GENETIC ANALYSIS OF SOME HORTICULTURAL TRAITS IN GARDEN PEA (*Pisum sativum* L.)

THESIS

By

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Submitted to

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Is there anything I can say,
anything I can give
or do for you…..
Because all that I'm
all that I have
I owe to you…..

Affectionately Dedicated
to my
Revered Parents

Who sacrificed
their present
to make my future better

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CERTIFICATE- I

This is to certify that the thesis entitled "**Genetic analysis of some horticultural traits in Garden Pea (*Pisum sativum* L.)**", submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the subject of **Vegetable Science** (Minor- Plant Breeding) of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Mr. Palash Santra (Admission No. A-2007-30-33)** son of **Sh. Jamini Kanta Santra** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

18/7/09

Place: Palampur
Dated: 18th July, 2009

(Dr. D. R. Chaudhary)
Chairman,
Advisory Committee

CERTIFICATE- II

This is to certify that the thesis entitled **“Genetic analysis of some horticultural traits in Garden Pea (*Pisum sativum* L.)”** submitted by **Mr. Palash Santra (Admission No. A-2007-30-33)** son of **Sh. Jamini Kanta Santra** to the Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** in the subject of **Vegetable Science** (Minor- Plant Breeding) has been approved by the Advisory Committee after an oral examination of the student in collaboration with an external examiner.

17/9/09.

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Needless to say, all omissions and errors are mine.

Place: Palampur
Dated: 18th July, 2009

Palash Santra
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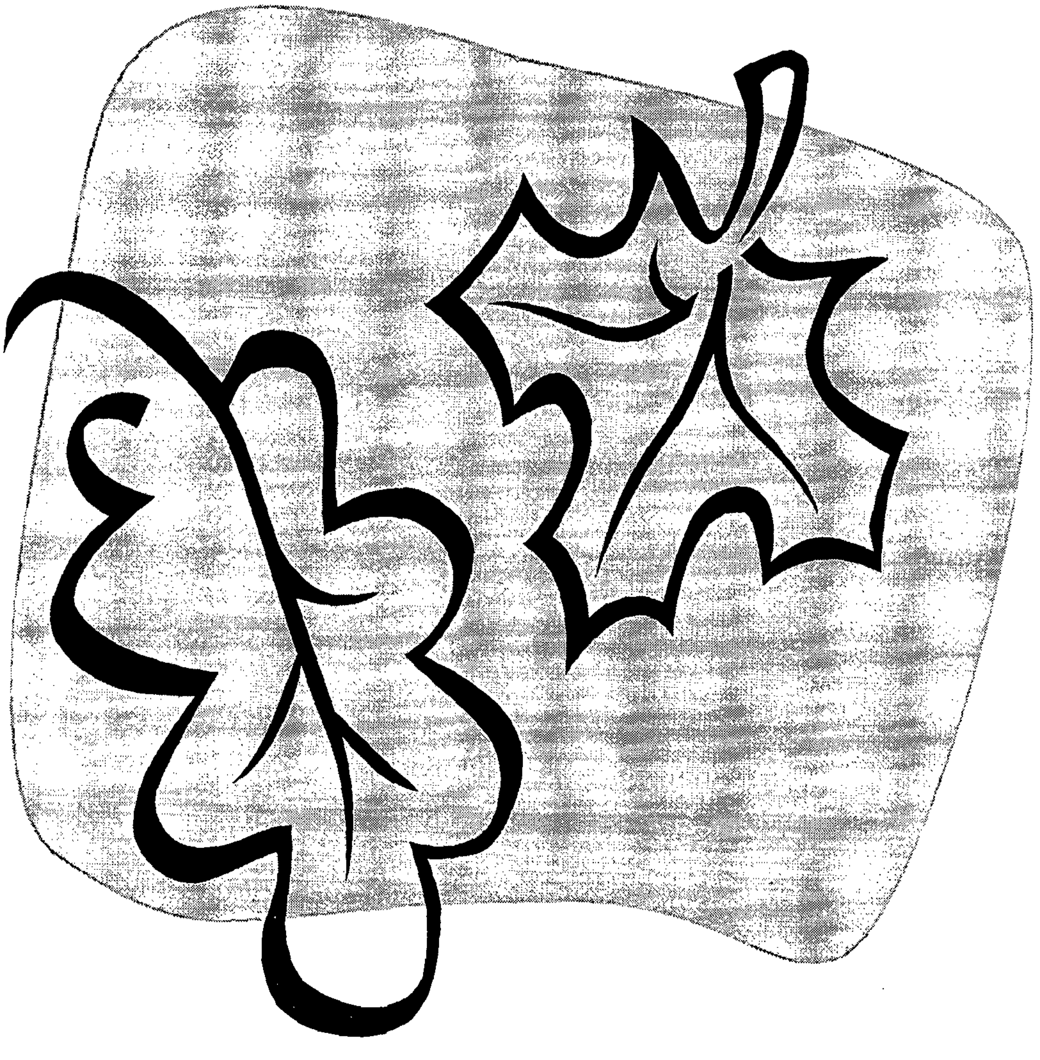


Chapter -I

INTRODUCTION

Garden pea (*Pisum sativum* L.), a member of the Leguminosae family is one of the most common and principal vegetable crops grown all the year round in the country. Pea, with a multipurpose use in human dietary system, is of Mediterranean origin and the Near East and Ethiopia are considered as secondary habitats (Blixt, 1970). In India, it is grown on commercial scale as winter vegetable in northern plains and during summer in high hills. It occupies an area of about 3,14,000 ha with an annual production of 25,60,000 tonnes (Anonymous, 2007-08).

Pea is palatable and nutritious vegetable, which can be consumed either fresh, canned, pulse, frozen or in dehydrated forms. Nutritionally, pea has its importance for proteins 7.2g, fats 0.1g, minerals 0.8g, fibre 4.0g, carbohydrates 15.8g, calcium 20mg, magnesium 34mg, oxalic acid 14mg, phosphorus 139mg, copper 0.23mg, sulphur 95mg, iron 1.5mg, sodium 7.8mg, vitamin A 139 I.U., thiamine 0.25mg, riboflavin 0.01mg, nicotinic acid 0.8mg and vitamin C 9.0mg per 100g of edible portion (Choudhary, 1998). Besides being a rich source of health building substances (proteins, vitamins, minerals and lysine), it plays an important role in economy of growers and ranks next to tomato as a processed vegetable (Talbert, 1953).

The agro-climatic conditions prevailing in the state are quite congenial for its off-season cultivation during rainy season in temperate wet areas and during summer in high hill temperate dry areas. The green pods from hilly areas are available at a time (April-September), when these cannot be grown in the plains due to high temperature. As a result, these sell at a higher premium, bringing lucrative returns to the growers. In Himachal Pradesh, it occupies an area of 16,348 hectares with a production of 1,77,036 metric tonnes (Anonymous, 2006) and acreage wise ranks first among vegetables excluding potato.

In the past, several high yielding varieties of pea have been identified, developed and made available to the growers for commercial cultivation. Keeping in view the diverse agro climatic conditions prevailing in the state and the ever increasing demand of the vegetable growers for high yielding varieties, there is an urgent need for the identification and development of location specific improved varieties. Hence, it becomes imperative to study the genetic architecture of important horticultural traits in the available germplasm for its rational manipulation in the development of high yielding varieties through appropriate breeding methodologies.

In order to exploit heterosis, identification of best parents for hybridization is a pre-requisite and one of the critical and difficult tasks for a plant breeder. The choice is relatively straight forward when some qualitative character is under consideration but complex traits such as yield, do not allow an easy handling. One of the two possible alternatives to choose the parents for hybridization involves careful study of as many parents as possible in multilocation tests over years. Secondly, one may resort to production of large number of crosses between the selected parents followed by the elimination of poor ones. The ability of parents to combine well with each other depends upon the complex interactions among the genes, which cannot be judged by mere yield performance of the parents (Allard, 1960). Thus, the information regarding general combining ability helps in identification of the lines in early stages, thereby resulting in the proper selection of the parents for hybridization. Further, the knowledge about the gene action helps in formulating an efficient breeding programme aiming to improve yield potential through its components.

Diallel analysis, developed by Jinks and Hayman (1953) and Hayman (1954), is an effective method for obtaining useful information on differential parental combinations, through an assessment of the overall genetic architecture of the parental lines, in relation to the character studied. On the basis of diallel analysis, Griffing (1956 b) described a method for the precise measurements of general and specific combining abilities, which is very useful technique in classifying parental lines in terms of their hybrid performance and as such an aid in selecting parents, which when crossed may give rise to more desirable segregants. Such information forms the backbone of any breeding programme and is of great significance to the breeders.

Based upon all these considerations, the present investigation entitled, **"Genetic analysis of some horticultural traits in Garden Pea (*Pisum sativum* L.)"**, comprising of 21 F_1s developed from 7 parents (Palam Priya, Azad Pea-1, Lincoln, DPP 9418-06, DPP-3, DPPLMR-41 and Pb-89) in a diallel mating design (excluding reciprocals) was planned and undertaken with the following objectives:

- To estimate the nature and extent of heterosis for yield and yield-contributing traits,
- to evaluate the parents and F_1 crosses with respect to their combining abilities for yield and its contributing traits, and
- to ascertain the nature of gene action controlling the inheritance of different horticultural traits as inferred from combining ability variances, components and graphical analyses.

Information, thus generated, will certainly facilitate the pea improvement programme in general and development of superior genotype (s) in particular.

REVIEW OF LITERATURE

Chapter II

REVIEW OF LITERATURE

The pea is an important leguminous vegetable crop being widely cultivated throughout the world. Green pods are an all time favourite vegetable as these befriend amicably with other vegetables. Remarkable changes in plant type, pod length and production potential have been observed through the exploitation of genetic variability. A number of high yielding genotypes have been developed through the suitable breeding methodologies based on the nature of gene action. A thorough scanning of the literature reveals that the studies on the genetic aspects are still inadequate and need further attention of the breeders.

The selection and formulation of a suitable breeding methodology in the improvement of a particular crop species depends upon the type of gene action present in the particular material (Murty and Arunachalam, 1966). A number of designs and analyses have been proposed to study the nature of gene effects which vary with the kind of material studied, the mating design used and the biometrical model applied.

Johannsen (1909) reported that the phenotypic expression of a quantitative trait is a function of genotypic effect and environmental deviation. Fisher (1918) divided the genetic variance into three components, i.e. additive, dominance and epistatic variance and constructed a gene model where he stated that deviations from simple additivity and dominance may be present if more than one gene affected a given character and called this deviation as epistacy. A number of genetic models have been described to study the epistatic gene effects present in the inheritance of complex traits (Hayman and Mather, 1955; Jinks and Jones, 1958 and Mather and Jinks, 1971). Hayman and Mather (1955) accounted further sub-division of epistatic part into digenic interactions of additive x additive (i), additive x dominance (j) and dominance x dominance (l) types alongwith other higher order genic interactions.

The fundamental approaches used in the determination of the genetic architecture of the quantitative traits are:

1. Analysis of variances and co-variances to estimate genetic components of variation i.e. diallel cross analysis which follows second degree statistics. It also determines the *per se* performance of the parents to be involved in a hybridization programme.
2. Analysis of generation means and variances to estimate gene effects including epistasis. This involves primarily the first and then the second degree statistics.

2.1 Diallel cross analysis

Diallel mating design is mainly used for selection of elite genotypes and suitable parents for hybridization programme. Statistical analysis of diallel mating design was first provided by Mather (1949) and further modified by Jinks and Hayman (1953); Hayman (1954); Jinks (1954, 1956); Griffing (1956 b); Kempthorne (1956) and Gilbert (1958). Hayman (1954) and Jinks (1954, 1956) studied the genetic properties of a particular set of parental lines and attempted to estimate components of genetic variation *viz.*, D, H_1, H_2 and F together with the graphical analysis involving Vr, Wr graphs to study the nature of gene action involved in the inheritance of a particular trait. Griffing (1956 a, b) emphasized the statistical concepts of general and specific combining abilities.

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

1. Heterosis
2. Combining ability
3. Gene action
4. Heritability

2.2 Heterosis

Heterosis for plant height in pea was reported by Mendel (1866) and Keeble and Pellow (1910). Heterosis and transgressive segregation for pod yield, number of pods and average seed weight were reported by Johnson (1957). Koranne (1966) observed hybrid vigour for pod yield per plant in a set of crosses developed through diallel mating design involving nine genotypes of garden pea. Singh and Singh (1970) reported the manifestation of heterosis over the better parent for pods per plant (11.0%), seeds per pod (15%) and seed yield (162%). Singh and Jain (1970) reported significant heterosis for pods per plant and days to flowering.

Heterosis for days to first picking, pods per plant and pod weight was reported by Brahmappa (1973). In the same set of material, Brahmappa and Singh (1975) reported that five crosses were more heterotic for earliness, pods per plant and pod weight. Srivastava and Sachan (1975) observed heterobeltiosis to the extent of 56.8, 36.5 and 24.9 per cent for seed yield per plant, seeds per pod and pods per plant, respectively. Heterosis over better parent for pods per plant (114.5%), pod yield per plant (86.6%), plant height (35.0%), seeds per pod (17.0%) and pod length (10.0%) was also reported by Singh *et al.* (1975). Gritton (1975) reported heterosis for pod yield to the extent of 55 and 28 per cent over mid and better parents, respectively. Singh *et al.* (1978) observed significant heterosis for plant height, branches per plant, pods per plant, green pod yield per plant and days to flowering. Vetrova (1978) reported significant positive heterosis for pods per plant, seeds per pod and pod yield per plant.

Narsinghani and Singh (1979) reported heterosis over better parent for days to maturity (13.0%), plant height (67.0%), pods per plant (70.0%), seeds per plant (128%) and seed yield per plant (109.0%). Positive heterosis for pods per plant and seeds per pod was noticed in many hybrids by Arndt and Dube (1980). Venkateswarlu and Singh (1982) analyzed 10 x 10 parental half diallel and reported significant positive heterosis for primary branches, pods per plant and pod yield per plant. Moitra and Singh (1986) reported heterobeltiosis for seed yield in the crosses *viz.,* R-701 x Kinnauri (91%), Batri Yellow x T-163 (69.6%), T-10 x T-163 (60.3%) and Batri Yellow x T-701 (33.8%). These crosses also displayed significant positive heterosis for pods per plant and seeds per pod and significant negative heterosis for days to flowering.

Naumkina (1986) reported significant positive heterosis for pods per plant and green pod yield. Further, Naumkina (1988) attempted a diallel set of crosses involving 12 varieties and observed 39.21 per cent hybrid vigour for pod yield. Singh and Santoshi (1989) observed significant positive heterosis for seed yield and protein content in the hybrid combinations namely, T-163 x BR-12, Rachna x 6113, KLMR-9 x EC 33866 and L-116 x BHU-397. Parmar and Godawat (1990) reported that the cross, Bonneville x 65871 had the highest positive heterosis of 58.8 per cent for yield per plant. Lejenue-Henaut *et al.* (1992) observed significant heterosis for pods per plant and seeds per pod. Considerable heterosis over the better parent for pod yield per plant, pods per plant, pod weight, seeds per pod and earliness in almost all the hybrids evaluated was reported by Mishra *et al.* (1993).

Significant heterosis for pod yield, pods per plant, seeds per pod, plant height and days to flowering was observed in three crosses *viz.,* Wirrega x Whero, Wirrega x SA-157 and Dundale x SA-123 as reported by Sarawat *et al.* (1994). Singh *et al.* (1994) observed maximum heterobeltiosis and standard heterosis to the extent of 228 per cent and 68 per cent for pod yield per plant, respectively. Highest heterosis for yield per plant was found in tall x medium and tall x dwarf combinations.

Singh and Mishra (1996) analyzed 6 x 6 diallel set of mid season pea genotypes and observed that most of the hybrids exhibited heterosis for pods per plant, seeds per pod and pod yield per plant. Mishra (1998) evaluated 17 hybrids and reported that the cross combinations, HFP-4 x P-1542 and HFP-4 x T-163 had the highest standard heterosis for pod length, pods per plant and pod yield per plant. Sharma *et al.* (1998) observed highest heterosis for fertile nodes per plant, seeds per pod, pods per plant and pod yield per plant. The highest heterobeltiosis to the extent of 64.5 per cent was recorded for pod yield per plant in the cross, HFP-8909 x OPFD-69. Abdou *et al.* (1999) studied 5 x 5 parental half diallel set and observed significant heterosis for pod yield, pods per plant, plant height, seeds per pod, earliness and shelling percentage.

Tyagi and Srivastava (1999) reported heterobeltiosis for seed yield per plant, pods per plant, biological yield per plant and harvest index. The potential heterotic combinations were HUP-2 x KPSD-1, FC-1 x T-163 and FC-1 x Pusa-10. Tyagi and Srivastava (2001 b) evaluated 20 crosses developed as a result of mating 10 lines with two testers in a line x tester mating design and observed more than 50 per cent heterosis over the better parent (HBP) and mid parent (HMP) in four crosses *viz.,* LMR-20 x Pusa-10, LMR-20 x PG-3, HFP-4 x HUP-12 and S-143 x Pusa-10 for days to flowering, days to maturity, plant height, pods per plant, seeds per pod, seed weight, seed yield per plant, biological yield per plant and harvest index.

Significant heterobeltiosis for days to marketable maturity and number of pods per plant in the cross Matar Ageta-6 x JP-179 and standard heterosis for all the horticultural traits except days to marketable maturity and number of pods per plant in the cross Punjab-87 x JP 501-A/2 were recorded by Kaur *et al.* (2003). Singh *et al.* (2005) reported that expression of heterobeltiosis was quite high for most of the characters studied except for days to flowering. The best heterotic combinations were NDVP-9 x JP-179, VP-7906 x Arkel, Mithi Phali x MA-6, NDVP-8 x JP-179 and Mithi Phali x JP-197 for green pod yield, branches per plant, pods per plant, plant height and days to marketable maturity. Ceyhan and Avci (2005) analyzed line x tester mating design involving four lines and three testers and reported significant average heterosis to the extent of 83.2 per cent and heterobeltiosis of 66.8 per cent for seed yield. Pandey *et al.* (2006) studied 10 x 10 parental half diallel cross and reported average heterosis for plant height, pods per plant, pod length, seeds per pod, pod yield and total soluble solids.

2.3 Combining ability

The study of combining ability is especially useful to compare the performance of parental lines in a series of hybrid combinations. Richey and Mayer (1925) were probably the first to realize the importance of combining ability of inbreds in maize followed by Davis (1927) suggesting the use of inbred x variety cross test for evaluating the general combining ability of corn inbreds.

Sprague and Tatum (1942) defined general combining ability as the average performance of a line in a series of hybrid combinations and specific combining ability to designate those cases in which certain combinations do relative better or worse than expected on the basis of average performance of the lines involved. In GCA, genes with additive effects are more important, while SCA is more dependent upon the genes with dominance or epistasis effects. Most of the combining ability studies have utilized diallel cross analysis for estimation of variances and gene effects. It is revealed in almost all the cases that both GCA and SCA variances have been reported to be significant but their relative magnitude vary depending upon the genotypes involved. Allard (1960) stressed the need to study the combining ability in case of self-pollinated crops by stating that phenotypically equal promising parents do not always produce superior off-springs in segregating generations, while certain combinations nick well and give superior segregants. Thus, performance and adaptation of parents are not always a good index of superior combining ability as it depends upon the complex interaction system among genes.

Epikhov and Flerova (1983) reported that the crosses *viz.,* GR-11 x Viola, RG-11 x PMU, Viola x PMU, RG-11 x Mirargin and Fridol x PMU for pod yield per plant and RG-11 x Rannii-301 (Early 301) for earliness were the best specific cross combinations. Dubey and Lal (1983) reported that the parents, T-10, P-185, 6583 and P-199 were the good general combiners for pod yield and its associated traits. Significant SCA effects for days to flowering, number of flowers per axil, branches per plant, plant height, pods per axil, pods per plant, pod length, seeds per pod and pod yield per plant were observed in crosses, P-199 x P-185, P-199 x 479, T-163 x T-10, T-163 x P-185, T-10 x 6113 and BR-12 x 6113. Singh *et al.* (1985 a) reported that T-163, EC 33866 and T-56 were the good general combiners and advocated that the estimates of specific combining ability variances were considerably higher than the general combining ability variances for days to flowering, plant height, branches per plant, pods per plant, seeds per pod, pod length, pod width, days to maturity, 100-seed weight and seed yield per plant, thereby indicating the importance of non-additive type of gene action. Gad and El-Sawah (1985) reported that the parent Meteor was the good general combiner for plant height and leaves per plant, whereas Progress-9 and Little Marvel for branches per plant. Both additive and non-additive gene actions were important in the inheritance of these traits. Srivastava *et al.* (1986) reported that the parents, Rachna, P-29 and P-185 were the best general combiners for days to flowering and pod yield per plant. Partial dominance coupled with high heritability estimates were observed for days to flowering, nodes upto the first pod and seed yield per plant.

Naumkina (1986) reported that the parents, Orlovskii-57, Aga and Starcovert were the best general combiners, while Naldino x UJ Yanovskii-68 and Orlovskii x Aga were the best cross combinations for pods per plant and pod yield. Singh and Ram (1988) observed that the parent, Arkel was the best general combiner for pod yield and its component traits followed by GC-141. Moitra *et al.* (1989) reported that parent, Batri Yellow was good general combiner for days to flowering; T-163 for 100-seed weight and T-10 for days to maturity, plant height, pods per plant, seeds per pod and pod yield per plant.

The genotype, JP-169 was the good general combiner for pod yield and its associated traits followed by VP-7802. Chung and Chang (1992) revealed that the parent, Alderman was the best general combiner for pod yield and its related traits as it exhibited significant positive GCA effects. Pant and Bajpai (1993) evaluated 45 crosses developed as a result of mating 15 lines and 3 testers and reported that the lines, Pant-8 and P-537 were the good general combiners for pod yield per plant; Pant P-101 and Pant P-638 for days to flowering, pods per plant and pod yield per plant; Pant P-106 for pod maturity and pod length and Pant P-6, Pant P-101, Pant P-638, Pant P-5 and Pant P-8 for pods per plant. Panda *et al.* (1996 a) evaluated 28 crosses developed as a result of mating 8 parents in a diallel mating design (excluding reciprocals) and reported that the lines, PH-1, HUVP-1, EC 33866 and VL-6 were the good general combiners for green pod yield, number of seeds per pod and days to maturity. Kumar *et al.* (1996) reported that the genotype, PH-10 was best general combiner for yield per plant and PH-1, JP-829 and LMR-6585 for earliness. The best specific combiners were HUVP-2 × IP-3 for green pod yield per plant, HUVP-2 × Arkel for earliness, PRS 18-6 × Bonneville for dwarfness and HUVP-2 × Bonneville for total soluble solids and protein content.

