Chapter-II

REVIEW OF LITERATURE
REVIEWS OF LITERATURE

Developments in biometrical genetics have led to the formulation of a number of biometrical models for the systematic genetic analysis of metric traits. Application of statistical mathematics to biological problems was primarily initiated by Galton (1889) and continued by Pearson and Lee (1903). The concept that quantitative characters are governed by polygenes was first given by Nilson-Ehle (1909) and that Fisher (1918) was the first who gave the estimation of variance and partitioned it into additive- resulting from average effect of genes, dominance-arising from interaction of alleles at the same locus and epistatic components- emerging from the interaction of alleles at different loci. Wright (1921, 1935) reported that the components of variances were comprised of additive and non-additive types.

Robinson et al. (1949) reported that additive genetic variance indicates the extent to which the parents and progenies are related. Mather (1949) found that variance were due to heritable and non-heritable sources. Heritable variance can be further partitioned into fixable and non-fixable types.

Following studies in biometrical genetics have led to the development of various concepts for the estimation of genetic parameters:

(i) Estimates based on segregating generations from crosses of two pure lines (Mather, 1949).


Partial diallel (Kempthorne and Curnow, 1961; Fyfe and Gilbert, 1963; Federer, 1967; Bray, 1971 and Ponnuswamy, 1972)

Triple test cross (Kearsey and Jinks, 1968, Ketata et al 1976)

Triallel and quadrallel analysis (Rawling and Cockerham, 1962)

A brief review of literature available on the following aspects to cover the objectives of the present study is given below

1. Diallel analysis
   a. Variance component study
   b. Combining ability study
2. Average degree of dominance
3. Heterosis and inbreeding depression
4. Heritability and genetic advance analysis

DIALLEL ANALYSIS

The Diallel cross mating system is one of the most important and widely used biometrical technique. Schmidt (1919) first of all named the term “diallel” to denote each group of female was crossed with each of males Hayman (1954 a)
defined it as “the set of all possible mating between several genotypes” Hull (1946), Jinks and Hayman (1953) and Hayman (1954a) developed the method for estimation of genetic components of variance from diallel crosses.

The basic assumptions of diallel analysis of Jinks and Hayman, 1953, Hayman, 1954a, b, Jinks, 1954 and Allard, 1956 are

(1) Normal diploid segregation
(2) Absence of reciprocal differences
(3) Absence of epistasis
(4) No multiple allelism
(5) Homozygosity of parents and
(6) Independent distribution of genes among parents
(absence of correlated gene distribution)

The failures of one are more of the above assumptions leads to invalidation of the estimated components of genetic variance to some extent Dickenson and Jinks (1956) examined the mathematical consequences of failure of these assumptions. Jinks (1956) extended the diallel to heterozygous parents The diallel cross was further used to cover autotetraploids by Dessureaux (1959), Gardner and Eberhart (1966) suggested the model for a fixed set of random-mating population Johnson (1953) discussed elaborately about the field application of diallel cross technique in plant breeding.

Another approach to analyse the diallel cross data in order to partition the total genotypic variance into additive and
non-additive components was outlined by Fisher (1941). In this context, the concept of component analysis of variance and general and specific combining ability was postulated by Sprague and Tatum (1942) as a measure of gene action, which is in fact very important to the breeders. They defined general combining ability as the average performance of line/lines, in a series of hybrid combination while specific combining ability is the combinations which do relatively better or poor that is expected on the basis of average performance of the lines involved. General combining ability includes additive genetic variance and additive x additive interaction variances. Specific combining ability on the other hand reflected non-additive genetic portion, arising from dominance and epistatic deviations. Griffing (1956a,b) gave three models (fixed, random and mixed), each with four methods for working GCA and SCA estimates in a set of diallel crosses and showed the relationship of diallel crossing method to Fisher’s (1918,1930) method of covariance between relatives as expressed in terms of additive and non-additive genetic variances.

Many other methods have been designed to estimate the GCA and SCA effects of different materials. Out of these, inbred x variety or top cross method proposed by Jenkins and Brunson (1932), polycross by Tysdal et al (1942), line x tester mating designed by Kempthorne (1957) and partial diallel (Kempthorne and Curnow (1961) are note worthy.

GCA indicates the nicking ability of parents. Likewise, SCA effects help to short out the superior crosses for yield and other desirable characters which could be used further in a breeding programme to exploit transgressive segregants.
Diallel analysis is the quickest method of understanding the genetic nature of quantitatively inherited traits and it also helps in determining the genetic prepotency of parents. The evaluation of a set of $F_1$ can provide several estimates required studying the genetics of the breeding materials. A brief review of literature on linseed pertaining to gene action, combining ability and genetic components of variances is furnished as under.

**ANALYSIS OF GENETIC PARAMETERS**

The phenotype of any plant can be expressed as a linear function of the individual genotype and the environmental effect (Falconer, 1960). The influence of environment is not the same over all the genotypes. Some are more or less sensitive while other stable. This is due to interaction between genotypes and environments. On expending the function, the phenotypic value ($P$) may expressed as:

$$P = G \times GE + E$$

Where $G$ is the genotypic value, $GE$ is the genotype x environment interaction effect and $E$ is the environmental effect.

While making the genetic analysis of quantitative attributes, Fisher (1918) partitioned the heredity variance (genotypic value) into additive, dominance and epistatic components. Wright (1935) defined these components as additive genetic variance, variance due to dominance and variance due to deviation from additive scheme resulting from the interactions of non-allelic interactions.
Cockerham (1954) and Kempthorne (1956) further partitioned epistatic variance into factorial components of digenic and higher order of interactions suggested as additive x additive, additive x dominance and dominance x dominance for the two loci situation and additive x additive x additive etc for three loci and so on.

Griffing (1956) pointed out that gca involved additive effects and additive x additive interactions. Sprague et al (1959), Carnahan et al (1960), Sprague (1966) and Gilbert (1967) also confirmed the above findings.

Kempthorne (1957) precisely defined the gca and sca in terms of variance, half sibs and full sibs, respectively which is analogous to Design II of Comstock and Robinson (1948, 1952).

Gardener (1963) studied and listed the following genetic parameters of breeding value.

1. Additive genetic variance \( \sigma^2 A \) which arise from the additive effects of the genes at all the segregating loci.

2. Dominance genetic variance \( \sigma^2 D_{p1} \) which results from inter allelic interactions of genes.

3. Epistatic genetic variance \( \sigma^2 (\overline{E_p}) \) which comes from inter allelic interaction of genes at two or more segregating loci and it can be divided into additive x additive \( (\sigma^2 AA) \), additive x dominance \( (\sigma^2 AD) \) and dominance x dominance \( (\sigma^2 DD) \) for two loci and into additive x additive x additive \( (\sigma^2 AAA) \) etc for three or more loci.
(4) Average degree of dominance or ratio of dominance variance to additive genetic variance

(5) Genotype-environmental interaction which can be divided into additive genetic variance x environmental variance and non-additive genetic variance x environmental variance.

