2. REVIEW OF LITERATURE

The relevant literature pertaining to the different aspects of the present investigation has been reviewed under the following heads:

2.1 Generation mean analysis

2.1.1 Genic effects based on trigenic interaction model

2.1.2 Genic effects based on digenic interaction model

2.1.3 Genic effects based on biometrical approaches other than generation mean analysis

2.2 Heterosis

2.1 Generation mean analysis

The knowledge of nature of gene action, the magnitude and relative importance of additive, dominance and epistatic genetic components of variance controlling various quantitative and qualitative characters is of paramount importance in determining the efficient breeding methodology and in accelerating the pace of genetic improvement.

The choice of plant breeding methodology for upgrading the yield potential largely depends on the availability of reliable information on the nature and magnitude of gene effects present in the population. Diallel and line × tester analysis, although effective and widely used, does not provide estimates of non-allelic interactions. Significant epistatic variation clearly indicates the role of epistatic gene action besides additive and dominance types, which play a major role in the expression of heterotic potential (Jinks 1955; Hayman 1958; Brim and Cockerham 1961; Gamble 1962; Hill 1966; Matinzinger 1968; Stuber and Moll 1974).

The presence or absence of epistasis can be detected by the analysis of generation means using the scaling tests, hence enables the gene action to be analysed cross-wise and provide precise information on the main gene effects (additive and dominance), their digenic [additive × additive (i), additive × dominance (j),
dominance × dominance (l), trigenic [additive × additive × additive (w), additive × additive × dominance (x), additive × dominance × dominance (y) and dominance × dominance × dominance (z)] and other higher order interactions which helps in understanding the performance of the parents used in crosses and the potential of crosses for heterosis exploitation or pedigree selection (Dvojkovic et al. 2010).

2.1.1 Genic effects based on trigenic interaction model

The information on the use of generation mean analysis for higher order interactions in pea is meager therefore, the relevant literature from other crops also reviewed along with pea as under:

Jangpo (1986) evaluated 16-18 generations of three pea crosses for estimation of non-allelic interactions and detection of various genic effects up to the level of trigenic [additive × additive × additive (w), additive × additive × dominance (x), additive × dominance × dominance (y) and dominance × dominance × dominance (z)] interactions and reported the inadequacy of trigenic model for various traits namely, seed yield per plant, pods per plants, seeds per pod, days to flowering and plant height in most of the crosses under study, which indicated the probable presence of linkage among interacting genes or higher order of interactions at four or more gene loci. Further, duplicate type of epistasis was also found in majority of the traits namely, seeds yield per plant, pods per plant, seeds per pod, days to flowering and days to maturity.

Joshi and Ugale (2002) evaluated eleven generations of three cross combinations of pearl millet to study the inheritance of downy mildew resistance. Most of the digenic and trigenic non-allelic interactions along with the main genic effects were found to be significant in all the crosses for both the disease traits namely, severity and prevalence. Duplicate type of epistasis for cross I and complementary epistasis for cross II and III were observed for both the disease traits revealed the consistency of gene effects over the crosses.

Sharma and Sain (2002) studied the inheritance of peduncle length from twelve generations of three inter-varietal crosses of durum wheat by using generation mean analysis and reported the adequacy of ten-parameter model for all the three crosses. Among non-allelic interactions, both digenic and trigenic interactions were
found significant in controlling the inheritance of this trait with preponderance of latter. Non-fixable gene effects were noticed to be higher than the fixable which indicated the greater role of non-additive gene effects and suggested to follow reciprocal recurrent selection or the biparental mating between selected plants from early segregating generations to improve the characters.

Sharma et al. (2002) observed the role of epistatic interactions in the inheritance of days to heading, days to maturity and plant height in durum wheat. The trigenic interaction model was found to be adequate for all the traits except for plant height which indicated its greater role than the digenic interactions. Among the trigenic interactions, additive × dominance × dominance (y) was found to be important in controlling days to heading whereas, additive × additive × dominance (x) and dominance × dominance × dominance (z) were important in governing the inheritance of days to maturity and plant height.

Sharma and Sain (2004) evaluated twelve generations of three crosses of wheat to determine the nature and magnitude of gene action governing the inheritance of grains per spike and reported the inadequacy of trigenic model, which indicated the more complex interactions or linkage involved in the inheritance of this trait. Further, duplicate type of epistasis was observed for grains per spike.