Kalia and Chauhan (1996) reported the predominant role of non-additive gene action in the inheritance of number of branches, pods per plant, pod yield per plant, plant height and seeds per pod in F_1 generation. Bhardwaj and Kohli (1998) studied 8 parental half diallel and reported that the parents *viz.*, VL-3, Lincoln, Kinnauri, Matar Ageta-6 and Arkel were the good general combiners for pods per plant, pod yield per plant, seeds per pod, shelling percentage and earliness. Two hybrids *viz.,* VL-3 x Lincoln and VL-3 x Kinnauri were the best specific cross combinations for pod yield and its component traits.

Sharma *et al.* (1999) reported that the parents, VG-9 and GC-195 were good general combiners for pod yield per plant, pods per plant and pod weight. The best specific combinations for pod yield were VG-9 x VL-3 and GC-66 x VL-3. Sharma *et al.* (2000) studied 5 x 5 half diallel and reported significant GCA variances for pod yield, pods per plant and pod length, whereas SCA variances was found to be of higher magnitude for pod breadth. Sood (2001) reported that the genotypes, Matar Ageta-6 and JI-2436 were the best general combiners for days to 50% flowering, days to first picking and shorter plant height. The genotype, Palam Priya was found to be the good general combiner for pod yield per plant, shelling percentage and protein content. The parent, Arka Ajeet exhibited the highest significant GCA effects for pods per plant and plant height, whereas the parent, Bonneville was observed to be the good general combiner for pod yield per plant, pods per plant and earliness. The cross, Arka Ajeet x Bonneville was the best specific cross combination for pod yield per plant and pods per plant followed by PMR-20 x KS-136.

Kumar and Tewatia (2003) reported that the parent, KS-245 was the best general combiner for pod yield per plant and earliness. The cross, AC-Tamor x PHPMR-1 was best specific cross combination for pod yield, pods per plant, pod weight, weight of edible seeds per pod, pod length, shelling percentage and branches per plant. Sharma *et al.* (2004) evaluated 45 hybrids developed by crossing 15 lines with three testers and reported that the crosses exhibiting highest specific combining ability effects involved poor x poor, poor x good and good x good general combiners as their parents.

Singh and Dhillon (2004) observed that the line, DPR-3 was good general combiner for pod yield per plant. The parent, Punjab-88 was the best general combiner for pod yield per plant, total sugar and alcohol insoluble matter. The parents, DPR-3, Arkel and Punjab-88 were rated as the superior general combiners for pod yield per plant coupled with quality traits which indicated their key role in hybridization programme. Gupta and Singh (2005) reported that F_1 hybrids, PMR-43 x Arkel and Azad Pea-1 x Arkel were the best specific cross combinations for pod yield per plant and pods per plant. Singh *et al.* (2005) reported that the cross, Mithi Phali x MA-6 was the best specific hybrid combination for pod yield and yield related characters which could be exploited for obtaining high yielding true breeding lines. Pandey *et al.* (2006) evaluated 10 x 10 parental half diallel set and reported that both general and specific combining ability variances were significant for plant height, pods per plant, pod length, seeds per pod, pod yield per plant and total soluble solids. The genotypes, Lincoln and NC-64086 were identified as the best general combiners for pod yield per plant.

Singh *et al.* (2007) studied 10 x 10 diallel analysis (without reciprocals) and reported that the mean squares due to GCA were higher than those of SCA for pod yield and its related characters. Sugar Bon exhibited highest GCA for days to 50% flowering and branches per plant and the second highest GCA for plant height. Mithi Phali had maximum GCA for total and marketable pod yield per plant. Cross combination, Sugar Daddy x JP-19 recorded highest SCA effects for total and marketable green pod yield per plant followed by Early Snap x Mithi Phali.

2.4 Gene action

The selection of suitable breeding methodologies in bringing desirable improvement in crop plant requires the complete knowledge about the mode of inheritance and nature of gene action involved in the inheritance of quantitative traits.

Jinks (1954) and Hayman (1954) proposed the method of graphic analysis based upon second degree statistics, which provides overall picture of the genetic architecture and preponderance of gene action involved in the inheritance of a particular trait. Johnson (1957) reported that one or two major genes alongwith partially dominant modifiers controlled late flowering in pea. Krarup and Davis (1970) reported that additive gene action controlled the inheritance of pods per plant, seeds per pod and average seed weight. The deviation from additivity was probably due to epistasis or linkage than dominance as indicated by the deviation of F_1 from mid parental values for pods per plant and seed weight per plant. Watts *et al.* (1970) reported that early flowering in pea was controlled by additive genes, whereas dominant gene action was observed for late flowering. Additive gene action for days to flowering, primary branches and pods per plant, whereas non-additive for pod yield, seeds per pod, pod length and plant height was also reported by Dhaliwal *et al.* (1971).

Nandpuri *et al.* (1973) studied diallel crosses involving nine varieties and observed that inter allelic interactions were more important than additive genetic effects. High yield and heavy bearing were controlled by dominant alleles. Koranne and Singh (1974) recorded overdominance for pods per plant, seeds per pod and yield per plant. Das and Kumar (1975) observed that additive gene effects were more important than dominance for days to flowering and days to marketable maturity.

Both GCA and SCA variances were important in the inheritance of pod yield, number of branches, number of pods and seeds per pod, but the relative magnitude of SCA variances was higher for pod yield per plant as reported by

Das and Kumar (1975). Pandey and Gritton (1975) studied eight parental half diallel and reported significant GCA and SCA variances for days to flowering, plant height, pods per plant, seeds per pod, weight per seed and seed weight per plant. The importance of both additive and non-additive gene effects for plant height in both F_1 and F_2 generations were observed by Kumar (1976). However, Webber (1976) reported that SCA variance was more important for plant height and GCA variance for seeds per pod. Brahmappa and Singh (1977) recorded significant differences among genotypes for days to flowering, branches per plant, pods per plant and seeds per pod. Further, significant variances due to GCA and SCA for early flowering and pod yield were also observed. Sharma *et al.* (1977) in a 8 x 8 parental diallel cross, reported over dominance for plant height, pods per plant and pod yield, whereas partial dominance for days to flowering. The predominant role of additive genes in the inheritance of pod yield, pods per plant and plant height was reported by Varlakhov (1978).

Dhillon and Chahal (1981) evaluated 15 hybrids developed as a result of six parental half diallel and observed the predominant role of non-additive genetic variance for pod yield, pods per plant and seeds per pod, whereas additive genetic variance for pod length and days to flowering. Kumar and Aggarwal (1982) studied 10 x 10 diallel set involving exotic and indigenous cultivars of pea and reported that genetics of earliness in terms of days to 50 per cent flowering was predominantly controlled by additive genes. Rastogi (1982) reported significant GCA and SCA variances in F_1 and F_2 generations for plant height, pod length, pod breadth, number of pods per plant and shelling percentage.

Venkateswarlu and Singh (1982) studied F_1 and F_2 generations of 45 crosses developed through 10 x 10 parental half diallel for pod yield and yield-contributing traits and revealed that both additive and non-additive genetic variances were important for plant height, primary branches, pods per plant, 100-seed weight and seed yield per plant. Rybnikova (1982) reported overdominance for plant height, pod length and number of seeds per pod. Singh *et al.* (1986) reported non-additive gene action for days to flowering in pea, but Srivastava *et al.* (1986) and Katiyar *et al.* (1987) reported dominance gene effects for days to first flowering.

Srivastava and Singh (1988) reported that both additive and non-additive gene effects were important in the genetic control of seeds per pod but the relative magnitude of non-additive gene effects was more than additive gene effects. Gupta and Lodhi (1988) studied partial diallel in pea and reported that additive and non-additive gene effects were important for days to pod formation and days to marketable maturity. Complete dominance was observed for days to pod formation and overdominance for days to maturity. The predominant role of additive genes in the inheritance of days to flowering and days to maturity was indicated by Parmar and Godawat (1990). Karmakar and Singh (1990) studied 5 x 5 parental half diallel and observed the preponderance of non-additive gene action in the inheritance of pod yield per plant, pod bearing nodes per plant, pods per plant and days to flowering. Singh and Singh (1990) evaluated P_1, P_2, F_1 , F_2, BC_1 and BC_2 generations derived from seven diverse genotypes of pea and suggested the importance of dominant gene action coupled with additive x additive (i) component of genetic variation for pod yield per plant, pods per plant and plant height. Singh and Singh (1991) observed the importance of additive gene action in the inheritance of seeds per pod. Sirohi and Gupta (1993) revealed epistatic variation as an integral component of the genetic architecture of harvest index, pods per plant and 100-seed weight. The additive gene action was more important in the inheritance of pod yield per plant, harvest index, pods per plant, pod length and 100-seed weight, whereas non-additive gene action was predominant for seeds per pod. Both additive and non-additive gene effects were observed to be important in the expression of grain yield, branches per plant, pods per plant, seeds per pod, plant height and days to flowering as reported by Sarawat *et al.* (1994).

The inheritance of traits like days to flowering, days to marketable maturity and plant height, depicted the involvement of additive x dominance (j) and dominance x dominance (l) types of non-allelic interactions as reported by Sirohi *et al.* (1995). Kumar and Bal (1995) observed dominance for pod yield, pods per plant and 100-seed weight. The dominance variance was of higher magnitude for all the traits except pod length and seeds per pod. Additive genetic variance for biological yield per plant and pods per plant, dominance genetic variance for seeds per pod and both additive and dominance variances for pod yield per plant were reported by Rathore *et al.* (1995). Singh and Singh (1996) observed non-additive gene action for pod yield per plant and protein content. However, Panda *et al.* (1996 b) found that the additive genetic variance was significant for green pod yield per plant. Singh *et al.* (1997) studied variance component analysis and reported that the direction of dominance (F value) was positive and significant for days to flowering, plant height, pods per plant and seed yield.

Sharma *et al.* (1999) indicated the predominant role of non-additive gene action in the genetic control of pod yield, pods per plant, seed weight, days to pod maturity and shelling percentage, whereas additive gene action was observed for plant height. Dixit (1999) studied six generations (P_1, P_2, F_1, F_2, BC_1 and BC_2) of three crosses and reported the inadequacy of simple additive-dominance model. Both additive and non-additive genetic components were important in the inheritance of pod yield per plant, seeds per pod and TSS as reported by Narayan *et al.* (1999).

Kalia and Sharma (2000) studied F_2 progenies of two intervarietal crosses, Arkel x VG-5 and Lincoln x VG-5 and reported that the dominance components were more important in the inheritance of TSS and ascorbic acid. Singh and Sharma (2001) analyzed 8 x 8 parental diallel set and found that non-additive genetic components were of higher magnitude than additive components for plant height, pods per plant, seeds per pod, pod length and pod yield per plant. Kumar *et al.* (2001) reported that the non-allelic interaction especially of dominance x dominance (I) type was more important in the genetic control of pods per plant, pod length, seeds per pod, days to flowering and shelling percentage in three crosses *viz.,* JP-71 x VL-3, JP-71 x NDVP-9 and JP-15 x VL-3. Sood (2001) reported the predominance of non-additive genetic variance for the characters, *viz.,* days to 50 per cent flowering, days to first picking, pods per plant, seeds per pod, seed weight per plant, plant height, protein content and shelling percentage. Tyagi and Srivastava (2001 a) suggested the presence of additive, dominance and epistatic gene action for seed yield per plant, pods per plant, biological yield per plant and harvest index, thereby indicating the importance of both additive and non-additive gene actions governing inheritance of these traits. Kumar *et al.* (2002) analyzed 8 x 8 parent diallel set (excluding reciprocal) and reported that GCA variances were of higher magnitude than SCA variance for days to 50 per cent flowering, pod length, pod breadth, seeds per pod, pods per plant and pod yield per plant, whereas SCA variances were of higher magnitude than GCA variances for plant height and pod weight.

Bhardwaj and Vikram (2002) observed the inadequacy of additive-dominance model and reported that the additive, dominance and epistatic interactions were significant for days to flowering, plant height, pod length, pods per plant, yield per plant, shelling percentage, seeds per pod and sugar content. Kaur *et al.* (2003) suggested the involvement of epistatic interactions in the genetic control of economic characters *viz.,* days to maturity, green pod yield, pods per plant, shelling percentage and plant height. Singh *et al.* (2005) reported the predominance of additive gene effects for green pod yield per plant and protein content. Dixit *et al.* (2006) reported that the magnitude of non-additive genetic components was higher in magnitude as compared to additive components for seeds per pod, pod length, pods per plant and seed yield per plant.

Narayan (2006) observed the significance of both additive and non-additive gene action alongwith additive x additive (i), additive x dominance (j) and dominance x dominance (l) types of epistatic interactions in the genetic control of pod yield per plant, shelling percentage, total sugar and protein contents. Singh *et al.* (2006) advocated that all types of gene action (additive, dominance and interaction components) played a significant role in the inheritance of days to flowering, pods per plant, pod length, seeds per pod, shelling percentage, plant height, crude protein and total sugars in crosses, Arkel x Matar Ageta-6 and Matar Ageta-6 x Bonneville. Duplicate type of inter allelic interactions were more pronounced for most of the economic traits studied.

2.5 Heritability

Das and Kumar (1975) reported high estimates of narrow sense heritability for days to flowering and maturity. High heritability for plant height and seeds per pod was also reported by Singh and Singh (1989). Mihailovic and Kralijevic (1991) estimated high heritability for plant height. Gupta *et al.* (1998) reported high estimates of narrow sense heritability for days to 50 per cent flowering, pod weight per plant and protein content in pea.

Abdou *et al.* (1999) from a study of heterosis expression observed that potential gene recombinations could occur for enhanced earliness and pod yield. Narrow sense heritability estimates suggested that selection could be effective in isolation of elite recombinant homozygous genotypes. High heritability estimates coupled with high percentage of genetic advance indicated additive gene effects and offered greater scope of selection for crude protein percentage, pod weight and yield per plant as reported by Shinde (2000).

Sharma and Kalia (2002) reported that the narrow sense heritability estimates were medium to high for pod yield, average pod weight, pod length, pods per plant and branches per plant. Chadha *et al.* (2008) reported high heritability along with high genetic advance for marketable pod yield, whereas number of pods per plant, seeds per pod and duration of marketable pods had high heritability with moderate genetic advance. Maximum heritability estimates were reported for seeds per pod (98.15%) and marketable pod yield (96.56%).

MATERIALS AND METHODS

Chapter-III

MATERIALS AND METHODS

The present investigation was carried out at the experimental farm of Department of Vegetable Science and Floriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur during the Rabi 2008-09. The material used and methods employed for the present investigation in order to understand the nature and extent of heterosis, combining ability effects, variances and nature of gene action governing the inheritance of different horticultural traits in garden pea (*Pisum sativum* L.) are given here under:

3.1 Experimental material

The experimental material used for present investigation consisted of F_1 population of 21 crosses developed as a result of mating seven diverse genotypes of garden pea *viz.,* Palam Priya, Azad Pea-1, Lincoln, DPP 9418-06, DPP-3, DPPLMR-41 and Pb-89 in diallel mating design (excluding reciprocals).

Seven genotypes used in diallel analysis were crossed with each other by hand pollination using a standard procedure of hand emasculation and pollination in diallel mating design (excluding reciprocals) and thus 7×7 parental diallel full-sib crossed true to type seeds were produced at the experimental farm, Department of Vegetable Science and Floriculture, during Rabi, 2007-2008. Selfing of parents was also done to get selfed seeds of the parents. The 21 F_1s thus developed were evaluated along with their parents during Rabi, 2008-2009 for yield and yield-contributing traits.

Brief description of genotypes used in the present investigation

Code No.	Genotype	Source	Salient features
1	Palam Priya	CSK HPKV, Palampur	Powdery mildew resistant
2	Azad Pea-1	CSAU A & T, Kanpur	Mid to late maturing and green straight pods
3	Lincoln	IARI, RRS, Katrain	Small dark green pods
4	DPP 9418-06	CSK HPKV, Palampur	Dark green, slightly curved pods and moderately resistant to powdery mildew
5	DPP-3	CSK HPKV, Palampur	Long pods and late in maturity
6	DPPLMR-41	CSK HPKV, Palampur	Leaf miner resistant and late in maturity
7	PB-89	PAU, Ludhiana	Attractive dark green straight pods

3.2 Location

The experimental farm of Department of Vegetable Science and Floriculture, CSK HPKV, Palampur is situated at an elevation of 1,290.8 m above mean sea level, $32^0$6' North latitude and $76^0$3' East longitude, representing mid-hill zone of Himachal Pradesh. It has a sub–temperate climate with very high rainfall during monsoon season. The soil of this zone is of podzolic type with pH range of 5.0-5.6. The mean meteorological data with regard to temperature, relative humidity, rainfall, sunshine hours, wind velocity, evaporation and soil temperature during the crop season (November, 2008 -May, 2009) are presented in Appendix I.

3.3 Experimental layout and design

The F_1 population of 21 crosses along with their parents were evaluated in randomized block design (RBD) with three replications during Rabi, 2008-2009. Each experimental plot comprised of two rows of 1.8 m length for each parents and F_1s, accommodating 18 plants per row. The plants were spaced at 45 cm row to row and 10 cm plant to plant. The recommended agronomic practices and plant protection measures were followed for raising the crop.

3.4 Recording of the experimental data

The data were recorded on ten competitive plants selected at random from each treatment and each replication for the following characters:

1) Days to 50% flowering

The number of days taken from the date of sowing to the date when first flower appeared on 50 per cent plants in each treatment were counted and average worked out.

2) Days to first picking

The numbers of days taken from the date of sowing to the first picking/harvesting in each case were recorded.

3) Duration of availability of marketable pods (days)

The number of days taken from the date of first picking to the final picking were counted and average worked out.

4) Pod length (cm)

Ten randomly selected pods each from second and third pickings were taken for measuring pod length from the point of attachment to the tip of the pod and the mean pod length was ascertained.

5) Pod width (cm)

Ten randomly selected pods each from second and third pickings were taken for measuring pod width and the mean pod width was calculated.

6) Seeds per pod

Seeds per pod were counted from the same pods used for recording data for pod length and pod width. Average number of seeds were calculated by dividing the total number of seeds by corresponding number of pods.

7) Shelling percentage

Twenty pods from each treatment from second and third pickings were taken at random and shelling percentage was computed as:

$$\text{Shelling \%} = \frac{\text{Seed weight of shelled fresh green pods (g)}}{\text{Fresh green pod weight (g)}} \times 100$$

8) Pods per plant

Total numbers of pods from selected plants were counted at every harvest and average number of pods per plant were worked out.

9) Branches per plant

At the time of final picking, all the branches arising from the primary branches were counted and mean values computed.

10) Plant height (cm)

Plant height was recorded from base to the tip of the central apical shoot at the time of final picking and average values were worked out.

11) Pod yield per plant (g)

The total weight of pods obtained from the randomly selected plants in all the pickings was recorded and averaged out.

12) Total soluble solids (°brix)

Five green seeds were taken at random after shelling the marketable pods each in second and third pickings. These seeds were crushed in pestle mortar and the liquid extract so obtained was used to record TSS with the help of "ERMA Hand Refractometer" and average values calculated.

3.5 Statistical analysis

The mean values obtained from the ten competitive plants selected at random from each genotype in each replication for different horticultural traits were subjected to statistical analysis for computing analysis of variance for design of experiment, heterosis, combining ability effects and variances, graphical analysis and variance component analysis.

3.5.1 Analysis of variance for the experimental design

In order to find out the differences between the genotypes (parents and their F_1s), the data recorded for each trait were analyzed by following the model as suggested by Panse and Sukhatme (1984)

$$y_{ij} = \mu + g_i + r_j + e_{ij}$$

where,

y_{ij} = phenotypic observation of i^{th} entry in j^{th} replication,

μ = general mean,

g_i = effect of i^{th} treatment,

r_j = effect of j^{th} replication and

e_{ij} = error component.

Analysis of variance

Source of variation	df	Sum of squares	Mean squares	Expected mean squares
Replication	(r-1)	SSr	SSr/(r-1) = Mr	$\sigma^2 e + g\,\sigma^2 r$
Treatment	(g-1)	SSg	SSg/(g-1) =Mg	$\sigma^2 e + r\,\sigma^2 g$
Error	(r-1) (g-1)	SSe	SSe/(r-1)(g-1) = Me	$\sigma^2 e$

Where,

r = number of replications,

g = number of treatments,

$\sigma^2 g$ = variance due to treatments,

$\sigma^2 r$ = variance due to replications, and

$\sigma^2 e$ = error variance.

The replications and treatments mean squares were tested against error mean squares by 'F' test for (r-1), (r-1)(g-1) and (g-1), (r-1)(g-1) degrees of freedom at 5% level of significance (P = 0.05). From this analysis, the following standard errors were calculated where the 'F' test was significant:

1. Standard error for the treatment mean:

$$SE\ (m) = \pm\sqrt{Me/r}$$

2. Standard error for the difference of treatment mean:

$$SE\ (d) = \pm\sqrt{2Me/r}$$

The critical difference (CD) was obtained by multiplying SE (d) by the Table value of 't' for error degree of freedom (r-1)(g-1) at 5% level of significance (P = 0.05).

CD = SE (d) x 't' value at error degree of freedom at P = 0.05.

$$\text{Coefficient of variation (CV)\%} = \sqrt{\frac{\text{Error mean squares (Me)}}{\text{General mean}}} \times 100$$

3.5.2 Estimation of heterosis

The estimates of heterosis were calculated as the deviation of F_1 mean ($\overline{F}_1$) from the mean values of mid parent ($\overline{MP}$), better parent ($\overline{BP}$), standard check 1 ($\overline{SC}_1$) and standard check 2 ($\overline{SC}_2$).

