 1% and 5% level of significance respectively
Table 2.2 (d) Heterosis (Ha), Heterobeltiosis (Hb) and Economic Heterosis (Hc) for harvest index (%) and Seed yield per plant (g) in linseed

| S.No | Genotypes                                | Harvest index (%) | Seed yield per plant (g) |
|------|------------------------------------------|-------------------|-------------------------|
|      |                                          | Ha    | Hb    | Hc    | Ha    | Hb    | Hc    |
| 1    | M-42(169) x FRW-6(973)                   | 28.62** | 17.97** | 76.25** | 28.10** | 23.43** | 63.21** |
| 2    | M-42(169) x C91538(456)                  | 35.09** | 23.37** | 53.81** | -16.47** | -26.49** | -2.80  |
| 3    | M-42(169) x POLF-19(1765)               | -0.33  | -8.15* | 35.82** | 92.22** | 85.82** | 145.70* |
| 4    | M-42(169) x POLF-17(1074)               | -20.76** | -23.49** | -4.61  | -2.36  | -6.03*  | 24.25** |
| 5    | M-42(169) x PbD2-42(2789)                | 30.66** | 16.68** | 45.47** | -16.83** | -30.49** | -8.08*  |
| 6    | M-42(169) x GS-234(1703)                | 48.58** | 30.21** | 62.33** | -16.64** | -29.31** | -6.53  |
| 7    | M-42(169) x GS-129(1018)                | -0.97  | -4.63  | 18.90** | -8.39** | -21.71** | 3.52   |
| 8    | FRW-6(973) x C91538(456)                | -4.57  | -19.37** | 20.45** | 119.23** | 99.49** | 144.56* |
| 9    | FRW-6(973) x POLF-19(1765)              | -13.26** | -13.70** | 28.93** | 81.72** | 81.11** | 123.52* |
| 10   | FRW-6(973) x POLF-17(1074)              | -9.38** | -19.48** | 20.29** | 20.36** | 20.20** | 47.36** |
| 11   | FRW-6(973) x PbD2-42(2789)              | 13.59** | -5.95  | 40.50** | 45.10** | 25.11** | 53.37** |
| 12   | FRW-6(973) x GS-234(1703)               | -25.83** | -39.62** | -9.80  | 82.13** | 59.43** | 95.44** |
| 13   | FRW-6(973) x GS-129(1018)               | 27.38** | 12.91** | 68.68** | 80.46** | 59.26** | 95.23** |
| 14   | C91538(456) x POLF-19(1765)             | -9.20** | -22.96** | 13.92** | 14.76** | 4.11   | 28.50** |
| 15   | C91538(456) x POLF-17(1074)             | -2.94  | -8.39  | 6.34    | -8.84** | -16.95** | 1.55   |
| 16   | C91538(456) x PbD2-42(2789)             | 51.07** | 47.37** | 51.86** | 10.78** | 4.33   | 4.87   |
| 17   | C91538(456) x GS-234(1703)              | -21.86** | -25.35** | -23.08** | 38.43** | 32.58** | 33.26** |
| 18   | C91538(456) x GS-129(1018)              | 13.20** | 7.11   | 23.67** | -2.40  | -5.67  | -5.18  |
| 19   | POLF-19(1765) x POLF-17(1074)           | 10.62** | -1.27  | 45.99** | 64.82** | 64.06** | 102.49* |
| 20   | POLF-19(1765) x PbD2-42(2789)           | -1.23  | -17.89** | 21.42** | 13.38** | -2.52  | 20.31** |
| 21   | POLF-19(1765) x GS-234(1703)            | 21.34** | -0.83  | 46.65** | 28.81** | 12.43** | 38.76** |
| 22   | POLF-19(1765) x GS-129(1018)            | -23.70** | -32.06** | 0.46   | 14.22** | 0.50   | 24.04** |
| 23   | POLF-17(1074) x PbD2-42(2789)           | 0.18   | -7.62  | 7.24    | 15.07** | -0.68  | 21.45** |
| 24   | POLF-17(1074) x GS-234(1703)            | 76.99** | 60.03** | 85.77** | 16.15** | 1.78   | 24.46** |
| 25   | POLF-17(1074) x GS-129(1018)            | -7.76* | -8.01  | 6.79    | -11.18** | -21.53** | -4.04  |
| 26   | PbD2-42(2789) x GS-234(1703)            | 6.00   | 3.74   | 1.67    | 22.64** | 20.50** | 10.88** |
| 27   | PbD2-42(2789) x GS-129(1018)            | 23.02** | 13.72** | 31.30** | 160.95** | 154.03** | 138.24* |
| 28   | GS-234(1703) x GS-129(1018)             | 19.17** | 8.01** | 24.71** | 67.43** | 65.86** | 55.54** |

** and *significant at 1% and 5% level of significance respectively
Table 2.2 (e) Heterosis (Ha), Heterobeltiosis (Hb) and Economic Heterosis (Hc) for 1000 grain weight (g) and biological yield per plant (g) in linseed

