REVIEW OF LITERATURE
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The previous research work carried out on the related topics is being discussed under the following subheadings.

VARIABILITY:

The quantitative characters are those in which variation is continuous so that classification in discrete categories is not possible. The quantitative characters are governed by polygenes and environment plays an important role in the expression of such characters. The quantitative inheritance primarily partitioned by magnitude, nature and interaction of genotypic and non-genotypic variation in various plants characters. This suggests the impetrating need of partitioning the overall variability into its heritable and non-heritable components.

Johansen (1909) a Danish biologist demonstrated the concept of genotype and phenotype. He formulated “pure line theory” and reported that both heritable and non-heritable components affect the somatic and phenotypic variation.

The review works related to variability in opium poppy are as follows:

Vetter and Dobos (1996) reported variation in morphine content in 80 winter poppy (P. somniferum) lines using thin layer chromatography. Average morphine content was 2729 p.p.m., with the range of 1700 to 5000 ppm. The cultivars Edelweiss and Marianne, mostly used in Austria for seed production were also evaluated and had average morphine content upto 4000 and 5000 p.p.m., respectively.
Saini et al. (1999) reported a wide range of phenotypic and genotypic variation in 10 quantitative traits, except number of capsules/plant in 75 indigenous and exotic genotypes of opium poppy (*P. somniferum*).

Bajpai et al. (1999) observed wide variation in seed shape, colour and yield and in oil content and fatty acid composition of seed oil of 109 accessions of opium poppy (*P. somniferum* L.), the majority of which were Indian landraces. The seeds were white, pale yellow or light brown in colour, reniform or round in shape and varied in size up to threefold. The oil content, seed and oil yield varied between 26 to 52%, 1.0 to 7.4 g/plant and 0.4 to 2.7 g/plant, respectively. The fatty acids palmitic, oleic and linoleic acid contents in the seed oil ranged between 9.3 to 40.0%, 7.5 to 58.4% and 0.7 to 72.7%, respectively. On a mean basis, the levels of major fatty acids in the seed oil were: oleic (37.1%) > palmitic (27.3%) > linoleic acid (17.2%).

Lal and Sharma (1999) reported ample genetic diversity among parents for all traits in 6 x 6 diallel cross progenies (n²=36) based on numerical and graphical analysis over two environments.

Havel et al. (2000) revealed marked variability in alkaloid content in individual poppy genotypes analysed from precise TLC method. The stability of thebaine content in the genotypes was verified, but no progeny with high and stable thebaine content have yet been found.

Bajpai et al. (2000) assessed a set of 208 Indian and two Thai germplasm accessions of opium poppy (*P. somniferum*) for variation in 17 morphological characters.
including seed yield and content of morphine from capsules and peduncles. The germplasm was found to be highly variable for all the characters evaluated.

Singh et al. (2000) reported significant variation among 35 genotypes for plant height, peduncle length, number of leaves/plant, number of branches/plant, number of effective capsules/plant, number of stigmatic rays, capsule length, capsule width, latex yield/plant, seed yield/plant, husk yield/plant and morphine content. The estimates of PCV were higher than those of GCV.

Tiwari et al. (2000) studied the genetic architecture of seed yield in 21 genotypes of opium poppy. Plant height and seed yield showed high variation at both genotypic and phenotypic level whereas peduncle length, peduncle weight and capsule weight revealed medium range of variation both at genotypic and phenotypic level. Capsule number had lowest genotypic (0.65) and phenotypic (2.02) variances whereas plant height and peduncle length had more phenotypic variance than genotypic variance.

Singh et al. (2001) reported significant variances among 10 lines, 4 testers, their hybrids and parents vs. hybrids for the characters plant height (cm), capsule length (cm), days to maturity, peduncle length (cm), husk and seed yield (g) and morphine content (%).

Singh and Shukla (2001) evaluated ten opium poppy (P. somniferum) inbred lines to study the stability of opium yield, seed yield and morphine content and reported significant differences for all the traits. Larger variation in regression coefficients revealed that the genotypes had different degree of environmental responses.
Jain et al. (2005) determined the genetic variability in 93 genotypes along with three checks, in opium poppy. Analysis of variance revealed significant differences among the genotypes for six characters, i.e. days to flower initiation, days to 50% flowering, seed yield/plant, husk yield/plant, latex yield/plant and morphine%, indicating sufficient amount of variability in the material under study.

Yadav et. al. (2006) studied phenotypic and genotypic variability, broad sense heritability, genetic advance under selection and interrelationship of traits. A total of 122 accessions were found to be highly variables for all the traits studied. Broad sense heritability ranged from 74.18% (for opium yield/plant) to 99.00% (for papaverine content).

VARIANCE COMPONENT AND ALLIED GENETIC PARAMETERS:

The first attempt to partition the genotypic variance into its component was made by Fisher 1918. He recognized three component of hereditary: 1. Additive 2. Dominance 3. Epistasis.

The three types of genetic variance were also recognized by Wright (1935) as

1. Additive genetic variance

2. Variance due to dominance deviation from the additive scheme

3. Variance due to epistatic deviation from the additive scheme.

Jinks and Hayman (1953) developed the analysis for estimating the genetic parameters and their ratios from a set of diallel cross involving homozygous lines.
Hayman (1954a) presented the algebraic basis analysis giving a new notation and added two more statistics, $h^2$ and $F_r$ in addition to those given by Jinks and Hayman (1953). Hayman (1958a) provided diallel analysis for $F_2$ data and described the method for estimation of $D_1$, $H_1$, $H_2$, and $F$. Hayman (1957) brought out the reliability of statistics $(H_1/D)^{1/2}$ as a measure of an average degree of dominance. He stated that multiple allelism and gene correlation in the parents distorted $(W_r,V_r)$, but did not seriously disturb the ratio $(H_1/D)^{1/2}$ as a measure of degree of dominance.

Jinks et al (1969) gave a new analysis method of detecting additive, dominance and epistatic variations which require only $2 \times n$ crosses out of a diallel set of $n^2$ crosses which showed a good agreement with those from extensive diallel analysis.

Gardner (1963) proposed the following parameters which are useful to plant breeder.

1. Additive genetic variance ($\sigma^2_A$), which results from the additive effects of genes at all corresponding loci.

2. Dominance variance ($\sigma^2_D$), which results from intraallelic interaction of genes at segregating loci.

3. Epistatic variance which results from inter-allelic interaction of genes of two or more segregating loci and is divisible into additive x additive ($\sigma^2_{AA}$), additive x dominance ($\sigma^2_{AD}$) and dominance x dominance ($\sigma^2$) for two locus situation and additive x additive x additive x additive ($\sigma^2_{AAA}$) etc for three or more loci.

4. Average degree of dominance i.e. ratio of dominance variance to additive variance.

5. $G \times E$ interaction which may be divided into additive gene effects x environment and non-additive effect x environment and
Genotypic correlation among quantitative characters of important for the particular crop.

Robinson (1966) opined two purposes for estimating genetic parameters i.e. (i) to obtain the nature of gene action concerned and (ii) to provide the basis for an evaluation of selection schemes for improvement of the population or possibly the information for development of a new approach in breeding.

However considering the gene actions in depth the genetic variance of interest to quantitative genetic and plant breeding are described as below:

1. Additive genetic variance \( (\delta^2_A) \)
2. Dominance variance \( (\delta^2_D) \)
3. Epistatic variance \( (\delta^2_I) \)

In addition to these genotype x environmental interaction variance is also important.

The work done on different gene actions, which govern the quantitative and quality traits in opium poppy, is briefly described below:

Hlavackova (1980) reported that additive and dominance type of gene action contribute significantly to the genetic variability for date of flowering. In both BULKarshy Fialorg (Bulgarian violet) and Fran Cauzsky dominant genes for early flowering and recessive genes for late flowering was noticed.

Nyman (1980) investigated pattern of alkaloids in \( F_1 \) and \( F_2 \) generations obtained from cross between different chemo provarieties of \( P. somniferum \) L. A monogenic recessive inheritance for the low alkaloid content was obtained in mutant. Extremely low content of morphine were obtained in the \( F_2 \) generation from an interspecific hybrids.
between the low alkaloid mutant of *P. somniferum* x *P. setigerum* varieties. In a cross with morphine rich variety of *P. somniferum* and Sr. Indra, high content of this alkaloid were achieved in the F₂ generation.