1) Heterosis over mid parent (MP)% $= \dfrac{\overline{F}_1 - \overline{MP}}{\overline{MP}} \times 100$

2) Heterosis over better parent (BP)% $= \dfrac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100$

3) Heterosis over standard check 1 (SC1)%$= \dfrac{\overline{F}_1 - \overline{SC}_1}{\overline{SC}_1} \times 100$

4) Heterosis over standard check 2 (SC2)%$= \dfrac{\overline{F}_1 - \overline{SC}_2}{\overline{SC}_2} \times 100$

3.5.3 Calculation of standard errors

1) SE for testing heterosis over MP $= \pm\sqrt{\dfrac{3Me}{2r}} = SE(H_1)$

2) SE for testing heterosis over BP $= \pm\sqrt{\dfrac{2Me}{r}} = SE(H_2)$

3) SE for testing heterosis over SC_1 $= \pm\sqrt{\dfrac{2Me}{r}} = SE(H_3)$

4) SE for testing heterosis over SC_2 $= \pm\sqrt{\dfrac{2Me}{r}} = SE(H_4)$

3.5.4 Test of significance for heterosis

1) Heterosis over MP = $\dfrac{\bar{F}_1 - \overline{MP}}{SE(H_1)} \times 100$ = 't$_1$' calculated value

2) Heterosis over BP = $\dfrac{\bar{F}_1 - \overline{BP}}{SE(H_2)} \times 100$ = 't$_2$' calculated value

3) Heterosis over SC$_1$ = $\dfrac{\bar{F}_1 - \overline{SC}_1}{SE(H_3)} \times 100$ = 't$_3$' calculated value

4) Heterosis over SC$_2$ = $\dfrac{\bar{F}_1 - \overline{SC}_2}{SE(H_4)} \times 100$ = 't$_4$' calculated value

The 't' calculated values (t_1, t_2, t_3, t_4) for heterosis over mid parent (MP), better parent (BP) and standard checks (SC_1 and SC_2), respectively were compared with 't' tabulated value (1.96) for error degree of freedom at $P = 0.05$ (Dabholkar, 1992).

3.5.5 Diallel analysis

Diallel tables were compiled from progeny means, obtained as average over three replications, for parents and their F_1s, for those characters where 'F' test exhibited significant differences among progenies. These tables were utilized for general and specific combing ability effects and variances, graphical and variance component analyses.

3.5.6 Combining ability analysis

The estimates of variances for general and specific combining abilities and their effects were computed by method II (parents plus one set of crosses and no reciprocals) Model I (fixed effect model) as described by Griffing (1956 b).

Model I assumes that variety and block effects are constant and environment effect is variable and the experimental material constitutes the population about which inferences are to be made. It compares combining ability of the parents, when these themselves are used as testers. Errors are independently distributed with the mean zero and variance 'Se'. The analysis of variance for combining ability was based on the following mathematical model:

$$P_{ijk} = \mu + g_{ii} + g_{jj} + S_{ij} + b_k + e_{ijk}$$

where,

P_{ijk} = phenotype of the hybrid between i^{th} parents, in k^{th} block,

μ = population mean,

g_{ii} = general combining ability of i^{th} parent,

g_{jj} = general combining ability of j^{th} parent,

S_{ij} = specific combining ability effect of the hybrid between i^{th} and j^{th} parents,

b_k = block effect, and

e_{ijk} = environmental effect associated with ijk^{th} observation

The restrictions imposed on this model were:

$\sum_i g_i = 0$ and

$\sum_j s_{ij} + s_{ii} = 0$ (for each i)

Analysis of variance for combining ability

Source	df	Sum of squares	Mean squares	Expected mean squares
General combing ability (GCA)	$(p-1)$	SSg	Mg	$\sigma^2 e + (p+2)\,\frac{1}{(p-1)}\,\sum_i g_i^2$
Specific combining ability (SCA)	$\frac{p(p-1)}{2}$	SS_s	Ms	$\sigma^2 e + \frac{2}{p(p-1)}\,\Sigma_i\,\Sigma_j\,S_{ij}^2$
Error	$(b-1)[\frac{p(p-1)}{2}+(p-1)]$	SS_e	Me'	$\sigma^2 e$

where,

SS_g = $\frac{1}{p+2}\left[\Sigma(x_{i.}+x_{ii})^2-\frac{4}{p}x^2_{..}\right]$

SS_s = $\Sigma i\Sigma jx_i^2-\frac{1}{p+2}\Sigma i(x_i+x_{ii})^2+\frac{2}{(p+1)(p+2)}x^2..$

Me' = error mean square,

p = number of parents,

b = number of blocks/replications,

$x_{i.}$ = total of the array of i^{th} parent,

x_{ii} = value of i^{th} parent,

$x_{..}$ = grand total of $\frac{[p(p-1)]}{2}$ progenies and (p) parental values, and

x_{ij} = progeny mean value in the diallel table.

3.5.7 Combining ability estimates/effects and their standard errors

General combining ability effect of ith parents:

$$\hat{g}_i = \frac{1}{(p+2)}(x_{i.} + x_{ii} + \frac{2}{p}x..)$$

Specific combining ability effect of ijth cross:

$$\hat{s}_{ij} = x_{ij} - \frac{1}{(p+2)}(x_{i.} + x_{ii} + x_{j.} + x_{jj}) + \frac{2}{(p+1)(p+2)}x.. \ ,$$

where,

p = number.of parents,

$x_{i.}$ = total of array involving ith parent,

$x_{j.}$ = total of array involving jth parent,

x_{ii} = value of ith parent,

x_{jj} = value of jth parent,

$x..$ = total of all the $\frac{[p(p+1)]}{2}$ items in the diallel table, and

x_{ij} = mean value of the cross involving ith and jth parent.

3.5.8 Standard errors for testing combining ability effects

Standard errors to test the significance of general and specific combining ability effects and the standard error of difference between the two estimates were computed from the following formulae:

1. SE for testing gca $(\hat{g}_i)$ effects = $\pm\sqrt{\frac{Me'(p+1)}{p(p+2)}}$

2. SE for testing sca $(\hat{s}_{ij})$ effects = $\pm\sqrt{\frac{Me'(p^2+p+2)}{(p+1)(p+2)}}$

3. SE for testing sca $(\hat{s}_{ii})$ effects $= \pm\sqrt{\frac{Me'(p-1)^2}{p^2}}$

4. SE for testing difference between two gca effects

$$(\hat{g}_i - \hat{g}_j) = \pm\sqrt{\frac{2Me'}{(p+2)}}$$

5. (i) SE for testing difference between two sca effects in the same arrays

$$(\hat{s}_{ii} - \hat{s}_{jj}) = \pm\sqrt{\frac{2(p-2)Me'}{(p+2)}}$$

5. (ii) SE for testing difference between two sca effects in the different arrays

$$(\hat{s}_{ij} - \hat{s}_{kl}) = \pm\sqrt{\frac{2(p)Me'}{(p+2)}}$$

Critical differences (CD) were calculated by multiplying the corresponding standard error of difference with Table value of ‘t’ at error degree of freedom at P = 0.05.

3.5.9 Genetic components of variance

1. Component due to gca (σ^2gca) $= \frac{1}{p-1}\sum g_i{}^2$

$$= \frac{Mg - Me'}{(p+1)}$$

2. Component due to sca (σ^2sca) $= \frac{2}{p(p-1)}\sum\sum s_{ij}{}^2$

$$= Ms - Me'$$

3. Ratio of gca variance to sca variance (σ^2gca/ σ^2sca)

$$= \frac{1}{p-1}\Sigma g_i^2 \bigg/ \frac{2}{p(p-1)}\Sigma\Sigma s_{ij}^2$$

3.5.10 Graphical or geometric analysis

The graphical analysis was based on variance-covariance matrix (Vr–Wr), following the methodology given by Jinks and Hayman (1953), Hayman (1954, 1958) and Jinks (1954, 1955). Data were set in diallel table and following second degree statistics computed from it.

1. Vr = Variance of all the off-springs in each parental array, when an array consisted of parental mean and mean values of all the crosses involving that parent,
2. Wr = the co-variance of the off-spring in each parental array with non-recurring parent,
3. Vp = Variance of parents, and
4. Vm = Variance of the array means.

The regression coefficient of Wr on Vr was calculated by using the following formula:

$$\text{b Wr/Vr} = \frac{\text{Sum of product Wr Vr}}{\text{Sum of squares Vr}}$$

where,

'b' denotes the regression coefficient of the slope of regression line in Vr–Wr graph. From the regression coefficient, expected values of Wr were estimated by the following equation:

$$Wrei = \overline{Wr} + b\,(\overline{Vr} - Vri)$$

where,

Wrei = expected values of Wr corresponding to Vri, and

$\overline{Vr}$ and $\overline{Wr}$ are means of Vr and Wr values for all the arrays.

The Vr – Wr graph has the limits, the limiting values of these graphs called parabolic limits, which were computed as follows:

$$Wr^2 = Vr \times Vp \text{ or } Wr = \sqrt{Vr \times Vp}$$

In the graphs, the Vr values were taken along X-axis while Wr values along the Y-axis using same/different scale on each axis. Since Vr value is always positive while Wr can be positive or negative, Vr – Wr is only a two quarter graph. The significance of difference of 'b' from unit slope was tested by using the following formula:

$$\text{Standard error for b Wr/Vr} = \sqrt{\frac{S.S.Wr - b \times S.P.Wr\,Vr}{(p-2)S.S.Vr}}$$

where,

S.S. denots sum of squares and S.P. the sum of product. The slope of the regression line 'b' and the Y– intercept 'a' were obtained from the relationship

$$Wr = a + b\overline{Vr} \text{ or say}$$

$$a = Wr - b\overline{Vr}\text{, and}$$

$$b = \frac{Co\text{-}var.\,Vr\,Wr}{Var.\,Vr}$$

The significance of 'b' from zero and from unity was tested by using 't' values of (b-0)/SE (b) and (1-b)/SE (b) with (p-2) degree of freedom.

3.5.11 Standardized deviation graph

The standard deviation graphs were drawn according to Johnson and Aksel (1959). The standardized deviation of Yr, the parental measurement and (Wr+Vr), the parental orders of dominance were computed by the formula:

$$\overline{Y}_{ri} = \frac{X_i - \overline{X}}{S}$$

where,

$\overline{Y}_{ri}$ = standardized values of parental means

X_i = value of the individual parent,

$\overline{X}$ = the mean of the parent, and

S = the standard deviation

The values of $\overline{Y}_{ri}$ were taken on the X-axis and those of (Wr + Vr) on Y-axis for plotting standardized deviation graphs.

3.5.12 Assumptions of interpretations

The valid inferences from diallel cross analysis can only be drawn when, the following assumptions are satisfied:

1. Diploid segregation
2. independent action of non-allelic genes,
3. homozygous parents,
4. genes independently distributed between the parents,
5. no maternal effects/reciprocal differences, and
6. no multiple allelism.

The validity of above hypothesis was tested by the significance of t^2

cal. 'F' value. $= \frac{t^2}{N-1} \times \frac{N-P}{p}$

For F; P, (N–P) degree of freedom (df)

where,

P = parents,

N = parents x replications.

3.5.13 Estimation of components of genetic variation

Hayman (1954, 1958) gave the following exceptions for the statistics calculated from a diallel table:

$$F_1 = V_0L_0 = \overline{V}_p = D + E$$

$$W_0L_1 = \overline{W}r = ½ D + ¼ F + E/n$$

$$V_1L_1 = \overline{V}r = ¼ D + ¼ F + ¼ H_1 + \frac{n-1}{2n} E$$

$$V_0L_1 = Vm = ¼ D - ¼ F + ¼ H_1 - ¼ H_2 + E/2n$$

The expected values of the components of variation obtained by the least squares are as follow:

$$D = V_0L_0 - E$$

$$F = 2V_0L_0 - 4 W_0L_{01} - 2 (n-2) E/n$$

$$H_1 = V_0L_0 - 4 W_0L_{01} + 4 V_1L_1 - (3n-2) E/n$$

$$H_2 = 4 V_1L_1 - 4 V_0L_1 - 2E$$

where,

V_0L_0 = Variance of the parents $\overline{V}p$,

W_0L_{01} = the mean covariance between parents and the arrays ($\overline{Wr}$),

V_1L_1 = the mean variance of the arrays ($\overline{V}r$),

V_0L_1 = the variance of the means of the arrays (Vm),

E = environmental or non-heritable variation associated with individual means and was calculated from the analysis of variance of the design of experiments,

D = component of variance attributed to additive effect of genes,

H_1 = component of variance attributed to dominance effects,

F = covariance of additive and non-additive effects in all arrays, has a positive or negative sign depending upon whether dominant genes or recessive genes were more,

H_2 = component of variance attributed to non-additive effects corrected for gene distribution,

= $H_1 [1 - (u-v)^2]$

where,

u = proportion of positive genes in the parents,

v = proportion of negative genes in the parents (or proportion of the genes with positive/negative effects), and

u + v = 1

In order to estimate the accuracy of these genetic components of variation listed above, the equation used is ½ var (Wr – Vr) = S^2, and the terms of the main diagonal of covariance matrix given by Hayman (1954), as corresponding multipliers. The formulae were used in computing the standard errors:

$$\text{SE of D} = \pm\sqrt{\frac{S^2(n^5+n^4)}{n^5}}$$

$$\text{SE of F} = \pm\sqrt{\frac{S^2(4n^5+20n^4-16n^3-16n^2)}{n^5}}$$

$$\text{SE of } H_1 = \pm\sqrt{\frac{S^2(n^5+41n^4-12n^3-4n^2)}{n^5}}$$

$$\text{SE of } H_2 = \pm\sqrt{\frac{S^2(36n^4)}{n^5}}$$

$$\text{SE of E} = \pm\sqrt{\frac{S^2 n^4)}{n^5}}$$

If the value of the parameters divided by its standard error exceeds 1.96, then it is significant and vice-versa. After testing the significance of components of D, H_1, H_2 and F, the following estimates were calculated:

1. Dominance ratio or mean degree of dominance = $\sqrt{H_1/D}$

2. The proportion of dominant and recessive genes in parents

$$= \text{KD/KR} = \frac{\sqrt{(4DH_1)+F}}{\sqrt{(4DH_1)-F}}$$

3. Relative distribution of positive (increasing) and negative (decreasing) genes among the common parents of arrays or the mean value of u, v over all loci = $H_2/4H_1$, where u refers to the frequency of dominant alleles and v to the recessive alleles.

4. Heritability (broad sense) = $\frac{1/2D+1/4H_1}{1/2D+1/4H_1E} \times 100$

5. Heritability (narrow sense) = $\frac{1/2D+1/2H_1-1/2H_2-1/2F}{1/2D+1/2H_1-1/4H_2-1/2F+E} \times 100$

where,

D = additive variance, and

H_1, H_2 = dominance variance

RESULTS

EXPERIMENTAL RESULTS

The results obtained from the present investigation entitled, **"Genetic analysis of some horticultural traits in Garden Pea (*Pisum sativum* L.)"** are presented trait-wise as under:

4.1 Diallel analysis

a) Mean performance and heterotic response

b) Combining ability effects

c) Graphical analysis

d) Components of genetic variation

4.1.1 Analysis of variance for experimental design

The analysis of variance for days to 50% flowering, days to first picking, duration of availability of marketable pods, pod length, pod width, seeds per pod, shelling percentage, pods per plant, branches per plant, plant height, pod yield per plant and total soluble solids is presented in Table 1. The variances due to treatments were found significant for all the traits studied. However, the variances due to replications were non-significant for all the traits studied except for pods per plant and plant height.

Further partitioning of the total variance into parents, F_1s, parents vs. F_1s and replications revealed that mean squares due to parents and hybrids

Table 1: Analysis of variance for design of experiment (RBD)

Source of variation		**Mean squares**	
Character	**Replication**	**Treatment**	**Error**
df	**2**	**27**	**54**
Days to 50% flowering	9.705	48.224*	12.207
Days to first picking	8.905	147.783*	25.141
Duration of availability of marketable pods	0.035	67.687*	6.430
Pod length	0.003	1.714*	0.138
Pod width	0.001	0.005*	0.0009
Seeds per pod	0.125	1.063*	0.078
Shelling percentage	3.726	27.492*	3.541
Pods per plant	12.520*	30.381*	3.432
Branches per plant	0.005	1.714*	0.043
Plant height	61.466*	168.247*	17.583
Pod yield per plant	309.625	1327.565*	99.212
Total soluble solids	0.193	1.234*	0.202

*Significant at 5% level of significance

Table 2: Analysis of variance for combining ability

Source of variation		**GCA**	**SCA**	**Error**
Character	**df**	**6**	**21**	**54**
Days to 50% flowering		43.301*	8.296*	4.069
Days to first picking		99.680*	34.855*	8.380
Duration of availability of marketable pods		64.763*	10.505*	2.143
Pod length		1.592*	0.279*	0.046
Pod width		0.004*	0.001*	0.0003
Seeds per pod		0.901*	0.198*	0.026
Shelling percentage		12.637*	8.171*	1.180
Pods per plant		27.989*	5.023*	1.144
Branches per plant		1.262*	0.374*	0.014
Plant height		64.692*	53.622*	5.861
Pod yield per plant		1252.992*	210.958*	33.070
Total soluble solids		0.469*	0.395*	0.067

*Significant at 5% level of significance

were significant for all the traits except mean squares due to parents for days to first picking and total soluble solids. However, the mean squares due to parents vs. hybrids revealed significant differences for all the traits except for shelling percentage, duration of availability of marketable pods and branches per plant (*Appendix II*).

4.1.2 Analysis of variance for combining ability

The mean squares due to GCA indicated significant differences for all the characters *viz.,* days to 50% per flowering, days to first picking, duration of availability of marketable pods, pod length, pod width, seeds per pod, shelling percentage, pods per plant, branches per plant, plant height, pod yield per plant and total soluble solids. The mean squares due to SCA were found significant for all the traits studied (Table 2).

The mean performance of the parents for all the characters studied has been presented in Appendix III.

1. Days to 50 per cent flowering

a) Mean performance and heterotic response

The mean performance of the parents, F_1s and per cent increase/ decrease over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89) has been presented in Appendix III (Table 3). The mean performance of the parents and F_1s for days to 50 per cent flowering ranged from 71.43 (Pb-89) to 80.97 days (DPLMR-41) and 64.97 (Azad Pea-1 x Pb-89) to 79.77 days (Palam Priya x Lincoln), respectively.

Table 3: Mean performance of hybrids and per cent heterotic response for days to 50% flowering

Hybrid	Mean	Per cent increase or decrease in F_1 over			
		Mid parent	Better parent	Standard check 1	Standard check 2
Palam Priya × Azad Pea-1	73.53	-4.42	-1.43	-7.23*	2.94
Palam Priya × Lincoln	**79.77**	-0.13	0.63	**0.63**	**11.67***
Palam Priya × DPP 9418-06	74.97	-0.68	4.56	-5.42	4.95
Palam Priya × DPP-3	77.07	-2.45	-2.12	-2.78	7.89*
Palam Priya × DPPLMR-41	75.50	-5.76	-4.75	-4.75	5.69
Palam Priya × Pb-89	68.87	-8.60*	-3.59	-13.12*	-3.59
Azad Pea-1 × Lincoln	77.47	-0.09	3.84	-2.27	8.45*
Azad Pea-1 × DPP 9418-06	70.03	-4.26	-2.32	-11.65*	-1.96
Azad Pea-1 × DPP-3	72.40	-5.57	-2.95	-8.66*	1.35
Azad Pea-1 × DPPLMR-41	74.97	-3.62	0.49	-5.42	4.95
Azad Pea-1 × Pb-89	**64.97**	**-11.02***	**-9.05***	**-18.04***	**-9.05***
Lincoln × DPP 9418-06	72.57	-4.62	1.21	-8.45*	1.59
Lincoln × DPP-3	77.37	-2.81	-1.74	-2.40	8.31*
Lincoln × DPPLMR-41	75.10	-6.96*	-6.67	-5.26	5.13
Lincoln × Pb-89	74.33	-2.13	4.06	-6.22	4.06
DPP 9418-06 × DPP-3	77.90	**3.57**	8.65*	-1.72	9.05*
DPP 9418-06 × DPPLMR-41	78.63	3.01	**9.67***	-0.80	10.08*
DPP 9418-06 × Pb-89	67.33	-5.92	-5.74	-15.05*	-5.74
DPP-3 × DPPLMR-41	74.87	-6.24*	-4.91	-5.55	4.81
DPP-3 × Pb-89	72.10	-3.97	0.93	-9.04*	0.93
DPPLMR-41 × Pb-89	77.77	2.06	8.87*	-1.89	8.87*
SE ±	2.02	2.47	2.85	2.85	2.85

*Significant at 5% level of significance

Table 4: General and specific combining ability effects for days to 50% flowering

Parents	1	2	3	4	5	6	7	GCA
1	2.289	-0.593	1.756	0.589	-0.015	-2.648	-3.667*	1.084
2		3.326*	2.307	-1.493	-1.830	-0.330	-4.715*	-1.768*
3			1.422	-2.844	-0.748	-4.081*	0.767	2.117*
4				-0.078	3.419	3.085	-2.600	-1.516*
5					1.548	-3.385	-0.537	1.188
6						1.648	4.063*	2.255*
7							3.340*	-3.360*

Standard errors

SE (U) = ± 0.381

SE (gi) = ± 0.622

SE (sii) = ± 1.540

SE (sij) = ± 1.810

SE (gi-gj) = ± 0.950

SE(sii-sjj) = ± 2.126

SE (sij-sik) = ± 2.689

SE (sij-skl) = ± 2.515

Since, earliness is an important attribute in vegetable crops, hence heterosis in the negative direction is desirable for days to 50 per cent flowering. The range of heterosis over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89) varied from -11.02 (Azad Pea-1 x Pb-89) to 3.57% (DPP 9418-06 x DPP-3), -9.05 (Azad Pea-1 x Pb-89) to 9.67% (DPP 9418-06 x DPPLMR-41), -18.04 (Azad Pea-1 x Pb-89) to 0.63% (Palam Priya x Lincoln) and -9.05 (Azad Pea-1 x Pb-89) to 11.67% (Palam Priya x Lincoln), respectively. Out of 21 crosses, four over mid parent, one each over better parent and standard check 2 (Pb-89) and seven over standard check 1 (Palam Priya) displayed significant negative heterosis. Maximum heterosis to the extent of -9.05% both over better parent and standard check 2 (Pb-89) and -18.04% over standard check 1 (Palam Priya) was recorded in the cross, Azad Pea-1 x Pb-89. The remaining crosses had either positive significant/non-significant or negative non-significant values for heterosis.

b) Combining ability effects

The genotypes, Azad Pea-1, DPP 9418-06 and Pb-89 exhibited significant negative GCA effects, indicating their good general combining ability. However, the genotypes, Lincoln and DPPLMR-41 exhibited significant positive effects which exhibited their poor general combining ability, whereas the parents Palam Priya and DPP-3 exhibited non-significant effects, thus rated as average general combiners for days to 50 per cent flowering (Table 4).