| S.No | Genotypes                        | 1000 grain weight (g) | Biological yield / plant (g) |
|------|----------------------------------|-----------------------|-----------------------------|
|      |                                  | Ha        | Hb        | Hc        | Ha        | Hb        | Hc        |
| 1    | M-42(169) × FRW-6(973)           | -4.44**   | -4.49**   | -21.47**  | -1.55     | -12.69**  | -7.39**   |
| 2    | M-42(169) × C91538(456)          | -0.65     | -3.34**   | -16.06**  | -37.92**  | -40.41**  | -36.80**  |
| 3    | M-42(169) × POLF-19(1765)        | 2.63*     | 0.00      | -13.42**  | 90.91**   | 70.57**   | 80.92**   |
| 4    | M-42(169) × POLF-17(1704)        | -25.93**  | -30.89**  | -34.45**  | 23.18**   | 22.82**   | 30.27**   |
| 5    | M-42(169) × PbD2-42(2789)        | 10.09**   | 4.26**    | -4.22**   | -35.74**  | -40.41**  | -36.80**  |
| 6    | M-42(169) × GS-234(1703)         | -16.02**  | -23.03**  | -24.11**  | -43.55**  | -45.68**  | -42.38**  |
| 7    | M-42(169) × GS-129(1018)         | 0.97      | -1.33     | -15.09**  | -6.91**   | -17.90**  | -12.92**  |
| 8    | FRW-6(973) × C91538(456)         | 18.66**   | 15.50**   | 0.31      | 126.07**  | 108.14**  | 103.03**  |
| 9    | FRW-6(973) × POLF-19(1765)       | 16.76**   | 13.82**   | -1.45     | 109.85**  | 108.10**  | 73.69**   |
| 10   | FRW-6(973) × POLF-17(1704)       | 31.18**   | 22.45**   | 16.15**   | 30.67**   | 16.19**   | 22.51**   |
| 11   | FRW-6(973) × PbD2-42(2789)       | 8.01**    | 2.35      | -5.98**   | 26.43**   | 20.47**   | 9.17**    |
| 12   | FRW-6(973) × GS-234(1703)        | 17.27**   | 7.54**    | 6.03**    | 140.55**  | 120.92**  | 116.67**  |
| 13   | FRW-6(973) × GS-129(1018)        | 6.98**    | 4.60**    | -9.99**   | 41.95**   | 41.03**   | 15.75**   |
| 14   | C91538(456) × POLF-19(1765)      | -0.20     | -0.35     | -13.46**  | 24.67**   | 15.67**   | 12.83**   |
| 15   | C91538(456) × POLF-17(1704)      | 3.44**    | -0.93     | -6.03**   | -5.88**   | -9.40**   | -4.47     |
| 16   | C91538(456) × PbD2-42(2789)      | -0.34     | -3.07*    | -10.95**  | -26.15**  | -28.77**  | -30.52**  |
| 17   | C91538(456) × GS-234(1703)       | -6.05**   | -11.65**  | -12.89**  | 77.58**   | 77.10**   | 73.69**   |
| 18   | C91538(456) × GS-129(1018)       | -3.05*    | -3.50*    | -16.19**  | -14.11**  | -21.39**  | -23.32**  |
| 19   | POLF-19(1765) × POLF-17(1704)    | 8.54**    | 3.80**    | -1.54     | 47.11**   | 31.78**   | 38.95**   |
| 20   | POLF-19(1765) × PbD2-42(2789)    | -14.50**  | -16.95**  | -23.71**  | 13.85**   | 9.35**    | -0.90     |
| 21   | POLF-19(1765) × GS-234(1703)     | 9.76**    | 3.08*     | 1.63      | 4.25      | -3.52     | -5.37*    |
| 22   | POLF-19(1765) × GS-129(1018)     | 11.37**   | 11.03**   | -3.87**   | 50.13**   | 47.92**   | 23.46**   |
| 23   | POLF-17(1704) × PbD2-42(2789)    | -0.05     | -1.62     | -6.69**   | 15.52**   | 7.40**    | 13.25**   |
| 24   | POLF-17(1704) × GS-234(1703)     | 1.84      | -0.09     | -1.50     | -34.00**  | -36.31**  | -32.84**  |
| 25   | POLF-17(1704) × GS-129(1018)     | 12.40**   | 7.19**    | 1.67      | -3.12     | -14.34**  | -9.68**   |
| 26   | PbD2-42(2789) × GS-234(1703)     | 4.13**    | 0.58      | -0.84     | 15.49**   | 11.10**   | 8.96**    |
| 27   | PbD2-42(2789) × GS-129(1018)     | 5.84**    | 2.49      | -5.85**   | 111.44**  | 100.23**  | 81.45**   |
| 28   | GS-234(1703) × GS-129(1018)      | 0.17      | -6.20**   | -7.52**   | 39.66**   | 27.51**   | 25.06**   |

** and *significant at 1% and 5% level of significance respectively
Table 1.3 First five best hybrids identified on the basis of economic heterosis for seed yield per plant

| S. No | Crosses                        | Economic heterosis (%) over the best check | Per se performance for seed yield per plant (g) | Days to 50% flowering | 1000-grain weight (g) | No. of capsules per plant |
|-------|--------------------------------|--------------------------------------------|-----------------------------------------------|-----------------------|----------------------|--------------------------|
| 1     | $P_1P_4$ (M-42(169)×POLF-19(1765)) | 35.82**                                   | 7.90                                          | 86.00                 | 6.56                 | 61.60                    |
| 2     | $P_2P_3$ (FRW-6(973)×C91538(456)) | 20.45**                                   | 7.86                                          | 94.00                 | 7.60                 | 265.70                   |
| 3     | $P_6P_8$ (PbD2-42(2789)×GS-129(1018)) | 31.30**                                   | 7.66                                          | 86.00                 | 7.13                 | 167.33                   |
| 4     | $P_2P_4$ (FRW-6(973)×POLF-19(1765)) | 28.93**                                   | 7.19                                          | 95.00                 | 7.46                 | 172.66                   |
| 5     | $P_2P_7$ (FRW-6(973)×GS-234(1703)) | -9.8                                      | 6.28                                          | 92.00                 | 8.03                 | 156.80                   |

**Days to 50% flowering (Table 2.2.a)**

Heterosis for days to 50% flowering ranged from -5.68** (M-42(169) × C91538(456)) to 15.18** (FRW-6(973) × POLF17(1704)). It was significant in 7 crosses for early flowering. Maximum significant negative heterosis was obtained in cross M-42(169) × C91538(456) (-5.68**) and M-42(169) × PbD2-42(2789) (-3.41**).

Significant heterobeltiosis for early flowering was observed in 13 crosses. Heterobeltiosis ranged from -6.74** (M-42(169) × C91538(456)) to 13.85** (FRW-6(973) × POLF17(1704)). The highest heterobeltiosis was exhibited by the hybrid M-42(169) × C91538(456) (-6.74**) followed by M-42(169) × POLF-17(1704) (-5.62**) and M-42(169) × PbD2-42(2789) (-4.49**).

Significant economic heterosis ranged from -6.82** (FRW-6(973) × GS-129(1018)) to 12.12** (FRW-6(973) × POLF17(1704)). It was significant in 17 cross. Highest negative economic heterosis was observed in FRW-6(973) × GS-129(1018) (-6.82**) followed by M-42(169) × C91538(456) (-5.68**) and M-42(169) × POLF-17(1704) (-4.55**) for early flowering.