(6) Genotypic correlation among quantitative traits of importance for particular crop

**GENE ACTION BASED ON COMPONENT OF VARIANCE**

Yates (1947) developed the concept of diallel cross in *Trifolium hybridum* in a set of \( n^2 \) possible single crosses and selves between homozygous lines

Jensen (1970) and Redden and Jensen (1974) suggested that out crossing and concurrent selection is a worthwhile tool for breeding the naturally inbred crops. They advocated the importance of additive component of genetic variation. Miller and Rawlings (1967) and Meredith and Bridge (1971) concluded that intermediate population could provide a better core material for selection than original F2 population, probably due to partial break-up of linkage block (repulsion phase) in the original material

Pederson (1974) recommended that bidirectional selection as against unidirectional should be preferred as method of increasing the frequency of desirable homozygotes

Sneeep (1977), Stam (1977) and Bos (1977) demonstrated that in self pollinated crops, inter-mating in early generation would leads to genetic drift
Jataasra and paroda (1979), while studying certain traits in wheat, observed that both the additive and non-additive type of gene actions were involved in determining such traits. The gca/sca ratio more than unity indicated the performance of additive type of gene action. They advocated the use of per se performance of crosses instead of their SCA effects of selecting best specific cross combinations. In further experiment conducted in (1981), they observed that the mean performance of the varieties could be predicted across environments, as it appeared to be associated with linear components of G x E interactions, whereas no such relationship of non-linear components with mean performance as well as regression coefficient was evident. In case of grain yield, F₁'s were more responsive than the segregating generations.

A very brief work has so far been conducted on the inheritance of quantitative characters in this crop however, work done on the nature of gene action through genetic component of variance analysis are reviewed here.

Joshi et al., (1961) studied the nature of genetic control for there taking to first flowering in linseed varieties using diallel cross technique and observed that 'D' values (additive effects) were highly significant while, 'H' values (dominance effects), though relatively lower in magnitude were also significant.

Anand et al., (1972) studied 60 hybrid combinations and observed that the parental lives differed in general combining ability but the variation could not be related to phenotypic differences. Additive gene action was found to be predominant for flowering time and height at branches whereas
non-additive effects were predominant for all the other characters under study.

Mishra (1977) observed additive genetic variance for days to flowering, plant height and seeds per capsule and non-additive genetic variance for number of branches per plant, days to maturity, number of capsules per plant, 1000-seed weight, yield per plant, length in days to reproductive phase, oil content and iodine value of oil in linseed crop.

Doucet (1978) observed partial dominance for stem length, seed yield and 1000-seed weight and total dominance for number of capsules per plant and seeds per capsule. He also found additive gene effects as significant for stem length and 1000-seed weight but epistasis was significant for seed yield.

Singh and Singh (1979) stressed the importance of both additive and non-additive variance for oil content and additive gene effects as for 1000-seed weight.

Bhatnagar and Mehrotra (1980) with 8 parental diallel (excluding reciprocals) in linseed noted the importance of both additive and non-additive types of gene action for oil content.

Wicks (1980) reported the presence of epistasis in respect of days to flowering, seed yield, seed weight and oil yield per plant. Some of the characters were found to be controlled by additive gene action.

Doucet and Filepescu (1981) found both the additive and unidirectional dominance as significant for oil content and linoleic acid while additive effects were significant for oleic,
linolenic and total saturated fatty acids only. They emphasized that high oil content, high linoleic acid and linolenic acid were controlled by recessive genes and oleic acid was controlled by dominant genes. Non-allelic interaction was also evident for linolenic and oleic acid content.

In (1982) they observed dominance $\times$ additive effects for oil content and oleic, linoleic and linolenic acid. Additive effects were predominant for oleic and linolenic acid, partial dominance was observed for oil content, oleic and linolenic acid. Whereas, almost total dominance was observed for linoleic acid content.

Kumar and Chauhan (1982) conducted the study in $F_2$ generation of a 10 parent diallel of linseed and reported high variance for general combining ability in case of plant height, capsules per plant and branches per plant and predominant additive gene action for seed yield.

Rao and Singh (1984) in their experiment found that additive gene action were predominant for all the characters studied except plant height and days to maturity. They also suggested that additive-dominance model was fit for primary branches per plant, seeds per capsule, 1000-seed weight and seed yield per plant.

Sharma (1986) studied $F_1$ and $F_2$ generations in a set of diallel for yield and some of its components and found non-additive gene effects as significant for all the characters except capsules per plant and seed yield in $F_1$. Additive gene action was predominant for plant height and 100-seed weight.
but dominance components were more important for the other characters.

Rao and Singh (1987) reported additive, dominance and epistatic effects in six crosses of linseed suggesting that additive and dominance effects being important contributed more in the expression of yield and its components.

Tak and Gupta (1989) derived information about components in 18 generations including parents of the crosses Himalini x Flake-1, KL-134 x LCK-69 and Neelum x Ayogi and reported additive and non-additive gene effects in the experiment and dominance effects were found predominant in most of the cases. They also suggested reciprocal recurrent selection method for improving seed yield.

Gorey et al. (1990) observed additive genetic variance for controlling seed yield and plant height and remaining traits by non-additive genetic variance.

Khorgade et al. (1992) observed that additive genetic was important for expression of capsules/plant, seed yield/plant and 100 seed weight.

Mishra (1992) found additive genetic variance as predominant for days to flowering and days to maturity in both the generations. The characters days to germination and oil content in F1, plant height, seeds per capsule, tillers per plant, capsules per plant, 100-seed weight and yield per plant in F1 and F2 displayed dominance variance to be more for these traits. Average degree of dominance showed that days to germination in F2 and days to flowering in F1 and F2 showed partial dominance.
Tak (1994) reported that seed yield was mainly controlled by duplicate gene while for fibre and oil content, complementary gene effects were more important. He further concluded that by and large there was predominance of non-additive gene action for these traits, although additive gene action was also pronounced.

Popescu et al., (1995) reported that both additive and dominance gene effects appeared to be involved in control of flowering duration. But dominance effects predominantly acted in accordance with another dominance model.

Tak (1996) investigated components of gene effects in 18 generations from each of the crosses, Himalini × Flake-1, KL-134×LHCK-69 and Neelum × Ayoudi. Dominance gene effects were important for seed yield per plant, primary branches per plant and plant height. However, additive gene effects occurred for seed yield per plant, capsules per plant and primary branches. All gene effects (additive, dominance and epistatic interaction) were involved in the crosses at the digenic and trigenic levels for most of the attributes.