The best specific crosses exhibiting significant negative specific combining ability effects were Azad Pea-1 x Pb-89, Lincoln x DPPLMR-41 and Palam Priya x Pb-89. However, the cross combination DPPLMR-41 x Pb-89

DAYS TO 50% FLOWERING

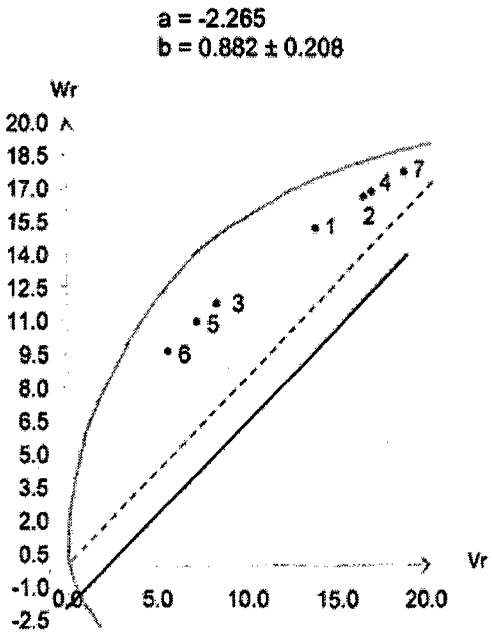


Fig.1a

DAYS TO FIRST PICKING

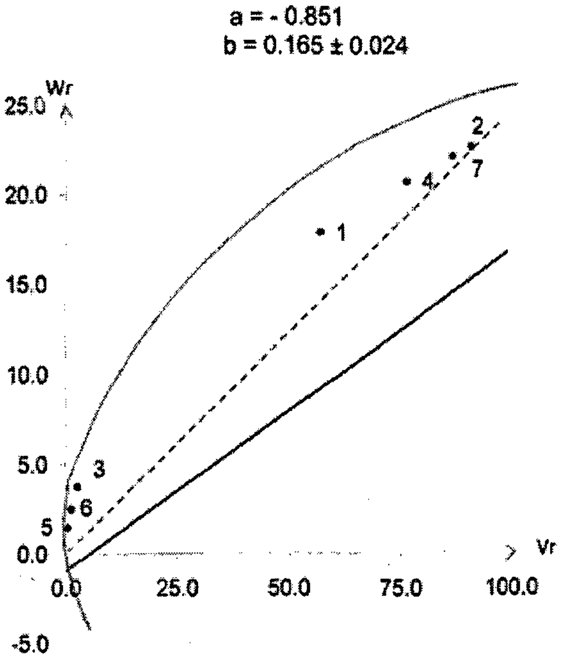


Fig.2a

Vr, Wr GRAPH

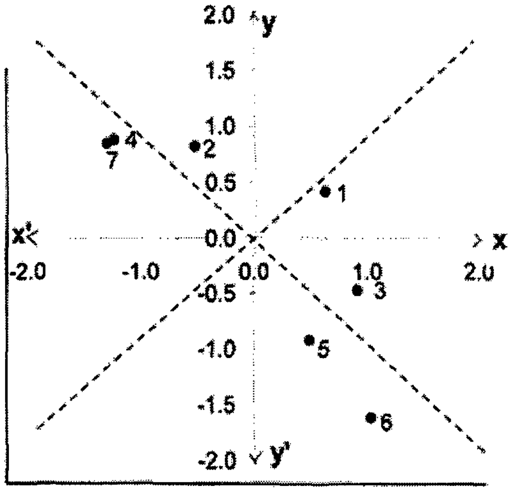


Fig.1b

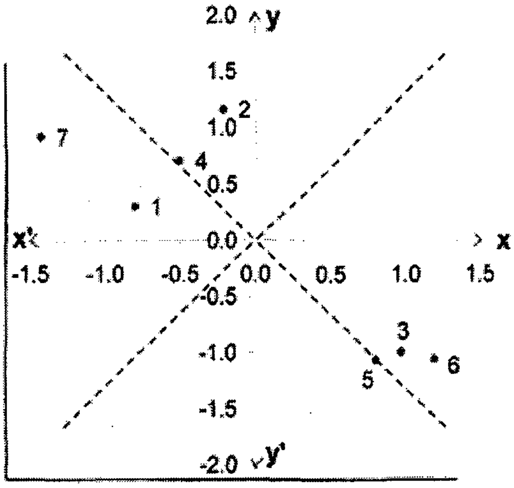


Fig.2b

STANDARDIZED DEVIATION GRAPH

Table 5: Estimation of components of genetic variation for days to 50% flowering and days to first picking

Parameter	Days to 50% flowering	Days to first picking
t^2	0.001	4.252
D	12.67* ± 1.94	-2.59 ± 26.74
H_1	20.70* ± 4.67	130.54* ± 64.384
H_2	21.22* ± 4.11	100.72 ± 56.73
F	-7.19 ± 4.65	-33.73 ± 64.15
E	4.04* ± 0.68	8.19 ± 9.45
Mean degree of dominance $(H_1/D)^{1/2}$	1.278	7.094
$H_2/4H_1$	0.256	0.193
KD/KR	0.637	0.044
Correlation coefficient between (Wr+Vr) and Yr	0.884	0.953
Regression (b)	0.882 ± 0.20	0.165 ± 0.02
Heritability (broad sense)	74.02	79.28
(narrow sense)	20.97	10.79

*Significant at 5% level of significance

exhibited significant positive value showing its poor specific combining ability. The other crosses had either positive/negative non-significant values, considered as average specific cross combinations for this trait.

c) Graphical analysis

The graphical analysis of the data on days to 50 per cent flowering is presented in Fig. 1a. The non-significance of 't^2' value in F_1 indicated that Wr, Vr values were homogeneous and satisfied the assumptions of diallel analysis. The 'b' value was high in magnitude (0.882 ± 0.20), which suggested the absence of non-allelic interaction. The regression line intersected Wr-axis below the origin, indicating over-dominance. The genotypes, Lincoln, DPPLMR-41 and DPP-3 appeared to have more number of dominant genes. The parents, Pb-89 and DPP 9418-06 had the maximum concentration of recessive genes and the rest of the parents *viz.*, Azad Pea-1 and Palam Priya had equal proportion of dominant and recessive genes controlling days to 50 per cent flowering.

The standardized deviation graph of Yr and Wr + Vr (Fig. 1b) revealed that the parental lines Pb-89, DPP 9418-06 and Azad Pea-1 possessed most of the recessive genes with negative effect on days to 50 % flowering. The parent, Palam Priya had majority of the recessive genes with positive effect. On the other hand, the parents Lincoln, DPP-3 and DPPLMR-41 contained majority of the dominant genes with positive effect on this trait.

d) Components of genetic variation

The estimates of components of genetic variation for days to 50 per cent flowering are given in Table 5. Both additive (D) and non-additive components (H_1 and H_2) were found significant but the relative magnitude of dominant components was more in comparison to additive component, which reflected the predominant role of non-additive genes in the expression of this trait. The value of 'F' was found to be negative and non-significant, which indicated that the parents had more of the recessive genes. The mean degree of dominance showed over-dominance. The ratio of $H_2/4H_1$, suggested symmetrical distribution of dominant and recessive genes in parents. The KD/KR ratio was less than unity which indicated that the frequency of recessive genes was more than dominant genes in the parents.

The correlation coefficient between Wr + Vr and Yr was positive and higher in magnitude, which showed that higher proportion of recessive genes was associated with positive effect on days to 50% flowering. The heritability estimates were high (74.02%) and low (20.97%) in broad and narrow sense, respectively.

2. Days to first picking

a) Mean performance and heterotic response

The mean performance of the parents, F_1s and per cent increase/decrease over mid parent, better parent and standard checks (Palam Priya and Pb-89) are presented in Appendix III (Table 6). The mean performance of parents varied from 110.63 (Pb-89) to 116.83 days (DPLMR-41) and F_1s from 92.93 (Azad Pea-1 x Pb-89) to 115.57 days (Palam Priya x DPPLMR-41).

Early maturing genotypes are more desirable in vegetable crops, more attention is given towards negative heterosis for this trait. The range of heterosis varied from -17.07 (Azad Pea-1 x Pb-89) to 2.06% (Palam Priya x DPP 9418-06), -16.0 (Azad Pea-1 x Pb-89) to 4.13% (DPPLMR-41 x Pb-89), -17.10 (Azad Pea-1 x Pb-89) to 3.09% (Palam Priya x DPPLMR-41) and -16.0 (Azad Pea-1 x Pb-89)

Table 6: Mean performance of hybrids and per cent heterotic response for days to first picking

Hybrid	Mean	Per cent increase or decrease in F_1 over			
		Mid parent	Better parent	Standard check 1	Standard check 2
Palam Priya × Azad Pea-1	99.03	-12.20*	-12.75*	-11.66*	-10.49*
Palam Priya × Lincoln	114.43	0.20	2.08	2.08	3.43
Palam Priya × DPP 9418-06	114.77	**2.06**	1.74	2.38	3.74
Palam Priya × DPP-3	114.73	0.64	-1.01	2.35	3.71
Palam Priya × DPPLMR-41	**115.57**	0.96	3.09	**3.09**	**4.46**
Palam Priya × Pb-89	98.93	-11.16*	-10.58*	-11.75*	-10.58*
Azad Pea-1 × Lincoln	111.83	-2.67	-1.47	-0.24	1.08
Azad Pea-1 × DPP 9418-06	96.23	-14.95*	-14.69*	-14.15*	-13.02*
Azad Pea-1 × DPP-3	114.67	-0.03	1.03	2.29	3.65
Azad Pea-1 × DPPLMR-41	114.17	-0.87	0.59	1.84	3.19
Azad Pea-1 × Pb-89	**92.93**	**-17.07***	**-16.00***	**-17.10***	**-16.00***
Lincoln × DPP 9418-06	115.33	0.68	2.25	2.88	4.25
Lincoln × DPP-3	115.03	-0.92	-0.75	2.62	3.98
Lincoln × DPPLMR-41	114.40	-1.86	-1.63	2.05	3.40
Lincoln × Pb-89	112.40	-0.94	1.60	0.27	1.60
DPP 9418-06 × DPP-3	114.40	0.04	1.42	2.05	3.40
DPP 9418-06 × DPPLMR-41	113.77	-0.91	0.86	1.49	2.83
DPP 9418-06 × Pb-89	96.50	-13.62*	-14.45*	-13.92*	-12.77*
DPP-3 × DPPLMR-41	114.27	-1.80	-1.41	1.93	3.28
DPP-3 × Pb-89	113.97	0.62	3.01	1.67	3.01
DPPLMR-41 × Pb-89	115.20	1.29	**4.13**	2.77	4.13
SE ±	2.89	3.54	4.09	4.09	4.09

*Significant at 5% level of significance

Table 7: General and specific combining ability effects for days to first picking

Parents	1	2	3	4	5	6	7	GCA
1	2.581	-7.619*	1.095	5.810*	1.081	1.673	-7.201*	-0.787
2		9.714*	1.362	-9.856*	3.881	3.140	-10.334*	-3.654*
3			-0.856	2.558	-2.438	-3.312	2.447	3.031*
4				4.406*	1.310	0.436	-9.071*	-1.350
5					-1.886	-3.760	3.699	3.346*
6						-1.434	4.692	3.587*
7							-7.884*	-4.172*

Standard errors

SE (U) = ± 0.547
SE (gi) = ± 0.893
SE (sii) = ± 2.211
SE (sij) = ± 2.598
SE (gi-gj) = ± 1.364
SE(sii-sjj) = ± 3.051
SE (sij-sik) = ± 3.960
SE (sij-skl) = ± 3.610

to 4.46% (Palam Priya x DPPLMR-41) over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89), respectively. Out of 21 crosses, five hybrid combinations *viz.,* Azad Pea-1 x Pb-89, Azad Pea-1 x DPP 9418-06, DPP 9418-06 x Pb-89, Palam Priya x Azad Pea-1 and Palam Priya x Pb-89, each over mid parent, better parent, standard check 1 and standard check 2 exhibited significant negative heterosis for days to first picking. The maximum average heterosis (-17.07%), heterobeltiosis (-16.0%) and standard heterosis (-17.10 and -16.0%) was recorded in a cross combination Azad Pea-1 x Pb-89.

b) Combining ability effects

The genotypes Pb-89 and Azad Pea-1 were observed to be the good general combiners as these displayed significant negative GCA effects. The parental lines Lincoln, DPP-3 and DPPLMR-41 were the poor general combiners as was evident from their significant positive GCA effects (Table 7).

Out of 21 cross combinations, five combinations exhibited significant negative SCA effects and were rated as good specific cross combinations. The top most hybrid combinations in order of merit were Azad Pea-1 x Pb-89, Azad Pea-1 x DPP 9418-06, DPP 9418-06 x Pb-89, Palam Priya x Azad Pea-1 and Palam Priya x Pb-89.

c) Graphical analysis

The graphical analysis for days to first picking is presented in Fig. 2a. The non-significance of 't^2' showed that Wr, Vr values were homogeneous and satisfied the assumptions of diallel analysis. The slope of regression of Wr on Vr was low (0.165 ± 0.024), indicating the presence of inter-allelic interactions. The position of regression line showed over-dominance as it intersected Wr axis below the point of origin. The genotypes, Azad Pea-1, Pb-89 and DPP 9418-06 had the maximum concentration of recessive genes, whereas DPP-3, DPPLMR-41 and Lincoln contained more of the dominant genes as indicated from their position in Wr, Vr graph.

From the standardized deviation graph of Yr and Wr + Vr (Fig. 2b), it was evident that the parental genotypes, Pb-89, DPP 9418-06, Palam Priya and Azad Pea-1 had excess of recessive genes with decreasing effect on days to first picking. However, DPPLMR-41, Lincoln and DPP-3 possessed more of dominant genes with positive effect on this character.

d) Components of genetic variation

The estimates of components of genetic variation for days to first picking are given in Table 5. The non-additive component (H_1) was found to be significant which clearly indicated the predominant role of non-additive gene action in the inheritance of this trait. Negative non-significant 'F' value indicated the presence of more recessive genes in the parents. The mean degree of dominance $(H_1/D)^{1/2}$ was in the over-dominance range. The ratio of $H_2/4H_1$ was far away from the expected value of 0.25 which suggested the asymmetrical distribution of dominant and recessive genes in the parents. The ratio of KD/KR deviated from unity and was low in magnitude which reflected that the parents contained more of recessive genes in the manifestation of this trait.

The correlation coefficient between Wr + Vr and Yr values was positive, suggesting directional dominance towards recessive genes. The heritability estimates were fairly high (79.28) and low (10.79) in broad and narrow sense, respectively.

3. Duration of availability of marketable pods (days)

a) Mean performance and heterotic response

The mean values of parents, F_1s and per cent increase/decrease of F_1s mean over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89) are given in Appendix III (Table 8). For this character, the mean performance of the parents and F_1s varied from 33.67 (Lincoln) to 46.67 days (Pb-89) and 34.33 (Palam Priya x DPP-3) to 53.00 days (Azad Pea-1 x Pb-89), respectively.

Extended duration of availability of marketable pods is an important attribute for getting higher yield, hence heterosis in positive direction is desirable for this trait. The magnitude of heterosis for duration of availability of marketable pods ranged from -14.88 (Palam Priya x DPP-3) to 18.66% (Azad Pea-1 x Pb-89), -15.57 (Palam Priya x DPP-3) to 13.57% (Azad Pea-1 x Pb-89), -14.17 (Palam Priya x DPP-3) to 32.50% (Azad Pea-1 x Pb-89) and -26.43 (Palam Priya x DPP-3) to 13.57% (Azad Pea-1 x Pb-89) over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89), respectively. Out of 21 F_1 hybrids, four over mid parent, two over better parent, five over standard check 1 (Palam Priya) and one over standard check 2 (Pb-89) had significant positive heterosis for this trait. Hybrid vigour to the extent of 32.50 and 13.57 per cent was exhibited by the cross Azad Pea-1 x Pb-89 over both the standard checks (Palam Priya and Pb-89).

b) Combining ability effects

The parents, Pb-89 and Azad Pea-1 were rated as the good general combiners, whereas Lincoln, Palam Priya and DPP-3 were the poor general

Table 8: Mean performance of hybrids and per cent heterotic response for duration of availability of marketable pods (days)

Hybrid	Mean	Per cent increase or decrease in F_1 over			
		Mid parent	Better parent	Standard check 1	Standard check 2
Palam Priya × Azad Pea-1	41.67	0.81	-2.34	4.17	-10.71*
Palam Priya × Lincoln	36.00	-2.26	-10.00	-10.00	-22.86*
Palam Priya × DPP 9418-06	37.33	-8.57*	-10.40*	-6.67	-20.00*
Palam Priya × DPP-3	**34.33**	**-14.88***	**-15.57***	**-14.17***	**-26.43***
Palam Priya × DPPLMR-41	38.67	-2.52	-3.33	-3.33	-17.14*
Palam Priya × Pb-89	49.00	13.08*	5.00	22.50*	5.00
Azad Pea-1 × Lincoln	36.00	-5.68	-15.63*	-10.00	-22.86*
Azad Pea-1 × DPP 9418-06	47.00	11.46*	10.16*	17.50*	0.71
Azad Pea-1 × DPP-3	36.00	-13.60*	-15.63*	-10.00	-22.86*
Azad Pea-1 × DPPLMR-41	46.67	13.82*	9.38	16.67*	0.00
Azad Pea-1 × Pb-89	**53.00**	**18.66***	**13.57***	**32.50***	**13.57***
Lincoln × DPP 9418-06	39.67	5.31	-4.80	-0.83	-15.00*
Lincoln × DPP-3	39.67	6.73	-2.46	-0.83	-15.00*
Lincoln × DPPLMR-41	35.67	-2.28	-9.32	-10.83*	-23.57*
Lincoln × Pb-89	42.33	5.39	-9.29*	5.83	-9.29*
DPP 9418-06 × DPP-3	36.00	-12.55*	-13.60*	-10.00	-22.86*
DPP 9418-06 × DPPLMR-41	41.00	1.23	-1.60	2.50	-12.14*
DPP 9418-06 × Pb-89	46.67	5.66	0.00	16.67*	0.00
DPP-3 × DPPLMR-41	40.00	0.01	-1.64	0.00	-14.29*
DPP-3 × Pb-89	44.00	0.76	-5.71	10.00	-5.71
DPPLMR-41 × Pb-89	41.67	-3.10	-10.71*	4.17	-10.71*
SE ±	1.46	1.79	2.07	2.07	2.07

*Significant at 5% level of significance

Table 9: General and specific combining ability effects for duration of availability of marketable pods

Parents	1	2	3	4	5	6	7	GCA
1	1.417	-0.102	-0.324	-2.806*	-3.620*	-0.509	4.528*	-1.190*
2		-2.287*	-3.509*	3.676*	-5.139*	4.306*	5.343*	1.995*
3			-0.398	1.787	3.972*	-1.250	0.120	-3.450*
4				-0.028	-3.509*	0.269	0.639	0.365
5					3.343*	1.454	0.157	-1.820*
6						-0.435	-3.398*	0.598
7							-3.694*	4.698*

Standard errors

SE (U) = ± 0.276

SE (gi) = ± 0.451

SE (sii) = ± 1.118

SE (sij) = ± 1.314

SE (gi-gj) = ± 0.690

SE(sii-sjj) = ± 1.543

SE (sij-sik) = ± 1.952

SE (sij-skl) = ± 1.826

combiners. The average general combiners for this trait were DPPLMR-41 and DPP 9418-06 (Table 9).

The best specific cross combinations were Azad Pea-1 x Pb-89, Palam Priya x Pb-89, Azad Pea-1 x DPPLMR-41, Lincoln x DPP-3 and Azad Pea-1 x DPP 9418-06, as these combinations displayed significant positive SCA effects.

c) Graphical analysis

The graphical presentation of the trait duration of availability of marketable pods is given in Fig. 3a. The non-significance of 't^2' value revealed that Wr, Vr values were homogeneous and satisfied the assumptions of diallel analysis. The 'b' value was low to medium (0.398 ± 0.11), suggesting the prevalence of inter-allelic interactions in the expression of this trait. The regression line intersected Wr-axis below the origin, indicating over-dominance. The position of the parental arrays indicated that Azad Pea-1 contained more of recessive genes, whereas Lincoln and DPPLMR-41 had more of the dominant genes for this trait.