**Days to maturity (Table 2.2.a)**

The estimates for heterosis for days to maturity ranged from –3.65** (M-42(169) × PbD2-42(2789)) to 10.26** (POLF-17(1704) × GS-234(1703)). It was significant in 2 crosses for early maturity. Maximum significant negative heterosis was obtained in cross M-42(169) × PbD2-42(2789) (-3.65**) and M-42(169) × C91538(456) (-1.47*).

Significant heterobeltiosis for early maturity was observed in 14 crosses. It was ranged from -4.31** ((M-42(169) × PbD2-42(2789)) to 9.85** (POLF-17(1704) × GS-234(1703)). Maximum significant negative heterosis was obtained in cross M-42(169) × PbD2-42(2789) (-4.31**) and M-42(169) × POLF-19(1765) (-4.08**). Significant economic heterosis for early maturity was observed in none of crosses.

**Plant height (Table 2.2.b)**

The range of heterosis for plant height was –
17.55** (GS-234(1703) × GS-129(1018)) to 15.75** (M-42(169) × POLF-17(1704)). The heterotic effect was significant in 18 crosses in negative direction.

Significant heterobeltiosis for plant height was observed in 27 crosses, of which 22 crosses are significant heterobeltiosis in desired direction. It ranged from -17.97** (GS-234(1703) × GS-129(1018)) to 7.12** (M-42(169) × GS-129(1018)). The maximum significant negative heterobeltiosis was obtained in the cross GS-234(1703) × GS-129(1018) (-17.97**) followed by POLF-19(1765) × POLF-17(1704) (-15.18**) and M-42(169) × C91538(456) (-15.11**).

Economic heterosis ranged from -10.93** (POLF-19(1765) × POLF-17(1704)) to 24.14** (M-42(169) × GS-129(1018)). The maximum significant economic heterosis was obtained in the cross POLF-19(1765) × POLF-17(1704) (-10.93**) followed by GS-234(1703) × GS-129(1018) (-9.92**) and FRW-6(973) × POLF17(1704) (-7.19**).

### Number of primary branches per plant (Table 2.2.b)

The heterosis over mid parent for this character varied from -31.38** (M-42(169) × FRW-6(973)) to 90.04** (POLF-17(1704) × GS-234(1703)). Out of 28 hybrids, 16 hybrids exhibited positive desirable heterotic effect. The cross combination POLF-17(1704) × GS-234(1703) (90.04**) exhibited highest heterosis followed by C91538(456) × POLF19(1765) (58.96**) and POLF-19(1765) × POLF-17(1704) (57.56**).

The heterobeltiosis ranged from -35.67** (M-42(169) × GS-234(1703)) to 72.26** (POLF-17(1704) × GS-234(1703)). Significant positive heterobeltiosis was observed in 13 crosses. Highest positive heterobeltiosis was obtained in the cross POLF-17(1704) × GS-234(1703) (72.26**). followed by POLF-19(1765) × POLF-17(1704) (57.05**) and C91538(456) × POLF19(1765) (44.74**).

Significant economic heterosis was noticed in all crosses, which ranged from -41.18** (A-202(183) × EC-12082) to 95.04** (C91538(456) × POLF19(1765)). The highest economic heterosis was observed in the cross C91538(456) × POLF19(1765) (95.04**) followed by POLF-17(1704) × GS-234(1703) (89.36**) and C91538(456) × PbD2-42(2789) (73.76**).

### Number of capsules per plant (Table 2.2.c)

The relative heterosis ranged from -56.47** (FRW-6(973) × GS-129(1018)) to 196.44** (C91538(456) × GS-234(1703)). Significant desirable heterotic effect was observed in 24 crosses. The cross combination C91538(456) × GS-234(1703) (196.44**) exhibited the highest heterosis followed by crosses C91538(456) × GS-234(1703) (191.93**) and C91538(456) × PbD2-42(2789) (185.33**).

The heterobeltiosis ranged from -34.30** (M-42(169) × GS-234(1703)) to 161.11** (POLF-19(1765) × PbD2-42(2789)). Significant positive heterobeltiosis effect was observed in 21 crosses. The highest positive heterobeltiosis was obtained in the cross POLF-19(1765) × PbD2-42(2789) (161.11**) followed by C91538(456) × GS-234(1703) (126.04**) and POLF-19(1765) × GS-129(1018) (120.14**).

Significant economic heterosis was noticed in all 20 crosses. It ranged from 0.57** (POLF-19(1765) × GS-234(1703)) to 140.74** (FRW-6(973) × C91538(456). The highest economic heterosis was observed in cross FRW-6(973) × C91538(456) (140.74**) followed by FRW-6(973) × POLF17(1704) (129.78**) and C91538(456) × PbD2-42(2789) (110.27**).
Number of seeds per capsules (Table 2.2.c)
The range of heterosis was -31.84** (FRW-6(973) × POLF19(1765)) to 7.87** POLF-19(1765) × GS-234(1703). Out of 28 crosses, 4 crosses depicted significant positive heterotic effect. The cross combination POLF-19(1765) × GS-234(1703) (7.87**) exhibited highest heterosis followed by PbD2-42(2789) × GS-234(1703) (6.36**) and POLF-17(1704) × GS-234(1703) (3.14*).

The heterobeltiosis varied from -45.05** (FRW-6(973) × C91538(456)) to 4.98** (POLF-19(1765) × GS-234(1703)). Out of 28 crosses, 3 crosses had significant positive heterobeltiosis effect. The cross combination POLF-19(1765) × GS-234(1703) (4.98**) exhibited highest heterobeltiosis followed by PbD2-42(2789) × GS-234(1703) (1.47**) and C91538(456) × GS-129(1018) (1.10**).

The economic heterosis ranged from 10.29** FRW-6(973) × C91538(456) to 105.15** (M-42(169) × C91538(456)). Out of 28 crosses, 28 crosses had significant positive economic heterosis.. The hybrid M-42(169) × C91538(456) (105.15**) exhibited highest significant economic heterosis.