Wang et al., (1996) studied nine parental diallel in flax for plant height, technological length, branch numbers, capsule numbers, fibre length, fibre weight per plant and reported that the variances of GCA and SCA were highly significant for all the characters studied suggesting that both additive and non-additive gene effects are important for controlling these traits.

Patel and Gupta (1997) observed, that additive and dominance components were significant for days to flowering,
days to maturity, plant height, capsules per plant, 500-seed weight, harvest index and seed oil content. Only dominance components were significant for seeds per capsule and biological yield. The degree of dominance indicated preponderance of additive genetic variance for days to flowering and days to maturity equal importance of both genetic components for 500 seed weight and seed oil content and greater magnitude of dominance component for rest of the characters.

Patel et al. (1997) reported the importance of both additive and non-additive type of gene action in the inheritance of all the characters studied. However, the preponderance of additive components was observed for phenological traits (days to flowering, days to maturity), equal importance of both additive and dominance components for plant height, primary branches per plant, 500 seed weight and seed oil content and preponderance of dominance components was observed for number of capsules per plant, seeds per capsule, seed yield per plant, biological yield per plant, harvest index and oil yield per plant.

Yadav and Gupta (1999) revealed the presence of both additive and non-additive gene effects. Over dominance was involved for number of tillers, number of branches, seed yield, oil content, harvest index and iodine value in both the generations. Over dominance was also involved for days to 50% flowering, plant height, days to maturity and 1000 seed weight in the F₂ generation. Complete dominance was observed only for 1000-seed weight in the F₁ generation. However, partial dominance was recorded for the rest of the traits, but the degree of dominance observed in both the generations was
inconsistent. The preponderance of dominant genes was observed for expression of days to 50% flowering, plant height, days to maturity and iodine value in both the generations and 1000-Seed weight and seed yield in the F₂ generation.

Sakhovich-VI (1999) reported that over dominance was noted in the control of technical length of the stem and number of seeds per capsule, while additive gene effects were noted for number of capsules per plant.

Kumar et al. (2000) reported non-additive gene action as predominant for all the traits except plant height.

Yadav et al. (2000) reported high magnitude of gca and sca effects indicated the involvement of both additive and non-additive gene interactions, respectively for inheritance of different characters. Parents, Garima, Laxmi-27 and Neelum were judged to be better general combiners for seed yield and they showed good combining ability for most of the characters as well. The common crosses on the basis of both heterotic response as well as sca effects in relation to gca effects were Neelum x T 397, Neelum x ES 44 and Garima x Neelum. Other crosses, Garima x ACC No. 692, Laxmi 27 x LCK 88062, ES 44 x LCK 88062 and RL 904 x ACC No. 692 manifested high heterotic response coupled with high sca effects, mean and significant gca effects of the parents involved. The crosses exhibited preponderance of additive x additive gene effects and other crosses revealed additive x dominance and dominance x dominance gene effects.
COMBINING ABILITY ANALYSIS

The concept of general and specific combining ability effect as a measure of gene effect was proposed by Sprague and Tatum (1942). They defined general combining ability as an average performance of a line in a series of crosses and specific combining ability referred to those cases in which certain cross combinations do relatively better or worse than the expected ones, on the basis of average performance. They concluded that gca is primarily due to additive effects of genes, while sca is a consequence of intra-allelic interaction or dominance and inter-allelic interactions as epistasis and so on.

Handerson (1952) considered gca as the average merit with respect to some traits or weighted combinations of traits as indefinitely large number of progeny of an individual line when mated in a random sample from some predicted population under a specific set of environment. He defined sca as deviation of average value of cross from the value, which would be expected on the basis of known gca of two lines.

Rajas and Sprague (1952) while studying the interaction of gca and sca with locations and year, reported that the variance due to sca ($6^2$s) was greater than the variance due to gca ($6^2$g). This clearly indicated that the variance of sca includes not only the non-additive deviations due to dominance and epistasis, but also a considerable portion of GxE interaction.

Hayman (1957) observed that in the absence of epistasis, gca comprised additive portion while sca involved dominance. Both the combining abilities, therefore, retain the
epistasis portion while sca is measure of dominance and epistasis in unselected and selected materials respectively.

Moll et al (1960) indicated that the magnitude of gene action based on combining ability variance is not much reliable due to serious biasness from genotype x environmental interaction

Anand and Murty (1969) studied the genetic control of 7 quantitative characters in linseed involving 10 parents. They observed significant general and specific combining ability as well as reciprocal effects for all the attributes of yield.

Badwal and Gupta (1970) observed that general combining ability is predominant for all the yield components, where as for yield, specific combining ability effect to be more important in linseed crosses

Shehata and Comstock (1971) reported general combining ability effects to be highly significant as compared to specific combining ability for the characters under study at all the densities in linseed

Kalja (1972) reported that the variances due to both general and specific combining ability were important for oil content, 100-seed weight, number of seeds per capsule, primary-branches, secondary -branches, days to 50 per cent flowering, plant height and days to maturity but for seed yield and number of capsules per plant general combining ability variances were less important

Rasbasco (1973) studied combining ability for oil content and iodine number from a diallel cross between 10
Argentinian cultivars. Analysis of variance showed that values for specific combining ability were lower than general combining ability and variances for specific combining ability was less in 'Puelche' than in others in respect of oil content. A positive correlation was found between the mean values for a given parent and its general combining ability.

Al-terfah (1974) found that relative magnitude of general combining ability variance was higher and therefore, more important for plant height, primary-branches, secondary-branches, seeds per capsule, percent oil and 1000-seed weight. However, the relative magnitude of general combining ability and specific combining ability variances was almost the same for grain yield.

Kaushal et al. (1974) studied combining ability in a diallel set of 10 varieties of linseed. Both general and specific combining ability variances were significant but the magnitude of specific combining ability variance was 14 times more than that of general combining ability variance. R-17 and T-397 showed significant general combining ability effects.

Rai and Das (1974) while working on six yield contributing characters in five linseed varieties concluded that the variance due to both general and specific combining abilities were significant for all the characters. They further reported that gca variance was of larger magnitude than that of sca variance. Specific combining ability effect was limited in almost all the traits of crosses studied.

Patil and Chopde (1981) evaluated a 10 x 10 diallel in F2 generation grown at three different locations for yield and
four yield components. Both general and specific combining ability mean squares were found as significant at all the three locations for all the traits. In the same study, significant ratio of gca and sca mean squares indicated the predominance of additive gene effects. The higher gca values than that of sca values reflected the presence of large component of additive x additive and epistatic variance. Authors further concluded about the possibilities of effective selections for all the traits.

