Introduction

Linseed (*Linum usitatissimum* L.) is a diploid (2n = 30, genome size ~370 Mb) self-pollinated annual oilseed plant. It has been under the cultivation for its seed or stem fibre (Flax) of both (dual purpose) for 1000 years (Dillman, 1953). Every part of the linseed plant is utilized commercially either directly or after processing. On a very small scale, the seed is directly used for edible purposes and about 20% of the total oil produced is used in farmer home. About 80% of the oil goes to the industries for the manufacturing of rapidly drying paints, varnish, oil cloths, polymer linoleum, pad-ink, printing ink, etc. The oil cake is a good feed for milch cattle. The oil contains different fatty acids like alpha linolenic acid (omega-3) 53.21%, linoleic acid (omega-6) 17%, oleic acid 18.51%, stearic acid 4.42% and palmitic/palmitoleic acid 4-6%. Linseed is the richest source of omega-3 fatty acid and it contains almost twice as much as of omega-3 in fish oil. The ratio of omega-3: omega-6 present in linseed is about 4:1, so this is a best herbal source of omega-3.
for improvement in human metabolism (Viorica-Mirela Popa, 2012). Through diallel analysis a number of parental lines can be tested in all possible combinations. Thus, the main objective of the present study was to identify the best combiners and their crosses on the basis of their general and specific combining ability for oil content and its quality parameters. Hybrid is an alternative approach to increase the productivity and most important step in the hybrid breeding program is the detection of suitable parents with high general (gca) and specific combining ability (sca) for grain yield and then the exploitation of heterosis. The study of heterosis has a direct bearing on the breeding methodology to be employed for varietal improvement and also provides useful information about usefulness of the parents in breeding programs.

Materials and Methods

Experimental material and design

The material for the investigation comprised of eight improved strains/varieties of linseed namely RKY-19, OLC-60, PADMINI, TL-27, SJKO-60, T L-11, S-36, KL-231 having desire genetic variability for oil content, yield and associated attribute. Parental seed were collected from Project Coordinating Unit (Linseed) C. S. Azad University. All possible crosses were made during rabi 2012-13 in a complete diallel fashion (8×8). The F1 and F2 along with their parents were grown in randomization block design using three replication during rabi season 2014-15 at the investigation research farm, Nawabganj, C. S. azad University of agriculture and technology Kanpur.

Analysis of variance

The analysis of variance for the experimental design was based on the model

\[ P_{ijk} = \mu + v_{ij} + b_{k} + e_{ijk} \]

(i, j = 1......t; k = 1.....b)

Where

\[ P_{ijk} = \text{the phenotype of } ijk^{th} \text{ observation} \]
\[ \mu = \text{the population mean} \]
\[ v_{ij} = \text{the progeny effect} \]
\[ b_{k} = \text{the block effect} \]
\[ e_{ijk} = \text{the error term for } ijk^{th} \text{ observation} \]

On the basis of above model, the data obtained were first subjected to randomized block analysis. The skeleton of analysis of variance is given as under

Combining ability analysis

Combining ability analysis was performed according to the procedure suggested by Griffing (1956b) Method 1, Model I. In this model parents, direct crosses and reciprocals crosses are included for the analysis.

This method permits estimation of reciprocal differences. It is also assumed that error is independently and normally distributed with the mean zero and error variance \( \sigma^2_e \). The analysis of variance for combining ability was based on the following mathematical model:

\[ X_{ijk} = \mu + \hat{g}_i + \hat{g}_j + \tilde{s}_{ij} + b_{k} + e_{ijk} \]

(i,j = 1,2,....., n; 1 = 1,2,..... b)

Where

\[ \mu = \text{the population mean} \]
\[ \hat{g}_i = \text{the general combining ability (gca) for } i^{th} \text{ parent} \]
\[ \hat{g}_j = \text{the gca of the } j^{th} \text{ parent} \]
\( s_{ij} \) = the specific combining ability (sca) for the cross between the \( i^{th} \) and \( j^{th} \) parents such that \( s_{ij} = s_{ji} \)

\( b_k \) = block effect

\( e_{ijk} \) = the environmental effect associated with the \( ijk^{th} \) individual observation on \( i^{th} \) individual in \( k^{th} \) block with \( i^{th} \) as female parent and \( j^{th} \) as male parent.

\( b = number \ of \ blocks/replications \)

The restrictions imposed on this model are:

\[ \sum g_i = 0 \quad \text{and} \quad \sum g_{ij} + s_{ii} = 0 \]

(For each \( i \)), where \( i = \text{variety} \)

Where,

\( b = \text{number of replications} \)
\( c = \text{number of progenies (parents + F_1s)} \)
\( r = \text{number of reciprocals} \)

\[ S_g = \frac{1}{n+2} \left[ \sum (x_{ij} + x_{ji})^2 + \frac{2}{(n+1)(n+2)} X^2 \right] \]

\( M'e = \frac{Me}{bc} \)

Where,

\( b = \text{number of replications} \)
\( c = \text{number of observations per plot} \)

\( M_e = \text{the error m.s.s. obtained from previous ANOVA} \)

\( S_g = \text{the sum of squares (s.s.) due to gca} \)