Biological yield per plant (g) (Table 2.2.e)
The relative heterosis ranged from -43.55** (M-42(169) × GS-234(1703)) to 140.55** (FRW-6(973) × GS-234(1703)). Out of 28 crosses, 18 crosses had significant positive heterotic effect. The hybrid FRW-6(973) × GS-234(1703) (140.55**) exhibited highest significant heterosis followed by PbD2-42(2789) × GS-129(1018) (111.44**).

Heterobeltiosis varied from -30.49** (M-42(169) × PbD2-42(2789)) to 154.03** (M-42(169) × POLF-19(1765)). Out of 28 crosses, 18 crosses had positive significant heterobeltiosis effect. The hybrid PbD2-42(2789) × GS-129(1018) (154.03**) exhibited highest heterobeltiosis effect followed by FRW-6(973) × C91538(456) (99.49**) and M-42(169) × POLF-19(1765) (85.82**).

The economic heterosis ranged from -8.08* (M-42(169) × PbD2-42(2789)) to 145.70** (M-42(169) × POLF-19(1765)). Out of 28 crosses, 21 crosses had significant positive economic heterosis.. The hybrid (M-42(169)

Seed yield per plant (g) (Table 2.2.d)
The relative heterosis for seed yield per plant ranged from -2.36 (M-42(169) × POLF-17(1704)) to 160.95** (PbD2-42(2789) × GS-129(1018)). Out of 28 crosses, 20 crosses had significant positive heterotic effect. The hybrid PbD2-42(2789) × GS-129(1018) (160.95**) exhibited highest significant heterosis, followed by FRW-6(973) × C91538(456) (119.23**) and M-42(169) × POLF-19(1765) (92.22**).

Heterobeltiosis varied from -30.49** (M-42(169) × PbD2-42(2789)) to 154.03** (PbD2-42(2789) × GS-129(1018)). Out of 28 crosses, 18 crosses had positive significant heterobeltiosis effect. The hybrid PbD2-42(2789) × GS-129(1018) (154.03**) exhibited highest heterobeltiosis effect followed by FRW-6(973) × C91538(456) (99.49**) and M-42(169) × POLF-19(1765) (85.82**).
× POLF-19(1765) (145.70**) exhibited highest significant economic heterosis followed by FRW-6(973) × C91538(456) (144.56**) and PbD2-42(2789) × GS-129(1018) (138.24**).

1000-grain weight (g) (Table 2.2.e)

The relative heterosis ranged from -25.93** (M-42(169) × POLF-17(1704)) to 31.18** (FRW-6(973) × POLF17(1704)). Out of 28 crosses, 15 crosses had significant positive heterotic effect. The hybrid FRW-6(973) × POLF17(1704) (31.18**) exhibited highest significant heterosis, followed by FRW-6(973) × C91538(456) (18.66**) and FRW-6(973) × POLF19(1765) (16.76**).

Heterobeltiosis varied from -30.89** (M-42(169) × POLF-17(1704)) to 22.45** (FRW-6(973) × POLF17(1704)). Out of 28 crosses, 11 crosses had positive significant heterobeltiosis effect. The hybrid FRW-6(973) × POLF17(1704) exhibited highest heterobeltiosis (22.45**) followed by FRW-6(973) × C91538(456) (15.50**) and FRW-6(973) × POLF19(1765) (13.82**).

Heterobeltiosis varied from -39.62** (FRW-6(973) × GS-234(1703)) to 60.03** (POLF-17(1704) × GS-234(1703)). Out of 28 crosses, 9 crosses had positive significant heterobeltiosis effect. The hybrid POLF-17(1704) × GS-234(1703) (60.03**) exhibited highest heterobeltiosis followed by C91538(456) × × PbD2-42(2789) (47.37**) and M-42(169) × GS-234(1703) (30.21**).

The economic heterosis ranged from -23.08** (C91538(456) × GS-234(1703)) to 85.77**(POLF-17(1704) × GS-234(1703)). Out of 28 crosses, 20 cross had positive economic heterosis. The hybrid POLF-17(1704) × GS-234(1703) (85.77**) exhibited highest significant economic heterosis followed by M-42(169) × FRW-6(973) (76.25**) and FRW-6(973) × GS-129(1018) (68.68**).

The commercial exploitation of heterosis in crop plants is regarded as a major breakthrough in the realm of plant breeding. It is a phenomenon of immense practical value, as its utilization has led to considerable yield improvement of several cereal and other crops such as maize, bajra, sorghum, cotton and castor etc. A better understanding of this phenomenon might lead to important advantages, including its commercial exploitation in other crops like linseed. In linseed inspite of high hybrid vigour and availability of male sterility. Its commercial exploitation has not been possible, because the flower of the male sterile flax had a small corolla which fails to open to allow cross pollination. The aim of heterosis study in this crop is to spot out heterotic hybrids which might throw desired, segregants in the succeeding generations.
The results revealed that estimates of significant positive as well as negative heterosis and heterobeltiosis were obtained in many crosses for different character studied. The high values for heterotic effects indicated that the parents used for the study were widely diverse. Considerable high heterosis in certain hybrids and low in other revealed that the nature of gene action varied with the genetic architecture of the parents. Such nature as well as magnitude of heterosis helps in identifying superior cross combination.

In the present study out of 28 crosses, 7 crosses for days to flowering, 2 crosses for days to maturity, 16 crosses for number of primary branches per plant, 24 crosses for number of capsules per plant, 4 crosses for number of seeds per capsule, 15 crosses for 1000-seed weight, 18 crosses for biological yield per plant, 13 crosses for harvest index and 4 crosses for seed yield per plant depicted significant relative heterosis in desired direction. Hybrid M-42(169) × POLF-19(1765) and FRW-6(973) × C91538(456) showed significant heterosis effect of seed yield along with earliness.

Positive significant heterosis for seed yield and other attributes in linseed were also reported by Elladi (1939), Dalal and Gill (1965), Bojeova (1966), Doucet et al., (1967), Anand and Murty (1968), Hakro and Baluch (1968), Anand and Murty (1969), Anand et al., (1972), Galkin (1972), Badwa and Gupta (1974), Bhatnagar (1977), Rao and Singh (1983), Dakhore et al., (1987 b), Rao et al., (1987), Singh et al., (1987 a), Heyland and Hemker (1991), Dhakar (1994), Patel (1995), Verma and Mahto (1996), Yadav (1997), Kumar et al., (2002), Ratnaparkhi et al., (2004), Sharma et al., (2005), Sood et al., (2006), Pant et al., (2007) and Pant et al., (2008).