The standardized deviation graph (Fig. 3b) showed that Azad Pea-1 had more of recessive genes with positive effect, whereas Pb-89, DPP 9418-06 and DPP-3 had more of dominant genes with positive effect and Lincoln, DPPLMR-41 had more of dominant genes with negative effect on duration of availability of marketable pods.

d) Components of genetic variation

The estimates of components of genetic variation and various statistics derived are presented in Table 10. All the components of variance (D, H_1 and H_2) were found significant. The magnitudes of dominance variances (H_1 and H_2)

DURATION OF AVAILABILITY OF MARKETABLE PODS

$a = -3.066$
$b = 0.398 \pm 0.113$

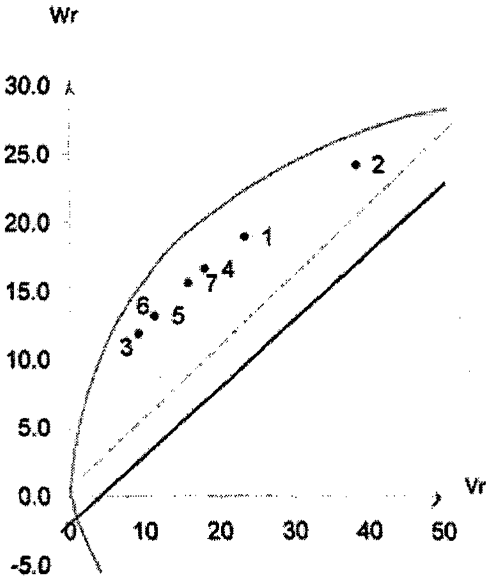


Fig.3a

POD LENGTH

$a = -0.064$
$b = 0.770 \pm 0.244$

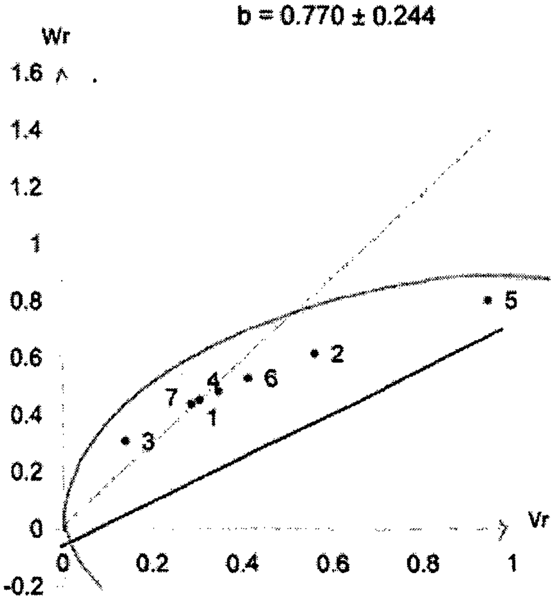


Fig.4a

Vr, Wr GRAPH

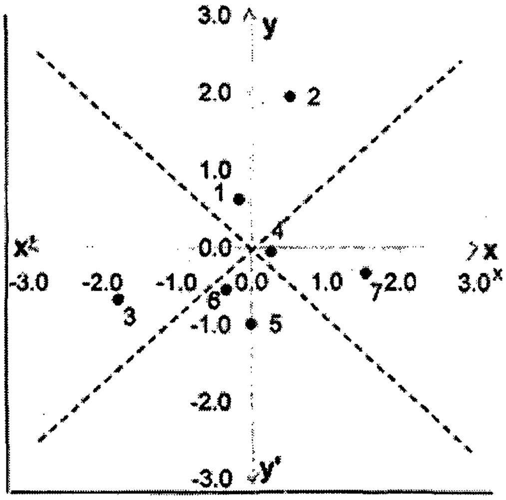


Fig.3b

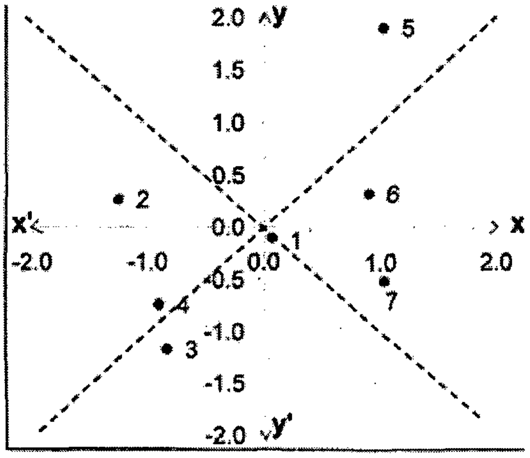


Fig.4b

STANDARDIZED DEVIATION GRAPH

Table 10: Estimation of components of genetic variation for duration of availability of marketable pods (days) and pod length (cm)

Parameter	Duration of availability of marketable pods	Pod length
t^2	11.85	0.05
D	13.30* ± 4.95	0.63* ± 0.12
H_1	41.21* ± 11.91	1.20* ± 0.28
H_2	33.93* ± 10.49	0.81* ± 0.25
F	-13.39 ± 11.87	0.22 ± 0.28
E	2.07 ± 1.75	0.04 ± 0.04
Mean degree of dominance $(H_1/D)^{½}$	1.76	1.38
$H_2/4H_1$	0.20	0.17
KD/KR	0.55	1.29
Correlation coefficient between (Wr+Vr) and Yr	0.84	0.82
Regression (b)	0.39 ± 0.11	0.77 ± 0.24
Heritability (broad sense)	89.12	93.89
(narrow sense)	25.41	71.88

*Significant at 5% level of significance

were higher in comparison to additive variance (D), indicating predominant role of non-additive gene action in the expression of this trait. The 'F' value was negative and non-significant which indicated the frequency of more recessive genes in the parents. Mean degree of dominance revealed the presence of over-dominance. The ratio of $H_2/4H_1$ was less than the expected value of 0.25, which reflected the asymmetrical distribution of dominant and recessive genes in the parents. The ratio of KD/KR was 0.55 which suggested that the parents contained more number of recessive genes than their dominant counterparts.

Positive correlation coefficient of Yr with Wr + Vr (0.84) indicated the tendency of high expression of the character to be associated with recessive genes. The character had depicted high broad sense and low narrow sense heritability estimates.

4) Pod length (cm)

a) Mean performance and heterotic response

The mean performance of the parents, F_1s, per cent increase/decrease over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89) are presented in Appendix III (Table 11). The mean performance of the parents ranged from 7.57 (Azad Pea-1) to 9.45 cm (Pb-89) and F_1s from 7.31 (Lincoln x DPP-3) to 9.95 cm (DPP-3 x Pb-89).

The magnitude of heterosis for pod length ranged from -15.81 (Lincoln x DPP-3) to 15.19% (Azad Pea-1 x DPP 9418-06), -22.60 (Lincoln x DPP-3) to 13.06% (Azad Pea-1 x DPP 9418-06), -15.56 (Lincoln x DPP-3) to 14.95% (DPP-3 x PB-89) and -22.68 (Lincoln x DPP-3) to 5.26% (DPP-3 x Pb-89) over mid

Table 11: Mean performance of hybrids and per cent heterotic response for pod length (cm)

Hybrid	Mean	Per cent increase or decrease in F_1 over			
		Mid parent	Better parent	Standard check 1	Standard check 2
Palam Priya × Azad Pea-1	8.11	0.02	-6.24	-6.24	-14.14*
Palam Priya × Lincoln	7.49	-9.60*	-13.44*	-13.44*	-20.74*
Palam Priya × DPP 9418-06	7.66	-7.23*	-11.48*	-11.48*	-18.94*
Palam Priya × DPP-3	8.35	-7.66*	-11.51*	-3.47	-11.60*
Palam Priya × DPPLMR-41	8.44	-6.12*	-9.54*	-2.43	-10.65*
Palam Priya × Pb-89	9.07	0.24	-3.99	4.85	-3.99
Azad Pea-1 × Lincoln	7.74	-0.04	-2.23	-10.55*	-18.10*
Azad Pea-1 × DPP 9418-06	8.89	**15.19***	**13.06***	2.70	-5.96
Azad Pea-1 × DPP-3	8.33	-2.10	-11.79*	-3.78	-11.89*
Azad Pea-1 × DPPLMR-41	7.88	-6.72*	-15.54*	-8.90*	-16.58*
Azad Pea-1 × Pb-89	9.70	13.98*	2.65	12.10*	2.65
Lincoln × DPP 9418-06	7.68	-2.60	-2.95	-11.21*	-18.69*
Lincoln × DPP-3	**7.31**	**-15.81***	**-22.60***	**-15.56***	**-22.68***
Lincoln × DPPLMR-41	7.47	-13.43*	-20.00*	-13.71*	-20.99*
Lincoln × Pb-89	8.43	-2.92	-10.79*	-2.58	-10.79*
DPP 9418-06 × DPP-3	7.45	-13.91*	-21.12*	-13.94*	-21.20*
DPP 9418-06 × DPPLMR-41	8.48	-1.32	-9.11*	-1.96	-10.23*
DPP 9418-06 × Pb-89	8.78	1.44	-7.09*	1.46	-7.09*
DPP-3 × DPPLMR-41	8.86	-5.65*	-6.18	2.35	-6.28*
DPP-3 × Pb-89	**9.95**	5.31	5.26	**14.95***	**5.26**
DPPLMR-41 × Pb-89	8.95	-4.67	-5.26	3.47	-5.26
SE ±	0.22	0.26	0.30	0.30	0.30

*Significant at 5% level of significance

Table12: General and specific combining ability effects for pod length

Parents	1	2	3	4	5	6	7	GCA
1	0.424*	-0.044	-0.241	-0.372*	-0.174	-0.044	0.028	-0.086
2		-0.515*	0.081	0.927*	-0.128	-0.531*	0.726*	-0.158*
3			0.685*	0.150	-0.722*	-0.521*	-0.117	-0.585*
4				0.026	-0.883*	0.194	-0.068	-0.284*
5					0.615*	0.072	0.604*	0.211*
6						0.589*	-0.349	0.171*
7							-0.412*	0.730*

Standard errors

SE (U)	= ± 0.041
SE (gi)	= ± 0.066
SE (sii)	= ± 0.164
SE (sij)	= ± 0.193
SE (gi-gj)	= ± 0.101
SE(sii-sjj)	= ± 0.226
SE (sij-sik)	= ± 0.286
SE (sij-skl)	= ± 0.268

parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89), respectively. Out of the 21 crosses, two over mid parent, one over better parent and two over standard check 1 (Palam Priya) exhibited significant positive heterosis for pod length.

The hybrids exhibiting maximum significant positive heterosis over better parent and standard check 1 (Palam Priya) were Azad Pea-1 x DPP 9418-06 (13.06%) and DPP-3 x Pb-89 (14.95%), respectively. None of the hybrid combination could exhibit significant positive heterosis over standard check 2 (Pb-89).

b) Combining ability effects

For this trait, the genotypes, Pb-89, DPP-3 and DPPLMR-41 were observed to be the good general combiners as these exhibited significant positive GCA effects. On the other hand, the genotypes, Lincoln, DPP 9418-06 and Azad Pea-1 exhibited significant negative GCA effects, thus rated as poor general combiners (Table 12).

The highest specific combining ability effects were observed in the crosses, Azad Pea-1 x DPP 9418-06, Azad Pea-1 x Pb-89 and DPP-3 x Pb-89. The other cross combinations had either negative significant/non-significant or positive non-significant SCA effects.

c) Graphical analysis

The graphical analysis of the data on pod length is presented in Fig. 4a. The non-significant 't^2' value in F_1 showed that Wr, Vr values were homogeneous and satisfied the assumptions of diallel analysis. The linear regression of Wr on Vr was low to medium (0.770 ± 0.244), which suggested the presence of non-allelic interactions. The interception of regression line in Wr, Vr graph indicated over-dominance. The genotype, DPP-3 had more of recessive genes and Lincoln, Pb-89 and Palam Priya had relatively more of dominant genes influencing pod length.

The standardized deviation graph of Yr and Wr + Vr (Fig. 4b) indicated that DPPLMR-41 and DPP-3 had recessive genes and Palam Priya and Pb-89 had dominant genes with positive effects on pod length.

d) Components of genetic variation

The estimates of components of genetic variation for pod length are given in Table 10. The additive (D) and non-additive components (H_1 and H_2) were significant but the magnitude of dominance components was more in comparison to additive components. The parents contained more of the dominant genes as reflected from the positive non-significant value of 'F'. The mean degree of dominance (1.38) showed the presence of over-dominance. The ratio of $H_2/4H_1$ (0.17) suggested the asymmetrical distribution of both dominant and recessive genes in the parents. The ratio of KD/KR (1.29) suggested that the frequency of dominant genes was more than recessive genes in the plants.

The correlation coefficient of Yr with Wr + Vr was positive, indicating tendency of high expression of the character was associated with recessive genes. The character had depicted high broad and narrow sense heritability estimates.

5) Pod width (cm)

a) Mean performance and heterotic response

The mean values of parents, F_1s, per cent heterotic response over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89) are given in Appendix III (Table 13). In the genotypes studied, the variation was considerable for pod width which ranged from 1.05 (Palam Priya) to 1.18 cm (DPP 9418-06) and 1.05 (DPP-3 x DPPLMR-41) to 1.20 cm (Palam Priya x Pb-89) in parents and F_1s, respectively.

The magnitude of heterosis for this trait varied from -6.67 (DPP 9418-06 x Pb-89) to 7.81% (Palam Priya x Pb-89), -9.69 (DPP-3 x Pb-89) to 3.79% (Lincoln x DPP-3), 0.01 (DPP-3 x DPPLMR-41) to 13.97% (Palam Priya x Pb-89) and -10.26 (DPP-3 x DPPLMR-41) to 2.28% (Palam Priya x Pb-89) over mid, better parents, standard check 1 (Palam Priya) and standard check 2 (Pb-89), respectively.

Out of 21 F_1s, three over mid parent and seven over standard check 1 (Palam Priya) exhibited significant positive heterosis for this trait. None of the crosses had significant positive heterosis over better parent and standard check 2 (Pb-89). The hybrids, Palam Priya x Pb-89, Azad Pea x Pb-89, Palam Priya x Azad Pea-1, Azad Pea-1 x DPP 9418-06, Azad Pea-1 x DPPLMR-41, DPP 9418-06 x DPPLMR-41 and DPPLMR-41 x Pb-89 displayed 13.97, 10.79, 8.89, 8.57, 6.98, 6.03 and 5.40 per cent standard heterosis (Palam Priya).

b) Combining ability effects

The combining ability effects of parents and F_1s are given in Table 14. The parents namely, Azad Pea-1, Pb-89 and DPP 9418-06 were observed to be good general combiners whereas, DPP-3, Lincoln and Palam Priya were the poor general combiners for this trait.

Table 13: Mean performance of hybrids and per cent heterotic response for pod width (cm)

Hybrid	Mean	Per cent increase or decrease in F_1 over			
		Mid parent	Better parent	Standard check 1	Standard check 2
Palam Priya × Azad Pea-1	1.14	3.94*	-0.58	8.89*	-2.28
Palam Priya × Lincoln	1.07	1.90	1.90	1.90	-8.55*
Palam Priya × DPP 9418-06	1.07	-4.04*	-9.32*	1.90	-8.55*
Palam Priya × DPP-3	1.06	0.32	0.01	0.63	-9.69*
Palam Priya × DPPLMR-41	1.06	-0.93	-3.04	1.27	-9.12*
Palam Priya × Pb-89	**1.20**	**7.81***	2.28	**13.97***	**2.28**
Azad Pea-1 × Lincoln	1.10	-0.30	-4.64*	4.44	-6.27*
Azad Pea-1 × DPP 9418-06	1.14	-2.15	-3.39	8.57*	-2.56
Azad Pea-1 × DPP-3	1.06	-3.93*	-7.83*	0.95	-9.40*
Azad Pea-1 × DPPLMR-41	1.12	0.01	-2.32	6.98*	-3.99
Azad Pea-1 × Pb-89	1.16	0.29	-0.57	10.79*	-0.57
Lincoln × DPP 9418-06	1.08	-2.84	-8.19*	3.17	-7.41*
Lincoln × DPP-3	1.10	4.11*	**3.79**	4.44	-6.27*
Lincoln × DPPLMR-41	1.08	0.62	-1.52	2.86	-7.69*
Lincoln × Pb-89	1.07	-3.90*	-8.83*	1.59	-8.83*
DPP 9418-06 × DPP-3	1.07	-4.02*	-9.04*	2.22	-8.26*
DPP 9418-06 × DPPLMR-41	1.11	-2.20	-5.65*	6.03*	-4.84
DPP 9418-06 × Pb-89	1.10	**-6.67***	-7.06*	4.44	-6.27*
DPP-3 × DPPLMR-41	**1.05**	-2.48	-4.26	**0.01**	**-10.26***
DPP-3 × Pb-89	1.06	-5.09*	**-9.69***	0.63	-9.69*
DPPLMR-41 × Pb-89	1.11	-2.35	-5.41*	5.40*	-5.41*
SE ±	0.02	0.02	0.03	0.03	0.03

*Significant at 5% level of significance

Table 14: General and specific combining ability effects for pod width

Parents	1	2	3	4	5	6	7	GCA
1	-0.029*	0.028	0.003	-0.035*	-0.001	-0.019	0.081*	-0.010*
2		-0.001	-0.007	-0.001	-0.034*	0.005	0.012	0.026*
3			-0.005	-0.010	-0.051*	0.010	-0.037*	-0.022*
4				0.049*	-0.010	0.005	-0.045*	0.016*
5					0.021	-0.011	-0.037*	-0.031*
6						0.011	-0.012	-0.007
7							0.019	0.026*

Standard errors

SE (U) = ± 0.003

SE (gi) = ± 0.005

SE (sii) = ± 0.013

SE (sij) = ± 0.015

SE (gi-gj) = ± 0.008

SE(sii-sjj) = ± 0.018

SE (sij-sik) = ± 0.023

SE (sij-skl) = ± 0.022

Out of 21 cross combinations, Palam Priya x Pb-89 was observed to be the good specific hybrid combination as it exhibited significant positive SCA effects. The remaining cross combinations had either negative significant or negative/positive non-significant SCA effects.

c) Graphical analysis

In Wr, Vr graph (Fig. 5a), the regression line intersected Wr axis below the point of origin indicating the presence of over-dominance. The genotypes, Azad Pea-1 and DPPLMR-41 had more of dominant genes, whereas Palam Priya and Pb-89 had more of recessive genes for pod width. The observed value of regression coefficient 'b' was low (0.44 ± 0.24) in magnitude, indicating the presence of inter allelic interactions.

The standardized deviation graph (Fig. 5b) showed that Azad Pea-1 contained more of dominant genes with positive effects, whereas the parents, Pb-89 and DPP 9418-06 had more of recessive genes with positive effects on pod width. The array points, Lincoln, DPP-3 and DPPLMR-41 had the excess of dominant genes with negative effects on this trait.

d) Components of genetic variation

The genetic components D, H_1, H_2, F and E and various proportional values calculated are given in Table 15. Both additive and dominant components of genetic variance were found to be significant, indicating that both additive and non-additive gene actions are equally important in the inheritance of this trait. The value of 'F' was positive and non-significant which showed that the parents possessed more of the dominant genes. The average degree of dominance was

POD WIDTH

a = -0.001
b = 0.515 ± 0.246

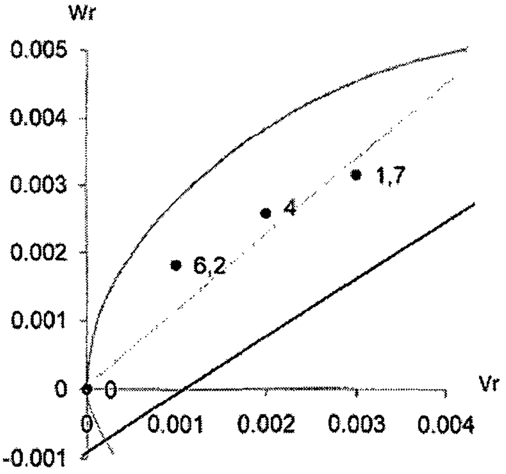


Fig.5a

SEEDS PER POD

a = -0.093
b = 0.845 ± 0.386

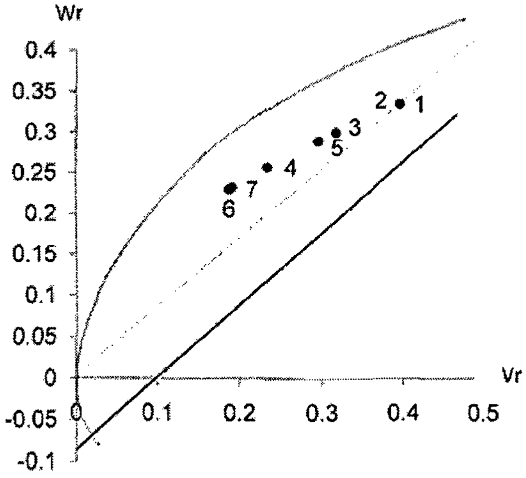


Fig.6a

Vr, Wr GRAPH

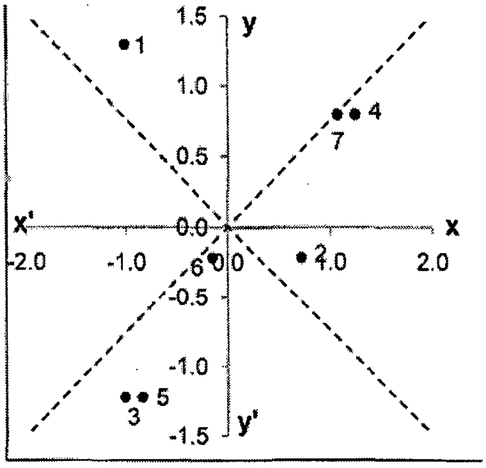


Fig.5b

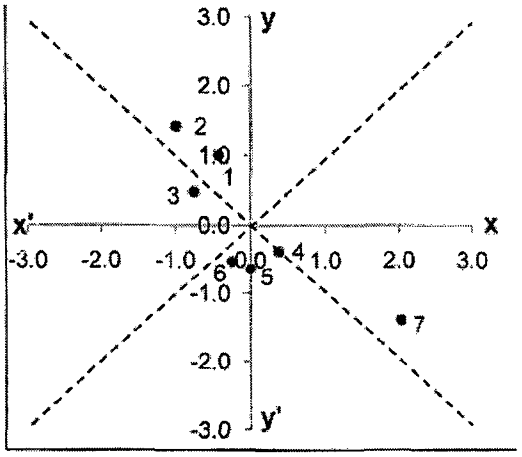


Fig.6b

STANDARDIZED DEVIATION GRAPH

Table15: Estimation of components of genetic variation for pod width (cm) and seeds per pods

Parameter	Pod width	Seeds per pod
t^2	1.01	0.35
D	0.003* ± 0.0006	0.25* ± 0.05
H_1	0.0038* ± 0.0016	0.75* ± 0.14
H_2	0.0031* ± 0.0009	0.63* ± 0.12
F	0.0018 ± 0.0016	-0.07 ± 0.14
E	0.0003 ± 0.0002	0.03 ± 0.02
Mean degree of dominance $(H_1/D)½$	1.12	1.72
$H_2/4H_1$	0.20	0.20
KD/KR	1.73	0.84
Correlation coefficient between (Wr+Vr) and Yr	0.63	0.70
Regression (b)	0.44 ± 0.24	0.84 ± 0.38
Heritability (broad sense)	88.24	93.98
(narrow sense)	65.57	45.80

*Significant at 5% level of significance

1.12 which reflected the equal involvement of both additive and dominant gene action. The ratio of $H_2/4H_1$ was below than the expected value of 0.25 which suggested asymmetrical distribution of both dominant and recessive genes in the parents.

The positive correlation coefficient of Yr with Wr + Vr, indicated tendency of high expression of the character to be associated with recessive genes. The character had depicted high broad sense and medium narrow sense heritability estimates.

6) Seeds per pod

a) Mean performance and heterotic response

The average performance of the parents, F_1s and heterotic response i.e. increase/decrease of F_1s over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89) are presented in Appendix III (Table 16).

