COMBINING ABILITY ANALYSIS FOR YIELD AND YIELD CONTRIBUTING TRAITS IN LINSEED (*Linum usitatissimum* L.)

THESIS

Submitted to
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
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By
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2022

DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the Thesis entitled, **"COMBINING ABILITY ANALYSIS FOR YIELD AND YIELD CONTRIBUTING TRAITS IN LINSEED (*Linum usitatissimum* L.)"** or part thereof has neither been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis / publication of any University or scientific organization. The source of materials used and all assistance received during the course of investigation have been duly acknowledged.

Place: Nagpur **(Shinde Jyoti Govind)**

Date: 28 / 10 /2022 Enrolment No. SS/3065

CERTIFICATE

This is to certify that thesis entitled **"COMBINING ABILITY ANALYSIS FOR YIELD AND YIELD CONTRIBUTING TRAITS IN LINSEED (*Linum usitatissimum* L.)"** submitted in partial fulfilment of the requirements for the degree of **"Master of Science in Agriculture (Agricultural Botany)"** of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola is a record of bonafide research work carried out by Shinde Jyoti Govind under my guidance and supervision.

The subject of the thesis has been approved by the Students Advisory Committee.

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(B) Abbreviations

%	:	Per cent
/	:	Per
AB	:	Alternaria Blight
AICRP	:	All India Coordinated Research Project
ALA	:	Alpha linolenic acid
ANOVA	:	Analysis of variance
C.D.	:	Critical difference
CVD_s	:	Cardiovascular disease
C.V.	:	Coefficient of variation
$Capsule^{-1}$	:	Per capsule
Cm	:	Centimetre
d.f.	:	Degrees of freedom
et al.	:	et alia (and associates)
etc	:	Etcetera
F	:	Disease free
g	:	Grams
GCA/gca	:	General combining ability
ha	:	Hectors
i.e.	:	that is

Kg/kg	:	Kilogram
Mb	:	Megabase
Mg	:	Milligram
MR	:	Moderately resistant
MS	:	Moderately susceptible
No./no	:	Number
Plant^{-1}	:	Per plant
R	:	Resistant
R. B. D.	:	Randomized Block Design
S	:	Susceptible
S. E. ±	:	Standard error
SCA/sca	:	Specific combining ability
Viz.,	:	Namely
vs	:	Verses

(C) THESIS ABSTRACT

a)	Title of the thesis	:	**"COMBINING ABILITY ANALYSIS FOR YIELD AND YIELD CONTRIBUTING TRAITS IN LINSEED (*Linum usitatissimum* L.)"**
b)	Full name of student	:	**SHINDE JYOTI GOVIND**
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ABSTRACT

The research consisted of fifteen diverged parents of linseed (*linum usitatissimum* L.) which were crossed following diallel mating design (Griffing's 1956) Model I Method II to generate one hundred and five crosses (excluding reciprocals). These fifteen parents and their 105 F_1s crosses were evaluated in randomized block design having three replications during *rabi* 2021-22 at the farm of AICRP on linseed and mustard, College of Agriculture, Nagpur. The data were recorded on five observational plants for nine quantitative characters *Viz*., days to 50% flowering (days), days to maturity (days), plant height (cm), number of branches plant^{-1}, number of capsules plant^{-1}, 1000 seed weight (g), seed weight plant^{-1} (g) to estimate general combining ability of parents and specific combining ability of crosses for yield and yield contributing characters and to select potential parents and crosses for linseed breeding programme.

The analysis of variance of parents revealed highly significant mean squares for all the characters studied indicating presence of considerable genetic diversity among the parents. The analysis of variance for parents and crosses revealed mean squares were significant for all the nine characters studied indicating substantial genetic variability among the parents and crosses which allows further estimation of experimental material.

The data of high mean performance for seed yield plant^{-1} were exhibited by parents JRF 2 (4.33**g) followed by Mutant-2 (4.03**g), Mutant-4 (3.47**g), Arpita (3.11**g). The cross PKV NL 260 × Indira Alsi-32 (8.73**g) followed by Mutant-2 × Kota Barani 3 (5.99**g) showed highest significant mean performance for seed yield plant^{-1}. The parents Mau Azad Alsi-2, Kota Barani 4, Indira Alsi-32 showed lower mean performance for bud fly infestation and were found to be resistant to bud fly infestation.

Analysis of variance for combining ability revealed that mean squares due to GCA and SCA were significant for all the characters studied. The predictability ratio ranged from 0.49 to 0.81. The ratio was found closer to unity, greater the predictability based on general combining ability alone.

Identification of parents on the basis of general combining ability and high mean performance gives high proportion of superior segregants. Based on mean performance and GCA effects of parental lines, the genotypes Kota Barani-3, TL 99, Indira Alsi-32, Neela were found to be the best general combiners for seed yield plant^{-1}, 1000 seed weight, number of capsules plant^{-1}. The parent Mutant-2 showed high significant mean performance and found to be good general combiner for seed yield plant^{-1}, 1000 seed weight. Seven parents namely PKV NL 260, Neela, Indira Alsi-32, JLS 95, Mau Azad Alsi-2, TL 99 possessed negative significant GCA effects for bud fly infestation and were found to be good general combiners for bud fly infestation. Hence Neela on crossing with JLS 95 and Mau Azad Alsi-2 can be used to produce transgressive segregants for yield and bud fly resistance in hybridization programme.

The crosses showing high mean performance, high gca effects of the parents involved in the cross and sca effects may serve as better source of population for deriving superior segregants. Among the one hundred and five crosses, the crosses PKV NL 260 × Indira Alsi-32, Kota Barani 4 × Arpita, PKV NL 260 × Neela, Mutant-2 × TL 99, Mau Azad Alsi-2 × TL 99, JLS 79 × Pratap Alsi 1, Neela × Mutant-4, JLS 95 × Mau Azad Alsi-2, JLS 9 × Mau Azad Alsi-2, JLS 95 × Kota Barani 3, JRF 2 × Kota Barani 3, JLS 95 × Kota Barani 4, Neela × JRF 2 possessed significant negative SCA effects for seed yield plant^{-1}, number of capsules plant^{-1},1000 seed weight. These crosses also recorded high significant or non significant mean performance for seed yield plant^{-1}, number of capsules plant^{-1} and 1000 seed weight. These cross combination possesses significant or non significant GCA effect

for one or both parents involved in the cross. The presence of negative SCA effects for several yield components in the above crosses indicates the presence of predominant role of additive gene action for yield components, which is general situation observed in the self-pollinated crop. These crosses therefore found to be best crosses which can be forwarded to the next generation for their use in varietal breeding programme in linseed.

Chapter I

INTRODUCTION

1.1 Background information

Oilseed crops occupy prestigious place in Indian agriculture due to their vital role in the sustainable economy of the country. Linseed (*Linum usitatissimum L*.) is an annual autogamous diploid (2x=2n=30, genome size~ 370 Mb) oilseed crop belonging to *Linaceae* family growing during *rabi* season in India. It has been under cultivation for seed and its fibre 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). Two morphologically distinct cultivated species of linseed are recognised namely, flax and linseed. The flax type is commercially grown for the extraction of fibre, whereas the linseed is meant for extraction of oil from seed.

Every part of the linseed plant is utilized commercially either directly or after processing. Its seed is rich source of fat (41%), protein (20%), dietary fibre (28%). It serves as a good source of minerals especially, Phosphorous (650 mg/100g), Magnesium (350-431 mg/100g), Calcium (236-250 mg/100g) and has very low sodium (27 mg/100g). (Bunga and Pragnya 2020). Flax is gluten free. Linseed oil is widely available botanical source of 75 per cent polyunsaturated fatty acids, 57 per cent alpha-linolenic acid (ALA), which is omega 3 fatty acid and 16 per cent linoleic acid, which is an omega 6 fatty acid. (Ekka *et al.* 2017*).* Omega-3 and omega-6 fatty acid, act as brain tonic known to cure the diseases like cardiovascular disease (CVD_S), diabetes, rheumatoid arthritis, cancer and major depression. Linseed oil is richest source of lignan, a group of plant substance known as phytoestrogen-natural anticancer agent. (Singh *et al.* 2016). It is extensively used for its seed, oil cake, fibre, and medicinal value. Seed contain oil ranging from 35 to 45%. Linseed oil possesses superior drying qualities due to high linolenic acid content which renders it as an indispensable

ingredient in paint and varnish, and the manufacture of linoleum, oil cloth, printers ink, patent leather and few other products. However low linolenic acid containing cultivars of flax have been also developed which directly used as edible oil. The linseed oil cake is a good feed for milch cattle and poultries. The flax stem yields fibre of good quality having high strength non-elasticity, repeated flexibility, a low density etc. which make it very attractive and suitable to use as a rope and thread that can be easily blended with cotton, jute, hemp to enhance textile properties (Nirala *et al.* 2018).

Area production and productivity of linseed during 2020-2021

Canada leads the world, followed by China, India, America, Ethiopia, and Egypt at (34, 25.5, 9.8, 3.5, 2.2%), respectively, of global production of linseed (Jassiml *et al.* 2021). In our country the crop occupies 1.83 lakh ha area with a production and productivity of about 1.11 lakh tonnes and 605 kg/ha respectively.

Season/Year/Region (2020-21)		**Area (ha)**	**Production (tonnes)**	**Productivity (kg/ha)**
Rabi	**India**	183000	111000	605
	Maharashtra	5160	1499	267
	Vidarbha	4847	1292	264

(Anonymous, 2021)

In India Madhya Pradesh ranks first in yield and acreage followed by Uttar Pradesh, Maharashtra, Bihar, Rajasthan, Karnataka, and West Bengal. Madhya Pradesh and Uttar Pradesh together contributes to national linseed production to the extent of about 70%. In Maharashtra linseed is grown on 5.16 thousand hectares with production of 1.499 thousand tonnes and having productivity of 267 kg/ha. In Vidarbha districts the crop occupies area of 4.847 thousand ha with production of 1.292 thousand tonnes and productivity of 264 kg/ha.

The major causes behind low production of linseed are that the crop is cultivated mostly in rainfed marginal lands and also due to the biotic and abiotic stresses. More than 36 insect pest are associated with linseed or flaxseed throughout the world. Among the all insect of linseed, budfly (*Dasynuera lini* Barnes) is the most important insect. It affect the buds of linseed. The infested buds become hollow and unproductive which leads to reduce the crop yield drastically. However, yield losses due to bud fly (*Dasyneura lini Barnes*) have been reported ranging between 17-49% with an average of 40 % at national level. Such heavy losses in seed yield due to bud fly incidence can be reduced up to some extent by manipulations in agronomic practices, but the successful management of this pest by the use of systemic insecticides is quite easy, encouraging and cost effective especially in late sown crop. The resistant varieties are one of the fundamental, widely accepted and eco-friendly tools of integrated pest management. (Rizwan *et al.* 2018, Pal and Malik 2018a). Linseed is adversely affected by different diseases. Alternaria blight is a major disease which causes heavy loss from 28 to 60 per cent in terms of quality and quantity of fibre and seed of linseed. Alternaria blight of linseed was first reported by Day from Kanpur, Uttar Pradesh in 1933. Alternaria blight caused by *Alternaria lini* and *Alternaria linicola*. The most economic means of managing this disease of linseed would be the use of resistant varieties (Kumar *et al.* 2018, Das *et al.* 2016).

The success of any hybridization programme chiefly depends on combining ability of parents used in crossing programme. Selection of superior segregants followed by the selection of the best ones are the basic tasks of any breeding process. To initiate an effective breeding programme, combining ability analysis is a powerful tool to identify parents with better potential to transmit desirable characteristics to the progenies and to identify the best specific crosses for yield parameters. The concept of combining ability plays a significant role in crop improvement as it helps the breeder to study and compare the performance of the new line in hybrids combination it provides the base

to select good combiners and also to understand the nature of gene action. Griffings method of diallel analysis provides reliable information on the nature and magnitude of gene defects that contribute to the expression of various threats and helps plant breeder to select appropriate parents for hybridization and producing desirable transgressive segregants (Nirala *et al.,* 2018).

1.2 Importance of study

In any crop improvement programme, the choice of the parents having abundant potential for hybridization is one of the critical task for breeder. Selection of appropriate inbreds helps in exploitation of maximum genetic variability and production of superior recombinant genotypes. The choice is relatively straight forward when qualitative traits is under consideration, but quantitative traits like yield, do not allow any such easy handling. The common approach of selecting parents on the basis of *per se* performance, adaptation and diversity does not necessarily lead to fruitful results because the ability of parents to combine well with each other depends upon the complex interactions among the genes. Therefore, the selection of the best parents for hybridization has to be based on the knowledge of combining ability of the parents. There are two types of combining abilities examined in biometrical genetics: general combining ability (GCA) and specific combining ability (SCA) (Sprague and Tatum 1942). Breeders face the challenge of selecting parents and crosses for both quantitative and qualitative qualities in crop development initiatives. Plant breeders typically utilize combining ability tests to analyse the nature of gene action involved in the inheritance of specific traits and to evaluate parental lines for their usefulness in crosses. The estimation of GCA helps in the selection of suitable parents for hybridization whereas SCA helps in the identification of superior cross combinations. Thus, combining ability analysis is a paramount tool to identify parents with better potential to transmit desirable characteristics to the progenies and selection of best combiners and

provides opportunity for the use of these combiners in hybridization programme. Crop yield increase necessitates a thorough understanding of the combining capacity of available parents for hybridization programs, as well as the nature of gene action involved in the expression of economically important quantitative features.

All these can be achieved by using suitable hybridization programme such as diallel mating design. Diallel is the pronounced approach to evaluate several genotypes and obtaining useful information on differential parental combinations through an assessment of the overall genetic architecture of parental lines in relation to the characters studied. 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 yield and yield contributing characters. 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 . General combining ability (GCA) and Specific combining ability (SCA) effects determine the potential of parent / cross for mobilizing them in an efficient breeding programme. The additive portion of the total variance is included in the variance for general combining ability, whereas the non-additive fraction of the total variance is included in the variance for specific combining ability, which is caused by dominance and epistatic deviations. Specific combining ability is a key measure of an inbred line's ability to produce superior hybrid combinations.

There is a need to develop varieties resistant to pests and diseases to stabilize the yield potentials of linseed varieties. Therefore, this research work helps in developing varieties resistant to pest and diseases to stabilize the yield potentials of linseed varieties. The manipulation of inherent potentials of plants in the form of resistant

varieties is a cheap, viable and environment friendly alternative to reduce losses from biotic stress.

1.3 Objectives

In view of the above facts, the present investigation entitled "Combining ability analysis for yield and yield contributing traits in linseed *(Linum usitatissimum* L.*)*" was implemented with the following objectives:

1) To estimate the GCA effects of parents and SCA effects of crosses.

2) To identify promising parents and crosses for further utilization in linseed breeding programme.

1.4 Scope and limitations

Srivastava *et al.* (1997) reported that linseed crop suffers from several diseases and insect pest in India. The significant yield losses occurs in linseed due to bud fly *(Dasyneura lini)* (20 to 60%), and alternaria blight (*Alternaria lini*) & powdery mildew (*Odium lini*) (up to 60%) and rust. Resistant varieties is a cheap, viable and environment friendly alternative to reduce losses from biotic stress. Therefore, there is a need to develop varieties resistant to pests and diseases to stabilize the yield potentials of linseed varieties. This has also adverse effect of drought and high temperature (about 32° C) during and after flowering stage that reduce yield, seed size, oil content of linseed. The limitations faced during implementation and the success of this programme were as follows:

1) Success rate of crossing

2) Percentage of seed set after crossing

3) Germination of crossed seeds

1.5 Hypothesis

This study of combining ability analysis will help in identification of parents with better potential to transmit desirable traits to the progenies and selection of best combiners and provides opportunity for the use of these combiners in hybridization programme. The development of varieties for higher yield with resistant against biotic or abiotic stress than existing varieties is the main aim of linseed breeding. This research work will also help in identifying the parents and their crosses which are resistant to bud fly and alternaria blight, which can be forwarded to next generation and help in development of superior varieties.

Chapter II

REVIEW OF LITERATURE

The literature cited on the present investigation has been reviewed under the following heads:

2.1 Half diallel analysis

2.1.1 Combining ability

2.2 Disease and pest studies

2.2.2 Bud fly

2.2.3 Alternaria blight

2.1.1 Combining ability

The ability of genotype to transmit the desirable traits to its progenies is termed as combining ability. Combining ability analysis is an important tool for selection of desirable parents together with the information regarding nature and magnitude gene effect controlling quantitative traits of economic importance. Sprague and Tatum (1942) proposed the idea of partionating genetic variance in to variation due to general combining ability (GCA) and specific combining ability (SCA). According to them, the general combining ability (GCA) “is the average performance of a line in a series of hybrid combination” and specific combining ability (SCA) “as those cases in which certain combination do relatively better or worse than would be expected on the basis of average performance of the lines involved”. They also suggested that GCA is expected to be the result of additive gene effects and epistatic interactions involving additive effects. While SCA is more dependent on genes with dominant and epistatic effect which are not included in general combining ability effects.

The breeding programmes aim at the development of superior varieties as well as the production of hybrid varieties the combining

ability analysis quite useful. The review of literature on combining ability studies in linseed the more relevant to the present study is presented below.

Mishra and Rai (1996) studied ten diverse varieties of linseed were crossed in all possible combinations excluding reciprocals. Seeds of parents and their 45 F_1s were sown under in RBD with three replications. Combining ability analysis was done by Method 2, Model 1 of Griffing. It revealed highly significant variances for gca and sca × E for all the characters and sca and gca × E for all the traits except oil content. Among the parents, T 397 proved to be a good general combiner for seed yield plant^{-1}, Neelum for palmitic acid and stearic acid, LCK 152 for oil, linoelic acid. In sca effects, the crosses SPC 23-10 × LC 185 for seed yield plant^{-1}, oleic acid and low content of linolenic acid and Neelum × R 17 for iodine value and higher linolenic acid.

Popescu *et al*. (1999) studied set of 66 direct hybrids, in F_1s generation, obtained in a half diallel system by crossing 12 parental linseed (*Linum usitatissimum* L.) genotypes to determine the general combining ability (GCA) and the specific combining ability (SCA). ANOVA for combining ability showed that both GCA and SCA were very significant for all traits analysed, whereas GCA variances were in all cases prevailing as compared to SCA variances. On the basis of GCA for all the traits studied the best parental genotypes were found L-5312-93, L-3060-91 and L-6106-94. The two hybrid combinations L-6529-90 / L-5312-93 and L-3060-91 / L-8254-91 were superior specific hybrids for three traits (boll number / m^2, seed yield plant^{-1} and oil yield).

Khan *et al*. (1999) evaluated six genotype of linseed crossed in a half diallel fashion to study combining ability analysis for seed yield and five components of seed yield. Significant GCA effects and SCA effects were noted for all traits. Highly significant mean squares due to genotypes (parents and hybrids) indicated that considerable genetic

diversity was present in the experimental material for six traits. Parents Chandni and LS-53 were identified as useful progenitors for the development of better yielding varieties. Chandni × P-250, LS-53 × P-250, LS-53 × LS-13, LS-53 x LS-62, Chandni × LS-62 and Chandni × LS-53 depicted positive SCA effect for seed yield and for at least one seed yield component. These crosses are expected to generate relatively higher degree of desirable segregants.

Srivastava *et al*. (2007) studied combining ability analysis using half diallel mating design involving 10 parents and their F_1 crosses for some metric and quality traits in linseed to derive the information on the relative magnitude of general and specific combining ability effects. The high magnitude of GCA and SCA effects indicated the presence of both additive and non-additive gene interactions. Parents were observed to be good general combiners for seed yield and they also showed good combining ability for days to 50 % flowering, days to maturity, no. of capsules plant^{-1}, 1000 seed weight, seed yield plant^{-1}.

Mohammadi *et al.* (2010) studied the analysis of variance due to genotypes for all the characters. They were found to be significant for all characters like days to 50 % flowering, days to maturity, plant height, primary branches plant^{-1}, number of capsules plant^{-1}, number of seeds capsule^{-1}, seed yield plant^{-1}, 1000 seed weight, seed yield and harvest index which indicated highly significant differences among the genotypes. Significant general combining ability (GCA), specific combining ability (SCA) and reciprocal effects revealed meaningful contributions of additive, non-additive type of gene actions and maternal influence in governing the traits. The results showed that additive gene actions had greater effects on inheritance of days to flowering, days to maturity, plant height and 1000 seed weight. However, number of capsules plant^{-1} were largely controlled by dominance genetic effects, whereas both additive and non-additive gene actions were important in genetic control of harvest index, seed yield plant^{-1}.

Shikha *et al.* (2011) studied combining ability analysis of yield components was worked out using diallel mating design to check out nature and magnitude of gene action to isolate good combiners for improvement of Linseed. The significance of gca and sca variances reflected the importance of both additive and non-additive gene actions for plant height, number of primary branches plant^{-1}, number of secondary branches plant^{-1}, number of capsules plant^{-1}. 1000 seed weight and seed yield plant^{-1}. However the estimates of sca variances were lesser than gca variances showing predominance of additive gene action in inheritance of traits. Parents Shubhra, EC 1424, and TL-27 were found to be good general combiners for number of capsules plant^{-1}, seed yield plant^{-1} and 1000 seed weight over the generations. The cross Shubhra × JRF 5, FRW- 1 × EC-1424, Shubhra × Ayogi, Shubhra × FRW 1 and FRW 1 × TL-27 were most promising crosses over the generations for improvement of seed yield.