In the present study seed yield per plant had significant desired heterobeltiosis in crosses. The highest heterobeltiosis value for seed yield was recorded by the cross (PbD2-42(2789) × GS-129(1018)) (154.03**) followed by FRW-6(973) × C91538(456) (99.49**) and M-42(169) × POLF-19(1765) (85.82**).

The above findings are in agreement with the findings of Kalia (1972), Makhi (1974), Ermakov and Megoraskaya (1975), Chandra (1978), Shrivast and Singh (1982), Patil and Chopde (1983), Singh et al., (1983), Dakhore et al., (1987), Dubey and Dixit (1991), Verma and Sinha (1993), Saraswat et al., (1993), Patel (1995), Kumar et al., (2002), Sharma et al., (2005) and Pant et al., (2008).

In the present study, seed yield per plant had significant positive economic heterosis in 20 crosses. The highest economic heterosis value for seed yield per plant was recorded by the cross (M-42(169) × POLF-19(1765)) (145.70**) followed by FRW-6(973) × C91538(456) (144.56**) and PbD2-42(2789) × GS-129(1018) (138.24**).

Among the top economic heterotic hybrids, the hybrid (259.83**) maximum seed yield per plant along with 1000 grain weight (7.44**) and number of capsules per plant (288.02**), whereas the hybrid A-72(112) X EC-41528 exhibited second highest seed yield per plant (221.98%) along with primary branches per plant (205.88**). Significant desired economic heterosis for seed yield and other attributes in linseed were also reported by Dakhore et al., (1987), Kumar et al., (2002), Ratnaparkhi et al., (2004) Sharma et al., (2005) and Pant et al., (2008).

Relative heterosis(MP) and heterobeltiosis (BP) are important parameters as they provide information about the presence of dominance and over dominance type of gene
actions in the expression of various traits.

Thus for characters viz., days to flowering, days to maturity and plant height some hybrids exhibited negative significant relative heterosis, there by indicating that for these traits the genes with negative effects were dominant on the other hand for characters like seeds per capsule, number of capsules per plant, number of primary branches per plant, seed yield per plant, biological yield per plant and harvest index, majority of the hybrids exhibited positive significant relative heterosis, thereby indicating that for these characters the genes with positive effects were dominant.

Similar results on heterosis in linseed were reported by Kumar et al., (1980), Patil and Chopde (1983), Singh et al., (1987), Dakhore et al., (1987), Saraswat et al., (1993), Verma et al., (1993), Mishra and Rai (1993), Ratnaparkhi et al., (2004), Sharma et al., (2005). Sood et al., (2006) and Pant et al., (2008). However, heterosis over check variety will be a better parameter for assessing superiority over existing varities and comparing heterosis effects of different crosses (Dakhore et al., 1987).

In the present investigation cross M-42(169) × POLF-19(1765) showed highest economic heterosis over the best check (Neelum) followed by T-397 and local check.

**References**

A. R. Hallauer and J. B. Miranda (1981), *Quantitative Genetics in Maize Breeding*, Iowa State University Press Ames, Iowa, USA.

A.B.Damania,(1997) “Near-eastern crop diversity and its global migration,” in *The Origin of Agriculture and Crop Domestication*.Proceedings of the Harlan Symposium (ICARDA ’97), A.

Anand, I.J. and B.R. Murty (1968). Genetic divergence and hybrid performance in Linseed. *Indian J. Genet.*, 28: 178-185.

Anand, I.J. and B.R. Murty (1969 a). Serial analysis of combining ability in diallel and fractional diallel crosses in Linseed.TAG, 39: 88-94.

Anand, I.J. and B.S.Rana (1972) Estimation of Genetic variances by full-sib and half-sib analysis in linseed. *Sabrao Newsl.*, 4: 33-37.

Babwal, S.S and V.P. Gupta (1974). Heterosis and inbreeding depression in linseed. *J.Cytol. Genet.*, 7 : 63-78.

Babwal, S.S, V.P. Gupta and K.S. Gill (1972). Combining ability studies of selected world germplasm lines of linseed. *J.Res. PAU.*, 9 : 383-388.

Bhateria et al., (2006) Genetic analysis of quantitative traits across environments in linseed (*Linum usitatissimum* L.) Springer Netherlands :185-194

Bhateria, S., A. Pathania, J.K. Sharma, D. Badiyala and J.C. Bhandari (2001). Combining ability for seed yield and its components in linseed (*Linum usitatissimum* L.). *J.Oilseeds Res.*,18 (1) : 44-47.

Bhatnagar, S.K. (1977). Combining ability and gene action studies in the inheritance of quality and quantity of oil in linseed (*Linum usitatissimum* L.). Phd. Thesis, university of Udaipur. Udaipur.

Bojeova, V.P. (1966). Hybridization of Linseed.*Indian J. Genet.*, 40(1): 99-101.

Bruce, A. B. (1910). The Mendelian theory of heredity and the augmentation of vigour. *Sci* 32 : 627-28.

Carnahan, H.L. (1949). The inheritance of oil content and other characters in the flax and association between characters in the cross of ‘Dakota x Minerva’ Ph.d Thesis University of Minnestola, St. Paul, Minnesota.

Castle, W.E.(1946). Gene which devide species or produce hybrid vigours.*Proc. National Acad. U.S.A.* 32: 145-149.

Comstock, R.E., H.F. Robinson, and P.H. Harvey (1949). A breeding procedure designated to make maximum use of both general and specific combining ability. *Agron. J.* 41:360-367.

Dakhore, S.R., M.N. Narkhede and P.W. Khorgade (1987b). Combining ability for oil content in linseed. *J. of Maharastra. Agri. Univ.*12 (3): 308-310.

Dakhore, S.R., M.N. Narkhede and P.W. Khorgade (1987b). Heterosis in relation to combining ability effects in Linseed. *PKV Res. J.*, 11 (1): 7-12.