**Khanna and Shukla (1989)** reported preponderance of additive gene action for plant height, days to maturity, capsule size and morphine content. Days of flowering, opium weight, capsule number and seed weight were controlled by dominance or epistatic effects.

**Lal and Sharma (1991)** reported that additive component was significant for latex yield and morphine content. Dominant alleles mostly with positive effects were asymmetrically distributed in parents except for narcotine content.

**Khanna and Shukla (1991)** reported epistatic interaction in the inheritance of papaverine content.

**Kandalkar et al. (1992)** reported non-additive gene action for capsule weight and capsule diameter.

**Shukla and Khanna (1992)** carried out genetic studies in 10 parents diallel and reported partial dominance in F₁ and over dominance in F₂ for days to flowering and over dominance in both the generation for day to maturity. Non additive gene action were predominant for both the traits.

**Shukla (1992)** reported that plant height, capsule number and capsule size were largely governed by additive gene action. Dominance variance was highly significant for dry weight of pant and seed weight.
Kandalker and Nigam (1993) reported additive gene action for days to flowering, leaf area, biological yield, harvest index in both F1 and F2 except leaf area in F1 generation.

Shukla et al. (1994) carried out experiment on additive dominance model for 2 crosses (NBRI -1 x BR222 and NBRI-2) to study the gene actions involved in the inheritance of morphine alkaloids in opium poppy. They reported that dominance effect was higher than additive effect gene effect for morphine and dominance x dominance for codeine and thebaine in both the crosses.

Singh et al. (1994) studied the genetic system involved in the inheritance of seed yield and oil content in F1 and F2 generations obtained through 6 parent half diallel and reported over dominance for both the traits. Parents IC30 and BR88 possessed maximum dominance and BR79 and BR87 maximum recessive genes for seed yield while for oil percentage parents BR79 and BR87 had maximum dominance and IC30 and BR76 had maximum recessive genes in both the generation.

Shukla et al. (1995b) studied inheritance of opium and its main component traits viz. capsules/plant, capsule size and seed yield. They reported that in general these traits were governed by additive, dominance and epistatic interactions. However, the magnitude of dominance was higher than additive gene effect.

Shukla and Khanna (1995) studied genetic variance for traits opium weight and morphine percentage in 10 parents and their 45 F1 and 45 F2 hybrids obtained through half diallel. They noticed that morphine percentage was governed largely by additive
gene effects while opium weight was mainly governed by non-additive gene effects. They further noticed overdominance for opium yield in both generations and for morphine percentage in the F2 and narrow-sense heritability was medium for morphine percentage and low for opium yield.

Singh et al. (1996) carried out genetic studies for seed yield and its contributing traits in F1 and F2 generation of a 6x6 parent half diallel and reported non-additive gene action for seed yield.

Singh and Shukla (1996) reported partial dominance for plant height and over dominance for days to flower. Component analysis revealed major effect of dominance component for all the traits.

Shukla and Khanna (1997) reported the importance of both additive and non-additive gene actions for various traits under study based on 10 x 10 parent full diallel crossing programme in opium poppy (P. somniferum L.). They noticed additive gene action for plant height and capsule number and non-additive for days to maturity, opium yield, seed yield and dry weight of plant while both additive and non-additive genetic variances were important for stem diameter, days to flower, capsule size and morphine percentage.

Tóth et al. (1997) reported complete dominance for low codeine content base on variance/covariance graphical analysis of 5 parents full-diallel cross in opium poppy (P. somniferum). The varieties Kompolti Resistant and B1 had the highest proportion of recessive genes, while Kompolti had the largest number of dominant genes.
Singh et al (1998c) estimated different gene systems involved in the inheritance of oil and fatty acids. They reported non-additive gene action for all the fatty acids viz. palmitic acid, stearic acid, oleic acid and linoleic acid. One gene group was noticed for all the fatty acids except stearic acid with two gene groups in F1

Singh et al. (1998d) investigated inheritance of morphine in opium poppy through 6 x 6 half diallel analysis and found prevalence of additive gene action in the inheritance of morphine. Parent IC30 in F1 and BR79 in F2 possessed maximum dominant alleles while BR85 possessed maximum recessive alleles in both the generations. Two groups of genes were reported for control of morphine.

Lal and Sharma (1999) reported that the dominance($A_1$) was in over dominance range without inflating non-allelic interactions in parents for the plant height (environment I) and capsules/plant (both environments) in 6 x 6 diallel cross progenies ($n^2=36$) over two environments. However, the additive (D) component was also significant for these traits. Dominant alleles mostly with positive effects were, asymmetrically distributed in parents.

Singh et al. (1999) evaluated F2 populations of the cross of opium poppy lines AP8 and BP12 to study the inheritance of yield components. Straw and seed yield/plant and morphine content (%) in straw were found to be controlled by dominance effects. The presence of additive components along with high narrow sense heritability estimates for capsules/plant and morphine content, makes these traits suitable for direct selection. The dominance component can be utilized through hybrid breeding for population improvement programmes.
Shukla and Singh (1999b) reported based on six parameter model that through backcrossing of better recombinants with the donor parents followed by recurrent selection, high papaverine line may be developed in opium poppy. Joint scaling test showed the adequacy of the additive-dominance model for the papaverine content in both the crosses. The interaction components indicated that additive x dominance (j) and dominance x dominance (l) gene action played an important role in the inheritance of papaverine content.

Singh (2000) reported the presence or absence of epistasis for morphometrical traits in 63 samples of opium poppy and also studied appropriate breeding strategies. The presence of epistasis was recorded for days to flowering, plant height and average weight of capsules. The presence of additive, dominance as well as epistatic components for all the traits except capsule/plant and capsule diameter, suggested simple selection procedures in the immediate progenies may not help much in achieving improvement in these traits. The presence of epistasis for the different traits can be exploited by recurrent selection techniques.

Shukla and Singh (2001) studied the inheritance of opium poppy in varieties NBRI-1 and NBRI-2 by selfing upto seven successive generations. Progenies with high morphine content segregated strongly and produced progenies with lower content, while selection in middle order produced high and intermediate progenies. Selection response was also high in progenies selected from middle range. The results suggested that high morphine content was due to some epistatic interactions.
Singh et al. (2001) reported predominant non-additive gene action for the characters plant height (cm), capsule length (cm), days to maturity, peduncle length (cm), husk and seed yield (g) and morphine content (%) except peduncle weight, suggested suitability of heterosis breeding for effective improvement in opium poppy (P. somniferum). Inter-breeding followed by biparental mating was suggested for rapid improvement.

Singh et al. (2001) reported that the additive-dominance model was not adequate in explaining the gene effects involved in controlling the inheritance of four traits i.e., capsules/plant, seed yield/plant, straw yield/plant and oil content in opium poppy. The adequacy of first-order interactions (digenic) indicated the importance of epistatic components in their inheritance. Besides dominance (main effect), duplicate type of epistatic (digenic) effects were found to be important in inheritance.

Singh et al. (2002) reported additive gene action for plant height, peduncle length, straw yield and straw morphine and dominance for capsule length and capsule diameter.

Singh et al. (2003b) reported additive gene action for the traits capsule weight/plant, opium yield/plant, capsules/plant and seed yield/plant.

Dubey et al. (2007) reported the presence of both additive and non-additive gene effects for latex yield, stem diameter, number of effective capsules/plant, plant height, peduncle length, days to flower initiation and days to 50% flowering in seven parents and their 21 hybrids of opium poppy.
CORRELATION STUDIES:

Correlation coefficient analysis shows the mutual relationship among various plant characters and indicates the component characters on which selection can be based for yield improvement. The study of correlation is regarded as an important step in a breeding program as it helps to ascertain the nature of selection that may be practiced for the improvement of yield.