Kumar *et al*. (2013) crossed ten parental lines namely Parwati, Ayogi, J-23, Shekhar, Himalini, T-397, Heera, Padmini, Garima, and J-17 in diallel fashion (excluding reciprocals). The experiment for raising parents and F_1 were conducted in RBD with three replications. Combining ability analysis was done following Griffing (1956 b) Method 2 Model 1. The analysis of variance revealed highly significant differences among parents themselves and F_1s for almost all traits studied. Parwati and Padmini had highly positive and significant GCA effect and was considered as good GCA, for oil content. Parents *Viz*., T-397 and Shekhar exhibited significant GCA effect. T-397 with maximum GCA effect found to be best general combiner. The cross Parwati × Himalini and Parwati × Shekhar were the best combinations for the oil content.

Yadav *et al.* (2014) selected seven potential genotypes and were crossed using diallel analysis (excluding reciprocals) for assessment of variability, heterosis, combining ability and gene action on seed yield and its components. Parents RLC-92 and Kritika would

prove good general combiner for seed yield and its components. Good Specific combiners for characters of economic importance were IA-32 × R-552 for seed yield plant^{-1}, oil content and earliness. RLC-92 × Kiran for seed yield plant^{-1}, oil content. RLC-92 × Deepika for seed yield plant^{-1}, oil content and harvest index.

Moneam *et al.* (2014) crossed six genotypes of flax representing different agronomic characters in a diallel model. The six parents and their 15 F_1 crosses were evaluated to study combining ability and mode of gene action for yield and its component traits in flax. Results indicated clearly that mean squares of genotypes, GCA and SCA were highly significant for all studies traits and their combined data except GCA for number of capsules plant^{-1} in both seasons were not significant. The best GCA were P1 (S2) for straw yield, plant height and technical length, P5 (Harmis) for seed and straw yield, P4 (Bleinka) for seed yield plant^{-1} and 1000 seed weight. Eight crosses and nine crosses showed significant or highly significant and positive sca effects for seed yield plant^{-1} and straw yield plant^{-1} respectively indicating that these crosses were the best combinations for increasing seed yield and straw yield.

Singh *et al.* (2016) evaluated twenty eight hybrids developed from eight genotypes of linseed through diallel mating design (excluding reciprocal) along with one check *Viz*., Shekhar. These crosses along with parents were evaluated in randomized block design to estimate the general combining ability (GCA) of the parents and specific combining ability (SCA) of hybrids considered for the development of high yielding varieties. The ANOVA for combining ability revealed significant mean sum of squares due to GCA and SCA for all traits under study. Genotype EC-1392 (0.50) and TL-11 (0.45) has been found to be good general combiners with highest magnitude of GCA effects for seed yield plant^{-1}. In addition to above, EC-1392 and TL-11 also showed good GCA effects for plant height, capsules plant^{-1} and biological yield plant^{-1}. Hybrids A.95.B × Shekhar (2.43), TL-

11 × EC-1392 (1.71) and NDL-2004-05 × GS-234 (1.53) showed higher positive significant SCA effects for seed yield plant^{-1}.

Singh *et al.* (2016) estimated combining ability estimates for yield and related traits of 45 F_1 and 45 F_2 progenies derived from 10 parent half diallel mating design. The GCA:SCA ratio revealed predominance of additive gene effects in both the generations except seed weight in F_1 and husk weight and oil content in F_2 generation. Among all the parents, EC-1392, JLS 9 and JWR-17 were the best general combiners for branches plant^{1}, capsules plant^{-1} and seeds capsule^{-1} and average to high combiners for other traits in both the generations.

Shalini *et al.* (2016) obtained the F_1s by crossing all eight parents in half diallel fashion. These crosses then evaluated along with parents and check, T-397. The experiment was laid out in Randomized Block design with three replications. The mean squares of General and Specific combining ability were highly significant for most of the characters under study. The ratio of gca variance to that of sca variance were less than unity for all characters. Four parents *Viz.,* Padmini, LMS-149-4, JLS 9 and KL-221 showed positive GCA effect among which Padmini, LMS-149-4 and JLS 9 showed highly significant positive GCA effect and observed to be good general combiners for seed yield plant^{-1} as well as oil content. The specific combining ability (sca) effects for seed yield plant^{-1} varied between -1.10 (Meera × JLS-9) and 2.32 (JLS-9 × KL-221).

Sedhom *et al.* (2016) estimated GCA and SCA effects in half diallel set of six parents. GCA and SCA were evaluated according to Griffing (1956) Method 2 Model 1. Results indicated that genotypes along with crosses mean squares were significant for all studied traits. GCA and SCA were found significant for all studied traits. GCA and SCA ratio revealed the predominance of additive and additive × additive gene action in controlling most of the traits.

Nirala *et al.* (2018) generated 28 crosses from eight diverse parents of linseed (*Linum usitatissimum* L.) in diallel mating design (excluding reciprocal) and were evaluated against Shekhar as check in randomized block design for nine quantitative traits, to estimate the general combining ability (GCA) of the parents and specific combining ability (SCA) of crosses. Analysis of variance revealed that the genotypes differed genetically from each other for all the nine characters studied. Combining ability analysis revealed that mean square due to GCA and SCA for days to 50% flowering, days to 50% maturity, plant height, number of primary branches, number of seeds capsule^{-1}, oil percent and grain yield were significant. The magnitude of GCA variance was higher than SCA variances for all traits which indicate preponderance of the additive gene effects for these characters.

Shekhar *et al*. (2019) studied combining ability analysis of 10 × 10 diallel (excluding reciprocal) on a set of 45 crosses for yield and its contributing characters. ANOVA for combining ability revealed the preponderance of additive gene effects for all the traits. On the basis of good gca effects for seed yield and other characters, Nagarkot was found to be a good general combiners for plant height, number of secondary branches plant^{-1}, number of capsules plant^{-1}, number of seed capsule^{-1}, seed yield plant^{-1}, and harvest index. On the basis of sca effects and performance promising crosses *Viz.,* Nagarkot × Shurbhi, Shurbhi × NDL-2004-05, PKDL × Chambal, T-397 × Shekhar and T-397 × Chambal were found suitable for seed yield improvement.

Ghige *et al.* (2020) carried out line × tester analysis using 34 lines and 3 testers in linseed. On the basis of SCA effects and performance promising crosses NL 448 × T 397, NL 436 × PKVNL 260 were found good specific combiners for seed yield plant^{-1}. The predictability ratios ranged from 0.433 to 0.876. Predictability ratio found close to unity which indicated the predominance of additive genetic component for development of studied characters.

Divya *et al.* (2020) studied eight parents of linseed which were crossed as per half diallel analysis (Model 1 and Method 2) to generate 28 crosses (excluding reciprocals). These crosses were evaluated along with eight parents and three checks *Viz.,* T-397, Neelum and Allahabad local in RBD having three replications. The significant mean square for all 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. Analysis of variance for combining ability revealed significant differences for all characters. The parents FRW-6 (973) and POLF-19 (1765) were good general combiners for seed yield and most of the traits. The highest positive SCA effect for seed yield plant^{-1} was expressed by the cross PbD-42 (2789) × GS -129 (1018).

Ahmad *et al*. (2021) synthesized twenty eight offspring by crossing eight diverse parents in a diallel scheme excluding reciprocals. These twenty eight crosses along with eight parents and one national check T-397 were sown. Differences among genotypes were highly significant for most of the characters under study. Four parents *Viz.,* Neelum, Divya, Surbhi and RLC-171 showed highly significant positive general combining ability effects. Divya showed highly significant positive gca effects and found good general combiner for seed yield plant^{-1}. Sixteen crosses showed positive SCA in which ten crosses showed highly significant and positive SCA effect. While cross combination Divya × RLC-171 exhibited positive and significant SCA effect for maximum character under study.

Suvarnlata *et al.* (2021) studied a set of ten genotypes of linseed and their forty five F_1s in diallel design excluding reciprocals in RBD. ANOVA showed highly significant differences among the genotypes for all characters studied. Four parents *Viz.,* NL 115, Neelam, Tiara and PKV NL 260 possessed positive significant gca effects and NL115 and PKVNL -260 were found to be good general combiners for seed yield plant^{-1}, number of capsules plant^{-1} and 1000 seed weight. Among the

45 crosses studied, the crosses NL 165 × Neelam, NL 142 × Padmini, EC 99001 × PKV NL 260, NL 367 × Tiara were found most promising as they possessed high mean performance, significant SCA effect for seed yield plant^{-1}, number of capsules plant^{-1} and 1000 seed weight.

Jassiml *et al.* (2021) studied eight flax genotypes and which were crossed as per half diallel mating design to estimate the combining ability and its general and specific effects for parents. Analysis of variance revelled that the parents were significant at the level of probability (1%) for the traits, days to 50% flowering, plant height, number of capsules plant^{-1}. As for the crosses it was significant at the level of probability (1%) for traits, number of branches plant^{-1}, seed yield plant^{-1}, total seed yield. The values of the dominant genetic variance were higher than the additive genetic variance in all traits except for plant height, days to maturity, and number of seed plant^{-1}, indicating the importance of the dominant gene action in controlling these traits.

Mahawar *et al*. (2021) synthesized twenty eight hybrids by crossing eight genotypes of linseed through diallel mating design (excluding reciprocal) along with checks and were evaluated in RBD with three replications to estimate the general combining ability (GCA) of the parents and specific combining ability (SCA) of hybrids. Significant General Combining Ability (GCA) and Specific Combining Ability (SCA) effects were noted for all the traits. Mean square due to both GCA and SCA were significant for seed yield and all other component characters. Non-significant GCA and significant SCA were observed indicated that these traits are controlled by non additive gene effects. Highly significant mean squares due to genotypes (parents and hybrids) indicated that considerable genetic diversity was present in the experiment for all twelve characters.

Achila *et al.* (2022) studied combining ability analysis for seed yield plant^{-1}, oil, and quality traits in a diallel set of eleven parents and their 55 F_1s. The analysis of variance revealed that the parents and

hybrids exhibited significant differences between treatments for all the characters, indicating a considerable amount of variability among the genotypes. The ratio of gca variance to that of sca variance was less than unity for almost all the traits except omega-6, suggesting that these traits were governed by non-additive gene action. T-397 proved to be the best general combiner for seed yield plant^{-1}, Shubhra for oil content and iodine value, omega-6 and omega-3. In sca effects, the crosses Sweta × T-397 for seed yield plant^{-1}, oil content, and Sweta × LC 185 for omega were found promising.

2.2.3 Bud fly

Linseed budfly is one of the most serious pests of linseed crop which occurs regularly as most destructive specific pest, not only on floral buds but also on leaf at the growing tips of the young plants. The extent of damage has been noticed from 13.6 to 75.8 per cent on flower buds (Jakhmola and Yadav, 1983).

It attacks the crop during flowering stage by infesting flower buds. The maggots of bud fly feed upon the reproductive parts of the flower buds. The infested buds turn hollow due to crumpling of the corolla and their reproductive parts become emaciated at green bud stage. These buds remain unfertilized and no seed formation take place. Complete failure of crop due to this pest has also been observed under epidemic conditions.

Such quantum of yield losses can be kept at bay through the adoption of bud fly resistant linseed varieties which would sustain the crop in the country. Among the various factors responsible for low productivity, biotic constraints play a significant role. A wide range of chemicals are being used to control the biotic stresses. But the chemicals besides being uneconomical and health hazard, do not provide permanent solution. Henceforth, incorporation of genetic resistance is a cheap, viable and eco-friendly alternative to reduce losses from biotic stresses.

A brief review of work pertaining to bud fly resistance in linseed are presented below.

Singh and Ramanand (2000), screened previously identified 12 tolerant linseed germplasms along with a susceptible control (Neelum) for bud fly *Dasyneura lini* resistance under natural conditions in U.P., India in *rabi* seasons of 1996-97 and 1997-98. The mean bud infestation ranged from 4.08 to 19.32 per cent among tested germplasm lines. Three lines *Viz*., Bengal sel-12, Cl-2200 and KB-96-10 showed resistance to the bud fly whereas, the remaining nine germplasm lines found as moderately resistant. It was concluded that these three resistant germplasms can be used in breeding programmes for the development of bud fly resistant varieties of linseed.

Tripathi *et al*. (2002) conducted screening of linseed germplasms against the bud fly (*Dasyneura lini*). Germplasm were categorised based on their degree of infestation: 0-10 per cent = resistant; 10.01-25.00 per cent = moderately resistant; 25.0-40.00 per cent = moderately susceptible; 40.01-60.00 = per cent susceptible; and above 60.01 per cent highly susceptible. Among the germplasm accessions, only 8 entries namely 2817, 2821, 2823, 2862, 2865, 2869 and 2873 proved the most promising against linseed bud fly infestation.

Ramakant *et al.* (2008) screened 250 linseed germplasm lines for resistances to bud fly and alternaria blight under artificial epiphytotic condition. Six genotypes NDL-2004, NDL-2005-03-02, EC-22704, EC41623, NDLS-169 and NDLS-164 showed resistant reaction against Alternaria blight and budfly. Neela showed susceptibility to bud fly and alternaria blight infestation.

Pal and Singh *et al.* (2010) conducted study on variety screening to identify the resistant source against bud fly. One hundred genotypes of linseed were screened under natural conditions in two consecutive years (2008-09 and 2009- 10) during *rabi* season. The

genotypes were sown three week delayed from the normal sowing. The infester rows of susceptible check (Neelum) were planted after each ten rows. On the basis of calculated data of bud fly incidence, the varieties were categorized into five reactions *Viz.*, resistant, moderately resistant, susceptible, moderately susceptible and highly susceptible. Out of one hundred germplasms, only three lines *Viz*., RL-49-4-5, RLC-33-4 and RL-15-1 were showing consistently resistant to bud fly and twenty lines namely, R-31, R-76, R-966, R 1141/41, R-1156, Raisen local, RCC-7, RH-41, K-4, RL-8-4, RL-9-2, RL-15-1, RL-34-1, RL-45-1, RLC-2, RLC-5, RLC29, RLC-29 (K), T-397, RLC-33-5 and RLC-47 were found moderately resistant to bud fly. Rest of lines were found to be susceptible, moderately susceptible and highly susceptible to bud fly.

Shaik *et al. (*2012) studied genetic analysis of bud fly resistance in linseed a highly selected lines of linseed were used to assess the genetics of bud fly resistance. The male parents Kiran, Nagarkot and Himani were good general combiners for bud fly resistance. The female PKV NL 260 and Neelam may be used for improvement bud fly and alternaria blight resistance. The parent Kiran was identified as good general combiner for bud fly resistance and alternaria resistance. The crosses *Viz.*, Padmini × T-397, Neelum × Deepika showed low bud fly infestation percentage.

Singh *et al.* (2015) studied the genetic analysis to determine the mode of inheritance of resistance to bud fly which is a key pest of linseed during flowering stage. Parents, F_1 , F_2 , BC_1 and BC_2 populations of three crosses involving two resistant, IC 15888 and JRF 4 and two susceptible parents, *Viz*., Neelum and GS-41. Reaction to bud fly in F_1s of all the three crosses indicated that resistance was dominant over susceptibility. The F_2 and back cross segregants were categorized in to resistant and susceptible classes based on *per se* bud infestation. The genetic analysis in F_2 generation revealed that two dominant complementary genes in IC 15888 to control the bud fly

resistance, while JRF 4 carried a single dominant gene for resistance. The F_2 results were confirmed by genetic analysis of back cross populations. It can be categorically stated that the knowledge of number and nature of resistance genes in IC 15888 and JRF 4 will be valuable for development of bud fly resistant varieties in linseed.

Sahoo, S. K. (2016) conducted field trial under natural condition to screen thirty four genotypes of linseed against bud fly. It is evident that among the germplasm lines, bud fly infestation ranged from 6.8 – 36.1%. Entries of Ireland (T flax), NDL-2011-23 and RLC -148 were found resistant with bud fly infestation up to 10%. The results revealed that the some entries were moderately resistant to bud fly with > 10–25% damage. During the investigation the germplasms recorded as resistant to bud fly had bud size with lesser length (4.0-4.5 mm) and width (2.0-2.2 mm). These resistant lines may be used as a donor parents in the multiple resistance breeding programme of linseed.

Ekka *et al.* (2017) studied the seasonal incidence of linseed bud fly (*Dasyneura lini* Barnes*)* in Linseed ecosystem. The peak activity of linseed bud fly was observed during 12th and 10th standard meteorological week of year 2015-16 and 2016-17, respectively. During this period, minimum and maximum temperatures, Morning and evening relative humidity and sunshine hour were found favourable for maximum activity of the pest. Direct effect of maximum and minimum temperature and sunshine hour on its correlation with linseed bud fly, *D. lini* was very high and positive.

Pal and Malik (2018 a) screened two hundred eighty and eight germplasm/varieties of linseed against budfly infestation to study the bud structure of resistance of linseed against bud fly. The results indicated that the bud length and width showed significant positive correlation coefficient relationship (r=0.1559 and 0.0761) bud infestation. The resistant germplasm line had (GS-234) minimum bud length and width with relative minimum bud infestation of 6.88% and was statistically at par other resistant germplasm lines while

susceptible germplasm line (Arny) exhibited maximum bud length and width maximum bud infestation (65.11%) which was statistically at par with other susceptible lines. The increased bud structure (length and width) suffered maximum bud infestation as compared to small bud structure and was favourable for maggots population and extent of buds damage at green bud stage.

Pal and Malik (2018 b) evaluated a set of 288 elite germplasm/ varieties of genotypes of linseed during *rabi* 2011-12 and 2012-13. This trial was executed in Augmented Block Design consisting 18 blocks of 16 test entries in each block. Two checks i.e. Neela (Resistant check) and Neelum (SC) were also planted in each block. Categorization of linseed genotypes based on their bud fly infestation (BFI) into five groups i.e. resistant, moderately resistant, moderately susceptible, susceptible and highly susceptible. During first year, a number of 11, 164, 98, 15 and zero entries were grouped as resistant, moderately resistant, moderately susceptible, susceptible and highly susceptible, respectively, while 8, 146, 116, 18 and zero genotypes were rated in respective groups during second year. Common entries were also selected from each group and 8, 137, 82, 7 and zero genotypes were registered as resistant.

Pal and Malik *et al. (*2020) screened 288 germplasm of linseed against bud fly infestation to study the historical basis of resistance of linseed against bud fly. The results indicated that the sepal thickness possessed negative highly significant relationship (r=-07224) with bud infestation. The resistant germplasm line having maximum sepal thickness (0.49 mm) had relative minimum bud infestation (6.88%) and was statically at par other resistant germplasm lines *Viz.,* A-95B, CI-1385, EC-1392, EC-1424, GS-234, IC-15888 and JRF-5. While minimum sepal thickness (0.24 mm) with maximum bud infestation (65.11%) which was statically at par with other susceptible lines *Viz.,* Ajgan-20M, Ajgan-3-1, Alipur (Hamirpur), Anand, GS-148, GS-440, Gunawal Local, NP(RR) 193, RAULD-7810 , RLC-28 (PM), MS-14,

SJKO-45. The genotpes with minimum thickness of sepal suffered maximum bud infestation as compared to those with maximum sepal thickness.

2.2.2 Alternaria Blight

Singh *et al.* (2003) studied analysis of alternaria blight incidence in linseed using Hayman's and Griffing's, diallel procedures. Estimates of variance components showed significant value of additive and non-additive gene effects over generations in the inheritance of alternaria blight resistance. The significant F value with negative sign in F_1, generation revealed that recessive genes were more frequent in the expression of this trait. Average degree of dominance was less than unity over generations indicating partial dominance accompanied with high heritability in narrow sense. The analysis of combining ability variances also revealed the importance of both additive and non-additive-gene effects with the preponderance of additive gene action. The good general combiners for low incidence of alternaria blight were adjudged as best specific combiner over generations. The present investigation suggested that single plant selection would be more effective for the development of altenaria blight (AB) resistant varieties in linseed.

Kumar *et al*. (2012) worked on line × tester analysis with 10 lines and 4 testers to derive 40 F_1s hybrids and evaluated against alternaria blight and wilt disease in field under artificial epiphytotic conditions. 28 genotypes were found resistant, 23 moderately resistant and 3 moderately susceptible against alternaria blight.

Reddy *et al.* (2013) evaluated genotypes for resistance to bud fly, alternaria blight and powdery mildew of linseed. Padmini, Neelum and the cross Padmini × Neelum exhibit greater degree of resistance for budfly. Neelum showed least infestation for alternaria blight.

Singh *et al.* (2015) conducted a field experiment for managing alternaria blight of linseed with different dates of sowing and using host

resistance. The result revealed that highest incidence (35.90%) of disease was on first sowing date i.e. 28th October, which was gradually reduced in subsequent sowing dates and minimum disease was scored in treatment sown 9th December (6.87%). However, the significantly highest grain yield (547.6 kg ha^{-1}) was obtained in treatment sown on 18th November followed by 8th November and 28th October sown crop. Out of forty six varieties evaluated against *alternaria lini* were found resistant reaction to leaves. Neelum and Padmini cultivars were moderately resistant.

Das *et al.* (2016) evaluated the performance of promising lines of 24 promising lines / varieties of linseed with one susceptible check variety (Chambal) and one resistant check variety (Sheela) against alternaria blight under natural condition. All were identified with significantly lower disease intensity of Alternaria blight in leaf and bud. But Meera, Gaurav, EC-41590, A-202 and JRF 2 showed lowest percent disease intensity in leaf (<10%) as well as bud infection to the extent of 8.4, 8.0, 9.0, 7.5, 7.8% respectively. Screening of promising lines/varieties revealed that among 24 lines, none was found immune or highly resistant against alternaria blight of linseed. These lines / varieties can be used as good donor for evolving resistant varieties against alternaria blight in linseed.