\( S_s = \text{the sum of squares (s.s) due to sca} \)

\( n = \text{number of parents} \)

\( x_i = \text{total of array involving } i^{th} \text{ as female} \)

\( x_{ij} = \text{the value of the } i^{th} \text{ parent of the array} \)

\( x_{..} = \text{the grand total} \)

\( x_{ij} = \text{the value of the cross with } i^{th} \text{ as female and } j^{th} \text{ as male parents.} \)

**Estimates of various effects**

**General Combining Ability Effects (GCA)**

\[ g_i = (1/2)(X_i. + X.i) - X_{..}/n^2 \]

Where:

\( g_i = \text{General combining ability effects for line } F1's \ i. \)

\( n = \text{Number of parents/varieties} \)

\( X_{i.} = \text{Total of mean values of } F_1's \text{ resulting from crossing } j^{th} \text{ lines with } i^{th} \text{ lines.} \)

\( X_{.i} = \text{Total of mean values of } F_1's \text{ resulting from crossing the } i^{th} \text{ line with the } j^{th} \text{ line.} \)

\( X = \text{Grand mean of all the mean values in the table} \)

**Specific Combining Ability Effects (SCA)**

\[ s_{ij} = (1/2)(X_{ij} + X_{ji}) - (1/2)(X_{i.} + X_{i.} + X_{.i} + X_{.i}) + X_{..}/n^2 \]

Where:

\( s_{ij} = \text{Specific combining ability between } i^{th} \text{ and } j^{th} \text{ lines.} \)

\( X_{ij} = \text{Mean value of the } F_1 \text{ resulting from crossing the } i^{th} \text{ and } j^{th} \text{ lines.} \)

\( X_{ji} = \text{Mean values for } F_1 \text{ resulting from crossing the } j^{th} \text{ and } i^{th} \text{ lines.} \)
X_i = Total of means of F_1’s resulting from crossing jth line with ith line.

X_i.j = Reciprocal values of Y_i.

X_j = Total values for F_1’s resulting from crossing the ith line with jth line.

X_j.i = Values of reciprocal F_1’s of Y_j.

X. = Grand values of the observations.

**Reciprocal Effects (REC)**

r_{ij} = (X_{ij} – X_{ji})/2

Where:

r_{ij} = Reciprocal effects of the ith and jth lines.

X_{ij} = Mean values for the F_1 resulting from crossing the ith and jth lines.

X_{ji} = Reciprocal effects of F_1 resulting from X_{ij}.

Estimated variances of the estimates of the effect and their differences:

\[ \hat{\sigma}_e^2 = \frac{n - 1}{2n^2} \sigma_e^2 \]

Esti. Var.

\[ \hat{\sigma}_s^2 = \frac{(n+1)(n+2)}{n(n+1)} \sigma_s^2 \text{, where } i \neq j \]

Esti. Var.

\[ \hat{\sigma}_{eij}^2 = \frac{2}{n+2} \hat{\sigma}_e^2 \text{, where } i \neq j \]

Esti. Var.

\[ \hat{\sigma}_{i}^2 = \frac{2n}{n+2} \hat{\sigma}_s^2 \text{, where } i \neq j \]

Esti. Var.

**Analysis of variance**

The analysis of variance for combining ability (Table 1) revealed highly significant variance for both general and specific combining ability in both generations for all the characters, indicating the importance of both additive and non-additive gene action in the expression of these traits. Reciprocal effects of maternal and paternal combining ability showed that use in both form of parent for almost characters. However, additive and non-additive effects were predominant for all the characters, as reported by various workers Singh et al.,(2008), Brahm Singh et al.,(2008), Singh et al.,(2009), Pali and Mehta (2014),

Additive genetic variance is the result of additive gene action whereas non additive variance is made up of dominance and epistasis gene action. The dominance variance decline by half with each other generation of selfing or in proportional reduction of heterozygosity, so it is un-exploitable in pure line. The epistatic variance is also reduce on selfing but its additive x additive remain constant, which is fixable.

The estimate of \( \sigma_e^2 \) and \( \sigma_s^2 \) and their ratio \( \sigma_e^2/\sigma_s^2 \) indicated a predominant role of additive gene action and non-additive gene action in F_1 and F_2 generation respectively. The different estimate obtained I F_1 and F_2 generation grow in the same environment may be attribute to the restricted sampling in the total variability available in F_2 or may be due to linkage. Robinson et al.,(1960) reported that if there
was preponderance of repulsion phase of linkage, additive genetic variance could increase (i.e. non-additive to additive) as the generation were advance and if the linkage phase was predominantly coupling, additive genetic variance could decrease (i.e. additive to non-additive). The estimated value of $\sigma^2_g$ were higher than those of $\sigma^2_g$, $\sigma^2_r$ indicating the predominance of additive gene action for days to 50% flowering, in F1 generation; plant height in F2 generation. Which indicated the predominance of additive gene action for these characters. Singh et.al. (2004). The value of $\sigma^2_{sca}$ and $\sigma^2_{rca}$ were higher than those of $\sigma^2_g$, indicating the predominance of non-additive gene action for number of primary branch, capsule size, day to maturity, number of seed per capsule, 1000 seed weight, oil content, all fatty acids in both generation; seed yield per plant in F2 generation. The ratio $\sigma^2_g/ \sigma^2_s$ was observed more than unity or closer to unity for days to 50 % flowering in F1 and plant height and number of primary branch in F2 generation which showed preponderance of additive gene action while rest traits showed preponderance of non-additive gene action.