Shekhawat et al. (2006) with the help of generation mean analysis studied the inheritance of grain yield and tillers per plant in wheat from twelve generations of two crosses and reported the inadequacy of ten-parameter model for the inheritance of aforesaid traits which indicated the presence of higher order interactions. Dominance and epistatic effects were found predominant. They further reported that to utilize non-fixable gene effects, breeding methods involving reciprocal recurrent selection or biparental mating would be employed for their improvement.

2.1.2 Genic effects based on digenic interaction model

The information on generation mean analysis on six parameters is reviewed here under:

Singh and Joshi (1982) observed epistasis in four crosses for pods per plant, two crosses for pod length and seeds per pods and all five crosses for seed yield. The
additive gene effect was more important for pods per plant and seeds per pod in majority of the crosses though there was some variation for some of the crosses. They also found varied behavior of gene action for seed yield in different five crosses. The additive gene action was significant for all the crosses and the magnitude was as wide as the component of dominance gene action. The dominance gene action was significant only for two crosses. The additive × additive and additive × dominance interactions were significant for three and two cross combinations, respectively. The complementary type of epistasis was also reported for only one cross.

Singh et al. (1987) revealed that additive gene action was more important than dominance gene action for plant height, but dominance gene action was highly pronounced for grain yield, though there was some cross variation. Additive × additive gene action (i) was significant in crosses ‘Flavanda × P29’ and ‘Rachna × UFA 75’, while both additive × dominance (l) and dominance × dominance (l) gene actions were significant in crosses ‘Rachna × HFP4’. Two crosses expressed duplicate epistasis, while complementary epistasis was noticed for only one cross. Singh and Singh (1991) noticed that yield and pods per plant were generally controlled by dominance gene effects but in some crosses, these traits were also controlled by additive as well epistatic gene effects.

Singh and Singh (1996) reported the importance of non-additive gene effects for the inheritance of grain yield and protein content. The three- parameter model was adequate for grain yield in five crosses. Amongst the interacting crosses, significant additive and dominance components in crosses ‘Multifreezer × P209’ and ‘Multifreezer × HUP4’, dominance and additive × additive components in ‘Multifreezer × Rachna’ and additive × dominance and dominance × dominance in ‘T76 × Rachna’ were noticed for grain yield. Duplicate type of epistasis was noticed for protein content in most of the crosses except ‘HUP4 × Rachna’.

Narayan et al. (1998) revealed the inadequacy of additive-dominance model for pod yield per plant, pod length, total sugars, shelling percentage and protein content for majority of the crosses except ‘Lincoln × Solan Nirog’ for protein content. They found the predominance of additive gene action for pod yield per plant in four crosses, protein content only in one cross, shelling percentage in three crosses and
total sugars in two crosses, while the other crosses showed the preponderance of dominance gene action. The digenic epistatic effect of additive × additive, additive × dominance and dominance × dominance were significant for all the characters in one or more than one cross. The duplicate type of interaction was also noticed for pod yield per plant, pod length, seeds per pod and pods per plant.

Kumar et al. (2001) construed that simple additive-dominance model was inadequate, indicating the importance of non-allelic interactions in the genetic control of pods per plant, pod length, seeds per pod, days to flowering and shelling percentage in three crosses viz., ‘JP71 × VL-3’, ‘JP71 × NDVP-9’ and ‘JP71 × VL-3’. The dominance × dominance component was predominant in all the three crosses for majority of the characters. Narayan et al. (2001) found additive effect for total sugars and protein content for most of the four crosses except ‘Bonneville × Kinnauri’ for protein and ‘VL-3 × Kinnauri’ for total sugars. Dominance component was significant for pod yield and shelling percentage in all four crosses. Epistasis was noticed for all the characters. Both duplicate and complementary types of epistasis were observed in one or the other cross.