Dash *et al.* (2016) screened two hundred and one genotypes of linseed including 60 local land races of Odisha and 231 cross derivatives and selections from different sources within and outside Odisha for resistance to Alternaria blight. All the entries were assessed visually based on percentage of leaf area affected using 0-5 scale. No entry was disease free, one entry ‘OL 2-7’ and ‘OL 4-1’ were moderately resistant, and the rest were moderately susceptible, susceptible or highly susceptible.

Kumar and Tripathi (2018) studied the resistance of 200 germplasm against alternaria blight under artificial epiphytotic conditions. Each germplasm was sown in second week of November in

single row of one meter length. Variety Raj 4015 was used as check and was sown after every 20 genotypes. Pure culture of pathogen was inoculated on genotypes by using cleaned sprayer, at evening. Disease data was recorded using double digit scale based on per cent blighted area on flag leaf and one leaf just below. Out of 200 genotypes, disease free (F) and highly susceptible (HS) germplasm were not found, 7 genotypes were found resistant (R), 66 were moderately resistant (MR), 102 were moderately susceptible (MS) and 25 were found susceptible (S) against blight disease of linseed.

Chapter III

MATERIALS AND METHODS

The present investigation “Combining ability analysis on yield and yield contributing characters in Linseed (*Linum usitatissimum* L.*)*” was carried out during *rabi* season of 2021-2022 at the farm of AICRP on linseed and mustard, College of Agriculture, Nagpur. The material used and methodology followed in this research work is described below:

3.1 Materials required

The experimental material required for present study comprised of 15 genetically diverse genotypes used to develop diallel set excluding reciprocals and the 105 crosses thus formed were sown following spacing of about 30 cm × 5 cm.

The parents used for crossing work along with their characteristic features given below.

Table 1. List of the parents

Sr. No.	Genotypes	Characters
1	PKV NL 260	High yield and tolerant to bud fly, high omega 3 content
2	Neela	Resistant to bud fly
3	Indira Alsi-32 (RLC-81)	Dwarf statured, moderately susceptible to *Alternaria* blight
4	JLS 9	Early maturity resistant to *Alternaria* blight, moderately susceptible to bud fly
5	JRF 2 (Tiara)	Resistant to bud fly
6	Mutant-2	High yield
7	Mutant-4	High yield
8	JLS 95	Moderately resistant to *Alternaria* blight and bud fly

9	JLS 79	Moderately resistant to *Alternaria* blight and bud fly
10	Mau Azad Alsi-2	Moderately resistant to bud fly and *Alternaria* blight
11	Kota Barani 4	Moderately resistant to *Alternaria* blight
12	Kota Barani 3	Moderately resistant to *Alternaria* blight and bud fly
13	Pratap Alsi 1	Early Maturity, Moderately resistant to *Alternaria* blight, bud fly
14	Arpita	Early maturity
15	TL 99	High yield and oil content, lower omega-3 content

3.2 Methods adopted

In *rabi* 2020-21, 15 diverse parental lines were crossed in all possible combinations excluding reciprocals to produce 105 crosses.

In *rabi* 2021-22, seeds of parents and their 105 crosses (F_1s) were sown in randomized block design with three replications. All the recommended agronomic practices were followed to raise a good crop.

Treatment details followed in experiment were as follows:

Design of experiment	Randomized block design (R.B.D.)
No. of replications	3
Number of genotypes	120 (105 crosses + 15 lines)
Spacing	30 cm × 5 cm
Plants under observation	5
Date of sowing	28/10/2021
Date of harvesting	As per the maturity.

Recommended cultural practices and plant protection measures were adopted as and when found necessary.

3.3 Recording of experimental data

Individual plant data were recorded on five randomly selected plants (except 50% flowering and days to maturity for which plot wise observations were recorded) from each replication for each genotype. The procedure followed for recording observations on each of the character are described below:

3.3.1 Quantitative traits

(a) On plot basis

1. Days to 50% flowering (days)

For each genotype number of days taken from the date of sowing to the day on which 50% of the plants showed flowering was recorded and expressed as number of days taken for 50% flowering.

2. Days to maturity (days)

The number of days taken by all the plants in each genotype to attain physiological maturity from the date of sowing was counted and presented as days of maturity.

(b) On plant basis

1. Plant height (cm)

Plant height was measured from ground level to the tip of the main stem of the plant at the time of maturity. Plant height divided into three classes namely, long (>70 cm), medium (51-70 cm) short (<51cm).The average height of the five plants was recorded as plant height in cm.

2. Number of branches plant^{-1}

The number of primary branches emerging from base of the plant was counted on the five randomly selected plants at the time of maturity and the average number of primary branches was noted.

3. Number of capsules plant^{-1}

The number of seeds bearing capsules borne by each plant of each genotype for five plants was counted at maturity and average was worked out and presented.

4. 1000 seed weight (g)

1000 well developed seeds from the bulk of plants selected were counted and weight was recorded in grams with the help of electronic balance. According to weight, it is grouped in 3 classes *Viz.* high (>8 g), medium (6-8 g), low (6 g).

5. Seed yield plant^{-1} (g)

All the capsules from each observational plant were picked up, threshed separately and the seed weight was recorded as seed yield plant^{-1}.

6. Bud fly infestation (%)

Individual observational plant was scored for bud fly infection. In each plant buds infected by bud fly (*Dasyneura lini*) were counted and percentage was taken from the total number of buds as follows (Anonymous 2018).

$$\text{Bud fly \%} = \frac{\text{Infected buds}}{\text{Total no. of buds}} \times 100$$

Arc sin transformation was used for data analysis.

7. Alternaria blight infestation (%)

Infected buds by *Alternaria lini* were counted in each plant and percentage was taken from the total number of buds (Anonymous, 2018).

$$\text{Alternaria blight \%} = \frac{\text{Infected buds}}{\text{Total no. of buds}} \times 100$$

Square root transformation was used for data analysis.

3.4 Statistical methods

The data were subjected to the following statistical and biometrical analysis.

1) Analysis of variance for experimental design (Panse and Sukhatme. 1954)

2) Analysis of variance for combining ability

   i) Estimation of general and specific combining ability effects

   ii) Standard Error

   iii) Critical Difference

3.4.1 Analysis of variance for the experimental design

The analysis of variance were performed to test the significance of differences between the genotypes (parents, crosses and checks) for all the characters as per the methodology suggested by Panse and Sukhatme (1954).

The statistical model used for the design was

$$Y_{ijk}=\mu + g_{ij} + b_k + e_{ijk}$$

Where,

Y_{ijk} = Phenotypic performance of ij^{th} genotype over k^{th} replication

μ = general mean

g_{ij} = the effect of ij^{th} genotype

b_k = effect of kth block

e_{ijk} = environmental effect

Analysis of variance for experimental design

Sources of variation	D.F	Mean squares	
		Observed	Expected
Replications	(r-1)	MS_r	$\sigma^2e+g\sigma^2r$
Genotypes	(g-1)	MS_g	$\sigma^2e+r\sigma^2g$
Error	(g-1)(r-1)	MS_e	σ^2e
Total	gr-1		

Where,

r= Number of replications

g= Number of genotypes

p= Number of parents

c= Number of crosses

e= Error

σ2= Sigma square

The significance of mean squares were tested against error variance by using 'F' test. The standard error of difference for comparing any two progeny means will be computed by using error variance of respective characters as follows:

$$\text{S.E. (Diff)} = \sqrt{\frac{\sigma^2 e}{r}}$$

The critical difference were computed by multiplying the standard error of difference with 't' values at error degrees of freedom at 0.05 and 0.01.

3.4.2 Analysis of variance for combining ability

The mathematical model for combining ability analysis (method -2 model -1) suggested by Griffings (1956) is assumed as:

$$X_{ij} = \mu + g_i + g_j + s_{ij} + \sum e_{ijk} + \frac{1}{K}\sum e_{ijk}$$

Where,

j = 1…….n

k = 1…….5

n = number of parental lines

μ = population mean

$g_i g_j$ = GCA effect of ith & j^{th} parent

e_{ijk} = error effect associated with ijk^{th} observation.

The restrictions,

$\sum_i \quad g_i = 0 \; and \; \sum_j \quad S_{ij} = 0$ (for each i) are imposed

The analysis of variance for combining ability based on above model was given below:

Source	**D.F.**	**S.S.**	**Mean Square**	**Expected mean square**
General combining ability	$(n-1)$	Sgca	Mg	$\sigma^2 e \cdot + (n+2)\left(\frac{1}{n-1}\right)\frac{\sum}{i} gi^2$
Specific combining ability	$\frac{n(n-1)}{2}$	Ssca	Ms	$e \cdot + \frac{2}{n(n-1)}\frac{\sum}{i}\frac{\sum}{j} Sij^2$
Within family Error	m	Sw		$\sigma^2 e'$

Where,

n = number of parents

m = g (k–1)

Me = mean square due to error

K = number of plants per genotype

The sum of squares was calculated as:

$$S_g = \frac{1}{n+2}\left[\sum_{i.}\left(x_i + x_{ij}\right)^2 - \frac{4}{n}x..^2\right]$$

$$S_s = \sum_i\sum_j x_{ij}{}^2 - \frac{1}{(n+2)}\sum(x_i + x_{ii})^2 + \frac{2}{(n+1)(n+2)}x..^2$$

Where,

S_g = sum of squares due to GCA

S_s = sum of squares due to SCA

n = number of parents

X_{ij} = value of cross between i^{th} and j^{th} parent

$x_{i.}$ = Total of ith array in diallel table or mean value of ith parents.

x.. = Total of all combinations.

Test of significance,

'F' test for GCA,

$$F_{[(n-1),m]} = \frac{Mg}{Me'}$$

'F' test for SCA,

$$F\left[\frac{n(n-1)}{n},m\right] = \frac{Ms}{Me'}$$

The relative importance of GCA vs. SCA was calculated for fixed effect model as suggested by Baker (1978).

GCA.vs.SCA = $\frac{2MSGCA}{2MSGCA + MSSCA}$

Where,

MS=Mean squares

i) Estimation of gca and sca effects

The effects were estimated as follows:

$$\mu = \frac{2}{n(n+1)}x..$$

GCA estimates of parent

gi = $\frac{1}{(n+2)}\ [x_{i.} + x_{ii} - \frac{2}{n}\ x..]$

SCA estimates of crosses $_{I \times j}$

$$S_{ij} = x_{ij} - \frac{1}{(n+2)}\left[x_{i.} + x_{ii} + x_{.j} + x_{ij}\right] + \frac{2}{(n+1)\ (n+2)}\ x..$$

ii) Standard Error

Standard error to test the significance of GCA and SCA estimates were calculated as follows:

S.E. for gca $\hat{e}$ffect :

$$S.E(gi) = \sqrt{\frac{(n-1)\sigma^2 e\cdot}{n\ (n+2)}}$$

S.E. for sca effect :

$$S.E.\ \hat{(}Sij) = \sqrt{\frac{n^2+n+2}{(n+1)\ (n+2)}\sigma^2 e\cdot}$$

iii) Critical Difference

CD = t = S.E

Where S.E= $\sqrt{Variance}$

And t =1.96 (at 5% level of significance)

Chapter IV

RESULTS AND DISCUSSION

The present investigation entitled “Combining ability analysis for yield and yield contributing traits in linseed (*Linum usitatissimum* L.)” was carried out using diallel mating design (without reciprocals) to estimate combining ability of important yield and yield contributing traits and to identify superior parents and cross combinations with desirable GCA and SCA effects for genetic improvement in linseed.

The results obtained on the different aspects of present study have been presented and discussed under following heads:

4.1 Analysis of variance for experimental design

4.2 Mean performance of parents and their crosses for various characters

4.3 Analysis of variance for combining ability

4.4 General and specific combining ability effects

4.5 Selection of promising crosses

4.1 Analysis of variance for experimental design

The data were subjected to analysis of variance to study the genetic difference among 15 parents and their crosses for nine traits for the year 2021-22. The analysis of variance of parents and analysis of variance of parents and crosses has been presented in Table 2a and 2 b respectively. The results are presented in Table 3a and 3b.

It is seen from table 2a that the data mean sum of squares due to the genotypes were highly significant for all nine characters studied *Viz.,* plant height (cm), number of branches plant^{-1}, number of capsules plant^{-1}, bud fly infestation (%), alternaria blight infestation (%), seed yield plant^{-1} (g), and 1000 seed weight (g), days to 50% flowering

(days), days to maturity (days) indicating substantial genetic variability for the traits studied.

It is seen from table 2b that the data mean sum of squares due to parents and crosses were highly significant for all nine characters studied *Viz*., plant height (cm), number of branches plant^{-1}, number of capsules plant^{-1}, bud fly infestation (%), alternaria blight infestation (%), seed yield plant^{-1} (g), 1000 seed weight (g), days to 50% flowering (days), days to maturity (days) indicating sufficient variability existed for traits studied. Similar results were also reported by Sedhom *et al.* (2016). Suvarnlata *et al.* (2021), observed highly significant mean squares for all characters like plant height, number of capsules plant^{-1}, 1000 seed weight, number of branches plant^{-1}, days to 50% flowering, alternaria blight infestation, days to maturity, seed yield plant^{-1}, capsule size (mm), seed length (mm) which indicated the presence of considerable genetic variation among the genotypes. Nirala *et al.* (2018), reported that analysis of variance showed that the genotypes differed genetically from each other for the characters *Viz*., plant height (cm), number of branches plant^{-1}, number of capsules plant^{-1}, bud fly infestation (%), alternaria blight infestation (%), days to 50% flowering, days to maturity, seed yield plant^{-1} (g) except 1000 seed weight (g). Kumar *et al.* (2013), found that analysis of variance revealed highly significant difference among parents themselves and F_1s for almost all characters studied. Ramakant *et al.* (2008), reported that Neela showed susceptibility to bud fly and alternaria blight infestation.

Table 2a. Analysis of variance of parents for nine characters

Sources of Variation	d.f.	Mean squares								
		Days to 50 % flowering (days)	Days to maturity (days)	Plant height (cm)	Number of branches plant^{-1}	Number of capsules plant^{-1}	1000 seed weight (g)	Seed yield plant $^{-1}$ (g)	Bud fly infestation (%)	Alternaria blight infestation (%)
Replication	2	7.49	24.62	1.92	0.04	50.11	0.86	0.03	2.25	0.06
Genotypes	14	112.51**	72.21*	823.11**	4.98**	2,437.05**	5.39**	1.32**	66.89**	0.79**
Error	28	7.94	33.10	18.72	0.05	44.96	0.20	0.19	1.84	0.08

Note: * Significant at 5% level, Significant at 1% level**

Table 2b. Analysis of variance of parents and crosses for nine characters

Sources of Variation	d.f.	Mean squares								
		Days to 50% flowering (days)	Days to maturity (days)	Plant height (cm)	Number of branches plant^{-1}	Number of capsules plant^{-1}	1000 Seed weight (g)	Seed yield plant $^{-1}$ (g)	Bud fly infestation (%)	Alternaria blight infestation (%)
Replication	2	7.26	1.00	30.85	0.08	83.12	0.18	0.02	23.30	0.21
Genotypes	119	32.22**	59.16**	468.82**	7.37**	2,256.59**	10.46**	4.29**	374.47**	16.49**
Error	238	6.57	22.92	13.98	0.06	44.25	0.17	0.11	12.03	0.38

Note: * Significant at 5% level , ** Significant at 1% level

4.2 Mean performance of parents and crosses for various characters

The mean performance of parents, parents and crosses for nine characters are presented in table 3.

1. Days to 50% flowering (days)

Among the parents days to maturity ranged from 49.33 days to 70.67 days. Mean performance of parent Neela (49.00** days) was found to be earliest for days to 50 % flowering followed by parents Indira Alsi-32, Mutant-4 and PKV NL 260 attained 50 % flowering in (49.33**) days. Late mean performance for this traits was recorded by JRF 2 (70.67 days), Kota Barani 4 (59.00 days), Kota Barani 3 (58.00 days).

Among the crosses studied, mean values for days to 50% flowering ranged from 49.33 days to 60.667 days. Crosses Arpita × TL 99 (49.33** days), PKV NL 260 × Indira Alsi-32 (49.33** days), PKV NL 260 × Mutant-4 (49.67** days), PKV NL 260 × TL 99 (49.67** days) was the earliest to attain days to 50% flowering. The crosses which attained days to 50% flowering late were PKV NL 260 × JLS 79 (61.0 days), JLS 95 × Mau Azad Alsi-2, JLS 79 × TL 99 (60.67 days) followed by JLS 79 × Pratap Alsi 1 (60.33 days).

2. Days to maturity (days)

Among the parents days to maturity ranged from 102.33 days to 117.67 days. The parents which matured earlier were Neela (102.33 days), Pratap Alsi- 1 (103.33 days), Arpita (103.67 days). The parent Kota Barani 4 (117.67 days) followed by Kota Barani 3 (115.33 days), Mau Azad Alsi-2 (114.67 days) matured late.

Among the crosses studied, mean values for days to maturity ranged from 102.67 days to 119.33 days. The crosses which attained maturity earlier were Mutant-2 × Pratap Alsi 1 (102.67 days), Mutant-2

× JLS 95 (103.67 days), JLS 95 × Kota Barani 3, Kota Barani 4 × Kota Barani 3 (104.00 days), followed by Mau Azad Alsi-2 × TL 99 (105.00 days). The crosses Mutant-4 × JLS 95, Mutant-4 × MAA-2, JRF 2 × Mutant-4 (119.33 days), followed by Neela × Pratap Alsi 1 (119.00 days) and JRF 2 × Mutant-2 (118.67 days) attained late maturity.

3. Plant height (cm)

The data on mean squares of parents for plant height at maturity ranged from 35.33 cm to 104.25 cm. The parent PKV NL 260 (35.33** cm) recorded lowest plant height followed by JLS 9 (36.33** cm), Neela (43.29 cm). The parent JRF 2 (104.25 cm) was the tallest followed by Mutant-2 (57.67 cm) and Arpita (56.67 cm).

Among the crosses, plant height at maturity ranged from 24.11 cm to 96.50 cm. The minimum value for plant height was seen in cross JLS 9 × JLS 79 (24.11** cm) followed by PKV NL 260 × Mutant-4 (26.00** cm), Mutant-4 × Mau Azad Alsi-2 (26.83** cm). The highest value for plant height was recorded for the cross JRF 2 × Mutant-2 (96.50 cm) followed by JRF 2 × Kota Barani 4 (85.55 cm) and JRF 2 × Arpita (76.35 cm).

4. Number of branches plant^{-1}

The data on mean squares of parents for number of branches plant^{-1} ranged from 1.97 to 6.63. Mean performance of parent Mutant-2 (6.63) was found to be maximum for number of branches plant^{-1} followed by parents Mutant-4 (6.33), JLS 9 (5.50) while, the parent Indira Alsi-32 (1.97**) as well as Kota Barani 3 (2.50**) recorded minimum number of branches plant^{-1}.

Among the crosses studied mean values for number of branches plant^{-1} ranged from 2.00 to 9.45. The cross Kota Barani 4 × TL 99 (9.45) showed high mean performance for this trait followed by JLS 9 × JRF 2 (9.10), JLS 95 × Kota Barani 4 (9.00) and also Mutant-2 × Arpita (9.00), while crosses Indira Alsi-32 × Mau Azad Alsi-2, JLS 95

× Pratap Alsi 1 expressed lowest mean value (2.00**) followed by cross JLS 9 × TL 99 (2.42**).

5. Number of capsules plant^{-1}

The range for number of capsules plant^{-1} in parents was between 11.42 to 69.75. The parent Mutant-4 recorded (69.75**) maximum number of capsules plant^{-1} followed by JRF 2 (54.83**) and Mutant-2 (53.58**), while the parents Kota Barani 3 (11.42), Pratap Alsi 1 (13.42) and Indira Alsi-32 (20.75) recorded lowest number of capsules plant^{-1}.

Among the crosses studied, mean values for number of capsules plant^{-1} ranged from 6.0 to 161.80. PKV NL 260 × Indira Alsi-32 (161.80**) had maximum number of capsules plant^{-1}. This was followed by Neela × JLS 9 (110.92**), PKV NL 260 × Kota Barani 4 (93.92**), Indira Alsi-32 × JRF 2 (94.11**), while least number of capsules plant^{-1} were recorded by the crosses Neela × Kota Barani 4 (6.00), JLS 9 × Kota Barani 3 (6.83), Indira Alsi-32 × Arpita (7.00).

6. 1000 seed weight (g)

Mean performance of the parents for 1000 seed weight ranged from 6.4 g to 11.59 g. The 1000 seed weight was recorded to be maximum in Kota Barani 3 (11.59** g) followed by Pratap Alsi 1 (9.84** g) and JLS 79 (9.61** g), while it was minimum in Neela (6.40 g) followed by Arpita (6.71 g) and PKV NL 260 (7.11 g).

Among the crosses studied, mean values for 1000 seed weight ranged from 4.57 g to 11.54 g. The 1000 seed weight was found to be maximum for cross Kota Barani 4 × Arpita (11.54** g), followed by JLS 9 × Pratap Alsi 1 (11.10** g) and JLS 9 × Kota Barani 4 (11.01**), while it was minimum in crosses Indira Alsi-32 × Mutant-2 (4.57 g), Indira Alsi-32 × Arpita (4.87 g) and JLS 79 × Kota Barani 4 (5.04 g).