**Combining ability**

**General combining ability**

The information regarding gca effect of parents is of prime importance as is help in successful prediction of genetic potentiality of crosses which produce desirable individuals in segregating generation as the choice of parents for hybridization is normally based on per se performance. The gca effect of parents was identified as good general combiner for all the characters in both generation. Parent KL-213 was found good general combiner for characters stearic acid, oleic acid and linoleic acid; OLC-60 was found good general combiner for characters plant height, days to 50% flowering, oil content, palmitic acid and stearic acid; Padmini was found good general combiner for characters plant height, days to 50% flowering, number of capsule per plant, capsule size, days to maturity, 1000 seed weight, seed yield per plant, oil content and oleic acid; RKY-19 was found good general combiner for characters plant height, days to 50% flowering, number of capsule per plant, capsule size, days to maturity, 1000 seed weight, seed yield per plant, oil content and oleic acid; SJKO-50 was found good general combiner for characters days to maturity and 1000 seed weight; TL-11 was found good general combiner for number of capsules per plant and linolenic acid; TL-27 was found good general combiner for leaf area, oil content and linolenic acid.

It indicated that per se performance of parents would provide an indication of their general combining ability for the utilization of them in hybridization programme.

The analysis of variance table for Method 1, Model I (parents and one set of F1s and its reciprocal) with expectations of mean sum of square is as follows

| Source     | df    | S.S.  | M.S.S. | Expectations of M.S.S. | 'F' test |
|------------|-------|-------|--------|------------------------|----------|
| Gca        | (n-1) | $S_g$ | $M_g$  | $\sigma^2_e+2n/(n-1)\sigma^2_g$ | $M_g/M_e$ for n-1, (b-1)(c-1)(r-1)df |
| Sca        | n(n-1)/2 | $S_s$ | $M_s$  | $\sigma^2_e+2/n(n-1))\sigma^2_{sij}$ | $M_s/M_e$ for n(n-1)/2, (b-1)(c-1) (r-1)df |
| reciprocals | n(n-1)/2 | $S_r$ | $M_r$  | $\sigma^2_e+2/n(n-1))\sigma^2_{rji}$ | $M_r/M_e$ for n(n-1)/2, (b-1)(c-1) (r-1)df |
| Error      | (b-1)(c-1) (r-1) | $S_e$ | $M_e'$ | $\sigma^2_e$ | |

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Table 1 (a) Analysis of variance for combining ability in 8 parent diallel cross (parents and their F\textsubscript{1}s) among 16\textsuperscript{th} characters in Linseed

| Source of variation | d..f. | Plant height (cm) | Day to 50\% flowering | leaf area | No. of primary branch | No. of capsules per plant | Capsule size (mm) | Days to maturity | No. of seed per capsule |
|---------------------|------|------------------|-----------------------|-----------|----------------------|-------------------------|-------------------|----------------|------------------------|
| GCA                 | 7    | 291.90**         | 151.17**              | 0.08**    | 0.63**               | 494.68**                | 0.34**            | 39.97**        | 1.23**                 |
| SCA                 | 28   | 19.34**          | 5.41**                | 0.02**    | 0.34**               | 103.06**                | 0.06**            | 14.34**        | 0.55**                 |
| reciprocal          | 28   | 12.01**          | 11.83**               | 0.55**    | 0.32**               | 7.74**                  | 0.09**            | 6.71**         | 0.60**                 |
| Error               | 126  | 0.75             | 0.96                  | 0.00      | 0.08                 | 2.86                    | 0.03              | 1.52           | 0.14                   |
| $\sigma^2$ g        |      | 18.19            | 9.38                  | 0.00      | 0.03                 | 30.73                   | 0.01              | 2.40           | 0.06                   |
| $\sigma^2$ s        |      | 18.58            | 4.45                  | 0.01      | 0.25                 | 100.19                  | 0.03              | 12.82          | 0.41                   |
| $\sigma^2$ reciprocal|     | 5.63             | 5.43                  | 0.00      | 0.12                 | 2.44                    | 0.02              | 2.59           | 0.23                   |
| ($\sigma^2$ g/ $\sigma^2$ s) |   | 0.97             | 2.10                  | 0.25      | 0.13                 | 0.53                    | 0.18              | 0.16           |                        |