Sharma and Rastogi (2001) revealed that the magnitude of dominance gene action was more than additive gene effects for plant height, though both were significant along with the presence of duplicate type of epistasis. For days to 50 per cent flowering, majority of the crosses exhibited complementary gene action coupled with additive and additive × additive gene effects. Singh and Sharma (2001) reported the inadequacy of the additive-dominance model for three crosses each for plant height, pods per plant, seeds per pod, pod length and pod yield per plant. The epistatic interaction showed additive gene effects in two crosses each for plant height, pods per plant, seeds per pod and pod yield per plant. In general, all the crosses revealed dominance gene effect with higher magnitude for plant height, pods per plant, seeds per pod, pod length and pod yield per plant along with the presence of duplicate type of epistasis. The dominance × dominance (l) interaction was usually higher with negative sign indicating their reducing effects in the expression of almost all these characters.
Tyagi and Srivastava (2001a) noticed the presence of additive and dominance gene effects along with epistatic interaction in almost all twelve pea crosses indicating the importance of additive and non-additive gene action in the expression of days to maturity, plant height, pods per plant, seeds per pod and yield per plant. Additive gene action was more important for days to flowering, days to maturity and seeds per pods while, dominance × dominance (l) for pods per plants and both (i) and (l) genic interactions for plant height were pre-dominant in majority of the crosses. All the crosses revealed duplicate type of epistasis. Further, Tyagi and Srivastava (2001b), in another study, observed that joint scaling test was found to be more efficient in detection of epistasis. Both additive and non-additive gene actions were important in the expression of different characters. However, fixable gene effects i.e. additive × additive (i) contributed significantly in the inheritance of days to flowering, days to maturity and seeds per pod, while dominance × dominance (l) mainly governed the inheritance of pods per plant. Both (i) and (l) type of interactions were important in the inheritance of plant height and seed yield. Duplicate type of epistasis was prevalent in most of the cases.

Bhardwaj et al. (2002) revealed the inadequacy of additive-dominance model for days to flowering, plant height, pod length, pods per plant, yield per plant, shelling percentage, seeds per pod and sugar content. All the characters showed the significance of additive, dominance and epistatic components. However, high proportion of dominance effects with significant dominance × dominance interaction was observed for all the characters. The presence of duplicate type of epistasis along with a positive sign of additive × additive type of gene action for days to flowering, shelling percentage, sugar content, pod length, pods per plant, seeds per pod and yield per plant indicated the possibility of getting transgressive segregants in later generations by resorting to selection.

Kaur et al. (2003a) showed the prevalence of epistasis for most of the economic characters viz., marketable maturity, green pod yield, pods per plant, shelling percentage and plant height except days to marketable maturity in ‘Punjab-87 × JP-501 A/2’. The digenic epistatic model showed the variation for pods per plant, shelling percentage and plant height in both ‘Matar Ageta-6 × JP-179’ and ‘Punjab-87 × JP-501 A/2’. In addition, they also found that higher order interactions were present
for days to marketable maturity, green pod yield per plant and shelling percentage in ‘Matar Ageta-6 × JP-179’ and for plant height in the other cross.

Bhardwaj and Vikram (2004) studied the genetics of yield components in garden pea cross ‘Ageta-6 × DRP-3’ and revealed the presence of additive, dominance and epistatic components for the control of most of the characters studied. The presence of duplicate epistasis along with positive sign of additive × additive (i) type of gene action for days to 50 per cent flowering, pod length, number of pods per plant, shelling percentage and number of seeds per pod indicated the possibility of getting transgressive segregants in later generations by resorting to selection.

Singh et al. (2005) observed the predominance of additive gene effects in one and two crosses for green pod yield per plant and protein content, respectively out of 15 crosses. Overall, dominance gene action had predominance in 14 crosses for green pod yield and in four crosses for protein content. The predominance of additive effect for green pod yield and protein content was observed in ‘Azad P2 × KS 149’ and ‘Azad P1 × KS 136’ and ‘KS 136 × Arkel’, respectively. The majority of crosses were characterized by the predominance of digenic interactions in the desirable direction, though additive × additive (i) component was also important and in desirable direction for green pod yield. This suggested that selection for green pod yield would be more beneficial in later generations, when dominance variation is reduced due to selfing.

Dixit et al. (2006) found digenic interaction in all the three crosses for most of the characters studied. The dominance component was mostly higher in magnitude than additive component for seeds per pod, pod length and pods per plant in majority of the crosses. Plant height had significant additive variance in desirable direction in two crosses. Duplicate type of epistasis was prevalent for days to 50 per cent flowering, plant height, seeds per pod and pod length in the crosses ‘DDR23 × IPF27’ and ‘IPF14 × HUDP16’, which decreases the variation in F2 and subsequent generations and will also hinder the pace of progress through selection. In this situation, reciprocal recurrent selection is likely to be useful and increase variability in later generations for effective selection by maintaining considerable heterozygosity through mating selected plants in early segregating generations.
Narayan (2006) observed significance of additive or dominance gene effects along with ‘i’, ‘j’ or ‘l’ type of epistasis in most of the crosses for pod yield per plant, shelling percentage, total sugars and protein content. Higher magnitude of dominance component along with interaction effects may be utilized for heterosis breeding or recurrent selections followed by pedigree methods for further improvement of these populations. Singh et al. (2006) observed that all three types of gene action (additive, dominance and epistasis) played a role in the inheritance of days to flower initiation, pods per plant, pod length, grains per pod, shelling percentage, plant height, crude protein and total sugars in crosses namely, ‘Arkel × Matar Ageta-6’ and ‘Matar Ageta-6 × Bonneville’. Duplicate type of epistasis was observed for most of the characters.