7. Seed yield plant^{-1} (g)

The mean value of parents for seed yield plant^{-1} ranged from 2.12 g to 4.33 g. The maximum yield was recorded by parents JRF 2 (4.33** g) followed by Mutant-2 (4.03** g), Mutant-4 (3.47** g), Arpita (3.11** g), while it was minimum in parent Neela (2.12 g) followed by PKV NL 260 (2.23 g) and Kota Barani 4 (2.28 g).

Among the crosses studied, mean values for seed yield plant^{-1} ranged from 0.57 g to 8.7 g. High yielding crosses were PKV NL 260 × Indira Alsi-32 (8.73** g), Mutant-2 × Kota Barani 3 (5.99** g) and JRF 2 × Kota Barani 4 (5.12** g), while the low yielding crosses found to be Indira Alsi-32 × Arpita (0.57 g) followed by JLS 9 × Mutant-4, Indira Alsi-32 × TL 99 (0.63 g) and Mutant-2 × JLS 95 (0.65 g).

8. Bud fly infestation (%)

The data on mean value of parents for Bud fly infestation ranged from 7.33 to 23.92%. The parent JRF 2 (23.92%) followed by Neela (19.50%) and PKV NL 260 (16.25%) showed more susceptibility to bud fly, while it was minimum in Mau Azad Alsi-2 (7.33**%) followed by Kota Barani 4 (7.75**%), Indira Alsi-32 (7.83**%). Mean performance for bud fly infestation of the parents *Viz.*, Mau Azad Alsi-2, Kota Barani 4, Indira Alsi-32 were found to be resistant and PKV NL 260, Neela, JRF 2 were found to be moderately resistant.

Among the crosses, bud fly damage ranged from 2.0 to 59.67%. The cross that showed greater degree of bud fly resistance was JLS 9 × TL 99 (2.00**%) followed by JLS 9 × Arpita (4.33**%), Neela × Indira Alsi-32 (4.83**%), PKV NL 260 × Mutant-4 (5.00**%). The crosses Indira Alsi-32 × Arpita (59.67%), Mutant-2 × TL 99 (51.33%), JLS 9 × Mutant-4 (50.00%) were found to be susceptible. Arc sin transformation were done for bud fly infestation.

9. Alternaria blight infestation (%)

Among the parents alternaria blight incidence ranged from 0.78 to 2.50%. The parents that showed the least infestation of alternaria blight was Kota Barani 3 (0.78**%) followed by Mau Azad Alsi-2, JLS 9 and Mutant-2 and were found to be resistant with (1.00**%) mean value. The parents Neela (2.50**%), JLS 95 (2.22**%), Pratap Alsi 1 (2.11**%) were found moderately susceptible.

Among the crosses, alternaria blight damage ranged from 0.83 to 11.50 %. The crosses that showed the resistance to alternaria blight were Indira Alsi-32 × Pratap Alsi 1 (0.83**%), Mutant-2 × Mau Azad Alsi-2 (0.85**%), Indira Alsi-32 × JLS 95 (0.92**%), while crosses JLS 95 × TL 99 (11.50%), Indira Alsi-32 × TL 99 (11.00%), JLS 79 × Mau Azad Alsi-2 (9.92%), JLS 95 × Pratap Alsi 1 (9.42%), JLS 79 × Arpita (9.22%) showed the highest susceptibility. Square root transformation were done for alternaria blight infestation.

Out of all the parents studied the mean performance of the parents namely JRF 2, Mutant-2, Mutant-4, Arpita, JLS 79 showed highly significant mean performance for seed yield plant^{-1} (g), while for 1000 seed weight mean performance for the parents were Mutant-2, JLS 79, Arpita found highly significant and non significant for Mutant-4, JRF 2. Mean performance for number of capsules plant^{-1} among the parents were JRF 2, Mutant-2, Mutant-4 found highly significant and highly non significant for JLS 79 and Arpita hence can be utilised in varietal development programme. Also out of all the parents studied Mau Azad Alsi-2, Kota Barani 4, Indira Alsi-32 were found to be resistant and PKV NL 260, Neela, JRF 2 and JLS 95, JLS 79, Mutant-2 were found to be moderately resistant to bud fly infestation. The parents Kota Barani 3, Mau Azad Alsi-2, Mutant-2, JLS 79 were found highly resistant for alternaria blight infestation. Reddy *et al*. (2013) found PKV NL 260 exhibited greater degree of resistant to bud fly. Kanwar *et al*. (2022), reported JLS 95 found to be highly susceptible to

Table 3. Mean performance of parents and their crosses for nine characters studied

Sr. No.	Genotypes	Days to 50 % flowering (days)	Days to maturity (days)	Plant height (cm)	Number of branches plant^{-1}	Number of capsules plant^{-1}	1000 seed weight (g)	Seed yield plant $^{-1}$ (g)	Bud fly infestation (%)	Alternaria blight Infestation (%)
	Lines									
1	PKV NL 260	49.33**	109.00	35.33**	3.33**	26.25	7.11	2.23	16.25 (23.76)	1.50** (1.58)
2	Neela	49.00**	102.33	43.29	3.63**	28.17	6.40	2.12	19.5 (26.13)	2.50** (1.86)
3	Indira Alsi-32	49.33**	105.00	51.83	1.97**	20.75	8.16	2.41	7.83** (16.25)	1.72** (1.65)
4	JLS 9	49.67**	112.00	36.33**	5.50	24.08	8.43	2.59	14** (21.96)	1.00** (1.42)
5	JRF 2 (Tiara)	70.67	109.00	104.25	4.50	54.83**	7.35	4.33**	23.92 (29.24)	1.17** (1.47)
6	Mutant- 2	50.67	106.67	57.67	6.63	53.58**	8.86**	4.03**	10.58** (18.96)	1.00** (1.41)
7	Mutant- 4	49.33**	112.33	44.50	6.33	69.75**	8.09	3.47**	15.75 (23.37)	1.5** (1.58)
8	JLS 95	49.00**	106.33	47.25	4.30**	25.75	9.55**	2.51	15.83 (23.44)	2.22** (1.79)
9	JLS 79	49.00**	105.00	47.58	3.63**	42.17	9.61**	3.03**	15.58	1.17**

									(23.24)	(1.47)
10	Mau Azad Alsi-2	59.00	114.67	44.92	4.60	27.83	8.20	2.67	7.33** (15.70)	1.00** (1.41)
11	Kota Barani 4	59.00	117.67	48.25	3.53**	26.58	8.28	2.28	7.75** (16.16)	1.67** (1.63)
12	Kota Barani 3	58.00	115.33	67.25	2.50**	11.42	11.59**	2.89**	9.83** (18.26)	0.778** (1.33)
13	Pratap Alsi -1	51.00	103.33	46.50	3.17**	13.42	9.84**	2.30	15.75 (23.36)	2.11** (1.76)
14	Arpita	50.33	103.67	56.67	4.17**	42.67	6.71	3.11**	15.42** (23.11)	1.50** (1.58)
15	TL 99	53.33	104.00	46.25	4.43	40.58	8.81**	2.48	10.08** (18.49)	1.00** (1.41)
16	PKV NL 260 × Neela	50.33	108.67	52.47	5.00	48.97	7.96	3.96**	5.38** (13.41)	4.70 (2.39)
17	PKV NL 260 × Indira Alsi-32	49.33	108.67	50.33	6.00	161.8**	8.58	8.73**	25.97 (30.62)	2.60 (1.90)
18	PKV NL 260 × JLS 9	50.67	107.33	42.65	4.15**	53.03	9.18**	2.17	18.33 (25.33)	4.83 (2.29)
19	PKV NL 260 × JRF 2	51.67	107.33	33.33**	3.17**	32.17	10.33**	1.84	16.17 (28.65)	2.50** (1.87)
20	PKV NL 260 × Mutant-2	57.67	112.33	37.04**	5.15	62.62**	8.15	3.16**	23.98 (28.65)	2.78 (1.94)
21	PKV NL 260 ×	49.67	110.33	26.00**	4.00**	21.33	5.23	1.47	5.00**	5.33

	Mutant-4								(12.92)	(2.52)
22	PKV NL 260 × JLS 95	52.00	109.00	41.73	3.53**	58.3**	7.87	2.95**	11.43** (19.75)	5.38 (2.53)
23	PKV NL 260 × JLS 79	61.00	114.33	31.67**	3.50**	45.50	9.17**	2.55	17.17 (24.47)	2.75** (1.93)
24	PKV NL 260 × Mau Azad Alsi-2	50.00	117.67	38.25**	3.70**	38.35	10.14**	3.00**	15.13** (22.88)	1.78** (1.67)
25	PKV NL 260 × Kota Barani 4	52.00	107.67	51.42	4.50	93.92**	9.90**	2.84	11.83** (20.11)	8.58 (3.10)
26	PKV NL 260 × Kota Barani 3	54.67	105.67	45.50	3.22**	69.11**	5.13	2.72	34.47 (35.94)	2.08** (1.76)
27	PKV NL 260 × Pratap Alsi 1	55.00	105.00	45.44	3.34**	57.06**	9.57**	3.28**	40.19 (39.20)	6.03 (2.65)
28	PKV NL 260 × Arpita	52.67	105.33	35.83**	6.00	86.89**	9.19**	3.27**	13.25** (21.34)	0.89** (1.37)
29	PKV NL 260 × TL 99	49.67**	105.00	44.33	6.00	57.00**	10.27**	1.93	10.42** (18.82)	1.58** (1.61)
30	Neela × Indira Alsi-32	51.00	113.00	38.83	4.42**	17.00	7.05	0.73	4.83** (12.69)	1.00** (1.41)
31	Neela × JLS 9	53	113.00	48.83	4.00**	110.92**	9.88**	4.75**	12.58** (20.77)	2.00** (1.73)
32	Neela × JRF 2	53	108.00	59.02	6.07	47.12	7.83	2.7	15.63 (23.28)	2.10** (1.76)
33	Neela × Mutant-	56.67	106.00	43.42	3.00**	55.75**	9.38**	2.56	44.39	2.94

	2								(41.76)	(1.98)
34	Neela × Mutant-4	52.67	112.67	40.33	6.17	88.50**	8.62	2.32	19.33 (26.07)	4.17 (2.27)
35	Neela × JLS 95	52.00	106.00	39.33	6.25	49.83	9.05**	3.07**	9.75** (18.19)	1.67** (1.63)
36	Neela × JLS 79	58.33	107.33	38.00**	5.17	11.17	5.38	0.87	20.67 (27.03)	3.83 (2.19)
37	Neela × Mau Azad Alsi-2	56.00	105.00	38.62	5.52	56.37**	10.64**	3.11**	13.58** (21.62)	4.25 (2.29)
38	Neela × Kota Barani 4	52.00	106.67	42.50	3.83**	6.00	5.15	0.70	32.5 (34.74)	2.33** (1.83)
39	Neela × Kota Barani 3	55.00	105.00	45.50	4.00**	64.67**	6.08	2.22	15.17** (22.91)	6.83 (2.80)
40	Neela × Pratap Alsi 1	53.00	119.00	45.08	6.00	34.42	10.11**	1.78	10.89** (19.26)	2.08** (1.72)
41	Neela × Arpita	53.33	107.00	43.11	6.00	29.22	10.31**	2.10	14.22** (22.15)	3.56 (2.134)
42	Neela × TL 99	53.00	106.33	42.28	4.70	54.50**	7.06	2.32	12.70** (20.87)	3.42 (2.10)
43	Indira Alsi-32 × JLS 9	49.33**	109.33	45.00	3.00**	11.33	5.55	0.80	10.83** (19.20)	1.83** (1.68)
44	Indira Alsi-32 × JRF 2	57.33	118.00	70.44	4.78	94.11**	5.15	2.50	19.89 (26.46)	3.44 (2.10)
45	Indira Alsi-32 ×	54.00	111.00	61.33	3.00**	16.33	4.57	0.90	32.67	1.33**

	Mutant-2								(34.84)	(1.53)
46	Indira Alsi-32 × Mutant-4	51.33	107.00	43.92	5.75	65.58**	5.90	2.50	15.08** (22.84)	1.33** (1.53)
47	Indira Alsi-32 × JLS 95	51.67	118.67	48.55	5.00	36.07	8.22	1.42	7.60** (15.99)	0.92** (1.38)
48	Indira ALSI-32 × JLS 79	53.00	107.00	29.83**	8.00	73.42**	8.16	1.40	12.17** (20.41)	1.25** (1.50)
49	Indira Alsi-32 × Mau Azad Alsi-2	53.33	107.33	31.00**	2.00**	8.17	5.08	0.68	16.5 (23.10)	7.17 (2.86)
50	Indira Alsi-32 × Kota Barani 4	52.33	107.33	54.33	5.00	50.67	9.09**	1.71	17.67 (24.40)	1.58** (1.60)
51	Indira Alsi-32 × Kota Barani 3	53.67	107.00	47.50	5.00	22.56	10.29**	1.63	29.56 (32.42)	2.19** (1.78)
52	Indira Alsi-32 × Pratap Alsi 1	55.00	104.33	41.75	4.00**	36.58	5.18	1.33	7.17** (15.52)	0.83** (1.35)
53	Indira Alsi-32 × Arpita	53.67	108.00	37.00**	5.00	7.00	4.87	0.57	59.67 (50.55)	9.67 (3.27)
54	Indira Alsi-32 × TL 99	51.00	108.00	30.67**	4.00**	14.33	5.55	0.63	46.67 (43.07)	11.00 (3.46)
55	JLS 9 × JRF 2	50.33	104.33	40.05	9.10	37.47	10.59**	2.10	24.02 (29.33)	4.02 (2.21)
56	JLS 9 × Mutant-2	52.67	108.00	29.25**	5.58	31.50	8.04	1.67	23.75 (29.15)	2.17** (1.76)
57	JLS 9 × Mutant-	54.33	107.00	27.33**	5.67	8.33	5.43	0.63	50.00	2.00**

	4								(44.98)	(1.72)
58	JLS 9 × JLS 95	55.67	103.33	44.27	8.67	31.50	9.72**	1.73	15.59 (23.12)	3.50 (2.20)
59	JLS 9 × JLS 79	52.67	108.00	24.11**	4.17**	14.33	5.85	1.00	45.00 (42.11)	3.33 (2.07)
60	JLS 9 × Mau Azad Alsi-2	51.00	107.00	36.5**	7.00	62.08**	8.55	2.42	9.83** (17.95)	1.917** (1.71)
61	JLS 9 × Kota Barani 4	52.33	110.67	37.67**	4.00**	30.50	11.01**	2.38	15.67 (23.31)	1.42** (1.55)
62	JLS 9 × Kota Barani 3	52.33	107.33	27.17**	4.33**	6.83	6.29	0.70	11.50** (19.81)	3.83 (2.19)
63	JLS 9 × Pratap Alsi 1	52.00	107.00	42.73	4.13**	13.57	11.10**	1.27	34.58 (35.90)	5.57 (2.56)
64	JLS 9 × Arpita	54.67	107.00	37.17**	4.00**	13.17	5.45	0.80	4.33** (11.93)	1.50** (1.58)
65	JLS -9 × TL 99	53.67	108.67	43.00	2.42**	16.67	9.06**	1.10	2.00** (8.13)	2.33** (1.82)
66	JRF 2 × Mutant-2	54.00	118.67	96.50	3.25**	36.50	8.05	1.88	13.5** (21.55)	1.42** (1.55)
67	JRF 2 × Mutant-4	55.00	119.33	58.42	4.00**	46.08	9.92**	2.43	11.67** (19.96)	3.67 (2.16)
68	JRF 2 × JLS 95	55.67	115.33	45.90	6.00	43.45	9.90**	3.09**	27.00 (31.29)	6.03 (2.64)
69	JRF 2 × JLS 79	54.33	108.67	55.80	4.00**	10.83	5.62	2.13	10.17**	1.08**

									(18.57)	(1.43)
70	JRF 2 × Mau Azad Alsi-2	56.67	108.33	55.18	4.67	50.68	8.84**	3.93**	20.32 (26.78)	1.27** (1.50)
71	JRF 2 ×Kota Barani 4	57.33	114.00	85.55	4.00**	78.98**	9.07**	5.12**	17.00 (24.12)	1.92** (1.71)
72	JRF 2 × Kota Barani 3	55.67	118.00	47.00	4.00**	26.02	9.40**	1.65	9.44** (17.89)	2.78 (1.93)
73	JRF 2 × Pratap Alsi 1	57.67	114.67	63.88	3.37**	31.88	7.45	1.96	29.52 (32.61)	2.95 (1.98)
74	JRF -2 × Arpita	54.00	106.67	76.35	6.00	42.80	8.85**	2.10	20.60 (26.98)	8.22 (3.03)
75	JRF 2 × TL 99	58.67	108.33	43.42	5.33	35.75	7.58	2.03	8.08** (16.46)	4.08 (2.25)
76	Mutant-2 × Mutant-4	58.67	107.33	40.47	5.00	14.75	6.33	1.70	25.39 (29.76)	1.75** (1.63)
77	Mutant-2 × JLS 95	52.33	103.67	33.83**	3.00**	10.67	5.60	0.65	31.83 (34.33)	3.67 (2.15)
78	Mutant-2 × JLS 79	53.33	108.67	34.28**	4.00**	54.42**	5.87	2.42	21.78 (27.81)	3.42 (2.10)
79	Mutant-2 × Mau Azad Alsi-2	55.00	106.00	36.17**	6.20	39.50	9.04**	2.30	24.10 (29.29)	0.85** (1.36)
80	Mutant-2 × Kota Barani 4	54.00	109.33	50.33	3.33**	14.33	5.80	1.23	47.00 (43.25)	1.67** (1.63)
81	Mutant-2 × Kota	53.67	106.33	64.89	6.17	156.00**	9.65**	5.99**	36.83	1.50**

	Barani 3								(37.35)	(1.58)
82	Mutant-2 × Pratap Alsi 1	57.33	102.67	30.06**	5.58	28.39	7.56	1.73	13.75** (21.76)	4.67 (2.37)
83	Mutant-2 × Arpita	52.33	107.00	36.56**	9.00	54.33**	9.17**	2.40	34.22 (35.77)	3.44 (2.11)
84	Mutant-2 × TL 99	58.67	111.67	40.67	3.00**	91.00**	4.84	2.97**	51.33 (45.75)	2.00** (1.72)
85	Mutant-4 × JLS 95	53.33	119.33	33.17**	4.17**	27.00	9.33**	1.87	12.19** (20.30)	1.25** (1.47)
86	Mutant-4 × JLS 79	53.333	119.00	54.75	4.00**	14.58	10.50**	1.28	6.78** (14.73)	2.08** (1.72)
87	Mutant-4 × Mau Azad Alsi-2	54.00	119.33	26.83**	5.00	14.33	6.17	0.77	10.17** (18.58)	1.67** (1.63)
88	Mutant-4 ×Kota Barani 4	55.33	108.00	31.17**	7.00	9.67	7.62	0.87	11** (19.36)	5.83 (2.60)
89	Mutant-4 × Kota Barani 3	55.67	108.00	33.00**	5.67	12.33	6.18	0.83	25.5 (30.32)	6.50 (2.73)
90	Mutant-4 × Pratap Alsi 1	54.33	106.00	42.67	5.58	34.42	10.43**	2.41	18.08 (24.66)	1.0** (1.41)
91	Mutant-4 x Arpita	54.67	107.00	39.83	4.83	37.42	9.17**	2.20	16.17 (23.70)	3.92 (2.16)
92	Mutant-4 × TL 99	52	105	36.75**	5.67	38.58	10.66**	1.62	13.17** (21.27)	3.58 (2.13)

93	JLS 95 × JLS 79	53.00	117.67	36.33**	4.00**	12.00	5.96	0.77	34.56 (35.95)	5.08 (2.46)
94	JLS 95 × Mau Azad Alsi-2	60.67	105.33	34.33**	5.00	42.44	5.34	2.37	19.33 (26.07)	5.0 (2.45)
95	JLS 95 × Kota Barani 4	56.33	106.00	36.60**	9.00	63.33**	6.47	1.61	25 (29.98)	3.33 (2.08)
96	JLS 95 × Kota Barani 3	51.33	104.00	46.25	5.00	79.50**	10.96**	2.18	26.25 (30.74)	5.5 (2.55)
97	JLS 95 × Pratap Alsi 1	53.00	106.33	44.50	2.00**	27.83	5.74	1.83	13.75** (21.75)	9.42 (3.22)
98	JLS 95 × Arpita	53.00	106.67	39.00	4.33**	75.83**	9.41**	1.30	12.33** (20.55)	2.42** (1.83)
99	JLS 95 × TL 99	53.00	106.67	43.67	4.00**	59.08**	8.65	2.32	27.89 (31.80)	11.5 (3.53)
100	JLS 79 × Mau Azad Alsi-2	57.00	106.00	38.00**	3.00**	13.83	5.16	1.23*	12.42** (20.62)	9.92 (3.09)
101	JLS 79 × Kota Barani 4	53.00	111.00	42.89	3.00**	15.67	5.04	1.00	31.00 (33.82)	5.00 (2.44)
102	JLS 79 × Kota Barani 3	56.33	107.67	42.87	3.67**	63.27**	8.39	3.13**	13.75** (21.75)	5.33 (2.52)
103	JLS 79 × Pratap Alsi 1	60.33	117.33	44.00	7.00	81.00**	6.17	3.12**	20.56 (26.10)	2.33** (1.82)
104	JLS 79 × Arpita	56.33	104.67	40.00	4.00**	29.00	8.87**	2.03	18.78 (25.67)	9.22 (3.20)