| Source of variation | d..f. | 1000 seed weight | Seed yield per plant | Oil content % | Palmitic acid | Stearic acid | Oleic acid | Linoleic acid | Lenolenic acid |
|---------------------|------|------------------|---------------------|--------------|--------------|-------------|------------|--------------|---------------|
| GCA                 | 7    | 2.45**           | 4.52**              | 19.67**      | 6.20**       | 15.91**     | 29.94**    | 31.72**      | 102.83**      |
| SCA                 | 28   | 1.09**           | 1.18**              | 4.74**       | 15.49**      | 19.58**     | 9.19**     | 22.20**      | 40.23**       |
| reciprocal          | 28   | 0.39**           | 0.59**              | 3.06**       | 13.36**      | 9.34**      | 22.82**    | 12.03**      | 22.41**       |
| Error               | 126  | 0.03             | 0.01                | 0.30         | 0.40         | 0.35        | 0.41       | 0.31         | 0.47          |
| $\sigma^2$ g        |      | 0.15             | 0.28                | 1.21         | 0.36         | 0.97        | 1.84       | 1.96         | 6.39          |
| $\sigma^2$ s        |      | 1.06             | 1.17                | 4.43         | 15.09        | 19.23       | 8.78       | 21.88        | 39.76         |
| $\sigma^2$ reciprocal|     | 0.18             | 0.28                | 1.37         | 6.47         | 4.49        | 11.20      | 5.86         | 10.97         |
| ($\sigma^2$ g/ $\sigma^2$ s) |   | 0.14             | 0.24                | 0.27         | 0.02         | 0.05        | 0.21       | 0.08         | 0.16          |

Note: * significant at p=0.05 and ** significant at p=0.01
**Table 1 (b)** Analysis of variance for combining ability in 8 parent diallel cross (parents and their F$_2$s) among 16$^\text{th}$ characters in Linseed

| Source of variation | d..f. | Plant height (cm) | Day to50%flo wering | leaf area | No. of primary branch | No.of capsules per plant | Capsule size(mm) | Days to maturit y | No. of seed / capsule |
|---------------------|-------|------------------|----------------------|----------|-----------------------|------------------------|------------------|------------------|----------------------|
| GCA                 | 7     | 231.46**         | 44.62**              | 0.04**   | 0.37*                 | 382.89**              | 0.40**           | 77.48**          | 0.57*                |
| SCA                 | 28    | 9.24**           | 6.20**               | 0.03**   | 0.15                  | 38.49**               | 0.18**           | 8.23**           | 1.08**               |
| reciprocal          | 28    | 14.35**          | 6.77**               | 0.06**   | 0.34**                | 23.55**               | 0.12**           | 10.89**          | 1.16**               |
| Error               | 126   | 0.58             | 0.61                 | 0.00     | 0.14                  | 3.28                   | 0.03             | 0.88             | 0.22                 |
| $\sigma^2_g$        |       | 14.43            | 2.75                 | 0.00     | 0.01                  | 23.72                  | 0.02             | 4.78             | 0.02                 |
| $\sigma^2_s$        |       | 8.66             | 5.59                 | 0.02     | 0.01                  | 35.21                  | 0.14             | 7.35             | 0.86                 |
| $\sigma^2_{\text{reciprocal}}$ |     | 6.88             | 3.07                 | 0.02     | 0.09                  | 10.13                  | 0.04             | 5.00             | 0.47                 |
| $\left(\sigma^2_g/ \sigma^2_s\right)$ |     | 1.66             | 0.49                 | 0.10     | 1.11                  | 0.67                   | 0.15             | 0.65             | 0.02                 |

| Source of variation | d..f. | 1000 seed weight | Seed yield per plant | Oil content % | Palmitic acid | Stearic acid | Oleic acid | Linoleic acid | Lenolenic acid |
|---------------------|-------|------------------|----------------------|--------------|--------------|--------------|------------|---------------|----------------|
| GCA                 | 7     | 2.04**           | 2.84**               | 29.38**      | 12.41**      | 13.39**      | 17.29**    | 31.62**       | 120.26**       |
| SCA                 | 28    | 0.49**           | 0.57**               | 8.77**       | 14.10**      | 6.57**       | 12.27**    | 16.25**       | 38.04**       |
| reciprocal          | 28    | 0.77**           | 0.87**               | 8.63**       | 12.17**      | 11.76**      | 10.59**    | 7.99**        | 50.14**       |
| Error               | 126   | 0.01             | 0.01                 | 0.24         | 0.37         | 0.38         | 0.36       | 0.38          | 0.53          |
| $\sigma^2_g$        |       | 0.12             | 0.17                 | 1.82         | 0.75         | 0.81         | 1.05       | 1.95          | 7.48          |
| $\sigma^2_s$        |       | 0.48             | 0.55                 | 8.52         | 13.73        | 6.19         | 11.90      | 15.86         | 37.51         |
| $\sigma^2_{\text{reciprocal}}$ |     | 0.37             | 0.43                 | 4.19         | 5.90         | 5.69         | 5.11       | 3.80          | 24.80         |
| $\left(\sigma^2_g/ \sigma^2_s\right)$ |     | 0.26             | 0.31                 | 0.21         | 0.05         | 0.13         | 0.08       | 0.12          | 0.19          |