Selection based on the performance of yield a polygenically controlled and end product of multiplicative component character is usually not very efficient but the selection based on its component characters could be more efficient in the enhancement of yield. The study of correlation is regarded as an important step in breeding programme as it helps to ascertain the nature of selection and the information obtained is quite useful in estimating the correlated response to directional selection in the formulation of selection indices.

The concept of correlation was presented by Galton (1889) which was later elaborated by Fisher (1918) and Wright (1921b). investigation of genotypic and phenotypic interrelationship between various agronomic traits are of interest of plant breeders from theoretical and practical stand point, since selection is usually concerned with changing two or more characters simultaneously. The utility of estimates of correlation considerably increases by partitioning into phenotypic, genotypic and environmental components (Burton, 1952).
Phenotypic correlation may be of genotypic and/or environmental origin and provides information about association observed between two characters. For selection point of view phenotypic correlation is of little practical value unless genetic and environmental correlations between pairs of characters are in the same direction and estimated separately. Genotypic correlation provides a measure of genetic association between characters and is usually used in selecting for one character as a means of improving another. Soch correlation coefficient provides information by themselves (Miller et al. 1958) and should be helpful to the breeder since they are based on transmissible genetic variance (Jerome et al. 1956). Dewey and Lu (1959) pointed out that many of the characters are correlated because of mutual association (positive and negative) with characters and as more variables are considered indirect selection become more complex, less obvious and some what perplexing. Moreover, the genotypic correlation is helpful to formulate the most effective breeding methodology under particular environmental conditions and simplify the approach for selection.

The major cause underlying genetic correlations are pleiotropy/linkage and developmentally induced relationship (Stebbins, 1950; Mode and Robinson, 1959; Adams, 1967). Pleiotropy, a property of gene where it affects two or more characters may not result in detectable correlation as it is the net effect of all segregating genes that affects both characters, some causing positive others negative correlations. If the association between two or more characters changes in segregating population the association may be due to linkage between two genes which breaks in segregating population resulting in recombination between such genes. The pleiotropy or linkage may involve two desirable traits or one desirable and one undesirable traits. The correlation
between two desirable traits is of paramount importance for a plant breeder to bring about genetic improvement in one character by selecting the other characters of a pair that is genetically correlated. Linkage is the cause of transient correlations. The developmental relationship occurs when two developing structures of the plant body compete for a common need possibly limited nutrient supply. If one structure is favoured for any reason, over other in the amount of nutrient received a negative correlation may arise between them. High degree of negative correlation between two characters would make the simultaneous improvement of these traits entirely incompatible and in such case, the selection for one character alone would be at the expense of other and vice versa. Environmental correlation reflects the influence of environmental factors on the joint variation of two characters. It is of no value in selection but it provides information about the relationship of characters irrespective of genotypic differences in the plant material. At genetic level, negative correlation, arises from “repulsion”, linkage of gene(s) controlling X and Y traits. Conversely, a positive correlation occurs due to coupling phase of linkage. No correlation (r=0) indicates that gene concerned are located far apart on the same chromosome. However, nature of correlation can be altered by selection and hybridization.

Relevant literatures on correlation analysis in opium poppy are as follows:

Singh et al. (1990) reported significant negative correlations between linoleic acid and oleic acid and between linoleic acid and stearic acid.

Bhandari and Gupta (1991) studied genotypic coefficient of variation, heritability and genetic advance in 18 genotypes of opium poppy and suggested that latex
yield can be improved by selecting for capsule volume and reduced number of capsules per plant

Singh et al (1995b) studied correlation coefficient among six parents, 15 F₁₅ and 15 F₂₅ for different fatty acids in opium poppy seed oil and noticed negative correlation among most of the combinations. They further opined that both the pathways of fatty acid biosynthesis i.e. by chain elongation and by desaturation suggested earlier by Stringam and McGregor (1980) are followed completely.

Singh et al. (1995d) studied suitability of direct and indirect selection of opium and seed yield, its seven component traits and reported highest correlated response in opium yield through days to flowering (15.72%), leaves/plant (14.72%), and capsule size (1.86%) and in seed yield through capsules/plant (19.22%), capsule size (13.84%) and branches/plant (12.56%). They further concluded that to derive multiple selection indexes, medium maturity, big capsule size, more leaves/plant and high seed yield should be considered to enhance the opium yield.

Lal et al. (1996) reported that plant height was positively correlated with peduncle length and latex yield and negatively correlated with capsule index. The association between flowering time and plant height had highest co heritability value (4.89), followed by the association between capsule index and morphine content.

Bhandari et al. (1997b) reported that latex yield was positively associated with days to flowering, capsule breadth, leaf area, seed yield and plant height but negatively with morphine, capsule number and leaf number. They observed that latex yield received
maximum contribution from capsule breadth (0.40) and leaf numbers. Morphine showed negative direct path (-0.52) towards latex yield. Plant height and capsule number showed negative direct path while days to flowering had indirect positive effect via capsule number, morphine content, leaf area and capsule breadth. Direct effect of plant height was negative. They suggested plant type having few capsules, dwarf height and broad leaves can increase latex yield.

Singh et al. (1999e) reported maximum correlated response for seed yield through capsules/plant and straw yield/plant. Relative selection efficiency was more than one in straw yield and capsules/plant indicated that these traits were expected to be as useful as the direct selection on seed yield itself.

Singh et al. (2000) reported that latex yield was positively and significantly associated with number of leaves/plant, number of branches/plant, number of capsules/plant, capsule length and seed yield/plant based on the correlation study of 35 genotypes of opium poppy. However latex yield was negatively associated with husk yield/plant and morphine content.

Tiwari et al. (2000) studied correlations among different characters for 21 genotypes. Seed yield showed positive and significant association at both genotypic and phenotypic level with capsule weight, plant height and peduncle length. The relationship between seed yield and capsule number at genotypic and phenotypic level was negative whereas genotypic correlation was very low for seed yield and plant height. The capsule weight had positive correlation with plant height, peduncle length, peduncle weight but negative correlation with capsule number.
Bajpai et al. (2001) reported that the correlation between morphine and codeine was positive and significant in a set of 184 Indian accessions of opium poppy. The proportion of codeine to morphine was 1:1.5 in the peduncles and 1: 5.5 in the capsules. Codeine content of peduncle was not correlated with codeine or morphine contents of capsule and vice versa.

Shukla et al. (2003) showed significant and positive correlation of seed yield with plant height, capsules/plant, stem diameter, capsule size, capsule weight/plant and husk yield/plant in opium poppy.

Singh et al. (2003b) evaluated 22 genotypes and reported that opium and seed yield were positively correlated with capsules/plant, stem diameter, capsule size, capsule weight and husk yield. Capsule weight/plant was positively and significantly associated with plant height, capsules/plant, stem diameter, capsule size, seed yield and husk yield/plant at genotypic level. They also reported that seed yield/plant contributed maximum towards opium/plant (20.174) directly and through plant height (0.772) and capsules/plant (7.874) indirectly. Husk yield also showed high direct contribution to opium yield and indirectly through seed yield/plant, capsules/plant and plant height.

Singh et al. (2004) reported that opium yield, seed yield, husk yield and capsule weight/plant exhibited positive and significant correlation among themselves and these four characters had also positive significant genotypic correlation with plant height, branches/plant, capsules/plant, capsule area and leaves/plant based on correlation and path coefficient analysis of a group of 101 germplasm lines of opium poppy.
Yadav et al. (2004a) reported maximum correlated response for seed yield by capsule weight/plant (2.09%), followed by husk yield/plant (1.84%) and stem diameter (1.45%); for opium yield through selection of capsules/plant (22.12%), capsule weight/plant (18.96%); for husk yield correlated response was maximum through capsule weight/plant (1.43%), and seed yield/plant (1.14%) and capsules/plant (1.03%). They concluded that to isolate superior genotypes for opium yield, selection should be based on stem diameter, more number of capsules/plant and high capsule weight and seed yield.

Yadav et al. (2004b) reported capsule weight/plant, capsule size and plant height as major yield component and thus practising selection for attainment of high opium and seed yield, maximum weightage should be given to these traits.