105	JLS 79 × TL 99	60.67	105.00	29.83**	3.00**	36.00	6.93	2.18	22 (27.96)	4.44 (2.33)
106	Mau Azad Alsi-2 × Kota Barani 4	53.00	108.00	46.00	8.00	41.58	9.10**	2.63	20.00 (26.55)	0.83** (1.35)
107	Mau Azad Alsi-2 × Kota Barani 3	53.00	106.00	46.50	8.50	44.42	7.91	3.37**	22.78 (28.50)	5.33 (2.52)
108	Mau Azad Alsi-2 × Pratap Alsi 1	53.67	107.33	39.89	7.00	61.75**	5.33	3.35**	22.33 (28.19)	3.22 (2.05)
109	Mau Azad Alsi-2 × Arpita	53.00	107.33	38.67	5.58	24.92	7.51	2.31	16.58 (24.02)	2.00** (1.73)
110	Mau Azad Alsi-2 × TL 99	50.00	105.00	45.38	4.33**	65.55**	8.18	3.33**	14.13** (22.00)	1.60** (1.61)
111	Kota Barani 4 × Kota Barani 3	54.00	104.00	50.58	5.33	42.58	9.89**	2.31	10.92** (19.29)	2.00** (1.73)
112	Kota Barani 4 × Pratap Alsi 1	57.67	108.67	40.33	6.17	60.33**	5.38	4.21**	35.67 (36.66)	1.33** (1.52)
113	Kota Barani 4 × Arpita	55.67	110.00	60.08	7.25	57.42**	11.54**	4.38**	11.33** (19.65)	1.17** (1.47)
114	Kota Barani 4 × TL 99	52.00	106.00	53.78	9.45	58.55**	8.50	4.30**	17.07 (24.39)	2.1** (1.76)
115	Kota Barani 3 × Pratap Alsi 1	54.33	105.67	37.67**	3.78**	46.11	9.97**	2.60	5.33** (13.34)	1.22** (1.48)
116	Kota Barani 3 × Arpita	58.00	119.00	51.8	3.33**	21.83	10.38**	2.23	38.92 (38.58)	2.00** (1.73)

117	Kota Barani 3 × TL 99	59.33	104.33	48.75	5.00	65.00**	10.63**	4.08**	24.42 (29.6)	1.25** (1.50)
118	Pratap Alsi 1 × Arpita	53.00	104.33	48.07	5.00	52.35	7.91	2.66	24.57 (29.70)	1.85** (1.69)
119	Pratap Alsi 1 × TL 99	51.67	106.67	35.08**	4.25**	47.58	7.10	2.98**	9.58** (18.02)	1.25** (1.50)
120	Arpita × TL 99	49.33**	108.67	42.33	5.00	36.17	7.59	1.62**	6.42** (14.64)	1.08** (1.44)
	Mean	**53.90**	**108.82**	**44.55**	**4.83**	**42.51**	**8.02**	**2.32**	**19.30 (25.22)**	**3.14 (1.96)**
	S.E. (m)	**1.48**	**2.764**	**2.16**	**0.15**	**3.84**	**0.30**	**0.19**	**1.37**	**0.14**
	C.D. 5%	**4.13**	**7.71**	**6.02**	**0.40**	**10.71**	**0.67**	**0.527**	**3.81**	**0.38**
	C.V. %	**4.75**	**4.40**	**8.39**	**5.21**	**15.65**	**5.17**	**14.11**	**9.40**	**1.96**

Note : Figures in the parenthesis indicates transformed values for bud fly infestation % and alternaria blight infestation %

bud fly infestation. Ramakant *et al.* (2008), Neela showed susceptibility to bud fly and alternaria blight infestation.

Among the crosses studied, the cross PKV NL 260 × Indira Alsi-32 showed highest significant mean performance for seed yield plant^{-1} (8.73** g), number of capsules plant^{-1} (161.80**) and non significant high mean performance for 1000 seed yield plant^{-1} (8.58 g), while the cross Mutant-2 × Kota Barani 3 showed highly significant mean performance for seed yield plant^{-1} (g), number of capsules plant^{-1}, 1000 seed weight (g). Also the crosses Neela × JLS 9, JRF 2 × Kota Barani 4 and Kota Barani 4 × Arpita were found with high significant mean performance for seed yield plant^{-1} (g), number of capsules plant^{-1}, 1000 seed weight (g), and were moderately resistant to bud fly infestation (%). Other cross Pratap Alsi 1 × TL 99 gaves the high mean performance for seed yield plant^{-1} (2.98** g), 1000 seed weight (8.00 g) and number of capsules plant^{-1} (47.58), early maturing hybrid (106.67 days) with bud fly resistance (9.58**%).

4.3 Analysis of variance for combining ability

Combining ability analysis helps in the identification of parents with high GCA and parental combinations with high SCA. The concept of general and specific combining ability as a measure of gene effects proposed by Sprague and Tatum (1942). They concluded that gca is primarily due to the additive effects of genes, while sca is a consequence of intra-allelic interaction or dominance or inter-allelic interaction or epistasis. General combining effect play important role in making choice of parents.

The estimate of GCA of a parent is an important indicator of its potential for generating superior breeding population. Another important aspect from practical point of view which needs consideration for the identification of potential cross combinations with respect to seed yield and its related traits. The SCA effects can be used as an

index to determine the usefulness of a particular cross combination for exploitation through heterosis and hybridization programme.

The results of analysis of variance for combining ability using diallel mating design (without reciprocals) are shown in Table 4. Where the mean squares due to GCA and SCA were highly significant for all the characters studied. highly significant mean squares due to genotypes (parents and hybrids) indicated the presence of considerable genetic diversity among the genotypes and crosses of linseed. Similar results were reported by Khan *et al*. (1999), Srivastava *et al.* (2007) and Sedhom *et al.* (2016), who concluded that presence of significant difference among the crosses for combining ability allows the estimates of gca and sca effects. Singh *et al.* (2019), reported that analysis of variance for combining ability revealed mean squares due to GCA and SCA were found highly significant for all the traits studied. Mahawar *et al.* (2021), revealed that mean squares due to GCA and SCA were significant for seed yield plant^{-1} and all other component characters except number of secondary branches plant^{-1} and biological yield plant^{-1}. Shekhar *et al.* (2019), studied combining ability analysis in linseed and reported that analysis of variance for combining ability treatments, parents and crosses showed sufficient variability in experimental material for all characters studied except number of seeds capsule^{-1} and 1000 seed weight. Shalini *et al.* (2016), reported that mean squares due to GCA and SCA were found significant for most of the characters studied. Kumar *et al.* (2013), found that analysis of variance revealed highly significant difference among parents themselves and F_1s for almost all characters studied except number of seeds per capsules.

The fixed effect model adopted in the present study does not provide the estimation of variance components. However in this model, an idea about relative importance of gca and sca in determining progeny performance can be obtained by calculating general predictability ratio on the basis of mean squares (Baker, 1978). The

predictability ratio (GCA vs SCA) ranged from 0.49 to 0.81. The predictability ratio for seed yield plant^{-1} (0.81), days to 50% flowering (0.78), days to maturity (0.75), 1000 seed weight (0.75), number of capsules plant^{-1} (0.73), Alternaria blight (0.73), bud fly (0.72), number of branches plant^{-1} (0.72), plant height (0.49).The closer the ratio to unity, the greater the predictability based on a general combining ability alone. Khan *et al* (1999), Mishra and Rai (1996), Sedhom *et al.* (2016), Mahawar *et. al.* (2021), have used relative magnitude of GCA vs SCA as index of relative role of additive and non additive variation which guides in the choice of breeding plan. Shalini *et al.* (2016), reported ratio of gca variance to that of sca variance were less than unity for all characters. Ghige *et al.* (2020) calculated predictability ratio and found close to unity which indicated the predominance of additive genetic component for development of studied characters.

4.6 General and specific combining ability effect

In linseed, positive GCA effects and SCA effects are desirable for all the traits studied except for days to 50% flowering, days to maturity, plant height, bud fly infestation and alternaria blight infestation for which negative GCA and SCA effects are desirable.

The gca effects of parents and sca effects of crosses were worked out for all nine characters for selection of parents and crosses for linseed breeding programme and have been presented in Table 5a and 5b respectively and described as follows:

1. Days to 50% flowering (days)

Early flowering is highly desirable trait so GCA effect in negative direction is desirable. The days to 50% flowering of particular genotype are indicators of earliness. Among the parents Neela (-1.573**), JLS 9 (-1.416**), PKV NL 260 (-0.965**), Indira Alsi-32 (-0.808*), JLS 95 (-0.475), TL 99 (-0.416), Arpita (-0.180), Kota Barani 4 (-0.180) observed negative GCA effect, while Mau Azad Alsi-2 (1.996**), Pratap Alsi 1 (1.388**), Kota Barani 3 (0.604), JLS 79 (0.349), Mutant-4 (0.231), JRF

2 (0.133**), Mutant-2 (0.131) showed positive GCA effect for days to 50 % flowering.

The cross JRF 2 × Mau Azad Alsi-2 (-5.03**) showed significant SCA effect for days to 50% flowering followed by PKV NL 260 × JLS 79 (-4.28**), Neela × Mau Azad Alsi-2 (-4.33**), PKV NL 260 × Mutant-4 (-3.83**), PKV NL 260 × Mutant-2 (-3.58**), PKV NL 260 × JLS 95 (-3.46**), JRF 2 × Pratap Alsi 1 (-3.42), JLS 79 × Kota Barani 3 (-3.52), PKV NL 260 × Pratap Alsi 1 (-3.32*), Kota Barani 4 × TL 99 (-3.30), Neela × Mutant-4 (-2.89), PKV NL 260 × Indira Alsi-32 (-2.79), Mau Azad Alsi-2 × Kota Barani 4 (-2.72), JRF 2 × Mutant-2 (-2.68), JLS 79 × Pratap Alsi 1 (-2.64), PKV NL 260 × Arpita (-2.42), PKV NL 260 × Neela (-2.36), JRF 2 × Kota Barani 3 (-2.30), Neela × TL 99 (2.25), Kota Barani 3 × TL 99 (-2.09), PKV NL 260 × JLS 9 (-1.85), JRF 2 × JLS 79 (-1.716), Arpita × TL 99 (-1.64), Mutant-4 × Arpita (-1.62), JRF 2 × Kota Barani 4 (-1.52), Indira Alsi-32 × Pratap Alsi 1 (-1.48), Kota Barani 4 × Pratap Alsi 1 (-1.44), JLS 95 × Mau Azad Alsi-2 (-1.42), JLS 9 × Mutant-4 (-1.38), Mutant-4 × JLS 95 (-1.32), Kota Barani 4 × Kota Barani 3 (-1.32), Mutant-2 × JLS 79 (-1.23), JLS 9 × Kota Barani 4 (-1.15), Mutant-4 × JLS 79 (-1.15), Mutant-4 × Mau Azad Alsi-2 (-1.13), JLS 9 × TL 99 (-1.07), JLS 79 × Arpita (-1.07) Mutant-4 × Kota Barani 3 (-1.07), Mutant-4 × Arpita (-1.03), JLS 95 × TL 99 (-1.01), Indira Alsi-32 × Kota Barani 4 (-0.91), JLS 79 × TL 99 (-0.83), Neela × JRF 2 (-0.79), Indira Alsi-32 × Mutant-4 (0.66), Indira Alsi-32 × JLS 95 (-0.62), Mutant-2 × Mau Azad Alsi-2 (-0.54), Kota Barani 4 × Arpita (-0.539), Mutant-2 × Mutant-4 (-0.441), JLS 95 × JLS 79 (-0.44), JLS 9 × JLS 95 (-0.34), Neela × JLS 9 (-0.25), Indira Alsi-32 × JRF 2 (-0.23), Mau Azad Alsi-2 × Kota Barani 3 (-0.17), Neela × Kota Barani 4 (-0.15), Mutant-2 × Kota Barani 3 (-0.15), JLS 95 × Pratap Alsi 1 (-0.5) indicating their good specific combining ability for this character, while fifteen cross combinations expressed significant positive SCA effect for days to 50 % flowering indicating their good specific combining ability.

Table 4. Analysis of variance for combining ability in linseed

Sources of Variation	d.f.	Mean squares								
		Days to 50% flowering (days)	Days to maturity (days)	Plant height (cm)	Number of branches plant^{-1}	Number of capsules plant^{-1}	1000 Seed weight (g)	Seed yield plant $^{-1}$ (g)	Bud fly infestation (%)	Alternaria blight infestation (%)
Due to GCA	14	53.58**	84.14**	1,288.51**	9.17**	2,953.89**	14.58**	8.20**	456.79**	21.15**
Due to SCA	105	29.37**	55.83**	359.53**	7.13**	2,163.62**	9.91**	3.77**	363.50**	15.87**
Error	238	6.57	22.92	13.98	0.06	44.25	0.17	0.11	12.03	0.38

Note: * Significant at 5% level, ** Significant at 1% level

2. Days to maturity (days)

Days to maturity is an important indicator of earliness, so GCA effect in negative direction is desirable. Among the parents only TL 99 (-1.950**) followed by Arpita (-1.558*) showed desirable and significant negative GCA effect for days to maturity. The parents *Viz*., Kota Barani 3 (-1.068), PKV NL 260 (-0.342), Neela (-0.342), Pratap Alsi 1 (-0.284), Mutant-4 (-0.146), JRF 2 (-0.950), Kota Barani 4 (-0.068), showed non significant negative GCA effects for this character. However parents such as Mutant-2 (3.148**), JLS 95 (1.893**), JLS 9 (0.795), JLS 79 (0.422), Mau Azad Alsi-2 (0.422), Indira Alsi-32 (0.030) recorded positive GCA effects for days to maturity.

Out of one hundred and five crosses, only six crosses showed significant negative SCA effect for days to maturity. The cross Mutant-4 × JLS 95 (-6.90**) showed negative significant SCA effect followed by JRF 2 × JLS 95 (-6.43*), Indira Alsi-32 × Mutant-2 (-6.00*), PKV NL 260 × Neela (-5.80*), Mutant-4 × Pratap Alsi 1 (-5.73*), JLS 9 × Pratap Alsi 1 (-5.00*), PKV NL 260 × Mutant-2 (-4.96), PKV NL 260 × Pratap Alsi 1 (-4.86), Indira Alsi-32 × JLS 95 (-4.75), JLS 95 × Pratap Alsi 1 (-4.43), JLS 79 × Mau Azad Alsi-2 (-4.33), Indira Alsi-32 × Mau Azad Alsi-2 (-4.28), JLS 79 × Kota Barani 3 (-4.18), Mutant-2 × Mau Azad Alsi-2 (-4.06), PKV NL 260 × JLS 95 (-4.04), PKV NL 260 × JLS 79 (-3.90), JLS 95 × TL 99 (-3.77), Mutant-2 × Arpita (-3.75), Mutant-2 × JLS 95 (-3.73), PKV NL 260 × Indira Alsi-32 (-3.51), PKV NL 260 × Arpita (-3.26), Neela × Pratap Alsi 1 (-3.20), JLS 79 × Kota Barani 4 (-3.18), Mutant-4 × Mau Azad Alsi-2 (-3.10), JLS 9 × JLS 79 (-3.04), JRF 2 × Mutant-2 (-3.02), Mau Azad Alsi-2 × Arpita (-3.02), Indira Alsi-32 × Kota Barani 3 (-2.79), JLS 9 × Mau Azad Alsi-2 (-2.71), JLS 95 × Kota Barani 4 (-2.65), JLS 79 × Pratap Alsi 1 (-2.63), JLS 9 × Mutant-4 (-2.47), Mau Azad Alsi-2 × TL 99 (-2.29), Pratap Alsi 1 × TL 99 (-2.30), JLS 9 × Kota Barani 4 (-2.22), JLS 95 × Arpita (-2.16), Indira Alsi-32 × Kota Barani 4 (-2.12), Neela × JLS 9 (-1.94), Indira Alsi-32 × JLS 79 (-1.94), Kota Barani 4 × TL 99 (-1.80), Neela × Kota Barani 3 (-1.75),

JLS 9 × Mutant-2 (-1.77), Mutant-2 × TL 99 (-1.69), Kota Barani 4 × Kota Barani 3 (-1.69), JLS 95 × Kota Barani 3 (-1.65), Neela × Arpita (-1.59), JLS 9 × Kota Barani 3 (-1.55), Neela × TL 99 (-1.53), Neela × JLS 95 (-1.37), JRF 2 × Mau Azad Alsi-2 (-1.29), Mutant-4 × Kota Barani 3 (-1.28), Kota Barani 4 × Pratap Alsi 1 (-1.14), JLS 79 × Arpita (-1.02), Neela × Kota Barani 4 (-0.75), JRF 2 × Mutant-4 (-0.73), JLS 79 × TL 99 (-0.63), JRF 2 × Pratap Alsi 1(-0.59), Indira Alsi-32 × TL 99 (-0.57), Mau Azad Alsi-2 × Kota Barani 3 (-0.51) Mutant-4 × JLS 79 (-0.43), Indira Alsi-32 × TL 99 (-0.29), JRF 2 × JLS 79 (-0.29), Neela × JRF 2 (-0.20), Mutant-4 × Arpita (-0.12), JLS 9 × Arpita (-0.06) indicating their good specific combining ability for days to maturity, while fourteen cross combinations showed significant positive SCA effects for days to maturity.

3. Plant height (cm)

Dwarf plant stature in linseed is desirable trait for seed purpose. In this case, lines showing general combining ability in significant negative direction would be more desirable for plant height. Among the parents Mau Azad Alsi-2 (-5.612**), JLS 79 (-4.694**), JLS 95 (-4.740**), Mutant-4 (-3.798**), TL 99 (-2.603**), Neela (-2.413**), JRF 2 (-0.967**), Pratap Alsi 1 (-0.592**), Indira Alsi-32 (-0.407**) showed significant negative GCA effects and were found good combiners for dwarf plant growth habit hence suitable for seed purpose whereas for tall stature is desirable trait for flax purpose. In this case, lines showing general combining ability in significant positive direction would be desirable for plant height. Among the parents Mutant-2 (14.139**) followed by PKV NL 260 (5.907**) and Kota Barani 3 (3.295**) and Kota Barani 4 (1.786**) showed significant positive GCA effects and were found good combiners for tall plant growth habit, hence suitable for flax type.

Out of one hundred and five crosses thirty three cross combinations revealed significant negative SCA effects indicating their good specific combining ability for dwarf stature leading desirable traits

for seed purpose types. The cross combination JRF 2 × Mutant-2 (-28.47**) expressed highest negative significant gca effect followed by, JRF 2 × Kota Barani 3 (-19.71**), Neela × Mutant-2 (-19.23**) , Mutant-2 × Kota Barani 3 (-14.98**), Indira Alsi-32 × Mutant-2 (-14.87**), JRF 2 × JLS 79 (-14.78**), PKV NL 260 × JLS 9 (-14.2**), Mutant-2 × TL 99 (-12.67**), JRF 2 × Mutant-4 (-12.45**), Neela × Mutant-4 (-12.34**), JLS 9 × TL 99 (-11.36**), JLS 95 × Kota Barani 4 (-10.43**), JLS 95 × Kota Barani 3 (-10.1**), JLS 9 × JLS 79 (-10.10**), Mutant-4 × Pratap Alsi 1 (10.1**), Kota Barani 4 × Arpita (-8.29**), JLS 9 × Arpita (-8.25**), Mutant-2 × JLS 95 (-8.05**), JLS 9 × Mau Azad Alsi-2 (-8.02**), Neela × JRF 2 (-7.84**), Arpita × TL 99 (-7.84**), JRF 2 × Kota Barani 4 (-7.70**), JLS 95 × Mau Azad Alsi-2 (7.36**), JRF 2 × Arpita (-7.03**), PKV NL 260 × Mutant-2 (-6.93**), Neela × Arpita (-6.92**), Kota Barani 3 × Pratap Alsi 1 (-6.92**), Mau Azad Alsi-2 × TL 99 (-6.50**), Kota Barani 4 × Pratap Alsi 1 (-5.85**), Neela × JLS 79 (-5.78**), JLS 79 × Kota Barani 4 (-5.04*), Mutant-4 × Arpita (-4.81*), Neela × TL 99 (4.80*), PKV NL 260 × Neela (-4.75*), whereas the cross PKV NL 260 × JRF 2 (54.76**) possessed maximum significant positive SCA effect followed by Mutant-2 × Kota Barani 4 (25.08**), JLS 9 × JRF 2 (26.78**),Mutant-2 × Kota Barani 4 (25.08**), Mutant-4 × Kota Barani 3 (20.84**), JLS 95 × JLS 79 (19.64**), Mutant-2 × Arpita (17.04**), Indira Alsi-32 × JRF 2 (15.84**), PKV NL 260 × Kota Barani 3 (13.50**), Kota Barani 3 × Arpita (11.62**), Kota Barani 3 × TL 99 (8.54**), JLS 9 × JLS 95 (8.66**), Neela × Indira Alsi-32 (8.60), Kota Barani 3 × TL 99 (8.54**), JLS 9 × Kota Barani 4 (7.92**), Mutant-4 × Kota Barani 4 (7.80**), Neela × Kota Barani 4 (7.50**), Pratap Alsi 1 × TL 99 (7.40**), Pratap Alsi 1 × Arpita (7.23**), Pratap Alsi 1 × TL 99 (7.40**), JLS 79 × TL 99 (6.41**), Mutant-2 × Pratap Alsi 1 (5.79**), Mau Azad Alsi-2 × Pratap Alsi 1 (5.66**), PKV NL 260 × Arpita (5.59**), JRF 2× JLS 95 (5.43**) and JLS 79 × Pratap Alsi 1 (5.24*) for plant height indicating their good specific combining ability for all tall plant growth habit leading desirable traits for flax types.