Note: * significant at p=0.05 and ** significant at p=0.01
Table 2 Estimates of mean performance and gca effect of 8 diallel parents for 16th characters in Linseed

| Parents  | Plant height (cm) | Day to 50% flowering | leaf area | Number of primary branch |
|----------|-------------------|----------------------|-----------|-------------------------|
|          | GCA effect        | Mean | GCA effect | Mean | GCA effect | Mean | GCA effect | Mean |
|          | F₁ F₂    |       | F₁ F₂    |       | F₁ F₂    |       | F₁ F₂    |       |
| KL-213   | 3.12** | 3.93** | 86.53 | 3.92** | 2.38** | 82.33 | -0.07** | -0.02 | 1.04 | 0.28** | 0.10 | 5.33 |
| OLC-60   | -1.79** | -1.33** | 73.76 | -2.51** | -1.12** | 68.33 | -0.07** | -0.03 | 1.21 | -0.06 | 0.04 | 5.33 |
| PADMINI  | -9.10** | -7.25** | 59.43 | -4.49** | -2.14** | 67.33 | -0.05** | -0.06** | 1.27 | -0.17* | -0.20** | 5.33 |
| RKY-19   | -2.30** | -3.49** | 68.66 | -3.41** | -2.20** | 66.66 | 0.05*  | 0.09** | 1.55 | -0.00 | 0.00 | 5.00 |
| S-36     | 1.74 | 1.92** | 79.90 | 2.60** | 0.60** | 78.00 | 0.04*  | 0.01 | 1.49 | 0.18** | 0.06 | 5.33 |
| SJKO-50  | 3.21** | 0.88** | 80.76 | 0.71** | 1.29** | 75.66 | -0.06** | -0.03 | 1.26 | -0.00 | 0.00 | 5.33 |
| TL-11    | 2.80** | 3.17** | 81.36 | 1.92** | 1.04** | 77.66 | 0.09** | 0.00 | 1.61 | 0.12 | 0.21* | 6.33 |
| TL-27    | 2.30** | 2.16** | 82.36 | 1.25** | 0.13 | 76.33 | 0.07** | 0.05** | 1.71 | -0.33** | -0.24** | 5.00 |
| SE±(Gi)  | 0.48 | 0.42 | 0.54 | 0.43 | 0.05 | 0.04 | 0.16 | 0.21 |
| SE±(Gi-Gj) | 0.72 | 0.63 | 0.82 | 0.65 | 0.07 | 0.07 | 0.24 | 0.32 |

Table 2 Continued

| Parents | Number of capsules per plant | Capsule size (mm) | Days to maturity | No. of seed per capsule |
|---------|-----------------------------|-------------------|-----------------|-------------------------|
|         | GCA effect | Mean | GCA effect | Mean | GCA effect | Mean | GCA effect | Mean |
|         | F₁ F₂    |       | F₁ F₂    |       | F₁ F₂    |       | F₁ F₂    |       |
| KL-213  | -4.47** | -4.87** | 62.66 | -0.18** | -0.23** | 6.00 | 1.28** | 2.67** | 144.33 | -0.06 | 0.19 | 8.00 |
| OLC-60  | -0.82*  | 1.00* | 74.33 | -0.19** | -0.09* | 6.16 | 0.09 | -1.43** | 133.0 | 0.00 | 0.06 | 8.33 |
| PADMINI | 11.48** | 10.54** | 86.33 | 0.19** | 0.29** | 6.83 | -1.65** | -1.41** | 128.33 | 0.39** | 0.21 | 8.00 |
| RKY-19  | 1.67** | -1.35** | 70.66 | -0.06 | -0.11* | 6.26 | -2.23** | -2.26** | 131.66 | 0.28** | -0.28* | 9.00 |
| S-36    | -4.82** | -1.91** | 71.66 | 0.00 | 0.09* | 6.83 | -0.38 | -0.80** | 132.33 | -0.38** | -0.16 | 8.00 |
| SJKO-50 | -353** | -4.02** | 66.66 | 0.19** | 0.03 | 7.00 | -0.88** | -1.89** | 131.66 | 0.09 | 0.00 | 7.33 |
| TL-11   | 3.79** | 2.52** | 80.00 | 0.02 | 0.00 | 7.06 | 1.64** | 2.85** | 139.00 | 0.05 | 0.15 | 8.00 |
| TL-27   | -3.28** | -1.89** | 63.66 | 0.03 | 0.03 | 6.53 | 2.12** | 2.27** | 138.00 | -38** | -0.18 | 7.33 |
| SE±(Gi) | 0.93 | 1.00 | 0.10 | 0.10 | 1.03 | 0.51 | 0.20 | 0.26 |
| SE±(Gi-Gj) | 1.41 | 1.51 | 0.15 | 0.15 | 0.68 | 0.78 | 0.31 | 0.39 |
### Table 2 Continued