The seeds per pod ranged from 5.5 (Azad Pea-1) to 7.1 (Pb-89) in the parents. The average performance of hybrids varied from 5.03 (Lincoln x DPP-3) to 7.53 (Palam Priya x Pb-89). Out of 21 F_1s, favourable heterosis was noticed in twelve hybrid combinations over their respective mid parent, ranging from -13.71 (Lincoln x DPP-3) to 16.80% (Palam Priya x Pb-89).The highest heterobeltiosis of 11.05 % was recorded in the cross, Azad Pea-1 x DPP-3 followed by 9.60 % (Palam Priya x DPPLMR-41) and 8.62 % (Palam Priya x Azad Pea-1). The range of standard heterosis was -13.22 (Lincoln x DPP-3) to 29.89 % (Palam Priya x Pb-89) over standard check 1 (Palam Priya) and -29.11 (Lincoln x DPP-3) to

Table 16: Mean performance of hybrids and per cent heterotic response for seeds per pods

Hybrid	Mean	Per cent increase or decrease in F_1 over			
		Mid parent	Better parent	Standard check 1	Standard check 2
Palam Priya × Azad Pea-1	6.30	11.50*	8.62*	8.62*	-11.27*
Palam Priya × Lincoln	6.10	6.71*	5.17	5.17	-14.08*
Palam Priya × DPP 9418-06	5.57	-7.48*	-10.70*	-4.02	-21.60*
Palam Priya × DPP-3	6.33	7.04*	4.97	9.20*	-10.80*
Palam Priya × DPPLMR-41	6.47	10.54*	9.60*	11.49*	-8.92*
Palam Priya × Pb-89	**7.53**	**16.80***	6.10	**29.89***	**6.10**
Azad Pea-1 × Lincoln	5.57	0.01	-1.18	-4.02	-21.60*
Azad Pea-1 × DPP 9418-06	6.73	14.77*	8.02*	16.09*	-5.16
Azad Pea-1 × DPP-3	6.70	16.18*	**11.05***	15.52*	-5.63
Azad Pea-1 × DPPLMR-41	6.10	7.02*	3.39	5.17	-14.08*
Azad Pea-1 × Pb-89	7.20	14.29*	1.41	24.14*	1.41
Lincoln × DPP 9418-06	6.23	5.06	0.01	7.47	-12.21*
Lincoln × DPP-3	**5.03**	**-13.71***	**-16.57***	**-13.22***	**-29.11***
Lincoln × DPPLMR-41	6.00	4.05	1.69	3.45	-15.49*
Lincoln × Pb-89	6.80	6.81*	-4.23	17.24*	-4.23
DPP 9418-06 × DPP-3	6.30	2.72	1.07	8.62*	-11.27*
DPP 9418-06 × DPPLMR-41	6.43	6.04	3.21	10.92*	-9.39*
DPP 9418-06 × Pb-89	7.13	7.00*	0.47	22.99*	0.47
DPP-3 × DPPLMR-41	5.63	-5.59	-6.63	-2.87	-20.66*
DPP-3 × Pb-89	6.13	-6.60*	-13.62*	5.75	-13.62*
DPPLMR-41 × Pb-89	6.93	6.67*	-2.35	19.54*	-2.35
SE ±	0.16	0.20	0.23	0.23	0.23

*Significant at 5% level of significance

Table 17: General and specific combining ability effects for seeds per pod

Parents	1	2	3	4	5	6	7	GCA
1	-0.416*	0.118	0.206	-0.756*	0.306*	0.310*	0.647*	-0.025
2		-0.649*	-0.294*	0.444*	0.706*	-0.023	0.347*	-0.058
3			0.062	0.232	-0.671*	0.166	0.236	-0.347*
4				-0.197	0.166	0.169	0.140	0.083
5					0.195	-0.334*	-0.564*	-0.214*
6						-0.197	0.106	-0.084
7							-0.456*	0.646*

Standard errors

SE (U)	= ± 0.036
SE (gi)	= ± 0.050
SE (sii)	= ± 0.123
SE (sij)	= ± 0.145
SE (gi-gj)	= ± 0.076
SE(sii-sjj)	= ± 0.170
SE (sij-sik)	= ± 0.216
SE (sij-skl)	= ± 0.202

6.10% (Palam Priya x Pb-89) over standard check 2 (Pb-89). Maximum standard heterosis over Palam Priya was recorded in the cross, Palam Priya x Pb-89 (29.89%) followed by Azad Pea-1 x Pb-89 (24.14%), DPP 9418-06 x Pb-89 (22.99%) and DPPLMR-41 x Pb-89 (19.54%).

b) Combining ability effects

The combining ability effects (GCA of parents and SCA of hybrids) are presented in Table 17. The parent, Pb-89 exhibited the significant positive SCA effects and was rated as the good general combiner. The parents, Lincoln and DPP-3 were found poor general combiners, whereas the remaining parents were observed to be the average general combiners for this trait.

The good specific cross combinations were Azad Pea-1 x DPP-3, Palam Priya x Pb-89, Azad Pea-1 x DPP 9418-06, Azad Pea-1 x Pb-89, Palam Priya x DPPLMR-41 and Palam Priya x DPP-3 as these displayed significant positive specific combining ability effects.

c) Graphical analysis

A graphical analysis of the data on seeds per pod is presented in Fig. 6a. The validity of assumptions of diallel analysis was confirmed as the value of 't^2' was found to be non-significant. The value of regression coefficient was higher in magnitude, which showed the absence of inter allelic interactions. The regression line intersected Wr-axis just below the point of origin, indicating over-dominance. The position of array points revealed that the array, Palam Priya had the maximum concentration of recessive genes, whereas DPPLMR-41 and Pb-89 had maximum of dominant genes. The remaining arrays *viz.*, DPP 9418-06, DPP-3, Lincoln and Azad Pea-1 had the equal proportion of both dominant and recessive genes.

The standardized deviation graph (Fig. 6b) revealed that DPP 9418-06, Pb-89 and DPP-3 possessed more number of dominant genes with positive effects and Lincoln, Palam Priya and Azad Pea-1 had more of recessive genes with negative effects on seeds per pod.

d) Components of genetic variation

The components of genetic variation and various statistics derived are presented in Table 15. Both additive (D) and non-additive genetic components (H_1 and H_2) were significant but the comparative magnitude of non-additive components was greater than additive components, indicating the predominant role of non-additive gene action in the inheritance of this trait. The mean degree of dominance reflected the presence of over-dominance. The $H_2/4H_1$ ratio (0.20) suggested asymmetrical distribution of dominant recessive genes in the parents. Negative and non-significant 'F' value indicated the presence of more number of recessive genes in the parents. The ratio of KD/KR further confirmed that the parents contained more number of recessive genes than the dominant ones.

The correlation between Yr and Wr + Vr was positive, which indicated directional dominance towards recessive genes for increased seeds per pod. The heritability estimates were 93.98 and 45.80 per cent in broad sense and narrow sense, respectively.

7) Shelling percentage

a) Mean performance and heterotic response

The mean performance of the parents, F_1s, per cent average heterosis, heterobeltiosis, standard heterosis over standard check 1 (Palam Priya) and standard check 2 (Pb-89) are given in Appendix III (Table 18).

The shelling percentage was found minimum in DPPLMR-41 (52.67%) and maximum in DPP-3 (61%). The mean values of F_1s ranged from 47.33 (Palam Priya x DPPLMR-41) to 61.00 % (Palam Priya x Pb-89). As many as four hybrids over mid parent, two over better parent, five over standard check 1 (Palam Priya) and two over standard check 2 (Pb-89) displayed significant positive heterosis. Maximum heterobeltiosis to the extent of 10.91% and standard heterosis (over Palam Priya) 12.96% were recorded in the cross Palam Priya x Pb-89.

b) Combining ability effects

The estimates of combining ability effects (GCA and SCA) are given in Table 19. The parents, Pb-89 and DPP-3 were good general combiners; DPPLMR-41, DPP 9418-06 and Azad Pea-1 were the poor general combiners and Palam Priya and Lincoln were the average general combiners for this trait.

The highest positive significant SCA effects for shelling percentage were observed in the crosses, Palam Priya x Pb-89, Palam Priya x Lincoln, Azad Pea-1 x Pb-89, DPP-3 x DPPLMR-41, Palam Priya x Azad Pea-1 and DPPLMR-41 x Pb-89.

Table 18: Mean performance of hybrids and per cent heterotic response for shelling percentage

Hybrid	Mean	Per cent increase or decrease in F_1 over			
		Mid parent	Better parent	Standard check 1	Standard check 2
Palam Priya × Azad Pea-1	56.00	4.02	3.70	3.70	1.82
Palam Priya × Lincoln	58.67	8.64*	8.64*	8.64*	6.67*
Palam Priya × DPP 9418-06	52.00	-4.00	-4.29	-3.70	-5.45
Palam Priya × DPP-3	52.33	-8.99*	-14.21*	-3.09	-4.85
Palam Priya × DPPLMR-41	**47.33**	**-11.25***	-12.35*	**-12.35***	**-13.94***
Palam Priya × Pb-89	**61.00**	**11.93***	**10.91***	**12.96***	**10.91***
Azad Pea-1 × Lincoln	51.67	-4.02	-4.32	-4.32	-6.06*
Azad Pea-1 × DPP 9418-06	50.33	-6.79*	-7.36*	-6.79*	-8.48*
Azad Pea-1 × DPP-3	52.00	-9.30*	**-14.75***	-3.70	-5.45
Azad Pea-1 × DPPLMR-41	53.33	0.31	-0.62	-1.23	-3.03
Azad Pea-1 × Pb-89	58.00	6.75*	5.45	7.41*	5.45
Lincoln × DPP 9418-06	54.00	-0.31	-0.61	0.01	-1.82
Lincoln × DPP-3	53.67	-6.67*	-12.02*	-0.62	-2.42
Lincoln × DPPLMR-41	53.33	0.01	-1.23	-1.23	-3.03
Lincoln × Pb-89	55.00	0.92	0.01	1.85	0.01
DPP 9418-06 × DPP-3	55.33	-4.05	-9.29*	2.47	0.61
DPP 9418-06 × DPPLMR-41	51.67	-3.43	-4.91	-4.32	-6.06*
DPP 9418-06 × Pb-89	55.67	1.83	1.21	3.09	1.21
DPP-3 × DPPLMR-41	57.33	0.88	-6.01*	6.17*	4.24
DPP-3 × Pb-89	56.00	-3.45	-8.20*	3.70	1.82
DPPLMR-41 × Pb-89	57.33	6.50*	4.24	6.17*	4.24
SE ±	1.09	1.33	1.54	1.54	1.54

*Significant at 5% level of significance

Table 19: General and specific combining ability effects for shelling percentage

Parents	1	2	3	4	5	6	7	GCA
1	-0.333	2.407*	4.444*	-1.481	-3.481*	-5.926*	4.704*	-0.095
2		0.815	-1.815	-2.407*	-3.074*	0.815	2.444*	-0.836*
3			-0.111	0.630	-2.037*	0.185	-1.185	-0.206
4				1.704*	0.370	-0.741	0.222	-0.947*
5					3.704*	2.593*	-1.778	1.386*
6						0.481	2.111*	-1.169*
7							-3.259*	1.868*

Standard errors

SE (U) = ± 0.205

SE (gi) = ± 0.335

SE (sii) = ± 0.829

SE (sij) = ± 0.975

SE (gi-gj) = ± 0.512

SE(sii-sjj) = ± 1.145

SE (sij-sik) = ± 1.448

SE (sij-skl) = ± 1.355

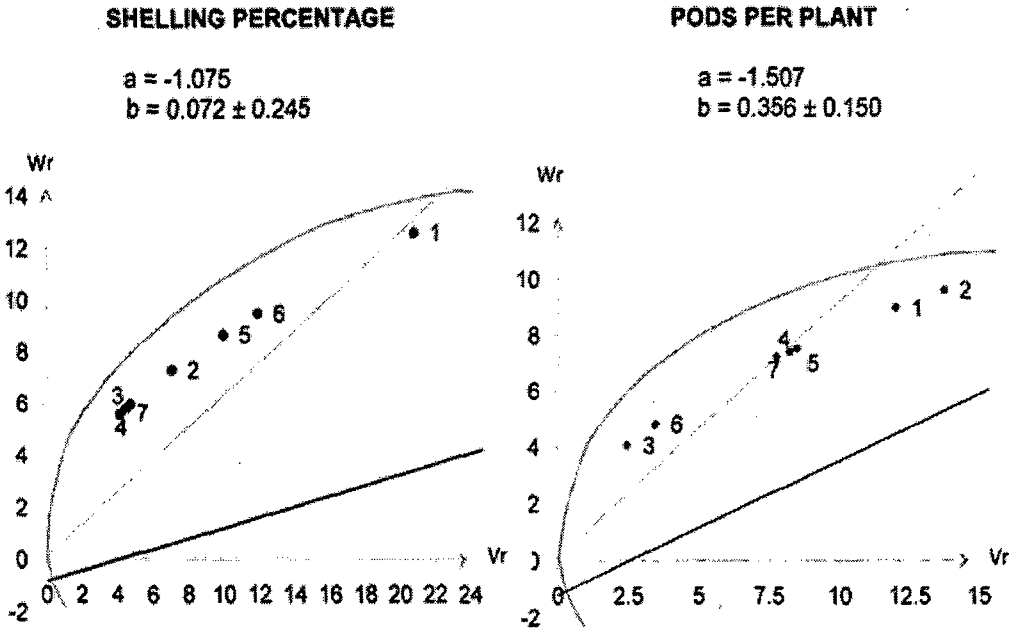
c) Graphical analysis

The graphic presentation for shelling percentage is given in Fig. 7a. The observed value of regression coefficient 'b' was low (0.072 $\pm$ 0.245), indicating the presence of inter-allelic interactions. The regression line intersected Wr-axis below the point of origin, indicating over-dominance. The genotypes, DPP 9418-06, Lincoln and Pb-89 contained dominant genes, whereas Palam Priya had more of recessive genes. The remaining genotypes *viz.,* Azad Pea-1, DPP-3 and DPPLMR-41 had the equal proportion of both dominant and recessive genes.

The standard deviation graph (Fig. 7b) revealed that DPP-3 possessed most of the recessive genes with positive effects on shelling percentage. The parents, DPPLMR-41 and Palam Priya had the excess of recessive genes with negative effects. The remaining parental lines *viz.,* Lincoln, Azad Pea-1, DPP 9418-06 and Pb-89 contained excess of dominant genes with negative effect on this trait.

d) Components of genetic variation

The estimates of components of genetic variation for shelling percentage are given in Table 20. The estimates of D, H_1 and H_2 components indicated that non-additive genetic components (H_1 and H_2) were more important in the expression of this trait. The mean degree of dominance showed over-dominance. The $H_2/4H_1$ frequency suggested asymmetrical distribution of dominant and recessive genes in the parents. The KD/KR ratio was 1.58 which revealed the presence of atleast one dominant gene or gene groups for every



SHELLING PERCENTAGE

a = -1.075
b = 0.072 ± 0.245

PODS PER PLANT

a = -1.507
b = 0.356 ± 0.150

Fig.7a

Fig.8a

Vr, Wr GRAPH

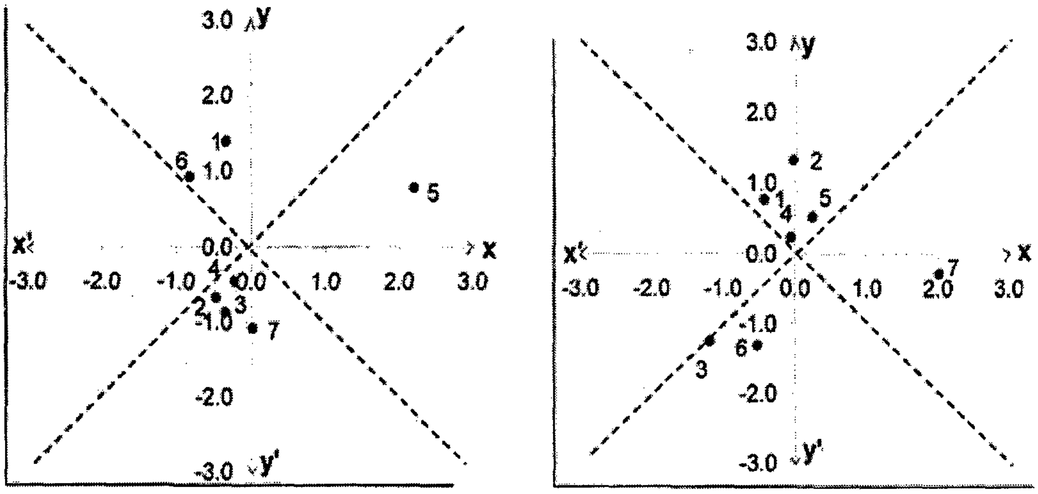


Fig.7b

Fig.8b

STANDARDIZED DEVIATION GRAPH

Table 20: Estimation of components of genetic variation for shelling percentage and pods per plant

Parameter	Shelling percentage	Pods per plant
t^2	2.00	6.48
D	6.42 ± 4.85	5.45* ± 2.24
H_1	33.47* ± 11.68	17.94* ± 5.41
H_2	26.87* ± 10.29	14.52* ± 4.77
F	6.65 ± 11.64	-5.82 ± 5.39
E	1.18 ± 1.71	1.25 ± 0.79
Mean degree of dominance $(H_1/D)^{½}$	2.28	1.85
$H_2/4H_1$	0.20	0.20
KD/KR	1.58	0.54
Correlation coefficient between (Wr+Vr) and Yr	0.13	0.73
Regression (b)	0.07 ± 0.24	0.36 ± 0.15
Heritability (broad sense)	90.75	85.22
(narrow sense)	55.46	23.81

*Significant at 5% level of significance

recessive gene or gene groups. The correlation coefficient between parental order of dominance and parental measurements was positive which showed that the increased shelling percentage was controlled by recessive genes. The character had depicted high broad sense and medium narrow sense heritability estimates.

8) Pods per plant

a) Mean performance and heterotic response

The mean performance of the parents, F_1s, per cent heterosis over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89) are given in Appendix III (Table 21).

The mean performance of parents and F_1s for pods per plant ranged between 15.87 (Lincoln) to 24.17 (Pb-89) and 16.00 (Palam Priya x DPP-3) to 27.40 (Azad Pea-1 x Pb-89). In F_1s, the magnitude of average heterosis, heterobeltiosis, standard heterosis over Palam Priya and standard heterosis over Pb-89 varied from -14.44 (Palam Priya x DPP-3) to 35.57% (Palam Priya x Azad Pea-1), -19.31 (DPPLM-41 x Pb-89) to 31.75% (Palam Priya x Azad Pea-1), -10.28 (Palam Priya x DPP-3) to 53.64% (Azad Pea-1 x Pb-89) and -33.79 (Palam Priya x DPP-3) to 13.38% (Azad Pea-1 x Pb-89), respectively. As many as seven crosses each over mid parent and standard check 1 (Palam Priya), four over better parent and one over standard check 2(Pb-89) exhibited significant positive heterosis. Maximum average heterosis and heterobeltiosis to the extent of 35.57 and 31.75 per cent, respectively was recorded in a cross, Palam Priya x Azad Pea-1. However, the cross, Azad Pea-1 x Pb-89 displayed the maximum

Table 21: Mean performance of hybrids and per cent heterotic response for pods per plant

Hybrid	Mean	Per cent increase or decrease in F_1 over			
		Mid parent	Better parent	Standard check 1	Standard check 2
Palam Priya × Azad Pea-1	24.90	**35.57***	**31.75***	39.63*	3.03
Palam Priya × Lincoln	19.30	14.54	8.22	8.22	-20.14*
Palam Priya × DPP 9418-06	18.33	0.09	-2.48	2.80	-24.14*
Palam Priya × DPP-3	**16.00**	**-14.44***	-18.23*	**-10.28**	**-33.79***
Palam Priya × DPPLMR-41	18.07	1.98	1.31	1.31	-25.24*
Palam Priya × Pb-89	24.53	16.83*	1.52	37.57*	1.52
Azad Pea-1 × Lincoln	17.07	-1.82	-9.70	-4.30	-29.38*
Azad Pea-1 × DPP 9418-06	24.10	27.85*	27.51*	35.14*	-0.28
Azad Pea-1 × DPP-3	19.63	2.08	0.34	10.09	-18.76*
Azad Pea-1 × DPPLMR-41	23.03	26.21*	21.87*	29.16*	-4.69
Azad Pea-1 × Pb-89	**27.40**	27.24*	13.38*	**53.64***	**13.38***
Lincoln × DPP 9418-06	18.63	7.50	-0.89	4.49	-22.90*
Lincoln × DPP-3	16.70	-5.74	-14.65	-6.36	-30.90*
Lincoln × DPPLMR-41	18.03	7.77	2.46	1.12	-25.38*
Lincoln × Pb-89	20.37	1.75	-15.72*	14.21	-15.72*
DPP 9418-06 × DPP-3	18.97	-1.13	-3.07	6.36	-21.52*
DPP 9418-06 × DPPLMR-41	18.47	1.47	-1.77	3.55	-23.59*
DPP 9418-06 × Pb-89	24.87	15.75*	2.90	39.44*	2.90
DPP-3 × DPPLMR-41	19.60	5.47	0.17	9.91	-18.90*
DPP-3 × Pb-89	25.03	14.48*	3.59	40.37*	3.59
DPPLMR-41 × Pb-89	19.50	-6.62	**-19.31***	9.35	-19.31*
SE ±	1.07	1.31	1.51	1.51	1.51

*Significant at 5% level of significance

Table 22: General and specific combining ability effects for pods per plant

Parents	1	2	3	4	5	6	7	GCA
1	-1.309	3.854*	1.820	-1.272	-2.950*	-0.531	1.698	-0.523
2		-4.050*	-2.317*	2.591*	-1.220	2.531*	2.661*	1.381*
3			0.050	0.691	-0.587	1.098	-0.806	-2.186*
4				-1.269	-0.446	-0.594	1.569	-0.060
5					0.809	1.194	2.391*	-0.715*
6						-0.454	-2.791*	-1.067*
7							-2.361*	3.170*

Standard errors

SE (U) = ± 0.202

SE (gi) = ± 0.330

SE (sii) = ± 0.816

SE (sij) = ± 0.960

SE (gi-gj) = ± 0.504

SE(sii-sjj) = ± 1.127

SE (sij-sik) = ± 1.426

SE (sij-skl) = ± 1.334

standard heterosis of 53.64 and 13.38 per cent over both the checks used in the present investigation.

b) Combining ability effects

The estimates of GCA of parents and SCA of hybrids are given in Table 22. For getting increased number of pods per plant, Pb-89 and Azad Pea-1 were observed as the good general combiners. The parents, Lincoln, DPPLMR-41 and DPP-3 were the poor general combiners as these displayed significant negative GCA effects whereas, Palam Priya and DPP 9418-06 were the average general combiners.