Dang *et al.* (1987) studied general and specific combining ability effects in 49 crosses of seven varieties/lines and reported that the inheritance of oil content was controlled by both additive and non-additive genes. Zhabgya-1 and 75-17 with the highest and second highest content (41.1 and 39.9 per cent oils respectively) showed the highest gca, while the variety 77134-269 had lowest content (35.1%) and Swiss Red (35.5%) showed lowest gca. Most of the combinations showed high sca involving one parent with high gca effect.

Thakur *et al.* (1988) studied a diallel set involving 8 linseed varieties and indicated that DPL-21 and Himalmi were the best general combiners for various yield components. The best specific combiners for seed yield, number of capsules and tillers per plant were, Flake-2 x BS-2 and Himalmi x TLP-1.

Manfroni *et al.* (1989) while studying combining ability for 6 yield related characters in 5 linseed varieties found that the varieties Reconquesta, INTA and CI 2703 were most suitable parental types. In general variety Al corta INTA showed significant positive gca for oil content and significant sca in crosses with Tape Parana, INTA and CI 2828. gca of Tape Parana INTA was positive and significant only for seeds per
capsule, while the sca for this characters was significant in a cross with Reconquesta INTA variety CI 2838 showed significant gca.

Singh \textit{et al} (1990) while studying combining ability on 6 yield components in 10 linseed varieties and their 45 F\textsubscript{1} hybrids, reported that Neelum and EC 41583 were the best general combiners for seed yield.

Niu \textit{et al} (1991) studied combining ability in NCD II with flax and reported that gca and sca appeared highly significant for all the characters studied with the exception of seed weight per plant and seeds per capsule. The gca variance ($\sigma^2$g) of the population was greater than sca ($\sigma^2$s) for the other characters. The $\sigma^2$g of seed weight per plant (23.84\%) was lower than its $\sigma^2$s (76.1\%) suggesting that non-additive effects were more important than additive effects.

Mishra (1992) reported that the magnitude of gca and sca variance, for all the traits indicated that both additive and non-additive gene action were involved in expression of these traits. The ratio of $\sigma^2$ gca/$\sigma^2$ sca for days to flowering in F\textsubscript{1} and F\textsubscript{2} were around unity indicating the importance of both type of gene actions.

Khorgade \textit{et al} (1993) worked out combining ability for eight yield related characters in 21 F\textsubscript{1} hybrids of linseed resulting from the crosses between 7 diverse lines (TLP-1, JLS (J) 1, R 17, AKL-33, LMH 300, LMH 354 and C 219-1-1) and three well adopted testers (T-397, SPS 77-23-10 and C-429) analyzed during rabi 1989-90.
Popescu et al. (1995) conducted an experiment with 9 varieties (2 flax, 5 linseed and 2 DP) and their hybrids from a half diallel set at three crop densities and reported that both additive and dominance gene effects appeared to involved in control of the duration of flowering period but dominance effects were predominated and acted in accordance with an over dominance model. Estimates of narrow sense heritability were fairly high for the trait, which were not correlated with seed yield.

Pillai et al. (1995) analyzed combining ability in eight diverse cultivars of linseed. The analysis revealed that both gca and sca variances were highly significant for all the characters except tillers per plant due to sca. However, the general predictability ratio indicated predominance of additive components for days to maturity, number of tillers per plant, capsules per plant, seed yield per plant, 100 seed weight and plant height.

Mishra and Rai (1996) conducted an experiment in a diallel set of 10 diverse linseed varieties grown in 4 environments. A highly significant variation was observed for GCA and SCA × E for all the characters, and SCA and SCA × E for all the traits except oil content. Among the parents T397 proved to be a good general combiner for seed yield/plant, Neelum for palmitic acid and stearic acid contents, LCK152 for oil, linolenic acid and reduced linolenic acid contents, LCK185 for high linolenic acid and reduced linolenic acid contents, and LC185 for high linolenic acid. SCA effects were high in SPC 23 × LC 185 for seed yield/plant and oleic acid and reduced linolenic acid contents, Sweta × LCK 152 for palmitic acid and oleic acid.
contents and Neelum × R 17 for iodine value and higher linolenic acid contents.

Patel et al. (1998) reported that both GCA and SCA were influenced by environment suggesting the necessity of tests over a wide range of environments for unbiased estimates of GCA and SCA. Chambal and Triveni were identified as good general combiners for seed yield and oil content, earliness and other yield components. LCK 88511 × Triveni exhibited high SCA effects for seed yield, earliness, oil content and other yield contributing characters.

Tewari (1999) reported that Shubhra was good general combiner for nine characters whereas, T 397 was good general combiner for seven characters. On the basis of gca effect the good general combiners, common in both the generations were, Shubhra, NL-93 and T 397 for early flowering and maturity, NL-93, Shubhra and Garima for plant height and technical plant height, Shubhra and RL-914 for tillers per plant; Shubhra for branches per plant; T 397 for capsules per plant; T 397 and Neelum for seeds per capsule, LCK 87132, T 397 and Shubhra for yield per plant, Neelum, LCK 89512, NL-93 and LCK 87132 for 1000-seed weight, Shubhra and LCK-89512 for oil content, LCK 88062 and LCK 88312 for palmic acid, stearic acid, oleic acid and linolenic acid.

The results of specific combining ability indicated that none of the cross is best specific combiner for all the characters. However, in respect of seed yield, 19 crosses in F₁ and 17 crosses in F₂ exhibiting significant and desirable SCA effects, involved all the three possible combinations between the parents of high and low GCA effects. Cross combination Shubhra
x LCK 88062 and Shubhra x LCK 87132 in F₁ generation came in first category (high x high) involving both parents having high gca effects for seed yield. While Shubhra x LCK 87132, Neelum x Shubhra and T 397 x Shubhra (high x high) in F₂ generation. T 397 x Neelum in F₁ generation and Shubhra x LCK 88062, T 397 x LCK 88062 and Neelum x 88312 in second category (high x low in F₂ generation and Garima x LCK 89512 in F₁ and LCK 89512 x NL-93 and RL 914 x LCK 88062 in third (low x low) category indicating additive and non-additive gene effect respectively.

Kumar et al. (2001) observed that the line LCK 8527 was good general combiner for seed yield, capsules per plant, seeds per capsule, harvest index and oil content; whereas, R 552 among testers was good general combiner for seed yield, early maturity, primary branches per plant and harvest index. T 397 and DPL 17 were good general combiners for seed yield along with seeds per capsule.

Yadav and Srivastava (2002) reported that variety Garima was good general combiner for early growth vigour, days to 50% flowering, days to maturity and seed yield per plant. Crosses, LCK 8528 xES 44, Garima x ACC. No. 692, Garima x T 397, Neelum xT -397, Laxmi 27 x LCK88062, ES 44 xLCK88062, RL 904 x Acc No. 392 and RL 904 xLCK 2023 were good specific combiners for both F₁ and F₂ generations.