| Parents | 1000 seed weight | Seed yield per plant | Oil content % | Palmitic acid |
|---------|------------------|----------------------|---------------|--------------|
|         | GCA effect | Mean | GCA effect | Mean | GCA effect | Mean | GCA effect | Mean |
| F<sub>1</sub> | F<sub>2</sub> | F<sub>1</sub> | F<sub>2</sub> | F<sub>1</sub> | F<sub>2</sub> | F<sub>1</sub> | F<sub>2</sub> | F<sub>1</sub> | F<sub>2</sub> |
| KL-213  | -0.53** | -0.34** | 4.51 | -0.52** | -0.38** | 3.15 | -1.06** | -1.24** | 33.54 | -0.62** | -0.38** | 6.72 |
| OLC-60  | -0.06 | -0.17* | 5.72 | -0.00 | 0.15** | 4.56 | 0.48** | 0.39** | 39.26 | 1.26** | 0.43** | 13.19 |
| PADMINI | 0.52** | 0.45** | 7.40 | 1.52** | 0.88** | 5.30 | 1.93** | 2.69** | 42.52 | -0.57** | 0.23 | 8.55 |
| RKY-19  | -0.16** | -0.50** | 5.05 | 0.11** | -0.29** | 3.65 | 1.59** | -0.69** | 36.38 | -0.36* | 0.43** | 8.92 |
| S-36    | -0.01 | -0.07* | 6.82 | -0.46** | -0.08** | 4.44 | -0.27* | -1.44** | 34.65 | 0.34* | -0.06 | 11.46 |
| SJKO-50 | 0.55* | 0.51** | 7.89 | 0.12** | 0.04 | 3.75 | 0.50** | 0.02 | 36.67 | 0.00 | -0.08 | 6.86 |
| TL-11   | -0.41 | 0.14** | 5.84 | -0.02 | 0.09** | 4.13 | -0.55** | -0.67** | 38.68 | 0.25 | 1.23** | 19.00 |
| TL-27   | 0.11 | -0.12* | 7.00 | -0.36** | -0.14** | 3.66 | 0.56** | 0.94** | 40.28 | -0.33* | -1.81** | 6.38 |
| SE±(Gi) | 0.10 | 0.06 | 0.06 | 0.07 | 0.46 | 0.41 | 0.53 | 0.51 |
| SE±(Gi-Gj) | 0.15 | 0.10 | 0.09 | 0.11 | 0.30 | 0.27 | 0.35 | 0.33 |

### Table 2 Continued

| Parents | Stearic acid | Oleic acid | Linoleic acid | Linolenic acid |
|---------|--------------|------------|---------------|---------------|
|         | GCA effect | Mean | GCA effect | Mean | GCA effect | Mean | GCA effect | Mean |
| F<sub>1</sub> | F<sub>2</sub> | F<sub>1</sub> | F<sub>2</sub> | F<sub>1</sub> | F<sub>2</sub> | F<sub>1</sub> | F<sub>2</sub> |
| KL-213  | 0.58** | 0.29* | 5.85 | 0.99** | 0.69** | 20.38 | 0.77** | 1.11** | 14.54 | -1.48** | -1.74** | 52.49 |
| OLC-60  | 1.33** | 0.53** | 13.35 | -0.80** | -0.01 | 14.51 | 0.99** | -0.46** | 9.46 | -2.46** | -0.41* | 49.50 |
| PADMINI | -0.44** | -0.45** | 7.62 | 1.42** | 1.22** | 20.43 | -1.44** | -0.93** | 4.73 | -0.06 | -0.06 | 58.66 |
| RKY-19  | -0.98** | 0.19 | 8.27 | 0.04 | 0.42** | 12.66 | 1.00** | 1.08** | 21.58 | 0.48** | -2.15** | 48.55 |
| S-36    | 1.23** | 0.87** | 10.75 | -1.09** | -0.53** | 10.60 | 2.16** | 0.40** | 12.54 | -2.24** | -0.77** | 54.63 |
| SJKO-50 | -0.38** | 0.95** | 5.95 | 1.92** | -0.01 | 19.28 | -0.68** | 2.11** | 17.30 | -1.71** | -2.98** | 50.60 |
| TL-11   | 0.08 | -0.61** | 10.20 | -2.08** | -2.21** | 8.73 | -1.29** | -1.39** | 13.42 | 3.25** | 3.00** | 48.63 |
| TL-27   | -1.41** | -1.78** | 5.41 | -0.41** | 0.43** | 17.43 | -1.53** | -1.92** | 13.45 | 4.23** | 5.12** | 57.31 |
| SE±(Gi) | 0.33 | 0.34 | 0.35 | 0.33 | 0.31 | 0.34 | 0.38 | 0.40 |
| SE±(Gi-Gj) | 0.49 | 0.51 | 0.54 | 0.50 | 0.47 | 0.52 | 0.57 | 0.61 |

Note: * significant at p=0.05 and ** significant at p=0.01
### Table 3: Heterosis range, number of desirable hybrids and best hybrids (better parental) for 16 traits in linseed