Punia et al. (2011) reported the inadequacy of additive-dominance model for days to flowering, days to maturity, plant height, pods per plant and seeds per pod. Generation mean analysis indicated the importance of dominance and epistatic gene interactions in the inheritance of all the traits. Additive × additive (i) and dominance × dominance (l) digenic interactions were important as compared to additive × dominance (j) for seed yield and its component traits. Duplicate type of epistasis played a greater role in the inheritance of days to flowering, days to maturity, plant height, pods per plant and seeds per pod and suggested selection in the later segregating generations to improve these traits.

Sharma et al. (2012) observed the presence of epistatic interaction for majority of the traits namely, days to 50 per cent flowering, days to first picking, pod length, shelling percentage, plant height, pods per plant and pod yield per plant in the cross combinations viz., ‘Green Pearl × Sugar Giant’, ‘DPP 9411 × DPP 9418-06’ and ‘Azad P-1 × Sugar Giant’. The results revealed that the nature and magnitude of gene effects differed in different crosses and showed the importance of additive as well non-additive gene effects in the inheritance of different characters with preponderance of latter. In view of parallel role of additive and non-additive gene effects, selection in the segregating generations should be delayed to later generations to diminish the dominance gene effects. Duplicate type of epistasis was observed for shelling percentage, plant height, pods per plant, pod yield per plant, powdery mildew disease incidence, total sugars, protein content and ascorbic acid. Sanwal et al. (2013)
revealed the importance of both additive and non-additive gene actions in the inheritance of powdery mildew disease resistance including non-allelic interactions. In view of the parallel role of additive and non-additive gene effects, it is suggested that selection in segregating generation should be delayed to diminish the dominance gene effects. Duplicate type of epistasis was detected for all the three pathological characters in all the crosses.

Sharma et al. (2013) reported that majority of the crosses exhibited non-allelic interaction due to the inadequacy of simple scaling test. They noticed the presence of additive gene action for the inheritance of plant height, pod length, pods per plant and pod yield in the cross ‘Palam Priya × Sugar Giant’. In cross ‘VRPMR-10 × Sugar Giant’, additive gene effects found to be in desirable direction for seeds per pod, plant height and pod yield. The preponderance of additive gene action in these crosses suggested that selection should be done in the early generations for obtaining transgressive segregants. They also reported duplicate type of epistasis for pod yield, seeds per pod, shelling percentage, pods per plant and powdery mildew disease incidence in cross ‘Green Pearl × DPP-9411’.

Kosev (2015) evaluated six generations each in two crosses viz., ‘Shtambovii × Pleven 10’ and ‘Pleven 10 × Shtambovii’ and revealed significant but negative additive (d), dominance (h) and additive × additive (i) gene interactions for number of pods per plant, number of seeds per plant and seed weight per plant whereas, additive × dominance (j) was found to be positively significant for the same traits.

2.1.3 Genic effects based on biometrical approaches other than generation mean analysis

The genetic variance estimates for various traits in garden pea by following biometrical approaches other than generation mean analysis have been reviewed as follows:

Rybinkova (1982) from a 4 × 4 diallel cross observed overdominance for plant height, pod length, seeds per pod and seed weight. Singh et al. (1985) from a ten parental diallel mating design recorded both additive and non-additive genetic variances for days to flowering, plant height, branches per plant, pods per plant, seeds per pod, pod length, days to maturity and seed yield per plant in both F1 and F2
generations. From a $10 \times 10$ diallel analysis, Singh et al. (1986) reported significance of both additive and non-additive genetic variances for pods per plant, seeds per pod, seed yield per plant and protein content. Additive gene action and partial to complete dominance were important for pods per plant and seeds per pod.

Sharma et al. (1999) by following line $(10) \times$ tester $(2)$ analysis reported the predominant role of non-additive gene action for pod yield, pods per plant, days to pod maturity and shelling percentage. Vikas and Singh (1999) observed additive and non-additive type of gene action for days to 50 per cent flowering. From a ten parent half diallel analysis, Kalia and Sharma (2000) observed that dominance component was of higher magnitude for total soluble solids, protein content and ascorbic acid alongwith powdery mildew incidence.