Dalal, J.L. and K.S. Gill (1965) General combining ability and heterosis in some F1 intervarietal crosses of linseed. *Indian Oilseeds J.*, 9 : 61-66.

Dang, Z. H., B.D. Chen, S.C. Xin and L.Q. Zheng
(1987). Analysis of combining ability for oil contents in linseed. Oil Crops, China, 3: 52-55.
Devenport, C. B. (1908). Degeneration, albinos and inbreeding. Sci. 28: 454-55.
Dhakar, J. M. (1994). Studies on heterosis, combining ability and stability parameters in linseed (Linum usitatissimum L.). unpublished Ph.d. Thesis, R.C.A., R.A.U. Udaipur.
Donald, C. M. and Hamblin, J. (1976). The biological yield and harvest index of cereals as agronomic and plant breeding criteria. Adv. Agron., (28): 361-405.
Douct, I., M. Coucet and F. Popescu (1979). Combining ability in some flax varieties analysed by the incomplete diallel-cross method. Analele- Institutului-de-Cercetari-pentru- cereal-si-plante-Technice-Fundulea, 44: 51-62.
Douct, M. and I. Douct. (1967). Contribution to study of heterosis in flax. An. Ins. certet. Cereal Pl. Tech. Fundulea. Ser. C., 34: 401-413.
East, E. M. (1936). Heterosis. Genetics, 21: 375-397.
East, E. M. and H. K. Hays (1912). Heterozygotes in evolution and in plant breeding. U.S. Dept. Agri Bur. Plant Indus. Bull. 243: p 58.
Elladi, K. V. (1939). Inheritance of length of vegetative period in flax hybrids. Bul. Acad. Sci. USSR. Ser. Biol., 37: 388.
F. L’opez Anido, V. Cravero, P. Asprelli, T. Firpo, S. M. Garca’a, and E. Cointry (2004), “Heterotic patterns in hybrids involving cultivar-groups of summer squash, Cucurbita pepo L.” Euphytica, vol. 135, no. 3, pp. 355-360.
Fonesca, S. and Patterson, p. (1968). Hybrid vigour in a seven parent diallel cross in common winter wheat. Crop Sci., 8: 85-88.
Galkin, F. M. (1972). Heterosis in inter varietal hybrids of linseed (Linum usitatissimum L.). Byul. Nauchnicteln inform Po. Maslichn. Kulturam. No. 3: 17-21.
Genter, G. F. and Alexander, M. N. (1962). Comparative performance of S1 progenies and test crosses of corn, Crop Sci., 2: 416-47.
Gill, K. S. (1967). Linseed, publication and information Division, New Delhi :I.C.A.R.
Goray, S. C., Khosla, H. K. and P. K. Nigam (1990). Analysis of combining ability in Linseed (Linum usitatissimum L.). Madras Agric., Crop Sci., 8: 77(9-12): 465-469.
Green AG (1986) Genetic control of polyunsaturated fatty acid biosynthesis in flax (Linum usitatissimum) seed oil. Theor Appl Genet 72:654-661.
Green, A. G. and D. R. Marshall (1981). Variation for oil quantity and quality in Linseed (Linum usitatissimum L.). Australian J. Agric. Res., 32 (4): 599-607.
Griffing, B. (1956b). Concept of general and specific combining ability in relation to diallel crossing system. Aust. J. Biol. Sci., 9: 463-493.
Gustafsson, A. (1936). Studies on the genetic basis of chlorophyll formation and the mechanism of inducing mutation. Hereditas 24 : 33-93.
Hakro, M. A. and M. A. A. Baulch (1968). Heterosis studies on plant height in linseed (Linum usitatissimum L.) west Pak. J. Agril. Res., 7 (3): 109-116.
Hatze, G. (1989) World importance of oil crops and their products. McGraw Hill Publishing company, New York, 1-21.
Hayman, B. I. (1954). The analysis of variance of diallel table. Biometrics, 10: 235-244.
Heyland, K. U. and R. Hemker (1991). Suitability of vegetative and reproductive traits as selection criteria in breeding for Concurrent use of soil, fibre and flax. Lein Bodenkultur. 42 (1): 45-56.
Hull, F. H. (1945). Recurrent selection for specific combining ability in corn. J. Amer. Soc. Agron. 37: 234-45.
Jeswani, L. M. (1953). Inheritance studies in varietal crosses in Linseed (Linum usitatissimum L.). Unpublished Assoc. Thesis I.A.R.I., New Delhi.
Jinks, J. L. (1955). A survey of genetic basis of heterosis in a variety of diallels crosses, Heredity, 9: 223-238.
Jinks, J. L. and Jones, R. M. (1958). Estimation of the components of heterosis. Genetics, 43: 223-234.
Kalra, N. R. (1972). Combining ability, graphical analysis and heterosis in linseed(Linum usitatissimum L.). Unpublished M.Sc. Thesis, P.A.U. Ludhiana.
Kandil, A. A. Sherai A. E. , Abo-Zaied T. A. and Gamil A. (2011). Genetic divergence and heterosis in linseed(Linum usitatissimum L.). J.Plant production mansours un. 1: 335-349.
Kansal, K. K. and S. C. Gupta (1981). Note on heterosis in Linseed. Indian J.Agric. Sci., 51 (9): 680-682.
Karmuka, K. S., Tasdidawa and G. S. Shethi (1988). Combining ability analysis for oil content and iodine value in linseed. (Linum usitatissimum L.). Indian J. Agric. Sci., 58 (4): 252-254.
Karpunia, I. I. and G. P. Kornienko (1981). Combining ability of flax varieties. Len.-l- Kaspaliva, 1, 35:36.
Kasim, M. H. (1964). The analysis of yield and its components and seed quality characteristics in diallel cross among ten varieties of flax.
Mishra et al., (2011). Biplot approach for identification of heterotic crosses in linseed (Linum usitatissimum L.). J. of Botany. 2011: Article ID 353102.

Mishra, V.K. and M. Rai (1996). Combining ability analysis for seed yield and quality components of seed and oil in Linseed. (Linum usitatissimum L.) J. Genet., 56 (2): 155-161.

Mishra, V.K. and Rai, M. (1993). Estimates of heterosis for seed yield, components of seed and oil in Linseed (Linum usitatissimum L.) Indian J.Genet., 53 (2) 161-164.