4. Number of branches plant^{-1}

In linseed, short stature with more number of branches is related to increase in seed yield plant^{-1}. Among the parents Kota Barani 4 (0.672**), JRF 2 (0.558**), Kota Barani 3 (0.493**), Arpita (0.385**), JLS 95 (0.331**), Mutant-4 (0.294**), Indira Alsi-32 (0.018) recorded GCA effect in desirable direction, while the parents PKV NL 260 (-0.684**), Neela (-0.430**), Mau Azad Alsi-2 (-0.403**), JLS 9 (0.354**), Mutant-2 (-0.351**), Pratap Alsi 1 (-0.233**), JLS 79 (0.200**), TL 99 (-0.095**) recorded significant negative GCA effect for number of branches plant^{-1}.

Among the crosses, JRF 2 × TL 99 (-2.87**), Mutant-4 × Kota Barani 4 (-2.46**), Mutant-4 × JLS 95 (-2.45**), PKV NL 260 × Indira Alsi-32 (-2.19**), Mau Azad Alsi-2 × Kota Barani 4 (-2.09**), PKV NL 260× Kota Barani 3 (-2.13**), JLS 9 × Mau Azad Alsi-2 (-2.07**), Mutant-4 × TL 99 (-2.03**), JRF 2 × Kota Barani 4 (-2.05**), JRF 2 × Arpita (-1.77**), JRF 2 × Kota Barani 3 (-1.54**), Indira Alsi-32 × Kota Barani 4 9 (-1.68**), Indira Alsi-32 × Mutant-2 (-1.49**), Pratap Alsi 1 × Arpita (-1.64**), Neela × JRF 2 (-1.79**), Neela × Kota Barani 3 (-1.67**),Indira Alsi-32 × Kota Barani 3 (-1.34**), Mau Azad Alsi-2 × TL 99 (-1.33**), Mau Azad Alsi-2 × Pratap Alsi 1 (-1.25**), PKV NL 260 × Kota Barani 4 (-1.28**), JLS 9 × Mutant-2 (-1.12**), Neela × JLS 95 (-1.19**), Mutant-2 × Kota Barani 4 (-1.15), Kota Barani 4 × TL 99 (-1.07**), JRF 2 × JLS 79 (-1.02**), JRF 2 × Pratap Alsi 1 (-1.01**), Mutant-2 × Kota Barani 3 (-0.97**), Mutant-4 × JLS 79 (-0.92**), JLS 95 × Mau Azad Alsi-2 (-0.96**), Mutant-2 × Pratap Alsi 1 (-0.87**), Arpita × TL 99 (-0.87**), Neela × Pratap Alsi 1 (-0.82**), Mau Azad Alsi-2 × Arpita (-0.81**), Mutant-2 × Mutant-4 (-0.77**), PKV NL 260 × Pratap Alsi 1 (-0.74**), JLS 95 × TL 99 (-0.71**), Neela × Mutant-4 (-0.69**),JLS 79 × Arpita (-0.68**), Neela × Kota Barani 4 (-0.57**), JLS79 × TL 99 (-0.53**), Indira Alsi-32 × JLS 9 (-0.49**), JLS 9 × TL 99 (-0.38**), PKV NL 260 × Arpita (-0.36**), PKV NL 260 × JLS 79 (-0.31*), Neela × Mau Azad Alsi-2 (-0.30*), Kota Barani 4 × Arpita (-

0.30*), showed significant negative SCA effect for number of branches plant^{-1}, while the cross Kota Barani 3 × TL 99 (4.23**) showed significant highest GCA effect followed by cross combinations JLS 9 × JLS 79 (3.73**), JLS 79 × Kota Barani 4 (3.70**), Mutant-4 × Arpita (3.50**), JRF 2 × JLS 95 (2.96**), PKV NL 260 × Mutant-2 (2.84**), Mau Azad Alsi-2 × Pratap Alsi 1 (2.81**), Kota Barani 4 × Kota Barani 3 (2.51**), JRF 2 × Mau Azad Alsi-2 (2.02**), PKV NL 260 × Mutant-4 (1.90**), PKV NL 260 × JLS 9 (1.71**), Kota Barani 4 × Pratap Alsi 1 (1.74**), Kota Barani 3 × Arpita (1.55**), Neela × Indira Alsi-32 (1.59**), Indira Alsi-32 × Pratap Alsi 1 (1.39**), Mutant-4 × Mau Azad Alsi-2 (1.48**), Neela × Arpita (1.22**), Mutant-2 × JLS 95 (1.20**), JLS 95 × Kota Barani 4 (1.17**), Mutant-2 × Arpita (1.14**), Neela × Mutant-2 (1.11**), Kota Barani 3 × Pratap Alsi 1 (1.08**), Indira Alsi-32 × Mau Azad Alsi-2 (1.08),Indira Alsi-32 × JLS 95 (1.08**), Indira Alsi-32 × Mutant-4 (1.03**), JLS 9 × Mutant-4 (0.99**), Mutant-2 × TL 99 (0.95**), PKV NL 260 × Mau Azad Alsi-2 (0.86**), JLS 79 × Mau Azad Alsi-2 (0.78**), Indira Alsi-32 × Arpita (0.77**), Mutant-4 × Pratap Alsi 1 (0.70**), JLS 95 × Pratap Alsi 1 (0.66**), Indira Alsi-32 × JRF 2 (0.67**), JLS 95 × TL 99 (0.61**), Mutant-2 × Mau Azad Alsi-2 (0.60**), Mutant-4 × Kota Barani 3 (0.55**), JRF 2 × Mutant-2 (0.55**), Indira Alsi-32 × JLS 79 (0.52**), Pratap Alsi 1 × TL 99 (0.50**), PKV NL 260× TL 99 (0.39**).

5. Number of capsules plant^{-1}

High seed yield is the basic objective of all crop improvement programmes. Number of capsules plant^{-1} have a direct bearing on the total productivity of linseed. Among the parents Neela (16.649**), Indira Alsi-32 (8.521**), Kota Barani 3 (8.085**), Mutant-4 (5.740**), TL 99 (4.257**) showed highly significant positive GCA effect indicating their good general combining ability. Among the parents, JLS 95 (-12.310**), showed highly significant negative GCA effect for number of capsules plant^{-1}. Other parents showing significant negative GCA effect were found to be JRF 2 (-8.735**), PKV NL 260 (-8.592**), Mau Azad Alsi-2

(-5.164**), JLS 9 (-2.625**), JLS 79 (-2.453**), Mutant-2 (-1.228), Pratap Alsi 1 (-1.203), Kota Barani 4 (-0.629), and Arpita (-0.316).

Out of one hundred and five crosses, thirty eight cross combinations showed significant SCA effect in positive direction. The cross Mutant-4 × Kota Barani 3 (99.67**) exhibited highest significant positive SCA effect for number of capsules plant^{-1} followed by Mutant-4 × Kota Barani 3 (99.66**), Neela × Indira Alsi-32 (94.12**), Indira Alsi-32 × JLS 9 (65.51**), JLS 9 × JRF 2 (62.96**), Mau Azad Alsi-2 × Pratap Alsi 1 (44.86**), Mutant-4 × TL 99 (38.49**), Mutant-2 × Mau Azad Alsi-2 (38.33**), JLS 9 × JLS 79 (35.99**), Neela × Kota Barani 4 (35.39**), JLS 79 × Arpita (36.09**), JRF 2 × Mau Azad Alsi-2 (33.47**), PKV NL 260 × Mutant-4 (30.09**), Indira Alsi-32 × Mutant-2 (31.73**), JLS 79 × Kota Barani 3 (31.36**) PKV NL 260 × JRF 2 (29.65**), Neela × Arpita (28.05**), JLS 79 × Kota Barani 4 (23.91**), Kota Barani 4 × Pratap Alsi 1 (21.07**), PKV NL 260 × Mutant-2 (20.89**), JLS 9 × Mutant-4 (19.96**), Pratap Alsi 1 × TL 99 (19.44**), Kota Barani 4 × Arpita (19.41**), JLS 79 × TL 99 (14.77**), Mutant-2 × JLS 95 (14.48**), Mutant-2 × JLS 79 (14.57**), Mau Azad Alsi-2 × Kota Barani 3 (17.84**), Indira Alsi-32 × JLS 95 (11.11**), Neela × JLS 95 (11.45**), JLS 9 × Kota Barani 4 (11.41**), Kota Barani 4 × TL 99 (10.94**), Indira Alsi-32 × Mau Azad Alsi-2 (10.50**), PKV NL 260 × JLS 79 (10.70**), JRF 2 × JLS 95 (10.04**), PKV NL 260 × Arpita (9.07*), Mutant-4 × JLS 79 (8.62*), JLS 9 × JLS 95 (8.49*), JLS 79 × Mau Azad Alsi-2 (7.55*), JLS 95 × Arpita (7.53*), Kota Barani 3 × Arpita (7.14*) indicating their good specific combining ability for this character, while thirty five cross combinations showed negative SCA effects for this character. The crosses Indira Alsi-32 × Kota Barani 4 (-44.40**), Neela × Mutant-4 (-43.60**), Indira Alsi-32 × JLS 79 (-37.40**), JRF 2 × Kota Barani 3 (-35.03**), Mutant-4 × Kota Barani 4 (-33.29**), JLS 9 × Arpita (-32.60**), JRF 2 × Mutant-2 (-31.18**), PKV NL 260 × Kota Barani 3 (-30.60**), JLS 9 × Arpita (-29.80**), Mutant-2 × JLS 79 (-28.00**), JLS 9 × Mau Azad Alsi-2 (-26.60**), JLS 95 × Kota Barani 3 (-25.95**), Mutant-4 × JLS 95 (-25.27**), JLS 9 × Kota

Barani 3 (-25.40**), Mutant-2 × Kota Barani 3 (-23.35**), PKV NL 260 × Neela (-22.40**), JLS 9 × JRF 2 (-22.30**), JRF 2 × TL 99 (-21.36**), PKV NL 260 × Indira Alsi-32 (-21.70**), Indira Alsi-32 × Arpita (-21.50**), Mau Azad Alsi-2 × Kota Barani 4 (-21.05**), JRF 2 × Arpita (-20.29**), JLS 95 × Kota Barani 4 (-19.91**), Pratap Alsi 1 × Arpita (-19.16**), PKV NL 260 × Pratap Alsi 1 (-19.3**), JRF 2 × Pratap Alsi 1 (-19.01**), Mutant-4 × Pratap Alsi 1 (-18.66**), Neela × JRF 2 (-18.3**), JRF 2 × JLS 79 (-16.99**), Kota Barani 4 × Arpita (-16.65**), Neela × Mau Azad Alsi-2 (-15.6**), Indira Alsi-32 × Pratap Alsi 1 (-15.1**), JLS 95 × JLS 79 (-13.16**) , Neela × JLS 79 (-11.2**), JLS 79 × Pratap Alsi 1 (-11.02**), JLS 95 × Mau Azad Alsi-2 (-10.7**), Mutant-2 × TL 99 (-9.79*), Mutant-2 × Pratap Alsi 1 (-8.20*), Mau Azad Alsi-2 × Arpita (-8.03*), PKV NL 260 × JLS 9 (-7.21*), showed significant negative SCA effect for number of capsules plant^{-1}.

6. 1000 Seed weight (g)

Among the parents nine parents showed positive GCA effect and were observed to be good general combiners for 1000 seed weight. Highest GCA effect was shown by Kota Barani 3 (0.514**) followed by Kota Barani 3 (0.52**), Arpita (0.409**), Neela (0.395**), Pratap Alsi 1 (0.381**), PKV NL 260 (0.340**), JRF 2 (0.24**), Mutant-2 (0.201**), Indira Alsi-32 (0.119*), TL 99 (0.09). Six parents showed significant negative GCA effect JLS 9 (-1.04**), Mutant-4 (-0.879**), JLS 95 (0.646**), Mau Azad Alsi-2 (-0.624**), JLS 79 (-0.570**), Kota Barani 4 (-0.222**).

Out of one hundred and five crosses, forty seven cross combinations expressed significant positive SCA effect indicating their good specific combining ability for 1000 seed weight. The cross combinations *Viz.,* Indira Alsi-32 × Mau Azad Alsi-2 (3.12**), JRF 2 × Kota Barani 4 (2.97**), JLS 9 × Kota Barani 3 (2.80**), JLS 79 × Kota Barani 3 (2.99**), PKV NL-260 × Kota Barani 3 (2.71**), Kota Barani 3 × Arpita (2.60**), Mutant-2 × Mutant-4 (2.58**), Mutant-4 × Mau Azad Alsi-2 (2.52**), JRF 2 × Pratap Alsi 1 (2.46**), JLS 95 × JLS 79

(2.40**),JLS 9 × Kota Barani 4 (2.34**), Neela × Mau Azad Alsi-2 (2.35**), Pratap Alsi 1 × TL 99 (2.13**), Mutant-4 × Kota Barani 3 (2.00**), JLS 95 × TL 99 (1.90**), PKV NL 260 × JLS 79 (1.82**), Neela × JLS 9 (1.81**), Indira Alsi-32 × Arpita (1.76**), JLS 9 × JLS 79 (1.75**), Neela × Kota Barani 4 (1.71), Mutant-4 × Arpita (1.62**), Neela × JRF 2 (1.68**), Indira Alsi-32 × Pratap Alsi 1 (1.59**), Pratap Alsi 1 × Arpita (1.57**), JLS 79 × Arpita (1.55**), JLS 95 × Pratap Alsi 1 (1.38**), Indira Alsi-32 × Mutant-4 (1.36**), Neela × JLS 79 (1.33**), Mutant-2 × Mau Azad Alsi-2 (1.24**), PKV NL 260 × JLS 9 (1.11**), JLS 79 × TL 99 (1.10**), PKV NL 260 × Pratap Alsi 1 (1.10**), Mau Azad Alsi-2 × Arpita (1.07**) Mutant-2 × Kota Barani 4 (1.07**), Indira Alsi-32 × Mutant-2 (1.04**), Mutant-2 × JLS 95 (1.04**), JRF 2 × Mau Azad Alsi-2 (0.92**), JRF 2 × JLS 95 (0.82**), Neela × Pratap Alsi 1 (0.77**), JRF 2 × TL 99 (0.71**), Mutant-2 × Kota Barani 3 (0.67**), PKV NL 260 × Mutant-4 (0.61**), JLS 9 × JLS 95 (0.59**), PKV NL 260 × JLS 95 (0.55*), Mau Azad Alsi-2 × Kota Barani 3 (0.48*), PKV NL 260 × Mau Azad Alsi-2 (0.46*) showed significant SCA effect in positive direction for 1000 seed weight, while forty one cross combinations showed significant negative SCA effect for 1000 seed weight.

7. Seed yield plant^{-1} (g)

Among the fifteen parents, eight parents Neela (0.755**), Kota Barani 3 (0.453**), PKV NL 260 (0.446**), Indira Alsi-32 (0.234**), Pratap Alsi 1 (0.173**) and Mau Azad Alsi-2 (0.115**) recorded significant positive GCA effect and were identified as good general combiners for seed yield plant^{-1}. Five parents *Viz.,* JLS 9 (-0.631**), JLS 79 (-0.547**), JRF 2 (-0.462**), JLS 95 (-0.471**), Mutant-2 (0.201**) recorded significant negative GCA effects.

Out of one hundred and five crosses, thirty two cross combination showed significant positive SCA effects indicating their good specific combining ability for seed yield plant^{-1}. The cross combinations *Viz.,* Neela × Indira Alsi-32 (5.42**), Mutant-4 × Kota

Barani 3 (3.29**), Indira Alsi-32 × JLS 9 (2.84**), Mutant-2 × Kota Barani 4 (2.58**), PKV NL 260 × JRF 2 (2.03**), Mutant-2 × Mau Azad Alsi-2 (1.52*), Kota Barani 3 × Arpita (1.61**), Kota Barani 3 × TL 99 (1.51**), Pratap Alsi 1 × TL 99 (1.56**), JLS 9 × JRF 2 (1.27**), Kota Barani 3 × Pratap Alsi 1 (1.26**), PKV NL 260 × Mutant-2 (1.07**), Indira Alsi-32 × JLS 95 (0.99**), Kota Barani 4 × TL 99 (0.98**), JLS 9 × Mutant-4 (0.88**), Kota Barani 4 × Pratap Alsi 1 (0.84**), PKV NL 260 × JLS 79 (0.82**), PKV NL 260 × Mutant-4 (0.77**), Mau Azad Alsi-2 × Pratap Alsi 1 (0.75**), Mutant-4 × JLS 79 (0.72**), Mutant-4 × TL 99 (0.70**), JRF 2 × Mau Azad Alsi-2 (0.68**), Indira Alsi-32 × Mau Azad Alsi-2 (0.67**), Arpita × TL 99 (0.65**), Indira Alsi-32 × JRF 2 (0.61**), Kota Barani 4 × Kota Barani 3 (0.58**), JLS 79 × TL 99 (0.52**), JRF 2 × Kota Barani 4 (0.51**), Mau Azad Alsi-2 × Kota Barani 3 (0.47**), PKV NL 260 × JLS 9 (0.46*), JLS 95 × Pratap Alsi 1 (0.39*) revealed significant positive SCA effects indicating their good specific combining ability for seed yield plant^{-1}, While thirty seven cross combinations showed significant negative SCA effects for this character.

8. Bud fly infestation (%)

Among the fifteen parents, PKV NL 260 (-5.128**), recorded the highest significant negative GCA effects followed by JLS 95 (-3.798**), Indira Alsi-32 (-2.586**), Mau Azad Alsi (-2.449), Neela (-2.073) and TL 99 (-1.557**). However parents such as JLS 9 (1.315**), JRF 2 (1.591**), Mutant-4 (7.036**), JLS 79 (2.007**), Kota Barani 4 (1.376**), Pratap Alsi 1 (1.611**), Arpita (1.511**), Mutant-2 (0.430), Kota Barani 3 (0.714) showed positive and significant GCA effects.

Significant negative SCA effects were noticed for thirty six crosses indicating their good specific combining ability for bud fly infestation. The cross combinations which expressed significant negative SCA effect were Neela × Mutant-4 (-19.27**), JRF 2 × Arpita (-18.08**), JRF 2 × TL 99 (-17.34**), Mutant-2 × Mutant-4 (-15.10**), JLS 9 × Pratap Alsi 1 (-15.06**), Mutant-4 × Pratap Alsi 1 (-14.20**),

JLS 9 × Mutant-4 (-12.57**), Mutant-2 × JLS 79 (-11.57**), Mutant-2 × Kota Barani 3 (-11.00**), Kota Barani 3 × Arpita (-10.20**), JLS 95 × JLS 79 (-10.74**), JLS 79 × Arpita (-10.49**), JLS 9 × JLS 79 (-10.46), JRF 2 × Kota Barani 3 (-10.11**), Mutant-2 × TL 99 (-10.10**), Arpita × TL 99 (-9.67**), JLS 9 × JLS 95 (-9.22**), JLS 79 × Pratap Alsi 1 (-9.17**), JRF 2 × Mau Azad Alsi-2 (-8.61**), PKV NL 260 × Kota Barani 4 (-7.80**), Indira Alsi-32 × Pratap Alsi 1 (-7.44**), Neela × Kota Barani 4 (-6.77**), JRF 2 × Kota Barani 4 (-6.60**), Mutant-4 × JLS 79 (-6.60**), JLS 95 × Kota Barani 4 (-5.88**), Kota Barani 4 × Arpita (-5.61**), Neela × Arpita (-5.49**), PKV NL 260 × Mutant-2 (-5.46**), Indira Alsi-32 × JLS 9 (-5.45**), Neela × TL 99 (-5.26**), PKV NL 260 × Kota Barani 3 (-5.06**), Kota Barani 4 × TL 99 (-4.99**), Indira Alsi-32 × Mutant-4 (-4.42*), PKV NL 260 × Mau Azad Alsi-2 (-4.40*), JLS 9 × Kota Barani 4 (-4.33*), Mutant-2 × Kota Barani 4 (-4.11*), PKV NL 260 × Mutant-2 (-4.02*), Indira Alsi-32 × Arpita (-4.01*), Mau Azad Alsi-2 × Kota Barani 3 (-3.82*), while twenty six crosses showed positive significant SCA effects for bud fly infestation.

9. Alternaria blight infestation (%)

Among the fifteen parents, PKV NL 260 (-1.584**) recorded the highest negative and significant GCA effect followed by Mutant-4 (-0.444**), JRF 2 (0.320**), Mutant-2 (-0.306**), Kota Barani 4 (-0.183*), Pratap Alsi 1 (-0.178*), Indira Alsi-32 (-0.280**). However parents such as Mau Azad Alsi-2 (1.224**), JLS 79 (0.941**), Neela (0.516), Arpita (0.246**), JLS 9 (0.116*), TL 99 (0.180*), Kota Barani 3 (0.059*), JLS 95 (0.013*) showed positive and significant GCA effect.