Singh and Sharma (2001) from eight parental diallel mating analysis, found dominance gene effects for plant height, pods per plant, seeds per pod, pod length and pod yield per plant. Singh et al. (2001) found that general combining ability (GCA) and specific combining ability (SCA) variances were highly significant with the predominance of SCA variances for days to flowering, days to maturity, plant height, branches per plant, pods per plant, pod length and yield per plant.

Kumar and Jain (2002) reported that GCA effects were higher than SCA for pod length, seeds per pods, pods per plant, pod yield per plant and days to 50 per cent flowering. Sharma and Kalia (2002) found the predominance of non-additive genetic variance for pod yield per plant, pods per plant, pod length, seeds per pod, shelling percentage and total soluble solids from ten parental half-diallel analysis. Dixit (2003) by using line $\times$ tester analysis revealed that non-additive gene action was predominant for plant height, pods per plant, seeds per pod and yield per plant, though additive component was also significant. Kumar and Tewatia (2003) by following line $\times$ tester analysis indicated the predominance of non-additive gene action in the inheritance of yield, pods per plant, pod weight, days to first picking, edible grains per pod, pod length and shelling percentage.

Sharma et al. (2003) observed that both D and H components of genetic variance were significant for days to 50 per cent flowering and days to first picking with predominance of former in $F_1$ and latter in $F_2$. The estimates of heritability were
quite high for these traits. Singh and Singh (2003) from 10 × 10 diallel analysis reported that both additive and non-additive genetic variances were important for the inheritance of grain yield and its components. However, magnitude of non-additive components was higher than additive for most of the traits except days to flowering, days to maturity and protein content in both F₁ and F₂ generations. From graphical and component analysis in a 10 parental diallel mating design, Singh et al. (2003) advocated that both additive and non-additive components of genetic variation were important for earliness, while non-additive component along with epistasis was significant for green pod yield.

Singh and Dhillon (2004) by following ten parental diallel mating design revealed that additive gene effects were predominant for shelling percentage and total sugars, while non-additive gene effects were important for pod yield and crude protein. Sharma et al. (2004) by following line × tester analysis found that magnitude of dominance component was greater than the additive component. However, considerable additive variance was also noticed for plant height and seed yield per plant.

Ceyhan and Avci (2005) by following lines × tester analysis reported that the ratio of additive variance to dominance variance indicated the predominant role of non-additive gene action for all the characters under study viz., grain yield, plant height, branches per plant, pods per plant, seeds per pod, pod yield and 100-seed weight. Ranjan et al. (2005) from a seven parent diallel analysis observed the prevalence of both additive and non-additive variance for plant height and seeds per pod, while predominance of non-additive gene action was noticed for days to flowering, days to maturity, pods per plant and seed yield per plant.

Singh et al. (2005) from different sets of crosses involving six diverse parents noticed the predominance of non-additive variance in controlling the expression of days to flowering, days to maturity, plant height, pod length, pods per plant, seeds per pod and grain yield. Dhillon et al. (2006) reported that additive and non-additive gene effects governed the inheritance of all the characters studied. Additive gene effects were more pronounced for days to flower initiation, branches per plant, plant height, pods per plant, days to marketable maturity and shelling percentage whereas, the non-additive gene effects had the same magnitude for seeds per pod and pod yield per plant. Singh and Sharma (2006) from triple test cross analysis revealed the
significance of both additive and dominance components of variation for total soluble solids, ascorbic acid, protein content and powdery mildew incidence. However, additive component was more pronounced than dominance component for total soluble solids, protein content and powdery mildew incidence.

Sood and Kalia (2006) from a diallel set of eight parents observed the prevalence of overdominance for most of the traits in both the generations i.e. $F_1$ and $F_2$, except for seeds per pod and pod yield per plant in the $F_1$, and days to first picking and plant height in the $F_2$, where partial dominance was observed. However, days to 50 per cent flowering showed complete dominance in the $F_2$. Non-additive gene action appeared to be more predominant for the inheritance of most of the characters studied, although the additive component also made significant contribution except for pods per plant in the $F_2$. Dominant alleles were more frequent in parental lines for the inheritance of most of the characters except for seeds per pod in both generations and plant height in the $F_1$. Sharma et al. (2007) reported that both additive and non-additive gene action were of prime importance for days to flowering, days to first picking, pod length, seeds per pod, shelling percentage, plant height, pods per plant and pod yield per plant.