HETEROSIS AND INBREEDING DEPRESSION

1. Magnitude of Heterosis:

Heterosis was recognized by Koelreuter as early as in 1763. Originally the classical term heterosis was coined by Shull (1914) implies the excellence of F₁ over strictly homozygous
parents involved in its formation. However, according to Hayes, Immer and Smith (1952) both the terms are now used and thus these are synonymous to each other.

Stebbins (1957) defined heterosis as greater adoptness to human needs which has been obtained in a particular environment through artificial selection after hybridization.

Fonseca and Petterson (1968) described heterosis as an improvement of heterozygotes in relation to better parents. Mather and Jinks (1971) defined heterosis as the amount by which mean of an F₁ family exceeds its better parent.

2. Genetic Basis of Heterosis:

The alternative genetic hypothesis explaining the phenomena of heterosis differs primarily in the role of favourable dominant genes, over dominance, epistasis and even sort of physiological stimulus in heterozygosity per se.

Among various genetic theories, dominance hypothesis was independently proposed by Davenport (1908), Bruce (1910) and Keeble and Pellow (1910), whereas over dominance hypotheses was proposed by Shull (1908) and East (1908). Both the hypothesis held good ground for practical breeders in order to obtain maximum return. Studies on heterosis aimed at analyzing the nature of combining ability in relation to hybrid vigour in order to obtain the genetic basis for development of an appropriate and precise breeding methodology.

3. Exploitation of Heterosis:

4. Inbreeding Depression:

Inbreeding is the mating between individuals related by descent or ancestry. Inbreeding depression has been recognized by man for a long time. It may not be surprising in view of the harmful effects produced by inbreeding. In many societies, marriages between closely related individuals have been prohibited since early times. Hindu societies perhaps present the extreme example where marriages between individuals related by ancestry, up to maximum distance, are prohibited. Inbreeding depression was noticed as early as in 1876 by Darwin (Cross and Self Fertilization in Vegetable Kingdom). It is measured as coefficient of inbreeding which is probably that two genes at any loci in an individual are identical by descent. Wright (1922) symbolized its coefficient as "F" and defined as the correlation between uniting gametes.

Inbreeding coefficient of any generation would be:

\[ F_N = (\frac{1}{2}N) + (1 - \frac{1}{2}N) F_{N-1} \]

Where,

'N' is the number of breeding diploid individuals. The information regarding inbreeding coefficient permits to measure the rate at which homozygosity would be attained. It also helps
in estimating the extent to which mating between gametes in a population of limited size departure from that of ideal panmictic or out bred population in which two alleles of an individual are not related. Accumulation of deleterious and harmful recessive genes in an inbred line makes it very weak, all of which can not be removed with any amount of selection pressure. Therefore, decrease in vigour, survival value and ultimately its yield is almost in vital consequence of inbreeding (Allard and Handerson 1964)

One of the characteristic of heterosis is that the increased vigour is expressed in F₁ generation exclusively. There is considerable depression as a consequence of inbreeding in F₂ and subsequent generations. The extents of such depression in the same crop varied from character to character, generation to generation and also the genotypes themselves. East (1908) observed that the genes for height were fixed after five generations of inbreeding while, yield is continued to decline for 20 generations. Generally, the depression is rapid in first few generations and slow down in later.

In self-pollinated species homozygosity is the normal condition for most of the genes are recessive and deleterious. Gene mutants are contributed in homozygous condition and soon after they get eliminated promptly. These species become adapted to homozygosity and develop genetically in a balanced condition. Mather (1943) called it “homozygous balance”

A brief review of literature relating heterosis and inbreeding depression in linseed is illustrated as under.
Daskalov (1963) concluded that estimated heterosis in F₁ was the combined expression of genetical, cytoplasmic, biometrical and physiological factors and might be attributed to estimation resulting from the interactions of different heritable factors of the parents and F₁'s. Turbin (1963) introduced the concept of genetic balance which accounted for not only the interaction between hereditary, but also the environmental factors.

Rowe and Andrew (1964) and Singhania and Rao (1976) observed that linear component of GxE interaction was greater in the parents than in F₁, the F₁ hybrids were reported to show higher mean performance than that of their respective parents indicating that the heterosis was associated with greater sensitivity to the environment. Allard (1956), Bouman (1959), Dickinson and Jinks (1956), Hayman (1954b, 1963), Jinks (1954, 55), Jinks and Jones (1968), Kempthorne (1956), Graffius (1959) and Eberhart (1964) demonstrated the correlation between heterosis and epistasis.

Robinson (1963) and Moll et al. (1964) suggested that genetic diversity of parental stocks and partial to complete dominance of the genes, might be the major factor for heterosis in yield and its components. Williams (1959), Durate and Adams (1963), Graffius (1964) and Coyne (1965) explained that studies of individual component could express manifestation and the genetic exploitation of heterosis.

Carnahan (1947) studied 16 crosses involving eight parents and observed 40 per cent hybrid vigour over the parental mean in *Linum*. 
Dubey (1967) studied seven morphological characters including yield of 36 hybrids and reported that the hybrids attain as high as 230.93 per cent increase over the better parents.

Sehata and Comstock (1971) observed heterosis among cultivars using diallel and noted 6 per cent heterosis in F₁ over mid parent. Four F₂ populations were found to be high yielding in the material studied than their parents.

Anand et al., (1972) while studying 60 hybrid combinations observed heterosis to be apparent in 6 out of 7 morphological characters.

Choudhury et al. (1972) noted that F₁ for seeds per capsule to be lower than the mid parental values while the values for 100-seed weight and seed yield per plant were higher.

Galkin (1973) reported 15 per cent heterosis for seed yield, 51 per cent for capsules per plant and 12 percent for 1000-seed weight. He further explained the extent of heterosis to be greatly influenced by agronomical condition and parental forms.

Bhatnagar and Mehrotra (1979) observed the heterosis in F₁ as compared to better parent in linseed for iodine value ranging from 6.69 to 7.59 per cent.

Patil and Chopde (1983) studied from a diallel cross and observed highest heterosis with regard to better parent as 89.81 per cent for seed yield, 65.5 per cent for capsules per plant and 63.2 per cent for tillers per plant.
Dakhore *et al* (1987) observed highest heterosis over the standard check for seed yield per plant (52.32%), 1000-seed weight (12.36%) and branches per plant (42.30%).

Saraswat and Kumar (1993) conducted diallel study on 12 accessions and observed high degree of heterosis for seed yield in the crosses L-27 x LC -1010 and SPS –2310 x LCK 152.

Mishra and Rai (1993) studied the extent of heterosis and relative magnitude of general and specific combining ability and reported that the extent of heterosis over better parent indicated that seed yield was most heterotic character followed by stearic acid, linoleic acid and protein content. Cross SPS-2310 x IC 185 was found most heterotic for seed yield and oleic acid.