Significant negative SCA effect were noticed for thirty nine crosses indicating their good specific combining ability for alternaria blight infestation. The cross combinations Neela × Mau Azad Alsi-2 (-3.10**), Mutant-4 × Mau Azad Alsi-2 (-3.07**), Neela × Arpita (-3.02**), JLS 9 × JLS 79 (-2.95**), Mutant-2 × Mau Azad Alsi-2 (-2.79**), Mutant-2 × JLS 79 (-2.69**), JLS 9 × JLS 95 (-2.35**), Arpita × TL 99 (-2.32**), JLS 9 × Pratap Alsi 1 (-2.25**), Neela × TL 99 (-2.25**), JRF 2

× Mau Azad Alsi-2 (-2.13**), JLS 95 × JLS 79 (-2.01**), JLS 95 × Pratap Alsi 1 (-1.98**), JLS 79 × Arpita (-1.91**), Pratap Alsi 1 × TL 99 (-1.89**), Mau Azad Alsi-2 × Pratap Alsi 1 (-1.85**), Neela × JLS 79 (-1.85**), PKV NL 260 × Mau Azad Alsi-2 (-1.78**), Kota Barani 3 × Pratap Alsi 1 (-1.69**), Neela × Kota Barani 3 (-1.63**), JLS 9 × Mutant-2 (-1.62**), JRF 2 × Arpita (-1.57**), Kota Barani 4 × TL 99 (-1.54**), JLS 9 × Mutant-4 (-1.48**), JLS 9 × Kota Barani 4 (-1.49**) , PKV NL 260 × JLS 79 (-1.33**), Mutant-4 × Kota Barani 3 (-1.26**), JRF 2 × Kota Barani 4 (-1.22**), Pratap Alsi 1 × Arpita (-1.21**), Indira Alsi-32 × JLS 95 (-1.21**), Kota Barani 4 × Arpita (-1.21**), JLS 9 × Kota Barani 3 (-1.12**), Indira Alsi-32 × JLS 9 (-0.98**), Mutant-4 × TL 99 (-0.88**), Mutant-4 × Kota Barani 4 (-0.85**), PKV NL 260 × Kota Barani 3 (-0.84*), Neela × JRF 2 (-0.84**), Neela × Indira Alsi-32 (-0.78**), PKV NL 260 × TL 99 (-0.74**), Mutant-2 × Kota Barani 4 (-0.74*), PKV NL 260 × JLS 9 (-0.67*), JRF 2 × TL 99 (-0.67*) expressed significant negative SCA effect for alternaria blight infestation, while twenty eight cross combinations showed positive significant effect for this character.

Among the fifteen parents studied, parents Indira Alsi-32, Neela TL 99 and Kota Barani 3 showed significant GCA effect for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight. The GCA effect for parents PKV NL 260 were positively significant for seed yield and 1000 seed weight and significantly negative for number of capsules plant^{-1}. GCA effect for Mutant-2 were found to be positively significant for seed yield plant^{-1}, 1000 seed weight and negatively significant for number of capsules plant^{-1}. Above parents were found good general combiners for seed yield plant^{-1}, 1000 seed weight, number of capsules plant^{-1}.

Among one hundred and five crosses, SCA effect for crosses Indira Alsi-32 × Kota Barani 4, JRF 2 × Kota Barani 3, Neela × Mutant-4, JLS 95 × Kota Barani 3, JLS 95 × Kota Barani 4, PKV NL 260 × Neela, Mau Azad Alsi-2 × TL 99 were found negatively significant for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight. Also

the cross PKV NL 260 × Indira Alsi-32 exhibited negative significant SCA effect for seed yield plant^{-1}, 1000 seed weight, number of capsule plant^{-1}.

Table 5a. General combining ability effects of the parents for different characters

Sr. No.	Genotypes	Days to 50% flowering (days)	Days to Maturity (days)	Plant height (cm)	Number of branches plant^{-1}	Number of capsules plant^{-1}	1000 seed weight (g)	Seed yield plant $^{-1}$ (g)	Bud fly infestation (%)	Alternaria Blight infestation (%)
	Lines									
1	PKV NL-260	-0.965**	-0.342	5.907**	-0.684**	-8.592**	0.340**	0.446**	-5.128**	-1.584**
2	Neela	-1.573**	-0.342	-2.413**	-0.430**	16.649**	0.395**	0.755**	-2.073**	0.516**
3	Indira Alsi-32	-0.808*	0.030	-0.407**	0.018	8.521**	0.119*	0.234**	-2.586**	-0.280**
4	JLS 9	-1.416**	0.795	0.080	-0.354**	-2.625**	-1.039**	-0.631**	1.315**	0.116*
5	JRF 2 (Tiara)	0.133	-0.950	-0.967**	0.558**	-8.735**	0.238**	-0.462**	1.591**	-0.320**
6	Mutant- 2	1.310**	3.148**	14.139**	-0.351**	-1.228	0.201**	0.201**	0.430	-0.306**
7	Mutant- 4	0.231	-0.146	-3.798**	0.294**	5.74**	-0.879**	-0.071	7.036**	-0.444**
8	JLS 95	-0.475	1.893**	-4.740**	0.331**	-12.31**	0.646**	-0.471**	-3.798**	0.013*
9	JLS 79	0.349	0.422	-4.694**	-0.200**	-2.453**	-0.570**	-0.547**	2.007**	0.941**
10	Mau Azad Alsi-2	1.996**	0.422	-5.612**	-0.403**	-5.164**	-0.624**	-0.115**	-2.449	1.224**
11	Kota Barani-4	-0.180	-0.068	1.786**	0.672**	-0.629	-0.222**	0.015	1.376**	-0.183*
12	Kota Barani-3	0.604	-1.068	3.295**	0.493**	8.085**	0.514**	0.453**	0.714	0.059*
13	Pratap Alsi 1	1.388**	-0.284	-0.592**	-0.233**	-1.203	0.381**	0.173**	1.611**	-0.178*
14	Arpita	-0.180	-1.558*	0.618	0.385**	-0.316	0.409**	-0.002	1.511**	0.246**
15	TL 99	-0.416	-1.950**	-2.603**	-0.095**	4.257**	0.092	0.023	-1.557**	0.180*
	S.E.	0.347	0.648	0.506	0.034	0.900	0.056	0.044	0.469	0.084

Note: *Significant at 5% level, ** Significant at 1% level

Table 5b. Specific combining ability effects of crosses for different characters

Sr. No.	Genotypes	Days to 50% flowering (days)	Days to maturity (days)	Plant height (cm)	Number of branches plant^{-1}	Number of capsules plant^{-1}	1000 seed weight (g)	Seed yield plant $^{-1}$ (g)	Bud fly infestation (%)	Alternaria blight Infestation (%)
	Lines									
1	PKV NL 260 × Neela	-2.36	-5.80*	-4.75*	-0.08	-22.40**	-2.35**	-1.40**	7.40**	0.43
2	PKV NL 260 × Indira Alsi-32	-2.79*	-3.51	1.78	-2.19**	-21.70**	-0.31	-0.59**	-3.76	0.44
3	PKV NL 260 × JLS 9	-1.85	2.73	-14.20**	1.71**	-7.21*	1.11**	0.46*	-1.49	-0.67*
4	PKV NL 260 × JRF 2 (Tiara)	17.60**	1.47	54.76**	-0.20	29.65**	-1.24**	2.03**	8.15**	-0.07
5	PKV NL 260 × Mutant-2	-3.58*	-4.96	-6.93**	2.84**	20.89**	0.30	1.07**	-4.02*	-0.25
6	PKV NL 260 × Mutant-4	-3.83**	4	-2.16	1.90**	30.09**	0.61**	0.77**	-5.46**	0.39
7	PKV NL 260 × JLS 95	-3.46*	-4.04	1.53	-0.17	4.14	0.55*	0.22	5.46**	0.65

8	PKV NL 260 × JLS 79	-4.28**	-3.90	1.82	-0.31*	10.70**	1.82**	0.82**	-0.60	-1.33**
9	PKV NL 260 × Mau Azad Alsi-2	4.07**	5.77*	0.07	0.86**	-0.92	0.46*	0.02	-4.39*	-1.78**
10	PKV NL 260 × Kota Barani 4	6.25**	9.26**	-3.99	-1.28**	-6.71	0.14	-0.50**	-7.80**	0.29
11	PKV NL 260 × Kota Barani 3	4.46**	7.92**	13.50**	-2.13**	-30.60**	2.71**	-0.33	-5.06**	-0.84*
12	PKV NL 260 × Pratap Alsi 1	-3.33*	-4.863	-3.37	-0.74**	-19.30**	1.10**	-0.64	-0.04	0.73*
13	PKV NL 260 × Arpita	-2.42	-3.26	5.59**	-0.36**	9.07*	-2.06**	0.35	-0.27	-0.30
14	PKV NL 260 × TL 99	0.81	-2.53	-1.60	0.39**	2.41	0.35	-0.31	-2.53	-0.74**
15	Neela × Indira Alsi-32	-2.19	0.157	8.60**	1.59**	94.12**	0.05	5.42**	11.32**	-0.78*
16	Neela × JLS 9	-0.25	-1.94	0.43	0.11	-3.50	1.81**	-0.28	-0.21	1.06**
17	Neela × JRF 2 (Tiara)	-0.79	-1.96	-7.84**	-1.79**	-18.30**	1.68**	-0.78**	-2.65	-0.84
18	Neela × Mutant-2	4.03**	0.71	-19.23**	1.11**	4.69	-0.46*	-0.11	6.32**	-0.57
19	Neela × Mutant-4	-2.89*	2.00	-12.34**	-0.69**	-43.56**	-2.31**	-1.54**	-19.27**	2.12**

20	Neela × JLS 95	0.15	-1.37	4.34*	-1.19**	11.45**	-1.19**	0.34	-1.20	1.71**
21	Neela × JLS 79	8.32**	5.43*	-5.78**	-0.70**	-11.21**	1.33**	0.03	-2.07	-1.85
22	Neela × Mau Azad Alsi-2	-4.32**	8.77**	1.73	-0.29*	-15.64**	2.35**	0.04	0.35	-3.10**
23	Neela × Kota Barani 4	-0.15	-0.75	7.50**	-0.57**	35.39**	1.71	-0.25	-6.77**	5.11**
24	Neela × Kota Barani 3	1.74	-1.75	0.07	-1.67**	1.87	-3.80**	-0.81**	16.53**	-1.63
25	Neela × Pratap Alsi 1	1.28	-3.20	3.90	-0.82**	-0.90	0.77**	0.03	21.35**	2.55**
26	Neela × Arpita	0.52	-1.59	-6.92**	1.22**	28.05**	0.37	0.20	-5.49**	-3.02**
27	Neela × TL 99	-2.25	-1.53	4.80*	1.70**	-6.42	1.76**	-1.17**	-5.26**	-2.25**
28	Indira Alsi-32 × JLS 9	1.32	3.35	4.61*	-0.49	62.51**	2.78**	2.84**	-5.45**	-0.98**
29	Indira Alsi-32 × JRF 2 (Tiara)	-0.23	0.10	15.84**	0.67**	4.82	-0.54*	0.61**	-2.67	-0.44
30	Indira Alsi-32 × Mutant-2	2.27	-6.00*	-14.87**	-1.49**	5.95	1.04**	-0.19	27.24**	0.39
31	Indira Alsi-32 ×	-0.66	3.96	-0.01	1.03**	31.73**	1.36**	-0.17	-4.42*	1.75**

	Mutant-4									
32	Indira Alsi-32 × JLS 95	-0.62	-4.75	-0.07	1.08**	11.11**	0.26	0.99**	-3.17	-1.21**
33	Indira Alsi-32 × JLS 79	4.89**	-1.94	-1.45	0.52**	-37.41**	-2.19**	-1.14**	1.94	0.03
34	Indira Alsi-32 × Mau Azad Alsi-2	0.91	-4.28	0.09	1.08**	10.5**	3.12**	0.66**	-0.69	0.16
35	Indira Alsi-32 × Kota Barani 4	-0.91	-2.12	-3.43	-1.68**	-44.40**	-2.77**	-1.87**	14.41**	-0.35
36	Indira Alsi-32 × Kota Barani 3	1.30	-2.79	-1.94	-1.34**	5.55	-2.57**	-0.79**	-2.26	3.91**
37	Indira Alsi-32 × Pratap Alsi 1	-1.48	10.43**	1.53	1.39**	-15.41**	1.59**	-0.94**	-7.44**	-0.60
38	Indira Alsi-32 × Arpita	0.42	-0.29	-1.65	0.77**	-21.49**	1.76**	-0.45*	-4.01*	0.45
39	Indira Alsi-32 × TL 99	0.32	-0.57	0.74	-0.05	-0.79	-1.17**	-0.25	-2.46	0.38
40	JLS 9 × JRF 2	4.72**	9.33**	26.783**	-0.25	62.96**	-2.07**	1.27**	-2.32	0.51
41	JLS 9 × Mutant-2	0.21	-1.77	2.57	-1.12**	-22.30	-2.61**	-0.99**	11.62	-1.62**
42	JLS 9 × Mutant-4	-1.382	-2.471	3.09	0.99**	19.96**	-0.20	0.88**	-12.57**	-1.48**

43	JLS 9 × JLS 95	-0.343	7.157**	8.66**	0.20	8.49*	0.591**	0.20	-9.22**	-2.35**
44	JLS 9 × JLS 79	0.17	-3.04	-10.10**	3.73**	35.99**	1.75**	0.26	-10.46**	-2.95**
45	JLS 9 × Mau Azad Alsi-2	-1.15	-2.71	-8.02**	-2.07**	-26.55**	-1.28**	-0.89**	-1.67	2.69**
46	JLS 9 × Kota Barani 4	0.03	-2.22	7.92**	-0.14	11.41**	2.34**	0.01	-4.33*	-1.49
47	JLS 9 × Kota Barani 3	0.58	-1.55	-0.42	0.04	-25.41**	2.80**	-0.51**	8.22**	-1.12**
48	JLS 9 × Pratap Alsi 1	1.13	-5.00*	-2.29	-0.24	-2.10	-2.18**	-0.54**	-15.06**	-2.25**
49	JLS 9 × Arpita	1.36	-0.06	-8.25**	0.14	-32.67**	-2.52**	-1.12**	37.54**	6.16**
50	JLS -9 × TL 99	-1.07	0.33	-11.36**	-0.38**	-29.80**	-1.53**	-1.08**	27.61**	7.56**
51	JRF 2 × Mutant-2	-2.68	-3.02	-28.47**	0.55**	-1.05	-0.416	-0.39	2.43	-0.35
52	JRF 2 × Mutant-4	0.07	-0.73	-12.45**	-0.01	-31.18**	-1.94**	-1.15**	22.07**	-0.38
53	JRF 2 × JLS 95	2.11	-6.43*	5.425**	2.95**	10.04**	0.817**	0.34	-1.51	0.67*
54	JRF 2 × JLS 79	-1.72	-0.29	-14.78**	-1.02**	-16.99**	-1.837**	-0.31	22.10**	-0.43

55	JRF 2 × Mau Azad Alsi-2	-5.03**	-1.29	-1.47	2.02**	33.47**	0.92**	0.67**	-8.61**	-2.13**
56	JRF 2 × Kota Barani 4	-1.52	2.86	-7.70**	-2.05**	-2.65	2.97**	0.51**	-6.60**	-1.22**
57	JRF 2 × Kota Barani 3	-2.30	0.53	-19.71**	-1.54**	-35.03**	-2.49**	-1.61**	-10.11**	0.95**
58	JRF 2 × Pratap Alsi 1	-3.42*	-0.59	-0.26	-1.02**	-19.01**	2.46**	-0.76**	12.08**	2.92**
59	JRF 2 × Arpita	0.82	0.69	-7.03**	-1.77**	-20.29**	-3.22**	-1.06**	-18.07**	-1.57**
60	JRF 2 × TL 99	0.05	2.75	2.02	-2.87**	-21.36**	0.71**	-0.78**	-17.34**	-0.67*
61	Mutant-2 × Mutant-4	-0.44	7.51**	3.53	-0.77**	-0.94	2.58**	-0.02**	-15.10**	1.28**
62	Mutant-2 × JLS 95	0.93	1.47	-8.05**	1.20**	14.48**	1.04**	1.04**	11.07**	3.19**
63	Mutant-2 × JLS 79	-1.23	-3.73	1.76	-0.27	-28.00	-2.03**	0.16	-11.57**	-2.69**
64	Mutant-2 × Mau Azad Alsi-2	-0.54	-4.06	2.10	0.60**	14.57**	1.24**	1.52**	3.03	-2.79**
65	Mutant-2 × Kota Barani 4	2.30	2.10	25.08**	-1.15**	38.33**	1.07**	2.58**	-4.11**	-0.74*

66	Mutant-2 × Kota Barani 3	-0.15	7.10**	-14.98**	-0.97**	-23.35**	0.67**	-1.32**	-11.00	-0.12
67	Mutant-2 × Pratap Alsi 1	1.07	2.98	5.79**	-0.87**	-8.20*	-1.15**	-0.74**	8.17**	0.29
68	Mutant-2 × Arpita	-1.03	-3.75	17.04**	1.14**	1.84	0.22	-0.42*	-0.65	5.14**
69	Mutant-2 × TL 99	3.87**	-1.69	-12.67**	0.95**	-9.79*	-0.74**	-0.51**	-10.09**	1.07**
70	Mutant-4 × JLS 95	-1.32	-6.90**	-2.18	-2.45**	-25.27	-2.19**	-1.13**	9.29**	0.957**
71	Mutant-4 × JLS 79	-1.15	-0.43	-1.78	-0.92**	8.62*	-0.71	0.72**	-6.57	-0.22
72	Mutant-4 × Mau Azad Alsi-2	-1.13	-3.10	1.03	1.48**	-3.59	2.52**	0.17	0.21	-3.07**
73	Mutant-4 × Kota Barani 4	0.05	0.73	7.80**	-2.46**	-33.29	-1.12**	-1.03**	19.29**	-0.85**
74	Mutant-4 × Kota Barani 3	-1.07	-1.28	20.84**	0.55**	99.66**	1.20**	3.29**	9.78**	-1.26**
75	Mutant-4 × Pratap Alsi 1	1.81	-5.73*	-10.10**	0.70**	-18.66**	0.04	-0.70**	-14.2**	2.15**
76	Mutant-4 × Arpita	-1.62	-0.12	-4.81*	3.50**	6.40	1.62**	0.15	6.37**	0.50
77	Mutant-4 × TL 99	4.95**	4.94	2.52	-2.02**	38.49**	-2.39**	0.70**	26.55**	-0.88**

78	JLS 95 × JLS 79	-0.44	7.86**	19.64**	-0.96**	-13.16**	2.40**	-0.03	-10.74**	-2.01**
79	JLS 95 × Mau Azad Alsi-2	-1.42	8.20**	-7.36**	0.25	-10.70**	-1.87**	-0.97**	-2.89	-2.71**
80	JLS 95 × Kota Barani 4	2.09	-2.65	-10.43**	1.17**	-19.91**	-0.83**	-0.98**	-5.88**	2.86**
81	JLS 95 × Kota Barani 3	1.64	-1.65	-10.10**	0.02	-25.95**	-3.00**	-1.47**	9.28**	3.29**
82	JLS 95 × Pratap Alsi 1	-0.48	-4.43	3.45	0.66**	5.42	1.38**	0.39*	0.97	-1.98**
83	JLS 95× Arpita	1.42	-2.16	-0.59	-0.71**	7.53*	0.10	0.35	-0.85	0.52
84	JLS 95 ×TL 99	-1.01	-3.77	-0.46	0.61**	4.13	1.90**	-0.26	-0.78	0.25
85	JLS 79 × Mau Azad Alsi-2	4.42**	-4.33	0.09	0.78**	7.55*	-1.49**	0.71**	0.47	-0.31
86	JLS 79 × Kota Barani 4	2.27	-3.18	-5.04*	3.70**	23.91**	-0.76**	-0.18	2.31	-0.57
87	JLS 79 × Kota Barani 3	-3.52*	-4.18	3.10	-0.12	31.36**	2.99**	-0.05	4.23*	1.36**
88	JLS 79 × Pratap Alsi 1	-2.64	-2.63	5.24*	-2.39**	-11.02**	-2.09**	-0.12	-9.17**	5.51**
89	JLS 79 × Arpita	-1.069	-1.02	-1.47	-0.68**	36.09**	1.55**	-0.47**	-10.49**	-1.91**

90	JLS 79 × TL 99	-0.83	-0.63	6.41**	-0.53**	14.77**	1.10**	0.52**	8.14**	7.24**
91	Mau Azad Alsi-2 × Kota Barani 4	-2.72	1.82	2.17	-2.09**	-21.05**	-2.14**	-1.22**	12.77**	0.82
92	Mau Azad Alsi-2 ×Kota Barani 3	-0.17	-0.51	0.64	-1.25**	17.84**	0.48*	0.47**	-3.82*	0.91**
93	Mau Azad Alsi-2 × Pratap Alsi 1	3.05*	8.37**	5.66**	2.81**	44.86**	-1.60**	0.75**	2.09	-1.85**
94	Mau Azad Alsi-2 × Arpita	0.62	-3.02	0.45	-0.81**	-8.03*	1.07**	-0.18	0.41	4.61**
95	Mau Azad Alsi-2 × TL 99	5.19**	-2.29	-6.50**	-1.33**	-5.60	-0.56*	-0.05	6.70**	-0.10
96	Kota Barani 4 × Kota Barani 3	-1.32	-1.69	-3.13	2.51**	-5.55	-0.41	0.58**	1.39	2.32**
97	Kota Barani 4 × Pratap Alsi 1	-1.44	-1.14	-5.85**	1.74**	21.07**	-2.85**	0.84**	0.04	0.44
98	Kota Barani 4 × Arpita	-0.54	0.14	-8.29**	-0.30*	-16.65**	-0.69**	-0.02**	-5.61**	-1.21**
99	Kota Barani 4 × TL 99	-3.30*	-1.80	1.65	-1.07**	19.41**	0.29	0.98**	-4.99**	-1.54**
100	Kota Barani 3 × Pratap Alsi 1	1.78	1.20	-6.92**	1.08**	10.94**	-3.54**	1.26**	14.04**	-1.69**
101	Kota Barani 3 ×	1.34	3.80	11.62**	1.55**	7.14*	2.60**	1.61**	-10.20**	-2.28**

	Arpita									
102	Kota Barani 3 × TL 99	-2.09	0.20	8.54**	4.23**	3.70	-0.13*	1.51**	-1.39	-1.28**
103	Pratap Alsi 1 × Arpita	2.89**	12.02**	7.23**	-1.64**	-19.16	1.57**	-0.27	16.49**	-1.21**
104	Pratap Alsi 1 × TL 99	4.46**	-2.26	7.40**	0.50**	19.44**	2.13**	1.56**	5.06**	-1.89**
105	Arpita × TL 99	-1.64	1.35	-7.48**	-0.87**	1.13	-0.52*	0.64**	-9.67**	-2.32**
	S.E. (sij)	**1.40**	**2.61**	**2.04**	**0.14**	**3.62**	**0.23**	**0.18**	**1.89**	**0.34**

4.8 Selection of promising crosses

Selection of parents in crop improvement programmes is of an immense significance. The common approach of selecting parents on basis of *per se* performance, adaptation and diversity does not necessarily lead to the fruitful results because the ability of parents to combine well with each other depends upon the complex interactions among the genes and also it is common experience that certain crosses produce many superior transgrates and some crosses between promising parents produce inferior progenies. Therefore, the selection of the best parents for hybridization has to be based on the knowledge of combining ability of the parents.