Thakur and Khosla (2008) studied seven parents in half-diallel set and reported that SCA and GCA were significant for all the characters. However, non-additive gene effects were found to play a major role in the inheritance of pod yield per plant, pods per plant, pod length and shelling percentage whereas, additive genes were found to control the inheritance of plant height, pod breadth and grains per pod. Brar et al. (2012) by following line (15) × tester (3) analysis, indicated the predominance of additive gene action for days to 50 per cent flowering, plant height, pod length, number of pods per plant, green pod yield, days taken to maturity and shelling percentage and suggested selections in early generations by following mass and simple recurrent selection.

Sharma and Sharma (2012) from diallel analysis reported the prevalence of over dominance for days to 50 per cent flowering, days to first picking, pod length, number of pods per plant, 100-pod weight and green pod yield per plant. However, additive and dominance genetic variance were highly significant for days to 50 per cent flowering and days to first harvest.
Esposito et al. (2013) reported that estimation of variance due to SCA and GCA effects and their relationship revealed the predominance of additive effects for all traits under study namely, numbers of pods, yield per plot, numbers of seeds per plot, 100-seed weight and numbers of days to flowering. Nassef and El-Rawy (2013) using 6 × 6 half diallel analysis revealed that both additive and non-additive effects were important in the control of branches per plant, pods per plant, green pods per plant, green pod weight per plant, total soluble solids, seeds per pod and ten pods weight with the predominant role of additive effects.

Punia et al. (2013) using twenty one hybrids generated by crossing seven diverse varieties of field pea in diallel mating design indicated the preponderance of non-additive gene action in the inheritance of days to flowering, days to maturity, number of pods per plant, number of seeds per pod and yield per plant. Thiyam et al. (2013) by following half diallel analysis involving eleven parents revealed the importance of both additive and non-additive gene effects for all the traits with preponderance of non-additive gene effects for days to first picking, pods per plant, pod length, seeds per pod and yield per plant while, additive gene effects found important for days to 50 per cent flowering and plant height. High general combiners for seed yield may be included in recombination breeding to produce desirable segregants for developing high yielding and acidic soil tolerant varieties of pea.

From a four parental full-diallel analysis, Kosev (2014) reported that overdominance was prevalent for plant height, first pod height, pod numbers per plant, seeds per plant, seeds per pod, nodes per plant, inter-nodal distance, seed weight per plant and fertile nodes per plant in both hybrid generations (F₁ and F₂) except for 1000-seed weight. A non-additive gene action appeared to be more predominant for the inheritance of most of the traits under study. Sharma et al. (2015) by following eight parental diallel mating design revealed the significant estimates of general and specific combing ability for all the traits namely, days to 50 per cent flowering, days to first picking, pod length, number of pods per plant, plant height, shelling percentage, pod yield per plant, total soluble solids, ascorbic acid and protein contents which indicated the importance of both additive and non-additive genetic variance in their inheritance.
2.2 Heterosis

Shull (1908) was the first who discovered hybrid vigour which resulted to heterosis breeding. Mendel (1866) and Keeble and Pellow (1910) reported heterosis for plant height in peas. Heterosis and transgressive segregation for yield, number of pods and average seed weight were reported by Johnson (1957).

Singh et al. (1978) recorded maximum heterobeltiosis for pods per plant (90.49%), green pod yield per plant (88.45%), plant height (50.89%) and days to flowering (31.17%). Ten crosses showed significant heterotic values over superior parents for yield per plant, five for pods per plant, ten for plant height and four for days to flowering.

Narsinghani (1979) reported heterosis over the better parent to the extent of 13, 67, 70, 128 and 109 per cent for days to maturity, plant height, pods per plant, seeds per plant and seed yield per plant, respectively. Arndt and Dube (1980) reported positive heterosis for pods per plant and seeds per plant with approximately 50 per cent advantage over the better parent. In a complete set of six parent diallel crosses, Dhillon and Chahal (1981) reported heterosis for pod yield and pod number.

Venkateswarlu and Singh (1982) from ten parental diallel cross recorded significant heterosis to the tune of 47 and 22 per cent for average seed yield over mid and better parent, respectively. Moitra and Singh (1986) reported heterosis for seed yield over better parent in crosses namely, ‘R701 × Kinnauri’ (91%), ‘Batri Yellow × T103’ (69.6%), ‘T10 × T163’ (60.3%) and ‘Batri Yellow × R701’ (33.8%). These crosses also showed heterosis for pods per plant and seeds per pod and negative heterosis for days to flowering. Srivastava et al. (1986) revealed that the degree and direction of heterosis varied greatly for different characters in different crosses. Out of 28 crosses studied, fifteen, seven and six crosses showed significant positive heterobeltiosis for days to flowering, pods per plant and plant height, respectively. They also indicated that heterosis over better parent was positively correlated with specific combining ability effects.