Verma and Sinha (1993) determined heterosis over mid parent and better parent for 8 quantitative traits in hybrids from 42 crosses under irrigated and rainfed conditions and observed significant heterosis for seed yield in 20 crosses related to better parents while they found corresponding figures under rainfed regime being 27 and 20 crosses, respectively.

Wang *et al* (1996) studied 8 parental diallel crosses in flax and observed that heterosis values averaged 5.94 per cent for plant height, 7.38 percent for technological length, 16.77 per cent for branch number, 20.87 per cent for capsules number, 9.57 per cent for fibre rate and 19.3 per cent for fibre weight per plant.

Yadav (1997) reported significant positive heterosis over economic parent for seed yield in twelve crosses. Majority of the hybrids also exhibited desirable and significant sca effects.
Crosses Neelum × T 397 (85.13%), Garima × Neelum (83.25%) and Garima × T 397 (74.40%) showed maximum heterotic response for seed yield and its related traits. He further observed the high per se performance for these crosses. Maximum heterosis for oil content (78.6%) were found in crosses Laxmi 27 × T 397 coupled with Neelam × Laxmi 27. Significant inbreeding depression for seed yield was also noted in 24 crosses. Increase in seed yield was found due to non-additive genetic component as manifested by the preponderance of dominant genes for high yield in this study.

Yadav (2001) observed pronounced hybrid vigour for yield and most of the yield components. Out of 45 different hybrids, eight hybrids were identified as promising for many desirable traits. Heterosis to the extent of 82.91 percent over the economic parent T397 was recorded for seed yield per plant. Crosses between high x high and high x low GCA parents exhibited greater heterosis. Heterosis for seed yield was generally accompanied by heterosis for yield components.

**HERITABILITY AND GENETIC ADVANCE**

Heritability is one of the most important direct selection parameters which determines whether the phenotypic differences observed among the various individuals are due to differences in their genetic make up or simply the results of environmental factors. Heritability is an index of transmissability of traits from parents to their offspring.

Lush (1940) suggested the following uses of heritability estimates:
(a) When heritability in narrow sense is high, emphasis should be placed mainly on mass selection and if it is low, more pressure should be given on pedigree, sib tests and progeny tests.

(b) In case where epistasis variance is relatively high emphasis should be placed an selection between families and line breeding.

(c) If over-dominance is strong, inbreeding programme is to be emphasized with an objective of commercial hybrid production.

(d) When the variance due to interaction between genotype and environment is relatively large breeding programme should be extremely lined up the development of superior varieties for different agro-climatic regions.

Heritability in narrow sense could be utilized for estimation of expected improvement based on selection. Whereas, the genetic advance is another parameter which helps breeders in estimation of the gain through selection pressure.

Comstock and Robinson (1952) defined that genetic advance is an improvement in the genotypic value in the new population as compared to the original one and depends upon the following three factors:

(1) The amount of genetic variability such as the magnitude of the differences among different individuals in the base or initial population.
(2) The magnitude of the masking effects of the environmental and interaction components of variability on the genetic diversity

(3) The intensity of selection which is being applied

Few important literature available on heritability and genetic advance in linseed is mentioned here as under.

Chaudhary et al. (1972) calculated heritability, genetic advance and various other components of variation influencing yield in *Linum* and concluded that additive genetic variance and expected genetic gain were high for capsule numbers, seeds per capsule and 1000-seed weight.

Dayal et al. (1975) recorded wide range of genetic and environmental variation for several characters in 21 linseed varieties. The genotypic coefficient of variation and heritability estimates showed the variability to be operative for days to flowering and maturity, plant height, 1000-seeds weight and seed yield per plant which were highly heritable due to the additive gene effects in respect of these characters.

Rai and Das (1975) recorded narrow sense heritability estimates and found to be high for plant height and seed index, and additive portion of genetic variance to be substantial for plant height and seed index, ascertaining further the possibility of selection for high genetic gain in these traits.

Rai (1976) observed high estimates of narrow sense heritability for days to flowering and maturity in parents, F₁ and F₂ generations of linseed.
Bhatnagar and Mehrotra (1979) studied heritability of iodine value in F₁ and F₂ generations in linseed crosses and observed that heritability value was high in both F₁ (59.8) and the F₂ (61.3) generations for the trait.

Singh (1979) observed lowest heritability for seed yield per plant and highest for plant height in linseed.

Kumar et al. (1980) analyzed 10 parental diallel in linseed and noted high heritability estimates for days to flowering and moderate for days to maturity.

Kumar and Chauhan (1982) observed high narrow sense heritability for plant height and 1000-seed weight while, moderate for seeds per capsule, tillers per plant and branches per plant. They further reported substantial genetic gain for capsules per plant, plant height and branches per plant, suggesting that these characters are useful for selection if considered simultaneously.

Srivast and Singh (1984) reported high estimates of heritability for days to maturity, plant height, number of primary and secondary branches per plant. Genetic gain was highest for plant height, secondary branches and capsules per plant.

Ingale (1985) studied ten characters in 93 strains of linseed and reported that all characters viz. seed yield, capsules per plant, tillers per plant, 1000-seed weight, days to flowering and maturity, capsule length and seeds per capsule, showed moderate heritability estimates. He also reported high genetic advance for seed yield and 1000-seed weight.
Rai et al (1985) analyzed the seeds for oil, protein, fibre, moisture, fatty acids profile, iodine value and saponification value of oil and reported that broad sense heritability was high for all the characters. Genetic advance was the higher for stearic acid content of the oil.

Rao and Singh (1985) studied F\textsubscript{1} and F\textsubscript{2} generations of inter-variety crosses of linseed and reported that heritability and expected genetic advances were moderate to high for yield components namely, primary branches, secondary branches, number of capsules and yield per plant.

Satpathi et al (1987) noted high heritability estimates and genetic advance for number of branches per plant, capsules per plant and seed yield per plant indicating additive gene effects.

Singh and Dikshit (1988) reported high heritability in plant height, capsules per plant and harvest index in F\textsubscript{1}, indicating that these characters can be improved by selections.

Jagdev (1990) observed high variability for harvest index (24.5-46.1) but low for economic yield (1.07-2.93). The estimates of heritability and genetic advance were high for both harvest index and economic yield.

Rai et al (1990) reported high heritability with medium to low genetic advance for oil content, protein content and iodine values from a study of 35 linseed genotypes.

Niu et al (1991) observed that broad sense heritability was higher than narrow sense. Relatively high
narrow sense heritability was reported for flowering date, 1000-seed weight and plant height

Mishra (1992) reported high estimates of heritability (narrow sense) for days to maturity in both the generations. Moderate for days to germination, seeds per capsule in F1, plant height and oil content in F2 and for capsules per plant and 100 seed weight in both F1 and F2 generations. Days to germination, seeds per capsules in F2 and yield per plant in F1 and F2 displayed low heritability.