Jain et al. (2005) reported from genotypic and phenotypic correlation studies of 93 genotypes alongwith three checks, of opium poppy that latex yield was positively and significantly associated with stem diameter, days to flower initiation, days to 50% flowering and number of effective capsules/plant. Seed yield was positively and significantly correlated with husk yield/plant.

Yadav (2006) reported from correlation analysis of some accessions that opium yield is negatively correlated with morphine and papaverine content. Among alkaloids codeine, thebaine, narcotine and papaverine showed positive correlation among themselves. The correlations among alkaloids were justified based on the biosynthetic pathway of opium alkaloids.

HETEROYSIS:
In general heterosis or hybrid vigour is a term to describe the phenomenon in which the performance of F1 generated by crossing of two genetically different individuals is superior over parents. Mather and Jinks (1971) defined heterosis as the amount by which the F1 hybrids mean exceeds its better parent. Heterosis is widely documented phenomenon in diploid organisms that undergo sexual reproduction. East (1908, 1909), East and Hayes (1912), Shull (1910, 1911 a, b) studied the effect of inbreeding and outbreeding in maize and Nicotiana which provided the genetic bassi to the phenomenon of heterosis. According to this concept crossing produces heterozygotes and inbreeding tends to produce homozygotes.

The term heterosis was first coined by Shull (1914). Later on another another term heterobeltiosis proposed (Bitzer et al. 1968; Fonesca and Patterson 1968) to describe the improvement of the heterozygotes in relation to better parent of the cross and now this term is precisely being used to connate the expression of the heterosis over better parent.

Two major hypothesis have been promulgated to explain the genetic basis of heterosis. The dominance hypothesis was proposed by Devenport (1908). The overdominance hypothesis was proposed by Shull (1908).

Jinks and Jones (1958) stated that heterosis is a complex genetical phenomenon depending upon the balance of additive dominance and interaction of homozygous/homozygous and homozygous/heterozygous component as well as on the distribution of the genes in the parental lines. Robinson (1963) and Moll et al. (1964) suggested that genetic diversity of per parental stocks and partial to complete dominance of the genes might be the major factor for heterosis in yield and component traits. Richey (1946
strongly supported the dominance hypothesis of heterosis and stated that the interaction of favorable dominant genes continued to be the best explanation for heterosis. Lonnquist (1951) considered that improvement in combing ability of inbreds through in the heterozygous population. Lonnquist (1953) further studied single crosses among a group of five high yielding and low yielding inbreds derived from the variety ‘King’ of maize. He reported that hybrid vigour could result from either the action of favorable dominant or partially dominant genes or from over dominance. The former type of gene action appeared to be more important than later, which explained the heterosis as a result of union of two unlike gametes in heterozygotes i.e. over dominance concept of heterosis.

Whaley (1944), Hayes (1946), Shull (1948) were of the views that heterosis could not be attributed to a single to a single cause as it was complexly inherited characters but all type of genetic causes in one or more contribution might be operative in its manifestation. Such causes could be due to dominance of linked genes, complementary gene action, masking of the effects of deleterious recessive by their dominant alleles, heterozygosis and inter-allelic interaction of multiple alleles.

Mather (1955) considered that heterosis resulted from certain polygenic combinations acting together and it was lost when their combinations were broken down by recombinations. He gave the idea that heterosis is an expression of genetic balance, which depends upon an adjustment and integration of polygenes.

Williams (1959), Durate and Adams (1963), Grafius (1964) and Coyne (1965) explained that the study of individual components (somatic analysis) could manifest the genetic explanation of heterosis. Genetic basis of heterosis for complex characters could
be explained by multiplicative interaction at phenotypic level of the component traits. It was suggested that heterosis could possible be explained on the basis of dominance rather than over dominance.

**Stuber et al. (1992)** used molecular markers to detect QTLs contributing to hybrid vigour in maize and reported that heterozygotes of most QTLs detected for grain yield had higher phenotypic values than respective homozygotes suggesting that over dominance is the principal factor controlling heterosis in this crop. However, Xiao et al. (1995) reported that dominance complementation is the major genetic basis of heterosis in rice revealed through QTL analysis.

An alternate theory was proposed by Milborrow (1998). He suggested that growth of a plant may be limited by the genes that regulate certain metabolic pathways down to lower levels than the maximum possible. Heterozygotes may partially escape this regulation because they have two slightly different alleles for these genes allowing greater flow on these pathways. This is not overdominance, but like the overdominance hypothesis. It predicts that heterozygotes have an inherent advantage in vigour that can not be duplicated by any amount of selection in open pollinated homozygous lines.

Apart from these genetical basis heterosis is also modified by the interactions between genotypes and environment cultivation. Chapman et al. (2000) reported that hybrid sorghum can show heterosis for yield; but this effect varies widely between trials conducted at sites differeing in seasonal water supply, so that it is more meaningful to characterize a particular hybrid line as showing heterosis for yield at a specific locality or under certain environmental conditions.
The review works on heterosis in opium poppy are as follows:

Shukla (1985) reported heterosis in 90 hybrids developed through 10 parent full diallel. He noticed maximum heterosis upto 65.40% for opium yield, 106.90% for seed yield, 37.14% for capsule/plant and 18.60% for capsule size over better parent. Days to flowering (2.00%) and days to maturity (2.40%) had very low heterosis.

Sharma et al. (1988) examined heterosis in the hybrids obtained through five parent full diallel for different important traits. They found that Shyama was most desirable parent to obtain most economic heterosis for opium yield, plant height and days to flowering. The study has further reflected that on judicious selection after inter-se mating in segregating population would be the best way to improve theses traits as non-additive genetic variance was important for these crosses.

Singh and Khanna (1991b) studied heterosis in 21 crosses obtained through seven parents half diallel and noticed marked heterosis for all the characters except days to flowering and plant height. Seed yield/plant (78.85%) showed maximum heterosis followed by capsules/plant (46.90%), branches/plant (44.96%) and opium yield/plant (40.77%). On the basis of per se performance and heterosis, the crosses Br85 x Br76, Br79 x Br87, Br87 x Br 85 and Br 79 x IC 30 were best for opium yield and IC 30 x Br 88, Br 85 x Br 76, Br 79 x Br 88 and Br 79 x Br 76 for seed yield. These crosses also had high heterosis for most of the component traits.

Patidar (1994) evaluated 124 hybrids obtained through line x tester of four male and 31 female lines in opium poppy and reported 42.90 to 77.80% heterosis over better
parent for opium yield, 43.80 to 134% for seed yield and 76.50 to 131.20% for husk yield. The best hybrids were MOP 187 x IC 42 for opium yield (408.00mg/plant), MOP 379 x IC 30 for seed and husk yield and IC 90 x IC 30 for morphine content.

Lal and Sharma (1995) reported from the genetic analyses of 36 F₁ crosses of opium poppy involving six parents that non-allelic interactions (particularly duplicate epistasis) manifested low or negative theoretical/expected heterosis (EH), while most of those without epistatic interactions exhibited sizeable EH. Substantial positive heterosis was noticed for latex yield but negative heterosis was observed for alkaloid content.

Sharma et al. (1997) noted high heterosis for straw yield, peduncle length and capsule yield. Six hybrids viz. mass-2B x IS14, Mass-2B x Shweta Fr, F₁ x Shweta Fr, IS14 x N3, Shweta BR x IS14 and SPS20 x G25 gave heterosis value exceeding 80% over the control and Sanchita for seed yield. Economic heterosis was reported to range from -71.90% to 80.70% for seed yield, -67.40 to 90.70% for straw yield, -6.30 to 5.30% for days to 50% flowering, -15.30 to 29.00% for plant height, -10.30 to 16.60% for peduncle length and -23.60 to 111.30% for capsule numbers.

Shukla (1998) studied heterosis in 90 hybrids of opium poppy obtained from 10 parents full diallel and reported that seven hybrids showed high opium and seed yield due to an increase in the number of capsules, capsule size and diameter. Five hybrids had high degree of heterosis for opium yield, three for seed yield and two for morphine content.