From a diallel analysis, Naumkina (1987) reported heterosis for individual traits in some crosses and for a combination of traits in others. Most of the hybrids showed heterosis for seeds per plant. Heterosis was rare for pods per plant and upto
39.21 per cent for yield in some crosses. Seventeen crosses showed significant heterosis for seed yield (Singh and Santoshi 1989).

Pant and Bajpai (1991) revealed that crosses involving parent ‘Pant P8’ showed marked heterosis for pod length, seeds per pod and grain yield. As many as twenty three crosses revealed heterosis for yield over better parent. Henaut et al. (1992) reported heterosis for pods per plant and seeds per pod. Mishra et al. (1993) studied sixteen hybrids produced by line (4) × tester (4) analysis and detected considerable heterosis over better parents for all the traits in some of the hybrids. However, all the hybrids exhibited heterosis for earliness.

Parmar (1993) observed highest heterosis for yield per plant (55.1%) and pods per plant (49.9%) in the cross ‘Bonneville × 35’. Singh et al. (1993) reported significant heterosis over better parent for seed yield in crosses ‘Cl × T163’ and ‘Cl × C23’. Karache and Narsinghani (1994) found that combinations ‘Arkel × JP9’ and ‘JP4 × JP9’ showed significant heterosis over better parents for days to maturity, pods per plant and seed yield. Sarawat et al. (1994) reported heterobeltiosis for plant height, pods per plant, seeds per pod and earliness of flowering.

Mishra (1998) observed higher standard heterosis for grain yield per plant and pods per plant while, negative heterosis for days to flowering. The highest value of heterosis over better parent was recorded by Sharma et al. (1998) for seed yield per plant (64.50%) and seeds per pod (74.60%) in cross ‘HFP 8909 × DPFD69’, pods per plant (70.20%) in ‘HPF4 × Rachna’ and pod length (69.90%) in ‘HFP8909 × DPFD 69’. Sharma et al. (1999) in a line × tester cross analysis observed that cross ‘Palam Priya × DPP19’ and ‘Azad P1 × DPP19’ registered significant heterosis for green pod yield and pod length, respectively. ‘DPP13’, ‘DPP25’ and ‘Azad P1’ parents were involved in atleast one cross combination which exhibited significant and high magnitude of heterosis for all the characters.

Kumar et al. (2000) recorded appreciable heterosis for days to 50 per cent flowering, pod length, seeds per pod, plant height and pod yield per plant except total soluble solids and protein content over better parent. Tyagi and Srivastava (2001a) reported highest heterosis over better parent in case of plant height and lowest for seed weight. They also reported substantial amount of heterosis (>50%) over better
parent and mid parent in crosses namely, ‘LMR × Pusa 10’, ‘LMR20 × PG3’, ‘HPF4 × HUP12’ and ‘S143 × Pusa10’ for seed yield.

Tyagi and Srivastava (2001b) found substantial amount of heterosis over better parent in crosses ‘HUP2 × KPSD1’, ‘PC1 × T163’ and ‘FC1 × Pusa10’ for seed yield per plant and pods per plant. Kaur et al. (2003b) revealed significant economic heterosis over commercial parents for all the economic characters except days to marketable maturity and green pod yield per plant in cross ‘Punjab-87 × JP501- A/2’. Ceyhan and Avci (2005) revealed significant heterosis for grain yield to the tune of 83.2 per cent over mid parent and 66.8 per cent over better parent.

Gautam et al. (2005) conducted line × tester analysis using thirteen lines and two testers of pea and observed heterobeltiosis for pod yield per plant (31.52%), pod length (4.06%), pod weight (15.85%) and plant height (39.55%). Kumar and Tewatia (2005) studied fourteen parental lines of pea along with their 40 F₁ hybrids and observed significant heterosis over better parent and top parent for pods per plant, mean pod weight, length of pod and branches per plant. Singh et al. (2005) reported significant negative heterosis for days to flowering and days to first picking, along with high heterosis over better parent for pod yield per plant and pods per plant.