Khorgade and Pillai (1994) studied 10 characters related to yield in 28 F1 hybrids involving eight parents of linseed and reported highest heritability and variability for capsule number per plant.

Jagdev (1995) conducted an experiment on 20 genotypes of linseed and found moderate heritability and genetic advance for economic yield, biological yield and harvest index emphasizing selection in respect of these attributes.

Popescu et al (1995) reported narrow sense heritability estimate as fairly high for flowering duration and was not correlated with seed yield in flax.

Mirza et al (1996) recorded heritability along with genetic advance as percentage of mean as high for plant height, harvest index, seed yield per plant and capsules per plant.

Foster et al (1997) studied 18 linseed and 10 flax varieties. Linseed varieties showed more heritable variation in seed and fibre traits than flax. In general, Linseed x Linseed and Linseed x Flax crosses would contribute better source material for
breeding high yielding dual-purpose cultivars compound to flax x flax crosses, especially when seed is the primary commercial product.

Foster et al (1998) estimated heritability from low (0.20) for number of branches to high (0.71) for height at flowering time. Seed weight and straw weight showed moderate heritability while flowering time and the various height traits were more highly heritable.

Mahto and Mahto (1998) studied 19 genotypes of linseed grown under rainfed conditions during the winter season of 1990-91 and 1994-95. The highest heritability was given by days to maturity.

Popescu et al (1998) observed in a set of 61 hybrids, that narrow sense heritability coefficients confirmed the uniform transmission of oil content and plant height. Character number of capsules/m², seed yield and oil yield showed sufficient heritability coefficients (above 0.5) except 1000 seed weight.

Yadav et al (1998) estimated high heritability coupled with high genetic advance was observed for 1000-seed weight. Character 1000 seed weight could be emphasized for selection breeding because predominance of additive gene action. High heritability coupled with low genetic advance for oil content and iodine value were observed suggesting that the recombination breeding programme will be more effective.

Mishra and Yadav (1999) observed high heritability coupled with high genetic advance for seeds/capsules, days to maturity and capsules/plant, indicating the importance of additive gene action for these traits.
Tiwari (1999) recorded high heritability estimates for days to flowering, plant height, technical plant height, days to maturity, seeds per capsule, 1000-seed weight, palmitic acid, stearic acid, oleic acid, linolenic acid and linoleic acid in both the generations. The characters viz branches per plant in both the generations and tillers per plant in F1 generation and oil content in F2 generation exhibited comparatively moderate values of heritability whereas, it was low for capsules per plant, yield per plant in both the generations, tillers per plant in F2 and oil content in F1 generation only.

Yadav and Gupta (1999) estimated high heritability for the characters 1000 seed weight, plant height, days to maturity, days to 50% flowering and oil content in percent. Characters, 1000 seed weight also indicated high genetic gain followed by harvest index and plant height manifesting that these characters should be highly emphasized for selection purposes.

Rai et al (2000) observed high heritability for linoleic acid, technical plant height, harvest index, oleic acid, fibre content, days to 50 per cent flowering, 1000-seed weight, days to maturity, plant height, linolenic acid, iodine value and oil content, moderate for protein content, number of seeds per capsule, palmetic acid, stearic acid and seed yield per plant and low for remaining traits. High genetic advance were noted for six traits moderate for nine and low for five traits out of twenty traits studied.
**Genotype × Environment Interaction Stability:**

A phenotype is the product of an interplay of a genotype and the environment. A particular genotype does not reflect the same phenotypic expression under different environments and different genotypes respond differently to the same environment. The variation arising out from the lack of correspondence between the genetic and non-genetic effects is known as genotype-environment interaction.

Environment is the sum total of physical, chemical and biological factors. Comstock and Moll (1963) classified the environments into two groups (i) Micro-environment and (ii) Macro-environment. Micro-environment is the environment of a single organism, as opposed to that of another organism growing at the same time and at almost the same place. Macro-environment which is associated with a general location and period of time and is a collection of macro-environments.

Allard and Bradshaw (1964) classified environments into predictable and unpredictable types. The predictable (controlled) environment included the permanent features of environment such as, climate, soil type, day length and agronomic practices followed. The unpredictable or uncontrolled environment means weather fluctuation such as, difference between seasons in terms of amount and distribution of rainfall, solar radiation and the prevailing temperatures. For the uncontrollable variables, a low level of interaction would be desirable so as to have maximum uniformity of performance over a number of seasons. Contrarily, for the controllable variables mostly agronomic practices, a high level of interaction will be required for maximum increase in performance of a genotype.
Quantitative characters are largely influenced by the environment. The genotype-environment interaction gives an idea of the magnitude of biasness in the estimation of genetic parameters. This bias is accounted for by growing the breeding material over a number of environments of breeder's interest.

Plant breeder is interested in the stability of productivity of the characters of economic importance such as grain yield and quality. The desirable genotypes should express less interaction of genotype and environment for the characters which are important from agricultural point of view. Phenotypic stability is attributed as the ability of an individual or population to produce narrow range of phenotypes in different environments. A variety could have stability of performance (Allard and Bradshaw, 1964) (i) by individual buffering, where each number of population is well adapted to wide range of environments and (ii) by population buffering, where each member of genotypes is adapted to somewhat different range of environments. Both individual and population buffering can be measured as genotype-environment interaction.

A dynamic approach to the interpretation of varietal adoption to varying environments was developed by Finlay and Wilkinson (1963). They used the stability parameters namely, (i) mean performance over all the environments, (ii) linear regression coefficient (b) for the performance of individual variety passed on environmental index (mean yield over all the varieties in each environment). The unity and zero regression coefficient indicated average and absolute stability, respectively. They proposed that a well adapted genotype should have high mean
performance and average stability and ideal variety was one with maximum yield potential and maximum phenotypic stability.

Mather (1943) proposed a polygenic system narrating stability which may be a material effect and level of stability appearing to depend on genic balance. Lewis (1954) defined phenotypic stability as the ability of an individual to produce a certain narrow range of phenotypes in different environments. He proposed that no-genetic variability of individuals within a single controlled environment due to “intangible environmental effect produced by developmental accidents” may be expressed for F$_1$ as relative variability. He further noted that there is a positive linear relationship between F$_1$ relative variability and the degree of dominance.

Mather and Jones (1958) demonstrated that how the interaction between genotype × environment influences variances and co-variances used for measuring variation in biometrical genetic models Plaisted and Peterson (1959) advocated a method to estimate the variance components of variety × location interactions. A combined analysis of variance over all the locations was computed for all possible combinations of pairs of varieties. The variety with smallest mean value of interaction variance (Variety × Location) was considered to be the most stable one. This technique was most cumbersome when the number of varieties are increased and did not provide partitioning of the interaction items.