| Traits                        | Heterosis type | Heterosis range   | Number of desired hybrids | Best hybrids                |
|-------------------------------|----------------|-------------------|---------------------------|-----------------------------|
| Plant height (cm)             | BP             | -30.08 to 8.30    | 48                        | KL-213 x Padmini            |
| Days to 50% flowering         | BP             | -21.00 to 1.17    | 35                        | S-36 x TL-11                |
| Leaf area                     | BP             | -26.60 to 43.85   | 6                         | KL-213 x OLC-60             |
| Number of primary branches per plant | BP         | -21.05 to 40.00   | 13                        | TL-27 x RKY-19              |
| Number of capsules per plant  | BP             | -4.04 to 23.58    | 26                        | TL-27 x RKY-19              |
| Capsule size                  | BP             | -14.15 to 9.19    | 1                         | OLC-60 x KL-213             |
| Days to maturity              | BP             | -12.24 to 2.50    | 34                        | TL-11 x KL-213              |
| Number of seeds per capsule   | BP             | -18.52 to 25.00   | 8                         | Padmini x S-36              |
| 1000 grain weight             | BP             | -18.50 to 33.29   | 19                        | KL-213 x OLC-60             |
| Seed yield per plant (g)      | BP             | -27.78 to 71.73   | 26                        | RKY-19 x SJKO-50            |
| Oil content (%)               | BP             | -17.17 to 13.28   | 5                         | SJKO-50 x OLC-60            |
| Palmitic acid                 | BP             | -81.86 to 125.36  | 13                        | TL-27 x SJKO-50             |
| Stearic acid                  | BP             | -78.80 to 107.34  | 10                        | KL-213 x TL-27              |
| Oleic acid                    | BP             | -60.44 to 54.17   | 7                         | RKY-19 x S-36               |
| Linoleic acid                 | BP             | -90.90 to 76.48   | 9                         | Padmini x OLC-60            |
| Lenolenic acid                | BP             | -28.24 to 36.72   | 17                        | RKY-19 x TL-11              |
Combining ability describes the breeding value of parental lines to produce hybrids (Romanus et al., 2008). The general combining ability has been equated with additive gene action and specific combining ability with non-additive gene action (Griffing 1956 a). The analysis of variance for combining ability was done for all the 16 characters (Table 2). Highly significant variances, of general, specific and reciprocal combining ability, were observed which indicated the importance of both additive and non-additive gene effects for all the traits both generations.

**Specific combining ability effects**

In general, sca effects do not make any worthwhile contributions in the improvement of self-fertilizing crops expect where there is possibility of commercial exploitation of heterosis. Breeders’ interest normally, however, rests in obtaining transgressive segregants through crosses in order to produce homozygous lines in autogamous crops like linseed. Jinks and Jones (1958) further emphasized that superior *per se* performance of the hybrids might indicate their ability to produce transgressive hybrids may not indicate their ability to between heterosis and non-segregants due to close correspondence between heterosis and non-additive gene effects. Therefore, study of sca and rca in segregating generating generation would be a better preposition for heterosis breeding. Padmini $\times$ SJKO-50 for plant height; KL-213 $\times$ OLC-60, KL-213 $\times$ RKY-19, S-36 $\times$ SJKO-50 for leaf area; KL-213 $\times$ SJKO-50, KL-213 $\times$ S-36, S-36 $\times$ TL-11 number of primary branch per plant; RKY-19 $\times$ TL-11, Padmini $\times$ TL-27, KL-213 $\times$ Padmini for number of capsules per plant; S-36 $\times$ TL-27 for capsule size; Padmini $\times$ RKY-19 for day to maturity; OLC-60 $\times$ SJKO-50, RKY-19 $\times$ TL-11 number of seed per capsule; OLC-60 $\times$ SJKO-50, Padmini $\times$ RKY-19, RKY-19 $\times$ SJKO-50, TL-11 $\times$ TL-27 and KL-213 $\times$ S-36 for 1000 seed weight; Padmini $\times$ RKY-19, OLC-60 $\times$ SJKO-50, Padmini $\times$ TL-27, KL-213 $\times$ Padmini for seed yield per plant; Padmini $\times$ S-36, KL-213 $\times$ Padmini for oil content; Padmini $\times$ TL-27, SJKO-50 $\times$ TL-11, Padmini $\times$ S-36 for palmitic acid; OLC-60 $\times$ Padmini, OLC-60 $\times$ S-36, SJKO-50 $\times$ TL-11 for stearic acid; Padmini $\times$ TL-11 for oleic acid; RKY-19 $\times$ S-36, KL-213 $\times$ S-36 for linoleic acid and RKY-19 $\times$ TL-27, RKY-19 $\times$ TL-11, Padmini $\times$ TL-11 for linolenic acid were found good specific combiner as well as *per se* performance in *F*₁ population. Padmini $\times$ SJKO-50 for plant height; Padmini $\times$ TL-11, Padmini $\times$ TL-27 for days to 50% flowering; SJKO-50 $\times$ TL-27 for leaf area; KL-213 $\times$ S-36 for number of primary branch per plant; OLC-60 $\times$ TL-11, KL-213 $\times$ Padmini, Padmini $\times$ TL-27 number of capsules per plant; S-36 $\times$ TL-27, Padmini $\times$ SJKO-50 for capsule size; S-36 $\times$ SJKO-50, RKY-19 $\times$ SJKO-50 for days to maturity; OLC-60 $\times$ TL-27, Padmini $\times$ S-36 number of seed per capsule; Padmini $\times$ S-36, OLC-60 $\times$ TL-27, RKY-19 $\times$ SJKO-50 for seed yield per plant; RKY-19 $\times$ S-36, SJKO-50 $\times$ TL-11, Padmini $\times$ TL-27 for oil content; Padmini $\times$ RKY-19, OLC-60 $\times$ TL-11, KL-213 $\times$ SJKO-50 for palmitic acid; S-36 $\times$ SJKO-50, KL-213 $\times$ SJKO-50 stearic acid; OLC-60 $\times$ S-36, Padmini $\times$ TL-27, OLC-60 $\times$ TL-11, RKY-19 $\times$ TL-27 for oleic acid; KL-213 $\times$ Padmini, OLC-60 $\times$ RKY-19, S-36 $\times$ SJKO-50 for linoleic acid and KL-213 $\times$ TL-27, S-36 $\times$ TL-27 linolenic acid were found good specific combiner as well as *per se* performance in *F*₂ population.