Pandey et al. (2006) observed average heterosis for plant height, pods per plant, pod length, seeds per pod, pod yield per plant and total soluble solids. Eleven crosses exhibited significant positive heterosis over the best parent for pod yield. Sharma et al. (2007) observed that ‘Green Pearl × DPP 9411’ and ‘Azad P1 × Sugar Giant’ had high heterosis and SCA effects for pod length, seeds per pod, shelling percentage, pods per plant and pod yield per plant. Ceyhan et al. (2008) noted heterosis for yield from line × tester analysis using eleven parents.

Thakur and Khosla (2008) reported 34.8,12.7, 39.6, 3.75, 19.1, 15.5 and 22.1 per cent heterosis over better parent for pod yield per plant, plant height, pods per plant, pod length, pod breadth, grains per pod and shelling percentage, respectively. Awasthi et al. (2009) studied 16 parental lines and 17 crosses and concluded that cross ‘EC 269396 × Pusa Pragati’ exhibited negative significant heterosis for days to maturity governed by dominant gene with negative effect, while cross ‘EC 328758 × Swarnamer’ exhibited positive significant heterosis for pods per plant and seed yield per plant, governed by genes with positive effect. Thus, cross ‘EC 328758 ×
Swarnamer’ is the best cross combination for seed yield and pods per plant and ‘EC 269396 × Pusa Pragati’ for early maturity.

Bora et al. (2009) reported significant and highest heterosis over standard check and better parent to the tune of 31.13 and 58.12 per cent for pod length, 73.21 and 50 per cent for pods per plant, 199.23 and 58.12 per cent for pod yield per plant, 71.02 and 16.66 per cent for primary branches per plant, 27 and 55.50 per cent for seeds per pod, 44.70 and 43.91 per cent for shelling percentage, -11.41 and -48.28 per cent for plant height, 34.48 and 21.87 per cent for total soluble solids and 77.68 and 70.89 per cent for ascorbic acid, respectively. Sarode et al. (2009) reported that nineteen crosses showed significantly positive heterosis over better parent for seed yield per plant. Ten crosses showed more than 50 per cent heterosis over better parent with the highest by ‘LMR 20 × JP Batri Brown’ (196.49%) and ‘HFP 4 × JP Batri Brown’ (169.78%) for seed yield per plant.

Karnwal and Kushwaha (2010) observed that amongst 28 crosses, only five crosses viz., ‘VL-9 × Pant Upahr’, ‘VL-9 × DARL-403’, ‘DARL-403 × Pant Upahr’, ‘DARL-403 × VP-316’ and ‘PSM-3 × DARL-403’ exhibited highly significant and maximum heterosis over better parent and economic heterosis for pod yield and its contributing horticultural traits like primary branches per plant and pods per plant under dry temperate region. Esposito et al. (2013) reported that amongst seventy six F₁ hybrids derived from crosses between nineteen female lines and four male testers, large number of hybrids showed superiority over their parents for various traits, indicating the existence of substantial heterosis in the hybrids and their potential for further pure lines development. Heterosis over better parent in 76 hybrids varied from -61.0 (‘ZAV17 x DDR14’) to 274.3 per cent (‘DMR7 x COME’).

Sharma and Bora (2013) observed that the crosses ‘VRP-5 × Pusa Pragati’ and ‘DVP-2 × VL-7’ manifested maximum significant heterosis for days to 50 per cent flowering and days to first picking, respectively while, ‘PMR-32 × Snow pea’ showed the same for number of green pods per plant and green pod yield per plant. They concluded that these crosses can be exploited for the improvement of earliness and yield related traits of garden pea. Sharma and Sharma (2013) studied eight
parental lines of pea along with their 28 F₁ hybrids and observed that the cross ‘VL-7 × DARL-405’ exhibited highest significant negative economic heterosis for earliness, while cross combination ‘Pb-89 × PSM-3’ had highest economic heterosis for green pod yield per plant.

Kushwah and Sharma (2015) reported that all the four crosses combinations namely, ‘CHPMR-1 × PSM 3’, ‘CHPMR 1 × Arkel’, ‘KTP 4× PSM 3’ and ‘FC 1× CHPMR-1’ showed significant negative heterosis for days to first flowering and days to maturity whereas, cross ‘CHPMR1 × PSM 3’ registered maximum yield heterosis of 53.14 per cent over the best commercial variety ‘PSM 4’. This cross also exhibited highly positive heterotic effects for other characters like number of primary branches, pod length, number of pods per plant, number of seeds per pod and number of seeds per plant.