Shukla and Singh (1999) studied the effect of inbreeding using 3 populations (selfed, open and sibbed) of 3 landraces (Early Red, Ghazipur, Kali Dandi) in opium
poppy and reported that Ghazipur and Early Red had significant inbreeding on selfing for seed yield and opium yield while Kali Dandi had no inbreeding for seed yield and very low non-significant for opium yield. The yield of sibbed population of each variety was at par to open pollinated population with higher magnitude in Kali Dandi.

Singh et al. (1999d) studied heterosis for yield and its related traits in 15 F1 hybrids in P. somniferum. Most of the hybrids gave higher yield over mid parent. Nine hybrids showed significant heterosis (upto 167.00%) for seed yield over better parent. The hybrids also showed significant heterosis for plant height (-21.70%), peduncle length (20.60%) and straw yield (159.10%) in comparison to better parent. Maximum heterosis (167.00%) for seed yield was noticed in cross AP9 x AP10 followed by AP7 x AP8 (148.00%) and AP5 x AP6 (129.30%).

Shukla et al. (2000) reported from 5 parents half-diallel, significant positive heterosis for the cross IS-16 x Early (102.60%) followed by IS-16 x Aphuri (100.00%) for opium yield and Aphuri x Early (150.29 %) followed by NBRI-5 x Early (42.86%) for seed yield over better parent. The heterosis study convincingly raised the possibility that a gene introgression breeding strategy based upon the diverse parents like “IS-16”, Aphuri and Early would ensure multifold increase in yield traits in opium poppy.

Shukla and Singh (2000) reported that the manifestation of heterosis over standard variety (economic heterosis) and better parents was (5.26%) and (5.56%) for plant height, (11.15%) and (8.15%) for seed yield and (55.08%) and (88.07%) for opium yield respectively in 7 parent half-diallel. The crosses of opium poppy IS1 x IS 17 and IS1 x IS22 showed positive hetrosis for seed yield as well as for opium yield. The crosses
IS19 x IS1, IS1 x IS22, IS17 x IS22 and IS17 x IS20 for opium yield and IS6 x IS2, IS6 x IS17 and IS19 x IS2 for seed yield had significant heterosis and low inbreeding depression and also showed significant residual heterosis in F2 generation over better parent and satandard variety BROP-1.

Singh (2000) reported that the hybrid AP14 x AP11 exhibited high heterosis for number of capsule/plant (88.20%) and straw yield/plant (43.60%) and medium for seed yield/plant (22.70%) in opium poppy. The hybrid AP13 x AP4 was more suitable for plant height on account of negative heterosis (-4.14%). The maximum heterosis (34.50%) over better parent for seed yield was recorded in cross AP14 x AP7. Out of 28 hybrids only four had significant heterosis and high per se for seed yield.

Shukla and Singh (2004d) estimated heterotic effect in 10 hybrids developed through 5 parents' half-diallel. They noticed maximum heterosis for opium yield in cross BR233 x BR225 (94.25%) which also showed maximum heterosis for seed yield (138.09%), plant height (29.52%), capsule size (112.92%), capsule weight (130.03%) and husk yield/plant (120.00%).

Dubey et al. (2007) evaluated 21 hybrids alongwith 7 parents and two checks of opium poppy for combining ability and standard heterosis for latex yield, stem diameter, number of effective capsules/plant, plant height, peduncle length, days to flower initiation and days to 50% floweing. The hybrid UOP-82 x MOP-204 exhibited the highest standard heterosis and per se performance for latex yield/plant. In general close association was observed between sca effects and standard heterosis among the best hybrids identified on the basis of sca effects for latex yield.
Yadav et al. (2007) studied the genetic divergence in 110 population (20 parents and 90 F-1 hybrids) of opium poppy was studied by multivariate analysis. All the entries were grouped in 14 clusters. Out of 20 parents, ten were accumulated in one cluster and rest 10 distributed over seven clusters. Estimates of cluster distance showed that maximum intra-cluster distance was in -cluster IX (25.62) followed by cluster I (22.41), V (22.23) and IV (21.06). The inter cluster distances varied from 16.62 (between cluster XII and XIV) to 195.10 (between cluster IV and IX). The cluster analysis indicated substantial diversity among the parental genotypes, which had the potential to release considerable variation in their crosses. The first four principal components (PCs) with eigen values > 1 accounted for 68% of variation among the population. The first and second components could account for 29 and 20% of the total morphological and alkaloidal variations, respectively. The PC1 was closely related to yield and yield related traits. The characters contributing greatest positive weight on PC1 were opium yield, plant height, stem diameter, capsule weight/plant and seed yield/plant. The possibilities of relationship between genetic divergence, F-1 performance, heterosis and GCA of parents have been explored.

Gumuseu and Arslan (2008) crossed seven lines of opium poppy reciprocally that were selected in first year of the study and was carried out two years. The parental lines were taken with their hybrids to yield experiments in the second year. Yield components of hybrid and parent lines were compared and investigated for heterosis and heterobeltiosis between these lines. Heterosis and heterobeltiosis values of some important traits of the material have been given below: for seed yield per plant changed between -13.42% to 37.14% and -22.48% to 36.29%; for capsul yield -33.92% to 45.39%
and -40.83% to 34.67%; for seed yield -32.05% to 45.89% and -38.34% to 43.22%; for morphine content -24.21% to 44.62% and -32.44% to 32.68%; for morphine yield -37.63% to 100.39% and -54.68% to 95.21%, respectively.

**INBREEDING:**

Inbreeding is mating between two closely related individuals and decrease in fitness and vigour due to inbreeding is referred as inbreeding depression. The closest form of inbreeding is self-fertilization. The degree of inbreeding is measured by the inbreeding depression Shull (1914) pointed out that inbreeding depression is associated with unfavourable biological effects resulting in loss of vigor. Wright (1921) stated that decline of vigour was proportional to decrease in heterozygosis. Crow (1952) observed decline due to decreasing homozygosity for the cases showing dominance or over dominance. The review of work done regarding inbreeding in opium poppy are given below:

**Ghiorghita et al. (1990)** studied the effect of self pollination on some morphophysiological indices in opium poppy. They reported decrease in capsule size, seed weight and morphine content due to self pollination.

Shukla (1998) studied inbreeding depression among 90 hybrids of opium poppy and reported maximum inbreeding depression of 45.7% for seed yield /plant, 43.5% for opium yield/plant, and 25.4% for morphine content. He further reported that most of the hybrids which had maximum heterosis also had proportionate inbreeding depression in F₂ generation.
**Shukla and Singh (1999a)** studied effect of inbreeding using 3 populations (selfed, open and sibbed) of 3 landraces (Early red, Ghazipur and Kalidandi). They reported that marked amount of inbreeding was noticed in Ghazipur and early red on selfing for seed yield and opium yield. However, Kalidandi showed very low inbreeding for opium yield and showed equal magnitude of seed yield to open pollinated, with slightly higher in Kalidandi. They concluded that marked inbreeding occurred on selfing, one of the common modes of inbreeding.

**Singh et al (1999c)** evaluated 6 parent half-diallel crosses of opium poppy to study inbreeding for palmitic acid, stearic acid, oleic acid linoleic acid and oil content. High degree of inbreeding depression was observed for pamitic acid and stearic acid.

**Singh et al. (1999d)** studied degree of inbreeding depression in 15 F2 hybrid of opium poppy. They reported that out of 15,12 heterotic hybrids for seed yield exhibited significant inbreeding depression in F2 generation. Maximum inbreeding depression of up to 196.80% for seed yield, 272.50% straw yield and 27.60% for peduncle were reported.

**Shukla and Singh (2000)** evaluated inbreeding depression in F3, developed through 7x7 cross diallel. They reported maximum inbreeding depression of 113.36% for opium yield, 30.36% for seed yield, 29.99% for capsule size, 54.95% for capsule/plant and 6.83% for plant height. They further reported that the hybrids showing maximum heterosis also exhibited proportionate inbreeding.

**Shukla and Singh (2004d)** studied inbreeding depression in 10 opium poppy hybrids developed through 5 parents half-diallel. Maximum inbreeding depression of 45.37% for
seed yield/plant, 36.39% for husk yield/plant, 29.84% for opium yield/plant, 28.79% for capsule/plant and 27.85% for branches/plant were reported. Days to flowering and morphine content showed low magnitude depression.