Mohammadi, A. A., Saedi G., Arjani A. (2010) Genetic analysis of some agronomic traits in flax (Linum usitatissimum L.). Australian J. of Crop Sci, 4:5, 343-352.

Muir AD, Westcott ND (2003) Flax: The Genus Linum. Taylor & Francis, London

Murty, B.R. and I.J. Anand (1966). Combining ability and genetic diversity in some varieties of linseed. (Linum usitatissimum L.) Indian J.Genet., 26:21-36.

Nie, Z. B.C. Gue, G.T. Chen and A.O. Liang (1991). Study on combining ability of the principal organic characters in Flax (Linum usitatissimum L.) Ningria J. Agro. Forestry Science and Technology, 4:7-11.

Noor-ul-Islam et al., (1999), Combining Ability Analysis in Linseed (Linum usitatissimum L.). Pakistan J. of Biol. Sci. 01/1999; DOI.

Pal, B.P. and Sikka, S.M., (1956). Exploitation of hybrid vigour in the improvement of crop plants, fruits and vegetables. Indian J. Genet. Plant Breed, 16: 95-193.

Panse, V.G. and Sukhatme, P.V. (1942). Statistical methods for agricultural workers (2nd Ed.), I.C.A.R., Publications, New Delhi.

Pant et al., (2007) Components of Genetic Variation in Yield Traits of Linseed(Linum usitatissimum L.). Indian Journal of Plant Genetic Resources.

Pant et al., (2008) Heterosis over Superior Parents under Diallel Cross in Linseed/Flax (Linum usitatissimum L.) Indian Journal of Plant Genetic Resources.

Patel, A.J. (1995). Genetic analysis of seed yield and quality characters in linseed (Linum usitatissimum L.) P.hd. Thesis, R.A.U Bikaner.

Patel, A.J., Y.K.Gupta, S.B. Patel and J.N. Patel (1997). Combining ability analysis over environments in linseed (Linum usitatissimum L.) Madra Agric. J., 84 (4) : 188-191.

Patil, V.D. and P.R. Chopde (1981) Combining ability analysis over environments in diallel crosses in linseed (Linum usitatissimum L.) Theo. and App.
Genet 60 (6): 339-343.

Patil, V.D. and P.R. Chopde (1984) Heterosis in relation to general and specific combining ability effects in linseed (Linum usitatissimum L.) Indian J. Genet., 43(2): 226-228.

Pillai, Beena, P.W. Khorgade and M.N. Narkhede (1995). Genetic behavior of yield and its components in Linseed. J. Oilseeds Res., 12(1): 5-9.

Popescu, F. I. Marinescu and I. Vasile (1998). Combining ability and heritability of important characters for improving Linseed. Probleme de-Genetica-Teoretica-Si-Aplicata. 30 (1-2): 105-122.

Prasad, R. (2004). Text Book of Field Crops production (1st Ed.). I.C.A.R. Book publication, New Delhi.

Prygun, V.S. and L.M. polonetskaya (1985). Combining ability of Flax varieties for the main economically useful characters in a Line x Tester crossing system. Sel’Skokhayaistvennaya-Bidogya, 9: 67-70

Rai, M. and K. Das (1974). Combining ability for components yield in linseed (Linum usitatissimum L.) Indian J. Gene., 34 (3) : 371-375.

Rao, S.K., S.P. Singh (1983). Heterosis and inbreeding depression in linseed. (Linum usitatissimum L.) J. Agric. Sci., 53 :409-417.

Rao, S.K., S.P. Singh and M.L. Talwar (1987). Heterosis for seed size and oil content in linseed (Linum usitatissimum L.) Oilseeds Res., 4 :242-245

Ratnaparkhi, R.D., M.Y. Dudhe, N.D. Gawande and S.A. Bhongle (2004). Heterosis in relation to combining ability effects in linseed. Ann. Plant Physio. 18 (2): 182-186.

Ratnaparkhi, R.D., N.N. Kolte and P.W. Khorgade (1998). Line x Tester analysis for combining ability in Linseed. (Linum usitatissimum L.) PKV Res. J., 22 (1): 3-6

Rowland GG (1991) An EMS-induced low linolenic acid mutant in McGregor flax (Linum usitatissimum L.). Can J Plant Sci 71:393-396.

Saraswat, A. V., Kumar Satyendra, S. Kumar, M. N. Verma, D. S. Virk and G. S. Chand (1995). Heterosis and inbreeding depression in some early hybrids of linseed. Heterosis breeding in crop plants- theory and applications: Short communications: Symposium Ludhiana, 1993 : 52-53.

Schidmt, J.(1919). La valeur l ‘individu a’ titre de generateur apperce S subsequent la method du croisment diable. Camp. Rend. Lab. Casriber, 14 No. 633.

Seetharam, A. and D. Srinivasachar, (1970). Mutational evidence for the origin of Indoganian and peninsular types of Indian Linseed. Current Sci., 39

Sharma et al., (2005) Heterobeltiosis and inbreeding depression in linseed. Agricultural Science Digest.

Shehata, A.H. and Comstock, V.E., (1971) Heterosis and combining ability estimates in F2 Flax populations as influenced by plant density. Crop Sci 11 :534-536

Shrivastava et al., (2004) Heterosis and combining ability estimates in linseed under salt affected soil. Indian Agriculturist. 48:3/4, 193-197.

Shrivastava et al., (2007) Heterosis and combining ability estimates in linseed under salt affected soil. Plant Archives. 7: 2, 905-908.

Shull, G. H. (1908). The composition of field of maize. Amer. Breeders Assoc. Rept. 4 :296-301.

Shull, G. H. (1911 a). Experiments with maize. composition of field of maize. Bot. Goz., 52: 430-435.

Shull, G. H. (1911 b). The genotypes of maize. Amer.Nat., 45 : 234-252.

Sikha, Tripathi, Mishra, V. and Tripathi, H. C. (2011). Combining ability analysis of yield and its components in linseed (Linum usitatissimum L.). Current Advances in Agril. Sci. 3: 2, 93-95.

Simmonds, N.W., (1976) Evolutions of crop plants,.Langman Inc., New York.