Among the cross combinations, *viz.,* Palam Priya x Azad Pea-1, Azad Pea-1 x Pb-89, Azad Pea-1 x DPP 9418-06, Azad Pea-1 x DPPLMR-41 and DPP-3 x Pb-89 were the good specific cross combinations as was evident from their significant positive SCA effects.

c) Graphical analysis

A graphical analysis of data on pods per plant is presented in Fig. 8a. The validity of assumptions of diallel analysis was confirmed as 't^2' was found to be non-significant. The regression line intersected Wr axis below the origin, indicating over-dominance. The genotypes, Azad Pea-1 and Palam Priya had more of recessive genes, whereas Lincoln and DPPLMR-41 possessed excess of dominant genes. The scatter of array points along the regression line indicated the genetically diverse nature of the parents.

The standardized deviation graph (Fig. 8b) showed that Pb-89 contained dominant genes with positive effect, whereas Lincoln and DPPLMR-41 had more of dominant genes with negative effect on pods per plant.

d) Components of genetic variation

The genetic parameters D, H_1, H_2, F and E and various proportional values calculated are given in Table 20. Both additive (D) and non-additive components (H_1 and H_2) were found to be significant. However, the relative magnitude of non-additive components was greater than additive component, indicating non-additive gene action in the inheritance of this character.

The negative and non-significant value of 'F' suggested the presence of more number of recessive genes in the parents. The mean degree of dominance indicated over-dominance. The ratio of $H_2/4H_1$ was below than the expected value of 0.25 which suggested asymmetrical distribution of both dominant and recessive genes in the parents. The KD/KR ratio further confirmed the presence of more number of recessive genes in the parents.

Positive correlation coefficient of Yr with Wr + Vr (0.73) indicated the directional dominance towards the recessive genes. The heritability estimates were 85.22 and 23.81 per cent in broad sense and narrow sense, respectively.

9) Branches per plant

a) Mean performance and heterotic response

The mean performance of the parents, F_1s and per cent increase/ decrease of F_1 over mid and better parents, standard check 1 (Palam Priya) and standard check 2 (Pb-89) are given in Appendix III (Table 23).

The number of branches per plant was found minimum in Azad Pea-1 (1.90) and maximum in Pb-89 (5.17). The average performance of hybrids ranged from 1.83 (Lincoln x DPPLMR-41) to 3.83% (DPP 9418-06 x Pb-89). Out

Table 23: Mean performance of hybrids and per cent heterotic response for branches per plant

Hybrid	Mean	Per cent increase or decrease in F_1 over			
		Mid parent	Better parent	Standard check 1	Standard check 2
Palam Priya × Azad Pea-1	3.10	57.63*	52.46*	52.46*	-40.00*
Palam Priya × Lincoln	2.13	9.40	4.92	4.92	-58.71*
Palam Priya × DPP 9418-06	3.37	**62.90***	**60.32***	65.57*	-34.84*
Palam Priya × DPP-3	2.67	24.03*	17.65*	31.15*	-48.39*
Palam Priya × DPPLMR-41	2.83	-5.56	-28.57*	39.34*	-45.16*
Palam Priya × Pb-89	3.37	-6.48	-34.84*	65.57*	-34.84*
Azad Pea-1 × Lincoln	3.00	59.29*	57.89*	47.54*	-41.94*
Azad Pea-1 × DPP 9418-06	3.23	61.67*	53.97*	59.02*	-37.42*
Azad Pea-1 × DPP-3	2.30	10.40	1.47	13.11	-55.48*
Azad Pea-1 × DPPLMR-41	2.67	-9.09	-32.77*	31.15*	-48.39*
Azad Pea-1 × Pb-89	3.23	-8.49*	-37.42*	59.02*	-37.42*
Lincoln × DPP 9418-06	2.70	36.13*	28.57*	32.79*	-47.74*
Lincoln × DPP-3	2.00	-3.23	-11.76	-1.64	-61.29*
Lincoln × DPPLMR-41	**1.83**	-37.14*	-53.78*	**-9.84**	**-64.52***
Lincoln × Pb-89	2.17	-38.39*	**-58.06***	6.56	-58.06*
DPP 9418-06 × DPP-3	2.63	20.61*	16.18*	29.51*	-49.03*
DPP 9418-06 × DPPLMR-41	3.17	4.40	-20.17*	55.74*	-38.71*
DPP 9418-06 × Pb-89	**3.83**	5.50	-25.81*	**88.52***	**-25.81***
DPP-3 × DPPLMR-41	2.37	-24.06*	-40.34*	16.39*	-54.19*
DPP-3 × Pb-89	2.37	-36.32*	-54.19*	16.39*	-54.19*
DPPLMR-41 × Pb-89	2.60	**-43.07***	-49.68*	27.87*	-49.68*
SE ±	0.12	0.15	0.17	0.17	0.17

*Significant at 5% level of significance

Table 24: General and specific combining ability effects for branches per plant

Parents	1	2	3	4	5	6	7	GCA
1	-0.617*	0.472*	-0.076	0.539*	0.313*	-0.024	0.009	-0.048
2		-0.706*	0.813*	0.428*	-0.031	-0.169	-0.102	-0.070*
3			0.098	0.313*	0.087	-0.583*	-0.750*	-0.488*
4				-0.906*	0.102	0.131	0.298*	0.130*
5					0.209*	-0.194	-0.694*	-0.344*
6						0.092	-0.965*	0.160*
7							1.102*	0.660*

Standard errors

SE (U)	= ± 0.022
SE (gi)	= ± 0.037
SE (sii)	= ± 0.091
SE (sij)	= ± 0.107
SE (gi-gj)	= ± 0.056
SE(sii-sjj)	= ± 0.126
SE (sij-sik)	= ± 0.160
SE (sij-skl)	= ± 0.149

of the 21 hybrids, favourable heterosis was noticed in seven combinations over their respective mid parent, ranging from -43.07 (DPPLMR-41 x Pb-89) to 62.90% (Palam Priya x DPP 9418-06). The range of heterosis over better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89) ranged between -58.06 (Lincoln x Pb-89) to 60.32% (Palam Priya x DPP 9418-06), -9.84 (Lincoln x DPPLMR-41) to 88.52% (DPP 9418-06 x Pb-89) and -64.52 (Lincoln x DPPLMR-41) to -25.81% (DPP 9418-06 x Pb-89), respectively. The highest heterobeltiosis of 60.32% was observed in a cross, Palam Priya x DPP 9418-06 followed by Azad Pea-1 x Lincoln (57.89%) and Azad Pea-1 x DPP 9418-06 (53.97%). Sixteen hybrid combinations displayed favourable standard heterosis over standard check 1 (Palam Priya), whereas none of the hybrids exhibited significant positive standard heterosis over Pb-89 (standard check 2).

b) Combining ability effects

The combining ability effects (GCA of parents and SCA of hybrids) are presented in Table 24. For branches per plant, Pb-89, DPPLMR-41 and DPP 9418-06 were observed to be good general combiners. The poor general combiners for this trait were Lincoln, DPP-3 and Azad Pea-1 as these displayed significant negative GCA effects.

Significant positive SCA effects were exhibited by seven cross combinations *viz.,* Azad Pea-1 x Lincoln, Palam Priya x DPP 9418-06, Palam Priya x Azad Pea-1, Azad Pea-1 x DPP 9418-06, Palam Priya x Azad Pea-1, Lincoln x DPP 9418-06, Palam Priya x DPP-3 and DPP 9418-06 x Pb-89. The remaining cross combinations were observed to be either average or poor specific combinations for this trait.

BRANCHES PER PLANT

a = - 0.034
b = 0.819 ± 0.228

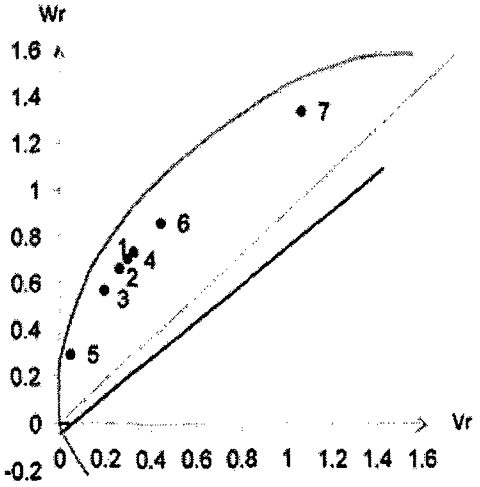


Fig.9a

PLANT HEIGHT

a = -18.399
b = -0.065 ± 0.322

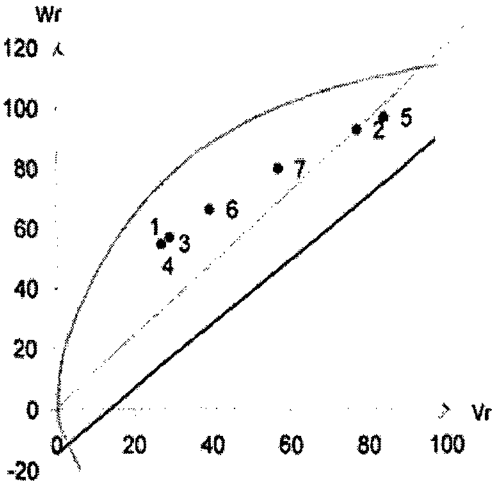


Fig.10a

Vr, Wr GRAPH

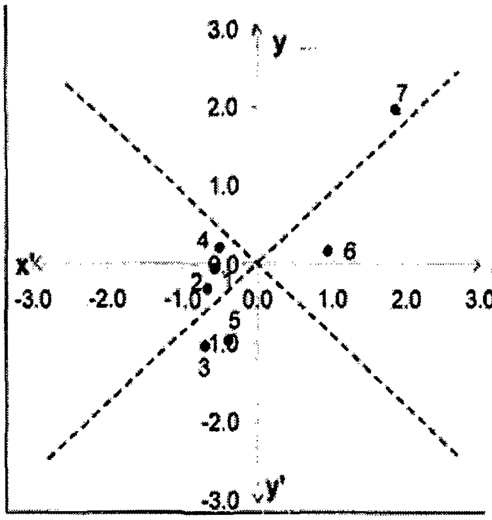


Fig.9b

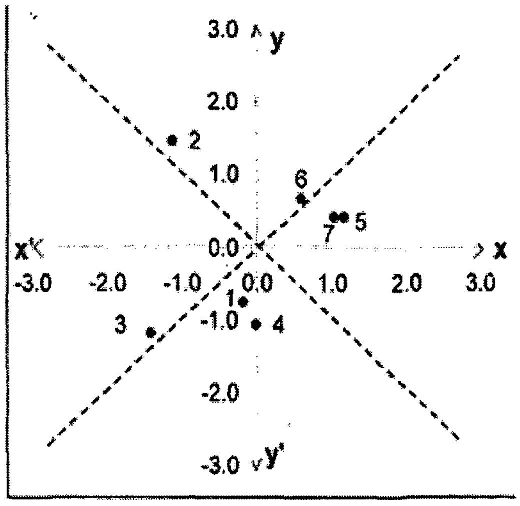


Fig.10b

STANDARDIZED DEVIATION GRAPH

Table 25: Estimation of components of genetic variation for branches per plant and plant height (cm)

Parameter	Branches per plant	Plant height
t^2	0.023	0.55
D	1.65* ± 0.34	105.55* ± 23.53
H_1	2.03* ± 0.32	227.51 *± 56.65
H_2	1.00* ± 0.28	160.27* ± 49.92
F	2.20* ± 0.32	153.67* ± 56.45
E	0.01 ± 0.04	6.38 ± 8.32
Mean degree of dominance $(H_1/D)^{½}$	1.11	1.46
$H_2/4H_1$	0.12	0.17
KD/KR	4.03	2.96
Correlation coefficient between (Wr+Vr) and Yr	0.85	-0.08
Regression (b)	0.82 ± 0.23	-0.06 ± 0.32
Heritability (broad sense)	99.26	94.50
(narrow sense)	90.37	77.85

*Significant at 5% level of significance

c) Graphical analysis

The graphical presentation for the character is given in Fig. 9a. The value of observed regression coefficient 'b' was high in magnitude (0.819 ± 0.228) which suggested the presence of additive gene action. The position of the regression line indicated complete to over-dominance and it intersected Wr axis just below the point of origin. Parental arrays, DPP-3 had more of dominant genes, whereas Pb-89 had more of recessive genes. The remaining parents *viz.*, Lincoln, Azad Pea-1, Palam Priya, DPP 9418-06 and DPPLMR-41 had equal proportion of dominant and recessive genes.

The standardized deviation graph (Fig. 9b) suggested that Palam Priya, Azad Pea-1, Lincoln and DPP-3 possessed more of dominant genes with negative effects, whereas DPPLMR-41 and Pb-89 contained more of recessive genes with positive effect on branches per plant.

d) Components of genetic variation

The components of genetic variation and various statistics derived are given in Table 25. Both additive and non-additive components were found significant which indicated the equal involvement of both additive and non-additive genes in the inheritance of this trait. The significant positive 'F' value indicated the preponderance of dominant genes in the parents. The over-dominance was reflected by the mean degree of dominance $(H_1/D)^{1/2}$. The ratio of $H_2/4H_1$ was far below than the expected value of 0.25 which suggested asymmetrical distribution of dominant and recessive genes in the parents. The KD/KR ratio indicated that for every recessive gene or gene group, there were atleast four dominant genes/gene groups present in the parents.

Positive correlation coefficient of Yr with Wr + Vr indicated directional dominance towards recessive genes. The heritability estimates both in broad and narrow sense were very high.

10) Plant height (cm)

a) Mean performance and heterotic response

The mean performance of the parents, F_1s and per cent increase/ decrease over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89) are given in Appendix III (Table 26).

For this trait, main attention is given towards negative heterosis as dwarf plants can be grown successfully without providing support, thereby reducing the input cost. The parent, DPP-3 showed maximum plant height of 94.93 cm and minimum plant was recorded in Lincoln (67.8 cm). Maximum plant height of 93.27 cm was recorded in the cross combination, Azad Pea-1 x DPP-3. In hybrids, the range of average heterosis, heterobeltiosis, standard heterosis over (Palam Priya) and standard heterosis over (Pb-89) existed between -23.82 (DPP-3 x Pb-89) to 21.42% (Azad Pea-1 x Lincoln), -24.37 (DPP-3 x Pb-89) to 18.82% (Azad Pea-1 x Lincoln), -14.23 (Azad Pea-1 x DPPLMR-41) to 15.28% (Azad Pea-1 x DPP-3) and -25.90 (Azad Pea-1 x DPPLMR-41) to -0.32% (Azad Pea-1 x DPP-3), respectively. Ten hybrids over mid parent, seventeen over better parent, seven over standard check 1 (Palam Priya) and nineteen over standard check 2 (Pb-89) exhibited significant negative heterosis.

The hybrid combination DPP-3 x Pb-89 displayed the highest significant negative average heterosis of -23.82% and heterobeltiosis of -24.37%.

Table 26: Mean performance of hybrids and per cent heterotic response for plant height (cm)

Hybrid	Mean	Per cent increase or decrease in F_1 over			
		Mid parent	Better parent	Standard check 1	Standard check 2
Palam Priya × Azad Pea-1	73.40	-3.21	-9.20*	-9.20*	-21.55*
Palam Priya × Lincoln	78.43	5.54	-2.97	-2.97	-16.17*
Palam Priya × DPP 9418-06	74.67	-8.66*	-9.68*	-7.63	-20.20*
Palam Priya × DPP-3	87.60	-0.32	-7.72*	8.37*	-6.38
Palam Priya × DPPLMR-41	75.77	-10.69*	-14.71*	-6.27	-19.02*
Palam Priya × Pb-89	72.97	-16.32*	-22.02*	-9.73*	-22.02*
Azad Pea-1 × Lincoln	84.17	**21.42***	**18.82***	4.12	-10.05*
Azad Pea-1 × DPP 9418-06	84.97	10.71*	2.78	5.11	-9.19*
Azad Pea-1 × DPP-3	**93.27**	12.53*	-1.76	**15.38***	**-0.32**
Azad Pea-1 × DPPLMR-41	**69.33**	-13.15*	-21.95*	**-14.23***	**-25.90***
Azad Pea-1 × Pb-89	81.57	-0.77	-12.83*	0.91	-12.83*
Lincoln × DPP 9418-06	71.27	-5.27	-13.79*	-11.84*	-23.83*
Lincoln × DPP-3	77.93	-4.22	-17.91*	-3.59	-16.71*
Lincoln × DPPLMR-41	73.17	-6.58	-17.64*	-9.48*	-21.80*
Lincoln × Pb-89	74.13	-8.12*	-20.77*	-8.29*	-20.77*
DPP 9418-06 × DPP-3	74.43	-16.18*	-21.59*	-7.92	-20.45*
DPP 9418-06 × DPPLMR-41	81.30	-5.19	-8.48*	0.58	-13.11*
DPP 9418-06 × Pb-89	81.77	-7.21*	-12.61*	1.15	-12.61*
DPP-3 × DPPLMR-41	79.83	-13.11*	-15.91*	-1.24	-14.68*
DPP-3 × Pb-89	71.80	**-23.82***	**-24.37***	-11.18*	-23.26*
DPPLMR-41 × Pb-89	77.57	-14.95*	-17.10*	-4.04	-17.10*
SE ±	2.42	2.97	3.42	3.42	3.42

*Significant at 5% level of significance

Table 27: General and specific combining ability effects for plant height

Parents	1	2	3	4	5	6	7	GCA
1	3.689*	-4.174	4.600*	-3.504	4.874*	-2.504	-6.670*	-1.049
2		-7.170*	9.904*	6.367*	10.111*	-9.367*	1.500	-0.620
3			-2.722	-3.593	-1.481	-1.793	-2.193	-4.360*
4				3.470	-9.319*	2.004	1.104	-0.023
5					6.626*	-4.019	-13.419*	4.532*
6						9.437*	-3.196	0.077
7							11.437*	1.443

Standard errors

SE (U) = ± 0.457

SE (gi) = ± 0.747

SE (sii) = ± 1.849

SE (sij) = ± 2.172

SE (gi-gj) = ± 1.141

SE(sii-sjj) = ± 2.551

SE (sij-sik) = ± 3.227

SE (sij-skl) = ± 3.019

Maximum standard heterosis to the extent of -14.23 and -25.90 per cent was exhibited by the cross Azad Pea-1 x DPPLMR-41 over both the standard checks (Palam Priya and Pb-89).

b) Combining ability effects

The estimates of general and specific combining ability effects for seven parents and their 21 F_1s are given in Table 27. For decreasing plant height, Lincoln was the good general combiner, whereas DPP-3 was the poor general combiner. The remaining parents *viz.,* Palam Priya, Azad Pea-1, DPP 9418-06, DPPLMR-41 and Pb-89 were rated as average general combiners. The best specific cross combinations for decreased plant height were DPP-3 x Pb-89, Azad Pea-1 x DPPLMR-41, DPP 9418-06 x DPP-3 and Palam Priya x Pb-89 as these combinations displayed significant negative SCA effects. For increased plant height, the best specific combinations were Azad Pea-1 x DPP-3, Azad Pea-1 x Lincoln, Azad Pea-1 x DPP 9418-06, Palam Priya x DPP-3 and Palam Priya x Lincoln as was evident from their significant positive SCA effects.

c) Graphical analysis

The linear regression of Wr on Vr and the limiting parabola for the diallel set are presented in Fig. 10a. The non-significant 't^2' value indicated that Wr, Vr values were homogeneous and satisfied the assumptions of diallel analysis. The interception of regression line indicated over-dominance. Arrays, Palam Priya, Lincoln and DPP 9418-06 had excess of dominant genes, whereas arrays, DPP-3 and Azad Pea-1 had excess of recessive genes.

The standardized deviation graph (Fig. 10b) showed that parental arrays, Pb-89, DPP-3 and DPPLMR-41 contained recessive genes with positive effect, whereas Azad Pea-1 had more of recessive genes with negative effect on plant height. The other parents *viz.,* Lincoln, DPP 9418-06 and Palam Priya possessed excess of dominant genes with negative effect on this trait.

d) Components of genetic variation

The estimates of various components of genetic variation for plant height are given in Table 25. The estimates of D, H_1 and H_2 components indicated that the non-additive genetic effects were predominant in the expression of this trait. The value of 'F' was positive and significant, suggested the presence of more number of dominant genes in the parents. The over-dominance was reflected from the mean degree of dominance $(H_1/D)^{1/2}$. The ratio of $H_2/4H_1$ deviated from the expected value of 0.25, suggested the asymmetrical distribution of positive and negative genes in the parents. The KD/KR ratio was 2.96, suggested the presence of approximately two to three dominant genes or gene groups for every recessive gene or gene groups.

The correlation coefficient between parental order of dominance and parental measurements was negative, indicating tendency of high expression of the character to be associated with dominant genes. The heritability estimates were medium in narrow sense (77.85%) and high in broad sense (94.50%).