None of the crosses showed significant rca effects for the characters with the expression of plant height. The significant rca effects for days to 50% flowering in S-36 $\times$ Padmini; leaf area in OLC-60 $\times$ KL-213; number of seeds per capsule in TL-27 $\times$ RKY-19, TL-11 $\times$ RKY-19; oil content Padmini $\times$ KL-213;
palmitic acid in TL-27 × Padmini; stearic acid in TL-11 × SJKO-50. Oleic acid in TL-11 × Padmini; linoleic acid in S-36 × KL-213; linolenic acid in TL-11 × Padmini, TL-27 × RKY-19 in F1 generation. Day to 50% flowering in TL-11 × KL-213; number of primary branches per plant in S-36 × KL-213; number of capsules per plant in Padmini × KL-213, TL-11 × RKY-19; number of seeds per capsule in S-36 × Padmini; 1000 seed weight in RKY-19 × OLC-60; seed yield per plant in TL-27 × OLC-60, SJKO-50 × RKY-19; oil content in S-36 × RKY-19, TL-11 × SJKO-50; palmitic acid in TL-11 × OLC-60; oleic acid in TL-27 × Padmini, TL-11 × OLC-60; linoleic acid in RKY-19 × OLC-60 in F2 generation. It is noteworthy that the crosses, showing consistently positive sca effects also exhibited positive significant heterosis. Thus, the results of the present study indicated some relationship between sca effects and heterosis. It is therefore suggested that sca performance may be considered as a criterion for selecting the best crosses in linseed. It may also be worthwhile to attempt bi-parental mating in the segregating generation among selected crosses to permit superior recombinations.

All the important crosses involving parents with high × average, average×/average and average×/low general combiners, indicated that non-additive type of gene actions, which are unfixable in nature were involved in selected cross combinations. The study demonstrates that both additive (fixable) and non-additive (non-fixable) components of genetic variances were involved in governing the inheritance of almost all the quantitative and quality traits, although additive genetic variance was predominant. Therefore, bi-parental mating and diallel selective mating which may allow intermating of the selects in different cycles and exploit both additive and non-additive gene effect could be useful in the genetic improvement of the characters of linseed. Inclusion of F1 hybrids showing high sca and having parents with good gca, into multiple crosses, could also be a significant approach for tangible improvement of almost traits.

Heterosis

Heterosis breeding plays an important role in crop improvement for obtaining higher production. The degree of heterosis should preferably be measured by superior in F1 hybrid over batter parent or best commercial variety. In the present investigation, heterosis was over batter parents for all the sixteen characters studied were found with all crosses. A wide variation of heterosis range, number of desired hybrids and best hybrid was found for most of the traits (Table 3). Singh et al., (2004) stated that the superiority of hybrids particularly over high parent is more useful for commercial exploitation of heterosis and also indicated the parental combinations capable of producing the highest level of transgressive segregants.

References

Dillman, AD., 1953. Classification of flax varieties, 1946 US Dept. of Agriculture, 1953.Series Information. Technical Bulletin/UnNited States Department of Agriculture.no. 1064. US Dept of Agriculture, Washington.

Griffing B. 1956 a. Concepts of specific and general combining ability in relation to diallel crossing systems. *Australian Journal of Biological Sciences* 9: 463–93.

Jinks, J.L. and Jones, J.M. (1958). Estimation of components of heterosis. *Genetics.* 43: 223-234.

Romanus K G, Hussein S and Mashela W P. 2008. Combining ability analysis and association of yield and yield components among selected cowpea lines. *Euphytica* 162: 205–10.
Singh H, Sharma S N and Sain R S. 2004. Heterosis studies for yield and its components in bread wheat over environments. *Hereditas* 141: 106–14.

Singh, H-C; Dixit, R-K; Pathak, R-K; Rajendra-Singh; Nalini-Tiwari (2004) Genetic analysis of quality traits in linseed (*Linum usitatissimum* L.).

Viorica Mirela Popa, Alexandra Gruia Diana Raba, Delia Dumbrava, Camelia Moldovan, Despina Bordean, Constantin Mateescu (2012) Fatty acids composition and oil characteristics of linseed (*Linum usitatissimum* L.) Banat’s University of Agricultural Sciences and Veterinary Medicine, 300645 Timisoara, Calea Aradului, 119, Romania.

**How to cite this article:**

Shalendra Kumar, P.K. Singh, S.D. Dubey, S.K. Singh and Alankar Lamba. 2017. Heterosis and Combining Ability Analysis Oil Content Seed Yield and Its Component in Linseed. *Int.J.Curr.Microbiol.App.Sci.* 6(11): 1504-1516. doi: [https://doi.org/10.20546/ijcmas.2017.611.178](https://doi.org/10.20546/ijcmas.2017.611.178)