Singh et al., (2008) Combining ability and gene action for Alternaria blight and powdery mildew resistance in linseed. The Indian Journal of Genetics and Plant Breeding.

Singh R. J., Ramakant P. K., Vimal S.C. (2010) Assessment of heterosis in linseed (Linum usitatissimum L.). Agril. And Biol. Research. 26:1,64-76.

Singh, B., J.S. Sindhu, Allah Rang and A. Rang (1990). Combining ability in Linseed. Res. and Dev. Reporter, 7 (1-2) : 47-52.

Singh, Brahm.G. Singh and J.S. Sindhu (1986) Combining ability and genetic architecture of oil content in Linseed. J. Oilseeds Res., 3 : 14-18.

Singh, K.P. and H.G. Singh(1979). Combining ability analysis for quantitative traits in Linseed.Indian J. Agric. Sci., 49 (8): 573-578.

Singh, Neelam, S.P. Singh and C.B. Singh(1981). Genetic studies in linseed using partial diallel technique.Indian J. Agric. Sci., 51 (12): 853-856.

Singh, P., A.N. Srivastava, I.B. Singh and R. Mishra (1987a). Heterosis and Inbreeding depression in relation to Per se performance in Linseed. Farm Sci. j., 2 (1): 68-73.

Singh, R.K. (1973). Comparision of selection indices on selection experiments in rye. H.A.U. J. Res., 2 : 145-149.
Singh, R.P., R.P. Singh, S.P. Singh and R.V. Singh (1979). Combining ability for yield components in rice. *Oryza.*, 16: 115-118.

Singh, R.S., S. Singh and R.K. Chidhary (1983). Heterobolitosis in relation to per se performance and effects of general combining ability in linseed (*Linum usitatissimum* L.) *Precongress scientific meeting on genetics and improvement of heterotic systems* :14

Singh, V., O.P. Pachauri and S.N. Tiwari (1987 b). Combining ability studies in linseed (*Linum usitatissimum* L.) *Indian J. Genet.*, 47 (2): 171-178.

Singh, P. K., Srivastava. R. L., Narayan Ved and Dubey. S. D. (2009) Combining ability and heterosis for seed yield and oil content in linseed (*Linum usitatissimum*). *Indian J.of Agric. Sci.* Vol 79, No 3.

Sood et al., (2006) Detection of genetic components of variation for some biometrical traits in *Linum usitatissimum* L. in sub-mountain Himalayan region.

Sood S., Kalina N. R., Bhatira S. (2011) Combining ability and heterosis studies across environments in linseed (*Linum usitatissimum* L.). *Acta Agronomica Hungarica*. 2011. 59: 1, 87-102. 27 ref.

Sprague, G.F. and L.A. Tatum (1942).General versus specific combining ability in single crosses of corn. *J.Amer. Sol. Agron.*, 34 923-932.

Sprague, G.F.(1966). Quantitative genetics in plant improvement in plant breeding. Ed. K.J. Frey IOWA state univ. press Ames. IOWA : 315-347.

Stadler, L. J. (1939). Some observations on gene variability and spontaneous mutation. Spragg Memorial Lectures, Michigan College. Pp. 1-15 (Read Abstr.).

Swarnakar et al., (2005) Studies on combining ability and heterosis in linseed (*Linum usitatissimum* L.). *Farm Sci. J.* 14:1,4-6.

Swarnakar, S.K., Poonam Singh and R.L. Srivastava (2003). Combining ability analysis in linseed (*Linum usitatissimum* L.) *Progressive Agric.*, 3(1-2): 103-106.

Thakur, H.L. and N.D. Rana (1987). Combining ability in linseed (*Linum usitatissimum* L.) *Indian J. Agric.*, 57 (5) : 303-308.

Thakur, H.L. and N.D. Rana and O.P. Sood (1987). Combining ability analysis for some quantitative characters in linseed (*Linum usitatissimum* L.) *Indian J. Genet.*, 47 (1) : 6-10.

Thakur, H.L. and S. Bhateria (1991). L x T analysis for Combining ability in linseed (*Linum usitatissimum* L.) *J.Oilseeds Res.*,8 : 14-18.

Tiwari,Nalini, R.K. Dixit and H.C. Singh (2004). Combining ability analysis for seed yield and its components in linseed. (*Linum usitatissimum* L.) *J. Oilseeds Res.*,21(2): 343-345.

Turner, J.H. (1953). A study of heterosis in upland cotton, combining ability and inbreeding effects. *Agronomy Journal*, 45 : 487-490

Vavilov, N.I. (1951). Phytogeographic basis of plant breeding. The origin, variation, immunity and breeding of cultivated plants. *Chronica Bat.*, 13 : 1-366.

Verma, A.K. and J.L. Mahto (1966). Hybrid vigour in linseed for yield and yield attributes under rainfed and irrigated environments. *J. Tropical Agric.*, 34 (1) : 54-57.

Verma, A.K., P.K. Sinha. M.M. Verma, D.S. Virk and G.S. Chahal (1993). Heterosis in linseed. (*Linum usitatissimum* L.). Heterosis Breeing in crop plants- theory and applications: Short communications: Symposium Ludhiana, 1993:82-83.

Visnu Ameta Shah, Lakshyadeep M. A. (2005) Studies on heterosis and combining ability for fatty acids in linseed (*Linum usitatissimum* L.). *J. of Medicinal and Aromatic Plant Sci.* 27: 4, 615-618. 8.

Yadav, R.K. and S.B.L. Srivastava (2002). Combining ability analysis over environments in linseed (*Linum usitatissimum* L.) *Crop Res., Hissar*, 23(2):277-282.

Yang, W. R. and T.Y. Bo (1988). Analysis of combining ability for qualitative characters in Flax cultivars. *Shanxi Agric. Sci.*, 3 : 7-10.

---

**How to cite this article:**

Divya Mahto, P. K Singh and Shailesh Marker. 2020. Half diallel analysis for estimation of heterosis for phonological traits in linseed (*Linum usitatissimum* L). *Int.J.Curr.Microbiol.App.Sci.* 9(02): 2451-2474. doi: [https://doi.org/10.20546/ijcmas.2020.902.280](https://doi.org/10.20546/ijcmas.2020.902.280)