Eberhart and Russell (1966) improved the regression technique as suggested by Finlay and Wilkinson (1963) by adding another stability parameter ($s^2_{di}$ deviation from regression) to describe the performance of a genotype over an
array of environments. They further advocated that regression of each cultivar on the basis of environmental index and function of the squared deviation from this regression would provide useful estimates of stability. They defined stable variety as one with unit regression coefficient $b_i = 1$ and having deviation not significantly different from zero ($s^2_{di} = 0$).

This enable repartitioning of the genotype × environment interaction of each variety and provided an useful estimate of stability. The genotypes contributing least to the $G \times E$ interaction, were the most stable.

Bucio Alanis (1966) developed a model to investigate the genotype × environment interaction in more detail and observed a linear relation of $G \times E$ interaction component of generation means to the environmental effects.

Perkins and Jinks (1980) abridged the gap between two approaches, i.e., statistical approach (Yates and Cochran 1938; Finlay and Wilkinson, 1963; Eberhart and Russell, 1966) and the approach based on contributions of genetic, environmental and their interaction with generations mean and variance (Mather and Jones, 1958. Jinns and Stevens 1959; Bucio Alanis 1966. and Alanis and Hill, 1966) and developed a model to measure the stability of genotypes. They expressed the expectations of statistical analysis in terms of gene, environmental interaction and genotype × environmental interactions. They further extended the analysis to cover many inbred lines and crosses among them and concluded that while a significant proportion of the $G \times E$ interaction component was linear function of the environmental components, there was still significant remainder which was not linear. Perkins and Jinks
(1968b) examined the non-linear component of the interaction by grouping varieties into homogenous groups on the basis of deviation from linear regression and reported a significant and marked reduction in the remainder component of the interaction as a result of grouping of varieties. They noted positive correlations between the regression remainder mean sum of squares values of the lines before and after grouping.

Freeman and Perkins (1971) argued that according to the models proposed by Eberhart and Russell (1966) and Perkins and Jinks (1968b), the performance of a genotype in the given environment is regressed over the environmental index. Which does not provide independent estimation of the two parameters. Hence, they suggested an independent estimate of environmental index by dividing replications into two groups, (i) group for measuring the average performance of genotypes in various environments and the (ii) group for estimating the environmental index and by using one or more genotypes as checks to assess the environmental index on the basis of performance. They further, partitioned the analysis of variance into components representing regression on a general measure of the environment, independent of the genotypes under study and deviations from regression.

Paroda and Hayes (1971) observed that genotype-environment interactions were operative in both the parents and F1 generation. A significant portion of these interactions exhibited (i) linear function of the environment, means while some of them were non-linear, (ii) both linear and non-linear components of the G × E interaction were under the control of different systems and (iii) the interaction between additive
component and environments was greater than that of the dominance component in different environments.

Hardwick and Weed (1972) used multiple regression of performance on the levels of environmental variables considered the deviation from regression. They found that the slopes of regression on the environmental means could be expressed in terms of the coefficient of regression on environmental variable.

Chaudhary and Paroda (1979) studied stability in relation to homogeneous and heterogeneous populations and noted that homogeneous population were less buffered than the heterogeneous populations. Heterozygous-heterogenous (F₂ and F₃) and homozygous-heterogeneous (mixtures) populations representing high genetic variability expressed relatively more stability over homozygous-homogeneous (parental) and heterozygous-homogeneous (F₁) populations.

Galkin and Sorochinskaya (1986) concluded that the effect of selection can be predicted satisfactorily on the basis of heritability for these traits only which had a high degree of genetic stability.

Khatelyeva et al (1987) studied the variation in the quantitative characters of 57 flax varieties and reported that genotype-environment interaction affected all the characters. They also studied high phenotypic variation for seed production.

Popescu (1991) worked out estimates of phenotypic stability in five varieties and 19 inbred lines Romania and one Hungarian variety Szegedi 62 in environments in 1990 using three non-parametric criteria recommended by M. Huehn. He
founded the superiority of the criteria used to the classical methods in assessing stability by various ways. He could not found significant differences in phenotypic stability for seed production and oil content in 25 different forms.

Mishra et al. (1992) studied genotype and environment interaction in eight Linum usitatissimum varieties grown at five different locations, which was significant. Genotypes RLC-1 and RLC-4 were most stable genotypes across the environments.

Mishra and Rai (1993) calculated genotype × environment interaction and stability of 10 genotypes and their 45 F1 hybrids in eight traits including seed yield and quality characters in four environments and reported stability in genotype T-397 for seed yield per plant and oil content, R 552 for protein content, R 17 for palmitic acid content.

Mehto et al. (1995) studied genotype and environment interaction which was significant for 26 genotypes grown during 1988-89, 1989-90 and 1990-91. Analysis of variance showed presence of significant variability among the genotypes for all the characters. Of the 26 genotypes, eleven had above average stability and seven were of high yields.

Mehto (1995) conducted studies on genotypic × environment interaction and stability analysis of 19 genotypes in the years 1989-90, 90-91, 91-92. He furnished that the genotype × environment interaction was significant for number of branches per plant and highly significant for plant height, number of seeds per capsule and number of capsules per plant.
BAUL 135, LCK 6857 and Sweta were found to be the most stable genotypes

Mahto and Singh (1996) conducted stability analysis of 20 strains during 1989-91 grown over 4 environments. Stability for individual strains was determined on the basis of 2 stability parameters: regression coefficient (\(b_1\)) and deviation from regression (\(s^2_a\)). A further 7 strains were selected with high seed yield per plant (higher than grand mean over environment) and stability for seed yield and for other yield contributing characters.

Payasi and Bose (1999) studied stability parameters for yield and its components in 80 genotypes under 8 micro-agroclimatic conditions. RLC4 had the highest yield followed by SPS49-2, Jawahar-23, LMH81 and ECZ-2583 and therefore, recommended for commercial cultivation under better management practices. R 1156, R 552, SPS 48-5 and LCK8323 showed wider adaptability for seed yield per plant and seed yield per hect, so they may be successfully grown in all types of environments. The highly stable genotypes T 397, EC 41484, RC23-1 and BAU95 are only suitable for rainfed farming system. RLC 41484, RLC 4 and IL 5164 were highly responsive for capsules/ plant, while LHCK5 and EC 15888 were responsive for seeds/ capsule.

Yadav et al (2000) studied stability in three locations for 13 metric and quality characters. T-397, Garima and ES 44 showed stability for seed per plant. Stability in yield was found to be associated with stability in yield components such as early growth vigour, days to 50% flowering, tillers per plant, branches per plant, days to maturity and seeds per capsule.