GENETICS DIVERGENCE

The genetic divergence measures the variability among different genotypes of a species. However, the variability differs from genetic diversity in the sense that variability has observed phenotypic differences, whereas genetic diversity may or may not have such expression. The knowledge of nature and degree of divergence at inter and intra-allelic levels is useful in understanding the course of evolution in the varieties. It is also useful in selecting the desirable parent for breeding program since it is known that exploitation of heterosis is dependent on the degree of divergence of parent (Singh, 1991). The hybrid between lines of diverse origin generally shows greater heterosis than those between closely related strains (Ramanujam et al. (1974); Singh and Sharma (1989); Singh et al. (2003a). However contrary to this, Behl et al. (1985), Dave and Joshi (1995), Dixit and Swan (2000) and Singh and (2004) reported that the genetic diversity is not directly associated with heterosis realized, but even restricted range of diversity may throw high heterosis. Among various statistical methods developed for measuring the divergence between populations, multivariate analysis has been a potent tool (Wilk, 1932; Rao 1952, 1960; Burnaby, 1966; Murty and Arunachalam, 1967). The quantitative assessment of genetic divergence was firstly proposed by Mahalanbis (1936) based on multivariate analysis. The models of multivariate analysis (i.e. simultaneous statistical treatment of a set of correlated metric traits in a group of populations), which satisfy the
propositions, are more than one; for instance, Duncan’s multiple range test, metroglyph
and index score method; D^2 statistic, canonical analysis, factor analysis. However, out of all
these, D^2 statistic and canonical analysis are now most frequently used for classification
purposes. While the former gives a quantitative measurement of the divergence among
the genotype, the later serves the same purpose in terms of spatial distance (Sharma
1998). It has been proved that multivariate is one of the best method of grouping or
classifying a number of genetically diverse groups or clusters and making meaningful
interpretation about the genetic divergence in germplasm collection. The details of this
techniques and its application to evaluate the genetic diversity group has been given by
Rao (1952), Wu (1939), Johanson and Hayes (1940). D^2 statistic measures the degree of
diversification and determines the relative proportion of each component traits to the
total divergence. The genotypes grouped together are less divergent than the ones which
are placed in different clusters. The clusters which are separated by greatest statistical
distance show the maximum divergence. Hayes (1963) presented conclusive evidence to
show the genetic diversity and origin of inbred lines used in crosses plays an important
role for expressing heterosis in yielding ability of the crosses in maize. Materials of
apparently equal values as inbred and similar sca may give greater hybrid vigor when
inbred line of diverse origin are crossed in comparison to the cross of inbred lines with a
closer degree of relationship (Hayes et. al., 1955). Sprague (1955 ) emphasized the role of
genetic diversity in the development of superior hybrids. Allard (1960) concluded that
crosses between inbred derived from different varieties would tend to be more productive
than crosses between inbred derived from the same or similar open pollinated source.
Moll et.al. (1962) reported greater diversity associated with greater heterotic response.

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The highest yielding crosses involved parental varieties from different region and different genetic background. Similar conclusion was also noticed by Singh et al. (1977, 1980); Singh (1991, 2002).

The review of earlier work done regarding divergence in opium poppy is as follows:

Kumar (1981), Khanna and Kumar (1983), Kumar and Khanna (1988) carried out multivariate analysis to classify and to access the extent of divergence among 28 major Indians cultivars. The material was evaluated for nine characters. The cultivars were grouped into 12 clusters, 4 of which had single cultivar each. The relative contribution of different characters to total diversity showed that the capsule weight (29.60%) and capsule size (26.98%) were maximum contributors towards diversity. The cluster XII (Aphuri-early flowering, violet petal and high papaverine in latex) and cluster X (DCG-bold capsules and dwarf plant type) are very unique and can be used as donor parents in hybridization program.

Saini and Kaicker (1987) studied genetic divergence among 75 varieties for 10 characters. The 75 varieties were grouped in 12 clusters. 5 clusters had 40, 11, 6, 5 and 3 varieties. 3 clusters comprised 2and 4 clusters had 1 variety each, suggesting that these 4 varieties were most diverged from others. Based on clusters means, leaf numbers, leaf size, capsule size and opium yield were the major factors of differentiation among varieties under study. Intercluster D² value range from 156.87 to 510001.5 suggesting very little domestication. Most of indigenous cultivars were grouped in cluster first. Intracluster distance ranged from 43.9-141.8. They concluded that exotic cultivars had
ample potential towards the enhancement of capsule size, leaf number, leaf size and capsule number.

**Lal et al. (1996)** estimated genetic divergence (D^2) for 19 opium populations based on 8 yield component characters under two environments. The populations were grouped into 5 clusters. Plant height was reported to be strongly and positively correlated with peduncle length and latex yield and negatively correlated with capsule index. The association between flowering time and plant height had highest coheritability value (4.89) followed by the association between capsule index and morphine content.

**Bhandri et al. (1997a)** analyzed genetic divergence among 18 advanced selections which were grouped into 5 clusters comprising 9,4,2,2, and 1 genotypes. Latex yield, capsule husk yield, seed yield, capsule breadth were major contributors to D^2 values. On the basis of wide diversity and highest contributing characters the crosses IC88 x IC85, IC88 x IC30, IC88 x IC42, IC128 x IC85, IC128 x IC30 and IC128 x IC42 were identified for high level of manifestation of heterosis and production of desired recombinants.

**Singh et al. (1998b)** studied genetic divergence for fatty acid in 30 genetic stock of opium poppy comprising 5 varieties of P.somniferum, one variety in of P.setigerum and 24 F8 genotypes derived from an interspecific cross between P.somniferum (2n=22) and P.setigerum (2n=44). All genotypes were grouped into 13 clusters. The intracluster distance was largest from IX to XII having single genotype. Intercluster distance was largest between XI and XIII (1042.21) followed by VIII and IX(722.6) and XI and XIII(634.04). The clustering pattern was much influenced by parentage. The F8 genotypes had wider diversity among themselves and tended to resemble *P.somniferum*.
Tiwari et al. (2001) studied the extent of genetic divergence among 21 genotypes which were grouped into 8 clusters. The cluster I and II contains 5 genotypes, III have 4 genotypes, IV and V have 2 genotypes, and cluster VI, VII and VIII had only one genotypes each. The intra-cluster distance ranged from 1.99 (cluster V) to 8.36 (cluster II) where as inter-cluster distance ranged from 11.52 (cluster III and VI) to 48.94 (III and V) with maximum value between III and V (48.94) followed by III and VIII (48.69). The genotypes included in cluster VI had the highest seed yield/plant, capsule dry weight/plant and peduncle dry weight.

Singh et al. (2003a) studied genetic divergence following multivariate and canonical analysis for ten characters including seed yield, opium yield and morphine percentage among 22 genotypes developed through intra-specific hybridization. The genotypes were grouped into 6 clusters and confirmed by canonical analysis. Fifty percent genotypes (11) were grouped in two clusters (I, IV) and apparent diversity was noticed for half of the genotypes, that diverged into rest four clusters (II, III, V, VI). Intracluster distance ranged from 11.75 to 67.31. The maximum intercluster distance was between III and V (178.03) followed by I and III (164.063), II and III (136.81) and III and IV (120.04). Cluster III was unique having high mean for most of the component traits. Cluster II had highest morphine content (17.07%) and plant height (115.62+-1.91cm) while cluster VI had genotypes with maximum opium yield (0.25+-0.01g) and capsule size (15.15+-0.12cm).

Singh et al. (2004a) evaluated 101 germplasm lines of different ecogeographical origin of country to find out genetic divergence for seed yield/plant, opium yield/plant and its 8 components traits. They found that all the genotypes were grouped in 13 clusters. Out of
101, 69 genotypes were close to each other and grouped in six clusters (II, III, IV, V, VIII, XII) while apparent diversity was noticed among 32 genotypes who diverged into rest 7 clusters (I, VI, VII, IX, X, XI, XII). Intercluster distance ranged from 47.28 to 234.55 maximum between cluster IX and X (234.55) followed by VII and IX (208.30) and IX and XI (205.53).