The breeder is interested in producing true breeding varieties in predominantly self pollinated crops as non-additive gene action of phenotypic variation is not fixable in later generation. Therefore a breeder would prefer to isolate the crosses which have low SCA effects but have high mean performance and better GCA for parent.

Considering the above points, the potentialities of varieties as parents may be determined by comparing it's *per se* performance of F_1 values involving that parents and the general combining ability while, potentiality of cross to be forwarded to next generation is determined on the basis of high GCA of one or both divergent parents involving in cross and SCA effect in negative direction. Based on these fact selected promising crosses and their performance are given in Table 8. The cross combinations showed all the three possible combinations between the parents with high and low gca effects *Viz.,* high × high, high × low, and low × low.

Among the one hundred and five crosses studied, the cross PKV NL 260 × Indira Alsi-32 showed negative significant SCA effect for number of capsules plant^{-1}, seed yield plant^{-1}, 1000 seed weight, bud fly infestation along with highly significant mean performance for number of capsules plant^{-1}, seed yield plant^{-1} and highly non significant

mean performance for 1000 seed weight, bud fly infestation and GCA effects of both parents were found positively significant for seed yield plant^{-1} and 1000 seed weight. The GCA effects were found significantly negative (PKV NL 260) and positive (Indira Alsi-32) for number of capsules plant^{-1} and for bud fly GCA effects were found significantly negative for both parents.

Other cross Kota Barani 4 × Arpita possessed significant negative SCA effect for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight and plant height along with high and significant mean performance for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight and non significant high mean performance for plant height. GCA effects for seed yield plant^{-1} were found non significant positive for both the parents involved in the cross. The same cross possessed GCA effects for number of capsules plant^{-1} non significant negative for both the parents Kota Barani 4 and Arpita. For 1000 seed weight GCA effects were found significant negative (Kota Barani 4) and positive significant (Arpita). For plant height the same cross possessed significant positive (Kota Barani 4) and non significant positive (Arpita) GCA effects.

The cross PKV NL 260 × Neela exhibited significant SCA effect in negative direction for number of capsules plant^{-1}, seed yield plant^{-1}, 1000 seed weight and plant height along with high non significant mean performance for number of capsules plant^{-1}, 1000 seed weight, plant height and also showed significant and high mean performance for seed yield plant^{-1}. GCA effects of both parents were found positively significant for seed yield plant^{-1} and for number of capsules plant^{-1}. GCA effects were found negatively significant (PKV NL 260) and positively significant (Neela) for 1000 seed weight, positively significant (PKV NL 260) and negatively significant (Neela) for plant height.

Other cross Mau Azad Alsi-2 × TL 99 possessed non significant negative SCA effect along with highly significant mean performance for seed yield plant^{-1}, and number of capsules plant^{-1}, and it also showed

significant negative effect for 1000 seed weight and plant height along with non significant mean performance. The GCA effects for the parents involved in the cross were significantly negative (Mau Azad Alsi-2) and non significant positive (TL 99) for seed yield plant^{-1}. For number of capsules plant^{-1} GCA effects were significantly negative (Mau Azad Alsi-2) and positive (TL 99) for the parents involved in the cross. For the same cross GCA effects for plant height were found negatively significant for both the parents.

Other cross JLS 79 × Pratap Alsi 1 exhibited significant negative SCA effect for number of capsules plant^{-1}, plant height and 1000 seed weight and non significant negative SCA effect for seed yield plant^{-1} and bud fly infestation along with non significant high mean performance for seed yield plant^{-1}, 1000 seed weight, bud fly infestation and significant high mean performance for number of capsules plant^{-1} and the GCA effects were found significant negative (JLS 79) and significant positive for seed yield plant^{-1}, plant height. GCA effects for both the parents found significant positive for 1000 seed weight and bud fly infestation. GCA effect were found significant negative (JLS 79) and significant positive (Pratap Alsi 1) for plant height.

Other cross Mutant-2 × TL 99 possessed significant negative SCA effect for number of capsules plant^{-1}, plant height and 1000 seed weight, seed yield plant^{-1} along with significant high mean performance for seed yield plant^{-1}, 1000 seed weight, number of capsules plant^{-1}, GCA effects for the parents involved in the cross were found positively significant (Mutant-2) and non significant (TL 99) for seed yield plant^{-1}, positively significant (Mutant-2) and non significant negative (TL 99) for plant height, negative non significant (Mutant-2) and positive signifificant (TL 99) for number of capsules plant^{-1}, positively significant (Mutant-2) and non significant (TL 99) for 1000 seed weight.

Other cross Neela × JRF 2 showed SCA effects in negatively significant direction for seed yield plant^{-1}, number of capsules plant^{-1}, plant height and non significant for 1000 seed yield, bud fly infestsation

along with non significant high mean performance for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight, plant height and bud fly infestation. GCA effects found to be positively significant (Neela) and negatively significant (JRF 2) for seed yield plant^{-1}, number of capsules plant^{-1}, negatively significant (Neela) and positively significant (JRF 2) for bud fly infestation and for plant height negatively significant for both parent.

Other cross JLS 9 × Mau Azad Alsi-2 possessed SCA effects significantly negative for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight along with significant high mean performance for number of capsules plant^{-1}, 1000 seed weight and non significant mean performance for seed yield plant^{-1}. GCA effects were found to be significantly positive (JLS 9) and negative (Mau Azad Alsi-2) seed yield plant^{-1}, whereas the same cross possessed GCA effects non significantly negative (JLS 9) and significantly negative (Mau Azad Alsi-2), 1000 seed weight for number of capsules plant^{-1} significantly negative for both parents.

Other cross JLS 95 × Mau Azad Alsi-2 showed significant negative SCA effects along with non significant high mean performance for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight, bud fly infestation and significant high mean performance for plant height. The parents involved in the cross possessed GCA effects significant negative for both parent for plant height, seed yield plant^{-1}, number of capsules plant^{-1} and for 1000 seed weight showed significant positive (JLS 95) and significant negative (Mau Azad Alsi-2) and for bud fly infestation showed significant negative (JLS 95) and non significant negative (Mau Azad Alsi-2).

The cross Neela × Mutant-4 exhibited significant SCA effect in negative direction for number of capsules plant^{-1}, 1000 seed weight, plant height and non significant SCA effect for seed yield plant^{-1} along with high significant mean performance for number of capsules plant^{-1} and non significant high mean performance for seed yield plant^{-1}, 1000

seed weight and bud fly infestation. The GCA effects of both the parents were found positively significant for number of capsules plant^{-1} and for seed yield plant^{-1} positively significant (Neela) and negative (Mutant-4) and for 1000 seed weight GCA effect were significantly positive (Neela) and significantly negative (Mutant-4) and for bud fly infestation GCA effect were found significantly negative (Neela) and significantly positive (Mutant-4).

Other cross JLS 95 × Kota Barani 3 possessed SCA effects significantly negative for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight along with non significant mean performance for seed yield plant^{-1} and significant high mean performance for number of capsules plant^{-1}, 1000 seed weight. GCA effects were found to be positively significant for seed yield plant^{-1}, 1000 seed weight for both parent and negatively significant (JLS 95) and positively significant (Kota Barani 3) for number of capsules $^{-1}$.

Other cross JRF 2 × Kota Barani 3 showed significant negative SCA effects for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight, plant height and bud fly infestation along with significant mean performance for bud fly infestation, 1000 seed weight and non significant mean performance for seed yield plant^{-1}, number of capsules plant^{-1}, plant height. For seed yield plant^{-1}, 1000 seed weight. GCA effects were found positively significant for both parents and for bud fly infestation GCA effect were found positively significant (JRF 2) and non significant (Kota Barani 3). Whereas for number of capsules plant^{-1}, plant height GCA effects were found negatively significant (JRF 2) and positively non significant (Kota Barani 3).

Other cross JLS 95 × Kota Barani 4 showed significant negative SCA effect for plant height, number of capsules plant^{-1}, 1000 seed weight, seed yield plant^{-1}, bud fly infestation with highly significant mean performance for seed yield plant^{-1}, 1000 seed weight, plant height and non significant seed yield plant^{-1}, bud fly infestation. The GCA effects for the parents involved in the cross were found significant

negative (JLS 95) and non significant positive (Kota Barani 4) for plant height and seed yield plant^{-1}, significant negative (JLS 95) and significant positive bud fly infestation, significant positive (JLS 95) and significant negative (Kota Barani 4) for 1000 seed weight, and for number of capsules GCA effect were significantly negative for both parent. The presence of SCA effect for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight and bud fly infestation in the above cross combinations showed the predominant role of additive gene action for yield components which is general situation observed in self pollinated crops. Due to the presence of additive gene action in these crosses the genotypes of inherent superiority can be produced from this population by blending and mixing favourable genes. These crosses were therefore found to be best crosses which can be forwarded to the next generation.

Table 6. Identification of potential crosses

Sr. No.	Name of crosses	Seed yield plant^{-1} (g)				Number of capsules plant^{-1}				1000 seed weight (g)			
		Mean	SCA effects	GCA effects of parents		Mean	SCA effects	GCA effects of parents		Mean	SCA	GCA effects of parents	
1	PKV NL 260 × Indira Alsi-32	8.73**	-0.59**	0.446**	0.234**	161.80**	-21.70**	-8.592	8.521	8.58	0.31	0.34**	0.119*
2	Kota Barani 4 × Arpita	4.38**	-0.02**	0.015	-0.002	57.42**	-16.65**	-0.629	-0.316	11.54**	-0.69**	-0.222	0.409**
3	PKV NL 260 × Neela	3.96**	-1.40**	0.446**	0.775**	48.97	-22.40**	-8.592	16.649	7.96	-2.35**	0.34**	0.395**
4	Mau Azad Alsi-2 × TL 99	3.33**	-0.05**	-0.115	0.023	65.55**	-5.60	-5.164	4.257**	8.18	-0.56*	-0.624	0.092
5	JLS 79 × Pratap Alsi 1	3.12	-0.12	-0.547	0.173**	81.00**	-11.02**	-2.453**	-1.203	6.17	-2.09**	0.570**	0.381**
6	Mutant-2 × TL 99	2.97**	-0.51**	0.201**	0.023	91.00**	-9.79*	-1.228	4.257**	4.84	-0.74**	0.201**	0.092
7	Neela × JRF 2	2.70	-0.78**	0.755**	-0.453**	47.12	-18.30**	16.649**	-8.735**	7.83	-1.68**	0.395**	0.238**

8	JLS 9 × Mau Azad Alsi-2	2.42	-0.89**	-0.631**	-0.115**	62.08**	-26.55**	-2.625**	-5.164**	8.55	-1.28**	-1.039	-0.624**
9	JLS 95 × Mau Azad Alsi-2	2.37	-0.97**	-0.471**	-0.115**	42.44	-10.70**	-12.31**	-5.164**	5.33	1.87**	0.646**	-0.624**
10	Neela × Mutant-4	2.32	-1.54**	0.755**	-0.071	88.50**	-43.56**	16.649**	5.74**	8.62	-2.31**	0.395	-0.879
11	JLS 95 × Kota Barani 3	2.18	-1.47**	0.471**	0.453**	79.50**	-25.95**	-12.31**	8.085**	10.96**	-3.00**	0.646**	0.514**
12	JRF 2 × Kota Barani 3	1.66	-1.61**	0.462**	0.453**	26.02	-35.03**	-8.735**	8.085**	9.40**	-2.19**	0.238**	0.514**
13	JLS 95 × Kota Barani 4	1.61	-19.91**	-0.471**	0.015	63.33**	-19.91**	-12.31**	-0.629	6.47	-0.83**	0.646**	-0.222**

Note: * Significant at 5% level, ** Significant at 1% level

Chapter IV

SUMMARY AND CONCLUSIONS

The present study of “Combining ability analysis for yield and yield contributing traits in linseed (*Linum usitatissimum* L.)” was carried out using diallel analysis (without reciprocals) Method II Model I to estimate combining ability of important yield and yield contributing traits and to identify potential parents and cross combinations for linseed breeding programme. The breeding material for the study comprised of one hundred and five crosses involving fifteen divergent parents were grown in randomized block design with three replications at the farm of AICRP college of Agriculture, Nagpur. The observations were recorded on five plants for nine quantitative traits. *Viz.,* days to 50% flowering (on plot basis), days to maturity (on plot basis), plant height (cm), number of branches plant^{-1}, number of capsules plant^{-1}, 1000 seed weight (g), seed yield plant^{-1} (g), bud fly infestation (%), alternaria infestation (%).

The analysis of variance of parents revealed mean sum of squares due to genotypes were highly significant for all the characters studied indicating presence of considerable genetic diversity among the parents. The analysis of variance for parents and crosses revealed mean sum of squares due to parents and crosses were significant for all the nine characters studied indicating substantial genetic diversity among the parents and crosses which allows further estimation of experimental material.

The data of high mean performance for seed yield plant^{-1} (4.33** g), number of capsules plant^{-1} (54.83**), 1000 seed weight (7.35 g) were exhibited by JRF 2. The parent Mutant-2 recorded high mean performance for seed yield plant^{-1} (4.03** g), number of capsules plant^{-1} (53.58**), 1000 seed weight (8.86**g), followed by Mutant-4 seed yield plant^{-1} (3.47** g), number of capsules plant^{-1} (69.75**), 1000 seed weight (8.09 g). The parents PKV NL 260 (35.33** cm), JLS 9

(36.33** cm), Neela (43.29 cm) recorded lowest mean performance for plant height thus it can prevent lodging. JRF 2 was found tallest so it can be used for dual purpose i.e. linseed oil and fibre flax. The parents Mau Azad Alsi-2, Kota Barani 4, Indira Alsi-32 were found resistant to be resistant to bud fly infestation. The parents Neela (102.33 days), Pratap Alsi 1 (103.33 days), Arpita (103.67 days) were found to be early maturing.

Analysis of variance for combining ability revealed mean squares due to parents were significant for all the characters studied indicating presence of sufficient genetic variability for general combining ability among the parents and mean sum of squares due to crosses were significant for all the characters studied indicating substantial genetic variability for specific combining ability among the crosses.

The predictability ratio ranged from 0.49 to 0.81. The predictability ratio for days to 50% flowering (0.78), days to maturity (0.75), plant height (0.49), number of branches plant^{-1} (0.72), number of capsules plant^{-1} (0.73), 1000 seed weight (0.75), seed yield plant^{-1} (0.81), bud fly infestation (0.72), alternaria blight infestation (0.73). The ratio was found closer to unity, greater the predictability based on general combining ability alone.

Selection of parents in crop improvement programmes is of an immense significance. The common approach of selecting parents on basis of *per se* performance, adaptation and diversity does not necessarily lead to the fruitful results because the ability of parents to combine well with each other depends upon the complex interactions among the genes and also it is common experience that certain crosses produce many superior transgrates and some crosses between promising parents produce inferior progenies. In order to obtain maximum genetic gain, the combining ability analysis of Griffings (1956) has been extensively used to identify best parents hybridization with high breeding value and better potential to transmit

desirable characteristics to its progenies and the best specific cross combination for desirable economic traits. The parents with high general combining ability effects may be used for improvement of individual trait *per se.* GCA effects are the measure additive gene action and additive × additive interaction which represents fixable components of genetic variance and are used to classify the parents for breeding behaviour in hybrid combinations. On the other hand, SCA effects are the measure of non-additive gene action which is related to non fixable component of genetic variance. Therefore, if both or one of the parents involved in the crosses with high SCA values they could be successfully exploited in varietal development program and expected to give superior transgressive segregants.

Identification of parents on the basis of general combining ability and high mean performance gives high proportion of superior segregants. The parents Neela, Kota Barani-3, Indira Alsi-32, TL 99 was found to be best general combiners as it recorded highly significant positive GCA effects for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight. The parent Kota Barani 3 showed high significant mean performance for seed yield plant^{-1}, 1000 seed weight and non significant high mean performance for number of capsules plant^{-1}. Mutant-2 recorded high significant mean performance for seed yield plant^{-1}, 1000 seed weight and number of capsules plant^{-1} along with significant GCA effect for 1000 seed weight and seed yield plant^{-1}. The parents namely PKV NL 260, Neela, Indira Alsi-32, JLS 95, Mau Azad Alsi-2, TL 99 possessed negatively significant GCA effects for bud fly infestation and were found to be good general combiners for bud fly infestation.

The crosses showed high mean performance, high gca effects of the parents involved in the cross and low sca effects of crosses may serve as better source of population for developing superior segregants. In the present study the cross PKV NL 260 × Indira Alsi-32 exhibited significantly negative SCA effects for seed yield plant^{-1},

number of capsules plant^{-1},1000 seed weight along with significant mean performance for seed yield plant^{-1}, number of capsules plant^{-1} and non significant mean performance for 1000 seed weight. The GCA effects for the parents involved in the cross possessed (high × high) for seed yield plant^{-1}, (high × low) number of capsules plant^{-1}, (high × high) 1000 seed weight,

The cross Kota Barani 4 × Arpita exhibited significant negative SCA effects for seed yield plant^{-1}, number of capsules plant^{-1},1000 seed weight and plant height along with high significant mean performance for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight and non significant high mean performance for plant height. GCA effects of the parents involved in the cross were found (Medium × Medium) for seed yield plant^{-1}, (Medium × Medium) for number of capsules plant^{-1} and (low × high) for 1000 seed weight. For plant height the same cross possessed (high × medium) GCA effect.

The cross PKV NL 260 × Neela exhibited significant SCA effects in negative direction for number of capsules plant^{-1}, seed yield plant^{-1}, 1000 seed weight and plant height along with high non significant mean performance for number of capsules plant^{-1}, 1000 seed weight, plant height also high and significant high mean performance shown for seed yield plant^{-1}. GCA effects of both parents were found (high × high) seed yield plant^{-1} and (high × low) for number of capsules plant^{-1}. GCA effects were found (high × high) for 1000 seed weight.

Other cross Mau Azad Alsi-2 × TL 99 exhibited non significant negative SCA effects along with highly significant mean performance for seed yield plant^{-1}, and number of capsules plant^{-1}, and it also showed significant negative effect for 1000 seed weight and plant height along with non significant mean performance. The GCA effects were found (low × medium) for seed yield plant^{-1}, (low × high) for number of capsules plant^{-1}, (low × medium) For 1000 seed weight, (low × low) for plant height .

Other cross Mutant-2 × TL 99 exhibited significant negative SCA effects for number of capsules plant^{-1}, plant height and 1000 seed weight, seed yield plant^{-1} along with significant high mean performance for seed yield plant^{-1}, 1000 seed weight, number of capsules plant^{-1}. GCA effects were found (high × medium) for seed yield plant^{-1}, (high × medium) for plant height, (medium × high) for number of capsules plant^{-1}, (high × medium) for 1000 seed weight.

The GCA effects for the parents involved in the cross combinations were JLS 79 × Pratap Alsi 1 (high × high), Neela × Mutant-4 (high × medium), JLS 95 × Mau Azad Alsi-2 (low × low), JLS 9 × Mau Azad Alsi-2 (low × low), JLS 95 × Kota Barani 3 (low × high), JRF 2 × Kota Barani 3 (low × high), JLS 95 × Kota Barani 4 (low × medium), Neela × JRF 2 (high × low) for seed yield plant^{-1} also these same crosses possessed significant negative SCA effects for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight. These crosses also recorded with high significant or non significant mean performance for seed yield plant^{-1}, number of capsules plant^{-1}, 1000 seed weight. These cross combination possessed significant or non significant GCA effects for one or both parents involved in the cross. The presence of negative SCA effects for several yield components in the above crosses indicates the presence of predominant role of additive gene action for yield components, which is general situation observed in the self-pollinated crop. These crosses therefore found to be best cross which can be forwarded to the next generation for their use in varietal breeding programme in linseed.

Chapter VI

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