Shukla and Singh (2004b) studied genetic divergence among 27 parents (24 female and 3 pollinators) along with their 72 hybrids developed through x line tester cross. They reported that all the 27 parents were grouped in 8 clusters exhibiting no parallelism between genetic divergence and geographical origin of parents. Intercluster III and VI (102.05) followed by IV and VI (93.92) and VII and VIII (73.42). Maximum intracluster distance was reported in cluster IV (13.67) followed by III (12.07) and II (10.35).

Yadav et al. (2007) studied the genetic divergence in 110 population (20 parents and 90 F-1 hybrids) of opium poppy was studied by multivariate analysis. All the entries were grouped in 14 clusters. Out of 20 parents, ten were accumulated in one cluster and rest 10 distributed over seven clusters. Estimates of cluster distance showed that maximum intra-cluster distance was in -cluster IX (25.62) followed by cluster I (22.41), V (22.23) and IV (21.06). The inter cluster distances varied from 16.62 (between cluster XII and XIV) to 195.10 (between cluster IV and IX). The cluster analysis indicated substantial diversity among the parental genotypes, which had the potential to release considerable variation in their crosses. The first four principal components (PCs) with eigen values > 1 accounted for 68% of variation among the population. The first and second components could account for 29 and 20% of the total morphological and alkaloidal variations,
respectively. The PC1 was closely related to yield and yield related traits. The characters contributing greatest positive weight on PC1 were opium yield, plant height, stem diameter, capsule weight/plant and seed yield/plant. The possibilities of relationship between genetic divergence, F-1 performance, heterosis and GCA of parents have been explored.

Shukla et al. (2010) studied diversity of alkaloid spectrum of 122 opium poppy accessions of Indian origin by means of a cluster analysis based on Mahalanobis generalised distances. The accessions were grouped into 11 clusters according to their relationship between the contents of morphine, codeine, thebaine, narcotine and papaverine in raw opium. The diversity of the alkaloid spectrum of 11 clusters reflected the very low correlations between the contents of the individual alkaloids across the 122 entries, found earlier. The clusters represented almost all possible combinations of the high content of an alkaloid with high or low content of another alkaloid. Although on average the morphine content exceeds the sum of the other four alkaloids, in one cluster the narcotine content (15.3%) was even higher than that of morphine (14.6%) and the content of the remaining alkaloids was also extremely high. The variation range among the clusters was for papaverine between 0.14% to 5.3%, while for morphine between 12.4% to 18.0%.

HERITABILITY AND GENETIC ADVANCE:

Shukla and Khanna (1995) estimated narrow sense heritability for opium yield and morphine content in F₁ and f₂ generations developed through 10 parent full diallel.
They reported high heritability (38.78% in F₁ and 44.64% in F₂) for morphine content and low (22.11% in F₁ and 12.08% in F₂) for opium weight.

**Bhandari et al. (1997b)** reported high heritability for capsule breadth (79.40%) and capsule numbers (67.60%) and low for morphine content (32.70%), seed yield (32.10%) and latex yield (28.60%).

**Toth et al. (1997)** studied inheritance of codeine content using five parent diallel and reported low heritability for codeine content.

**Lal and Sharma (1999)** estimated high heritability for plant height (59.26-67.09%), moderate for days to 50% flowering (35.80-36.09%) and low for capsules/plant, straw yield/plant and seed yield/plant (4.26-20.39%) respectively.

**Singh et al. (1999e)** reported high heritability for plant height (71.80%), capsules/plant (60.10%) and straw yield/plant (61.80%) and medium for seed yield/plant (45.30%) and low for peduncle length (39.50%).

**Pant et al (1999b)** reported high heritability for seed yield, straw yield, flowering time, maturity time and plant height in two populations except seed yield in population 1.

**Saini et al. (1999)** evaluated 75 indigenous and exotic genotypes for different quantitative traits and reported high heritability for leaf size, leaf numbers, capsule size and husk yield. They recommended that for selection of high yielding genotypes these traits should be given due weightage.
Singh et al. (1999b) studied inheritance of yield components and reported high narrow sense heritability for capsules/plant and morphine content. They found narrow sense heritability to the extent of 6, 8, 21 and 31 percent for straw yield/plant, seed yield/plant, morphine and capsules/plant respectively.

Tiwari et al. (2000) observed high heritability estimates for capsules weight/plant (99.49%), peduncle length (98.00%), seed yield/plant (97.50%) and plant height (72.20%).

Singh et al. (2000) reported high heritability coupled with high genetic advance for latex yield/plant and plant height.

Singh et al. (2002) carried out genetic study on seven economic traits and reported that the broad sense heritability ranged from 52.56-88% with highest value recorded for morphine.

Singh et al. (2003b) reported high heritability in broad sense, ranging from 61.80 - 85.50 percent among 10 characters including opium yield and seed yield. Genetic advance in the percentage of mean was variable from 10.77 - 37.19%, maximum being for capsules/plant followed by opium yield/plant, capsule weight/plant and seed yield/plant. High heritability coupled with high genetic advance was observed for capsule weight/plant, opium yield/plant, capsules/plant and seed yield/plant while high heritability with low genetic advance or vice versa was noticed for plant height, stem diameter, capsule size, husk yield and morphine content.
Singh et al. (2004) reported high heritability in a group of 101 germplasm lines of different ecogeographical origin for all the characters except capsules/plant. High heritability coupled with high genetic advance was noticed for capsule weight/plant, capsule area, husk yield/plant, seed yield/plant, opium yield/plant and leaves/plant.

Yadav et al. (2008) reported high heritability in broad sense for capsule weight/plant, stem diameter and opium yield in a group of 22 strains of opium poppy.

Mishra et al. (2010) examined the genetic gain and heritability for 5 quantitative traits in different generations of opium poppy (Papaver somniferum L.) during 2003-08. They found that for the formulation of effective selection strategy in opium poppy (P somniferum L.), cyclical process of testing selections, discarding inferior genotypes and retesting the superior selections, i.e. multistage testing is an essential step for its evaluation. The progenies of randomly selected individuals from 14 promising hybrids were evaluated over F2 to F6 generations for opium and seed yield and their contributing traits, viz capsules/plant, capsule size (cm²), seed yield/plant (g), opium yield/plant (mg) and morphine content. In general heritability and genetic gain declined from generation to generation. A cross between 'MOP 541' x 'BR 241' showed similar pattern for genetic gain in all the traits. The values of broad sense heritability decreased from F2 to F6 generation for most of the traits.

Combining ability:

The concept of combining ability was first proposed by Sprague and Tatum (1942). They recognized two classes of comning ability i.e. general combining ability and
specific combining ability. They defined the general combining ability (gca) as an average performance of a line in hybrid combinations, while and specific combining ability (sca) was referred to those cases in which certain cross combinations do relatively better or worse than would be expected on the basis of the average performance of lines involved. They further explained that general combining ability was primarily due to additive genetic variance and additive x additive interaction variance, where as specific combining ability is due to non-additive genetic portion arising from dominance and epistatic deviation.

**Henderson (1952)** defined general combing ability as the average merit of a line with resoect to some traits or weighted combinations of traits of large number of progenies of an individual or line when mated with a random sample from some specified population under a specific set of environment circumstances. He defined and specific combining ability as the deviation of an average of an indefinitely large number of progenies of two individuals or lines from the values which would be expected on the basis of the known general combining ability of these two lines or individuals and maternal ability of the female parent.

**Griffing (1956a)** pointed out that general combining ability involved both additive effects as well as additive x additive interactions. Sprauge (1966) and Gilbert (1967) also agreed with above findings. Hayman (1957) reported that in absence of epistasis, gca comprises both additive and dominance portions while sca involves only dominance.
Kempthorne (1957) precisely gave the explanation of general and specific combining ability variances in terms of covariance of half sib (H.S.) and full sib (F.S.) in random mating population where $\delta^2_{gca-cov}(H.S.)$ and $\delta^2_{sca} = cov (F.S.) - 2cov (H.S.)$. Moll et al. (1960) pointed out that the magnitude of gene action based on combining ability variance is not much reliable due to serious bias from genotype and environmental interaction.

The review works on combining ability in opium poppy are as follows:

Saini et al. (1985) evaluated 50 F1s and 50 F2s developed through 10 exotic lines x five indigenous testers for combining ability for seed yield. They reported that non-additive genetic variance was predominant in the inheritance of seed yield. They identified four best crosses i.e. EC11547 x DCG, DC11538 x KP, EC11556 x KD and EC11511 x Hariana on the basis of sca and per se performance.

Saini et al. (1986) studied combining ability for opium yield in 10 exotic and 10 indigenous parents under line x tester programme over different environments and reported that additive variance was high in F1 of the first year while non-additive genetic variance was preponderant in both F1 and F2 generation of the second year. EC11569, EC11571 and DCG were reported as good general combiners and highest opium yielders. The cross combinations EC 11538 x DCG, EC11551 x Katala dandi and EC11569 x Kalidandi showed high estimates of sca.
Khanna and Shukla (1989) reported additive effect was most dominant for all the traits except days to flowering, dry weight/plant, opium weight/plant and seed weight/plant.

Lal and Sharma (1990) studied different parameters of combing ability by 6 x 6 parent diallel and reported parent IS-18 followed by SPS-32 was most desirable for seed yield and IS-19 for opium yield as they manifested high mean, desirable gca with low sca variance. The parent SPS-24 was identified to be good combiner for opium alkaloids.

Mishra and Barche (1991) studied combining ability among six parent diallel and reported significant differences for latex yield and non significant for days to 50% flowering, plant height and capsules/plant. The cross Dhatura x Golania and Telia x Gulabia gave highest yield.

Kandalkar et al. (1992) studied combining ability for eight yield related components traits in F₁ and F₂ generation of an eight parent half diallel. They observed that both additive and non-additive gene actions were significant in the expression of all the characters. Non-additive gene action was predominant for capsules/plant, capsule weight/plant, leaves/plant and seed yield/plant in F₁ generation. However, additive gene action was reported for harvest index, husk yield and capsule diameter in both F₁ and F₂ generations and capsule weight/plant in F₂ generation.

Saini (1992) studied combining ability for capsule size and capsules/plant and noticed the crosses Ec11540 x DCG and EC11552 x KD as best specific combiners for both the traits.
Shukla and Khanna (1992) studied genetic variance and combining ability for ten parental lines involved in diallel crossing programme. They noticed that non-additive gene action was predominant for all the traits. The parent Br29 was the best general combiner for days to flowering and days to maturity. They identified Gz x Kalidandi Baunia and Gz x BR9 for days to flowering and Kalidandi Baunia x BR9 for days to maturity were best cross combinations.

Kandalkar and Nigam (1993) studied combing ability for opium yield and yield component reported both additive and non-additive genetic components of variances. Additive gene action was reported for days to flowering, leaf area, biological yield, number of effective lancing and harvest index in both F1 and F2 except leaf area in F1 generation. MOP 539 for opium yield, harvest index, days to flowering, leaf area and leaf area index, MOP 507 for opium yield, biological yield, NBPGRI for opium yield and early flowering and MOP4 for harvest index were reported as good general combiners.

Singh et al. (1995) studied combining ability for 11 yield component traits and found that variances due to gca and sca were significant for all the traits indicating importance of both additive and non-additive gene actions. They noticed that the parent IC30 in F1 and Br76 in F2 were the best general combiners for seed yield/plant. They also reported that crosses having significant sca effect involved high x high, high x low and low x low general combiners.

Shukla and Khanna (1997) estimated combing ability variances separately for F1 and F2 generations obtained from 10 x 10 parent full diallel. The variances due to gca, sca and rec effects were highly significant for all the traits in both the generations except
stem diameter in F2 for gca, capsule size in F2 for the reciprocal effects, indicates the importance of both additive and non-additive gene actions. The best specific crosses for opium yield were Te x DCG followed by No. 74 x DCG and M-11 x DCG in F1 and Gz x KDB followed by Gz x Te and KD x KDB in F2. the crosses with high sea effects were involved in majority of cases, both good or one being good and other being a poor general combiner and in some cases both poor combiners.

**Pant et al. (1999)** evaluated 60 hybrids developed from 30 lines and 2 testers in line x tester mating design. They reported that the lines IS9, P46, P45, Mass-2B for plant height, IS9, P45, G24, P46 and Shyama for straw yield were good general combiners.

**Singh (1998)** estimated combining ability of eight genotypes involved in diallel cross. He reported that gca and sea variances were significant for all the traits indicating importance of both additive and non-additive gene actions. The parent AP2 was found best general combiner. He further reported that the best cross combinations for seed yield involved high x high and low x low general combiners. AP2 x AP8 and AP2 x AP7 were best combinations for seed yield.

**Singh (2000)** evaluated 28F1 hybrids along with their eight parents for combining ability and observed AP8 and AP11 as good combiners for all the traits except capsules/plant. AP3 was good combiners for days to maturity and AP4 for plant height.

**Singh et al. (2001)** reported non-additive gene action for plant height, capsule length, days to maturity, peduncle length, husk yield, seed yield and morphine content and additive gene action for peduncle weight. They suggested heterosis breeding will
most suitable for effective improvement in opium poppy. They found AP5, AP6 and AP10 from lines and AP13 from testers as good combiners.

**Shukla and Singh (2004)** studied combing ability among 72F1 and F2 developed by crossing 24 lines with 3 testers in line x tester manner. They reported that among tester Gz was good general combiner for seed and husk yield in both the generations. Among lines IS11, IS12 and IS13 in F1 and IS 9, IS17 and IS 18 in F2 were good general combiners for opium yield. IS4 x NB5, IS6 x Gz, IS-17 x NB5, IS22 x NB6 and IS23 x NB6 in F2 were the best specific cross combinations for opium yield.

**Yadav et al. (2005)** reported non-additive gene action for yield (opium/seed) and its component traits studied through 20 parent fractional diallel analysis. Br 226 and Br 241 reported as good general combiner for seed yield/plant, opium yield/plant and capsule weight/plant.

**Yadav et al. (2009a)** studied the combining abilities for yield, its component traits and morphine content in opium poppy to understand the inheritance pattern of these traits, and to identify genotypes suitable for genetic improvement of yield and morphine content. The experiment comprising a total of 64 treatments (28 F-1 + 28 F-2 and parents) was evaluated in RBD. The results showed that most of the traits are governed by non additive gene action however additive gene action is also important. The parents BR-232, BR-245, BR-234 were found to be good general combiners for yield and its related traits and can be utilized in multiple breeding programs SCA effects in relation to GCA effects of parents showed that most of the cross combinations with high SCA effects involved high x high, high x low and low x low GCA combiners.
Yadav et al. (2009b) analyzed the F₁ and F₂ generations of a twenty parent fractional diallel cross of opium poppy (P. somniferum L.) for combining ability for ten quantitative and five quality (alkaloids) traits. The results indicated significant differences among the parents for combining ability for all the traits. The GCA and SCA components of variances were significant for all the characters. However, the SCA component of variance (delta²'s) was predominant indicating the preponderance of non-additive gene effect for all the traits except for leaves/plant and papaverine in F₁ hybrids. The average degree of dominance (delta (2)s/delta (2)g) was more than unity indicating over dominance and also confirming non-additive mode of gene action. Among the parents IS-16, IS-13 and NBRI-1 for early flowering, BR226 and BR241 for branches/plant, capsule weight/plant, seed yield/plant and husk yield/plant, BR227 for leaves/plant, UO1285 for capsule size and opium yield/plant, NBRI-5 for husk yield/plant, morphine, codeine, and thebaine and 'Papline' for plant height and papaverine content were found good general combiners. Parent ND1001 was good combiner for codeine and narcotine content. Inclusion of good general combiners in a multiple crossing program or an intermating population involving all the possible crosses among them subjected to bi-parental mating may be expected to offer maximum promise in breeding for higher opium, seed yield and alkaloid contents.