11) Pod yield per plant (g)

a) Mean performance and heterotic response

The pod yield is a complex trait and is dependent upon various other characters *viz.,* pods per plant and pod weight. The average performance of the parents, F_1s and per cent heterosis over mid parent, better parent, standard

Table 28: Mean performance of hybrids and per cent heterotic response for pod yield per plant (g)

Hybrid	**Mean**	**Per cent increase or decrease in F_1 over**			
		Mid parent	**Better parent**	**Standard check 1**	**Standard check 2**
Palam Priya × Azad Pea-1	121.80	33.26*	31.96*	34.59*	2.18
Palam Priya × Lincoln	84.40	1.97	-6.74	-6.74	-29.19*
Palam Priya × DPP 9418-06	89.37	-2.53	-3.77	-1.25	-25.03*
Palam Priya × DPP-3	72.67	**-22.12***	-24.38*	-19.71*	-39.04*
Palam Priya × DPPLMR-41	82.63	-4.76	-8.69	-8.69	-30.68*
Palam Priya × Pb-89	129.67	23.67*	8.78	43.28*	8.78
Azad Pea-1 × Lincoln	86.27	3.11	-6.54	-4.68	-27.63*
Azad Pea-1 × DPP 9418-06	109.50	18.27*	17.91*	20.99*	-8.14
Azad Pea-1 × DPP-3	100.80	7.01	4.89	11.38	-15.44*
Azad Pea-1 × DPPLMR-41	113.47	29.43*	22.93*	25.38*	-4.81
Azad Pea-1 × Pb-89	**168.53**	**59.37***	**41.39***	**86.22***	**41.39***
Lincoln × DPP 9418-06	83.53	-0.50	-10.05	-7.70	-29.92*
Lincoln × DPP-3	**67.17**	-21.50*	**-30.11***	**-25.78***	**-43.65***
Lincoln × DPPLMR-41	87.07	10.16	4.86	-3.79	-26.96*
Lincoln × Pb-89	106.30	9.46	-10.82	17.46	-10.82
DPP 9418-06 × DPP-3	92.20	-2.42	-4.06	1.88	-22.65*
DPP 9418-06 × DPPLMR-41	89.60	1.88	-3.52	-0.99	-24.83*
DPP 9418-06 × Pb-89	116.17	9.56	-2.54	28.36*	-2.54
DPP-3 × DPPLMR-41	101.37	13.17	5.48	12.01	-14.96*
DPP-3 × Pb-89	123.73	14.94*	3.80	36.72*	3.80
DPPLMR-41 × Pb-89	101.47	0.35	-14.88*	12.12	-14.88*
SE ±	5.57	7.04	8.13	8.13	8.13

*Significant at 5% level of significance

check 1 (Palam Priya) and standard check 2 (Pb-89) are presented in Appendix III (Table 28). In the genotypes studied, the value of pod yield per plant ranged from 75.03 (Lincoln) to 119.2 g (Pb-89) and 67.17 (Lincoln x DPP-3) to 168.53 g (Azad Pea-1 x Pb-89) in parents and F_1s, respectively.

The magnitude of heterosis for this trait ranged from -22.12 (Palam Priya x DPP-3) to 59.37 per cent (Azad Pea-1 x Pb-89), -30.11 (Lincoln x DPP-3) to 41.39 per cent (Azad Pea-1 x Pb-89), -25.78 (Lincoln x DPP-3) to 86.22 per cent (Azad Pea-1 x Pb-89) and -43.65 (Lincoln x DPP-3) to 41.39 per cent (Azad Pea-1 x Pb-89) over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89), respectively.

Out of 21 hybrids evaluated, six crosses *viz.,* Azad Pea-1 x Pb-89 (59.37%), Palam Priya x Azad Pea-1 (33.26%), Azad Pea-1 x DPPLMR-41 (29.43%), Palam Priya x Pb-89 (23.67%), Azad Pea-1 x DPP 9418-06 (18.27%) and DPP-3 x Pb-89 (14.94%) had significant positive heterosis over mid parent. Heterobeltiosis to the extent of 41.39, 31.96, 22.93 and 17.91 per cent was exhibited by the crosses, Azad Pea-1 x Pb-89, Palam Priya x Azad Pea-1, Palam Priya x Pb-89 and Azad Pea-1 x DPP 9418-06, respectively. As many as seven crosses namely, Azad Pea-1 x Pb-89 (86.22%), Palam Priya x Pb-89 (43.28%), DPP-3 x Pb-89 (36.72%), Palam Priya x Azad Pea-1 (34.59%), DPP 9418-06 x Pb-89 (28.36%), Azad Pea-1 x DPPLMR-41 (25.38%) and Azad Pea-1 x DPP 9418-06 (20.99%) displayed significant positive heterosis over standard check 1 (Palam Priya). Only one cross combination Azad Pea-1 x Pb-89 expressed significant positive heterosis to the tune of 41.39 per cent over standard check 2 (Pb-89).

Table 29: General and specific combining ability effects for pod yield per plant

Parents	1	2	3	4	5	6	7	GCA
1	-1.598	15.987*	3.050	-3.239	-18.165*	-7.257	12.820*	-3.535*
2		-27.228*	-8.798	3.180	-3.746	9.861	37.972*	10.179*
3			4.431	1.676	-12.917*	7.924	0.202	-14.284*
4				-0.246	0.861	-0.798	-1.187	-3.028
5					6.535	12.743*	8.154	-4.802*
6						-4.650	-13.172*	-5.743*
7							-22.394*	21.213*

Standard errors

SE (U) = ±1.086

SE (gi) = ± 1.774

SE (sii) = ± 4.392

SE (sij) = ± 5.161

SE (gi-gj) = ± 2.710

SE(sii-sjj) = ± 6.061

SE (sij-sik) = ± 7.667

SE (sij-skl) = ± 7.172

b) Combining ability effects

The general combining ability effect of the parents and specific combining ability effects of the hybrids are presented in Table 29. The genotypes, Pb-89 and Azad Pea-1 displayed significant positive general combining ability effects for pod yield per plant and were rated as good general combiners. The genotypes namely, Lincoln, DPPLMR-41, DPP-3 and Palam Priya exhibited significant negative GCA effects, thus categorized as poor general combiners. The genotype, DPP 9418-06 was the average general combiner as it displayed negative non-significant general combining ability effects.

Out of 21 hybrids studied, four specific hybrid combinations namely, Azad Pea-1 x Pb-89, Palam Priya x Azad Pea-1, Palam Priya x Pb-89 and DPP-3 x DPPLMR-41 expressed significant positive SCA effects and were designated as good specific cross combinations. The poor specific cross combinations were Palam Priya x DPP-3, DPPLMR-41 x Pb-89 and Lincoln x DPP-3 as reflected from their significant negative SCA effects. The remaining fourteen specific cross combinations were rated as average specific cross combination as evidenced from their positive or negative non-significant specific combining ability effects.

c) Graphical analysis

The graphical presentation for pod yield per plant is given in Fig. 11a. The value of observed regression coefficient 'b' (0.26 ± 0.12) was positive and low in magnitude, indicating the presence of inter-allelic interactions. The regression line intersected Wr-axis below print of origin indicating the presence of over-dominance. The scatter of array points along the regression line suggested

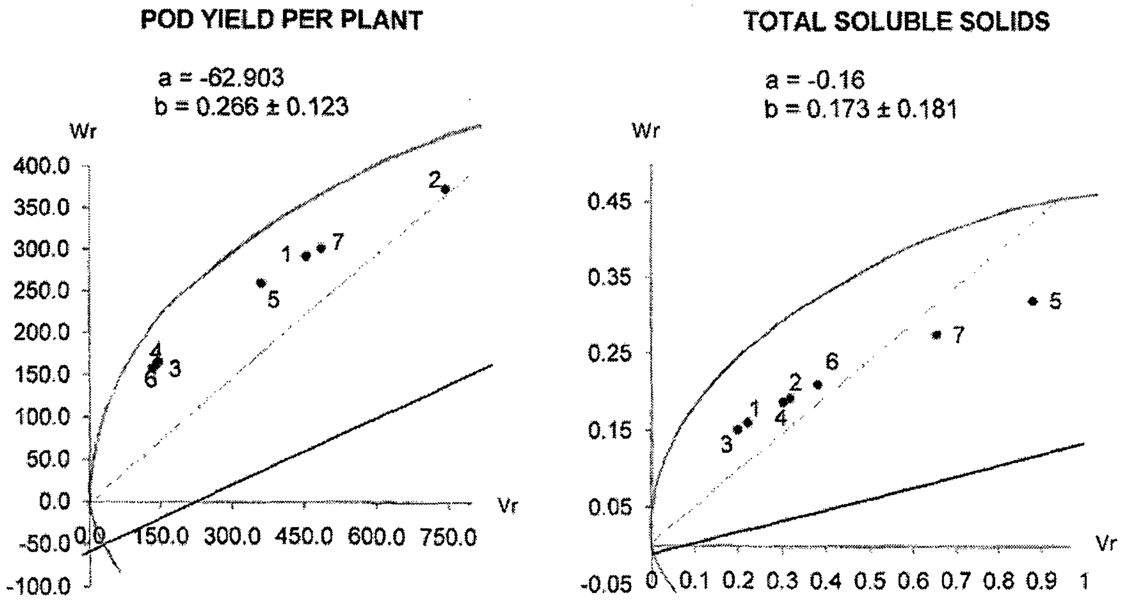


Fig.11a

Fig.12a

Vr, Wr GRAPH

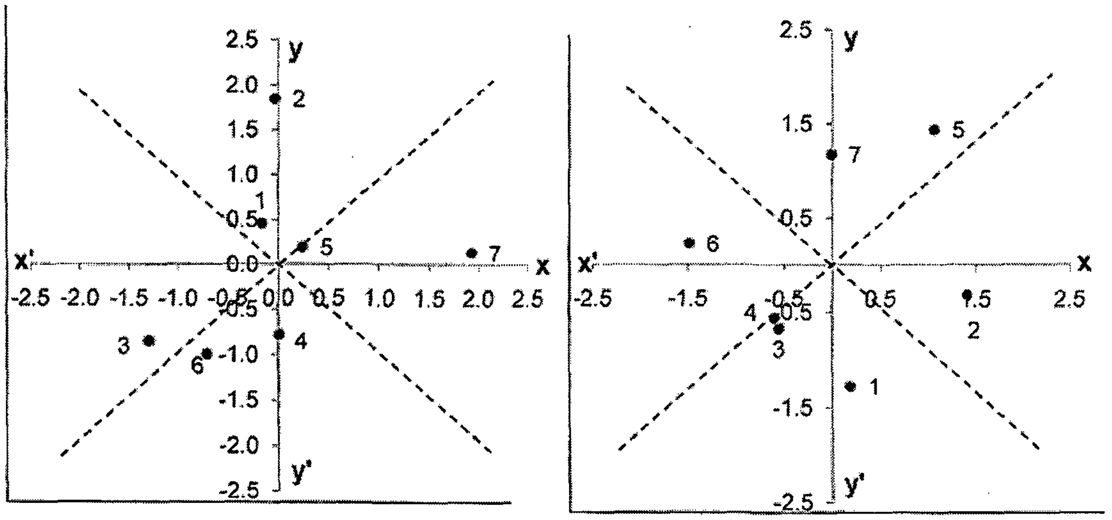


Fig.11b

Fig.12b

STANDARDIZED DEVIATION GRAPH

Table 30: Estimation of components of genetic variation for pod yield per plant (g) and total soluble solids (° brix)

Parameter	Pod yield per plant (g)	Total soluble solids (° brix)
t^2	12.03	4.94
D	151.82 ± 136.05	0.05 ± 0.17
H_1	874.48* ± 327.54	1.39* ± 0.42
H_2	613.85* ± 228.61	1.28* ± 0.37
F	-303.40 ± 326.39	-0.09 ± 0.42
E	35.57 ± 48.10	0.07± 0.06
Mean degree of dominance $(H_1/D)^{½}$	2.40	5.36
$H_2/4H_1$	0.17	0.23
KD/KR	0.41	0.70
Correlation coefficient between (Wr+Vr) and Yr	0.69	0.39
Regression (b)	0.26 ± 0.12	0.17 ± 0.18
Heritability (broad sense)	89.22	86.13
(narrow sense)	22.39	8.43

*Significant at 5% level of significance

that the parents used in the present study were genetically diverse. The parental arrays, DPPLMR-41, DPP 9418-06 and Lincoln were very close to the point of origin indicating that these parents possessed excess of dominant genes, whereas array, Azad Pea-1 was far away from the point of origin which suggested the presence of excess of the recessive genes influencing pod yield. The standardized deviation graph (Fig. 11b) revealed that the parents, Pb-89 and DPP-3 contained excess of recessive genes with increased effect on pod yield per plant. Lincoln and DPPLMR-41 possessed excess of dominant genes with negative effect, whereas DPP 9418-06 contained more of the dominant genes with increased effect on this trait.

d) Components of genetic variation

The genetic parameters D_1, H_1, H_2, F and E and various proportional values calculated are presented in Table 30. The non-significant 't^2' revealed that the Wr, Vr values were homogeneous and fulfilled the basic assumptions of diallel analysis. The non-additive components (H_1 and H_2) were found significant which indicated the predominant role of non-additive genes in the expression of this trait. The value of 'F' was found negative and non-significant which suggested that the genotypes used in the present investigation possessed more of the recessive genes.

The relative distribution of increasing (positive) and decreasing (negative) genes among the common parents of arrays as inferred from the ratio of $H_2/4H_1$ suggested their asymmetrical distribution. The ratio of KD/KR deviated from unity and low in magnitude which revealed that the parents contained excess of the recessive genes for the manifestation of this trait.

Positive correlation coefficient between parental order of dominance (Yr) and parental measurements (Wr + Vr) indicated that the increased pod yield was controlled by the recessive genes. The character had depicted fairly high broad sense (89.22%) and low narrow sense (22.39%) heritability estimates.

12) Total soluble solids (° brix)

a) Mean performance and heterotic response

The mean values of parents, F_1s and per cent heterosis over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89) are given in Appendix III (Table 31).

For this trait, DPPLMR-41 showed minimum (17.5 °brix) and Azad Pea showed maximum (18.48 °brix) total soluble solids. The average performance of hybrids ranged from 17.42 (Lincoln x DPPLMR-41) to 20.25% (DPP-3 x Pb-89). The range of heterosis was from -2.87 (Palam Priya x Azad Pea-1) to 11.37% (DPP-3 x Pb-89), -4.26 (DPP 9418-06 x DPP-3) to 10.25% (DPP-3 x Pb-89), -3.60 (Lincoln x DPPLMR-41) to 12.08% (DPP-3 x Pb-89) and -3.24 (Lincoln x DPPLMR-41) to 12.50% (DPP-3 x Pb-89) over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89), respectively. Out of 21 F_1s ten over mid parent, four over better parent, six over standard check 1 (Palam Priya) and seven over standard check 2 exhibited significant positive heterosis for this trait. The top most heterotic combination exhibiting maximum average heterosis (11.37%), heterobeltiosis (10.25%), standard heterosis over Palam Priya (12.08%) and standard heterosis over Pb-89 (12.50%) was DPP-3 x Pb-89.

Table 31: Mean performance of hybrids and per cent heterotic response for total soluble solids (° brix)

Hybrid	Mean	Per cent increase or decrease in F_1 over			
		Mid parent	Better parent	Standard check 1	Standard check 2
Palam Priya × Azad Pea-1	17.75	**-2.87**	-3.97*	-1.75	-1.39
Palam Priya × Lincoln	18.67	4.04*	3.32	3.32	3.70
Palam Priya × DPP 9418-06	18.87	5.20*	4.43*	4.43*	4.81*
Palam Priya × DPP-3	17.83	-2.10	-2.90	-1.29	-0.93
Palam Priya × DPPLMR-41	18.75	5.44*	3.78	3.78	4.17*
Palam Priya × Pb-89	18.67	3.51*	3.32	3.32	3.70
Azad Pea-1 × Lincoln	18.08	-0.37	-2.16	0.09	0.46
Azad Pea-1 × DPP 9418-06	18.17	0.14	-1.71	0.55	0.93
Azad Pea-1 × DPP-3	19.28	4.66*	4.33*	6.73*	7.13*
Azad Pea-1 × DPPLMR-41	18.50	2.83	0.09	2.40	2.78
Azad Pea-1 × Pb-89	19.17	5.07*	3.70	6.09*	6.48*
Lincoln × DPP 9418-06	18.08	1.54	1.50	0.09	0.46
Lincoln × DPP-3	18.08	-0.05	-1.54	0.09	0.46
Lincoln × DPPLMR-41	**17.42**	-1.37	-2.25	**-3.60**	**-3.24**
Lincoln × Pb-89	18.67	4.23*	3.70	3.32	3.70
DPP 9418-06 × DPP-3	17.58	-2.76	**-4.26***	-2.68	-2.31
DPP 9418-06 × DPPLMR-41	18.00	1.98	1.12	-0.37	0.01
DPP 9418-06 × Pb-89	19.08	6.61*	6.02*	5.63*	6.02*
DPP-3 × DPPLMR-41	19.00	5.95*	3.45	5.17*	5.56*
DPP-3 × Pb-89	**20.25**	**11.37***	**10.25***	**12.08***	**12.50***
DPPLMR-41 × Pb-89	17.83	0.47	-0.93	-1.29	-0.93
SE ±	0.26	0.32	0.37	0.37	0.37

*Significant at 5% level of significance

Table 32: General and specific combining ability effects for total soluble solids

Parents	1	2	3	4	5	6	7	GCA
1	-0.255	-0.710*	0.571*	0.688*	-0.721*	0.669*	0.012	-0.014
2		-0.116	-0.151	-0.151	0.590*	0.281	0.373	0.125
3			-0.053	0.131	-0.245	-0.438	0.238	-0.240*
4				-0.236	-0.829*	0.062	0.571*	-0.156*
5					-0.421*	0.686*	1.362*	0.220*
6						-0.340	-0.581*	-0.254*
7							-0.988*	0.320*

Standard errors

SE (U) = ± 0.049

SE (gi) = ± 0.080

SE (sii) = ± 0.198

SE (sij) = ± 0.233

SE (gi-gj) = ± 0.123

SE(sii-sjj) = ± 0.274

SE (sij-sik) = ± 0.347

SE (sij-skl) = ± 0.324

b) Combining ability effects

The genotypes, Pb-89 and DPP-3 were observed to be the good general combiners, whereas DPPLMR-41, Lincoln and DPP 9418-06 were the poor general combiners. The remaining parents namely, Palam Priya and Azad Pea-1 were observed as the average general combiners for this trait (Table 32). Out of 21 cross combinations, six combinations namely, DPP-3 x Pb-89, Palam Priya x DPP 9418-06, DPP-3 x DPPLMR-41, Azad Pea-1 x DPP-3, Palam Priya x Lincoln and DPP 9418-06 x Pb-89 displayed significant positive specific combining ability effects and hence were rated as good cross combinations. The top most hybrid combinations in order of merit were DPP-3 x Pb-89, Palam Priya x DPP 9418-06 and DPP-3 x DPPLMR-41.

c) Graphical analysis

A graphical analysis for total soluble solids is given in Fig. 12a. The non-significant 't^2' value indicated that Wr, Vr values were homogeneous and satisfied the basic assumptions of diallel analysis. The magnitude of observed regression coefficient 'b' (0.26 ± 0.12) was low which indicated the presence of inter-allelic interactions. The regression line intersected Wr axis below the point of origin, indicating over-dominance. The parents, Lincoln and Palam Priya had more concentration of dominant genes, whereas DPP-3 had excess of recessive genes.

The standardized deviation graph (Fig. 12b) depicted that parental arrays, Azad Pea-1 and Palam Priya carried most of the dominant genes with positive effect, whereas DPP-3 and Pb-89 had excess of recessive genes with positive effects on total soluble solids. The parents namely, Lincoln and DPP 9418-06 possessed more of dominant genes with negative effect on this trait.

d) Components of genetic variation

The estimates of components of genetic variation for TSS are given in Table 30. A perusal of the values indicated that non-additive (H_1 and H_2) components played a major role in the expression of this trait. The negative and non-significant 'F' value indicated the presence of more number of recessive genes in the parents. The mean degree of dominance was in over-dominance range. The value of $H_2/4H_1$ was very close to the expected value of 0.25, suggesting symmetrical distribution of positive and negative genes in the parents. The ratio of KD/KR was less than unity which implied that frequency of recessive genes were more than the dominant ones.

The correlation coefficient between parental order of dominance and parental measurements was positive, suggested that high expression of the character was associated with recessive genes. The heritability estimates were fairly high in broad sense (86.13 %) and low in narrow sense (8.43%).

4.1.3 Estimates of genetic components of variation

The estimates of combining ability variances (σ^2gca and σ^2sca) and their ratio (σ^2sca/σ^2gca) have been presented in Table 33.

A glance values indicated that the estimates of σ^2sca were higher in magnitude as compared to σ^2gca for all the characters except for days to 50% flowering. Further the ratio of specific combining ability variances (σ^2sca) to general combining ability variance (σ^2gca) was more than unity for days to first

Table 33: Estimates of genetic components of variance

Character	Component		
	σ^2 gca	σ^2 sca	σ^2sca/ σ^2gca
Days to 50% flowering	4.359	4.227	0.970
Days to first picking	10.144	26.475	2.610
Duration of availability of marketable pods	6.957	8.362	1.202
Pod length	0.171	0.233	1.356
Pod width	0.0004	0.0007	1.750
Seeds per pod	0.097	0.172	1.773
Shelling percentage	1.273	6.991	5.492
Pods per plant	2.982	3.879	1.301
Branches per plant	0.138	0.36	2.608
Plant height	6.536	47.761	7.307
Pod yield per plant	135.546	177.888	1.312
Total soluble solids	0.044	0.328	7.454

picking, duration of availability of marketable pods, pod length, pod width, seeds per pod, shelling percentage, pods per plant, branches per plant, plant height, pod yield per plant and total soluble solids, thereby indicating non-additive genetic control for the inheritance of these traits. However, both additive and non-additive genetic variances were important in the manifestation of days to 50% flowering. The ratio of specific combining ability variances to the general combining ability variances further confirmed the involvement of both additive and non-additive gene action in the inheritance of days to 50% flowering.

DISCUSSION

Chapter V

DISCUSSION

The genetic architecture and the mode of inheritance of different horticultural traits are important considerations for planning an efficient breeding programme. Sufficient improvement has been made through the exploitation of heterosis breeding in vegetable crops yet it offers further scope for future utilization. Hybrid breeding, through, theoretically a good approach for the improvement of pea (*Pisum sativum* L.), yet it has certain apparent limitations, especially, the non-availability of stable genetical mechanism for hybrid seed production and thus making large scale hybrid seed production non-feasible. However, heterotic combinations can best be exploited by effecting selection for best plants/plant progenies in later filial generations. The present investigation entitled, **"Genetic analysis of some horticultural traits in Garden Pea (*Pisum sativum* L.)"** was designed and undertaken with the objectives to infer about the nature and extent of heterosis, combining abilities and gene action as reflected from combining ability variances, component and graphical analysis with respect to yield and yield contributing traits following diallel analysis. The results obtained have been discussed here under:

5.1 Heterosis, Combining ability and Gene action

Ever since the discovery of hybrid vigour by Shull (1914), it has become the most important genetic tool in improving the yield of self as well as cross-pollinated crops. The commercial exploitation of heterosis in self-pollinated (Rick, 1945; Bishop, 1954; Allard and Workman, 1963; Athwal and Borlaug, 1967 and Singh and Singh, 1978 a) and cross-pollinated crops (Hutchins, 1939 and Rao, 1968) suggested that self and cross fertilized plants are essentially similar in their heterotic response but its commercial exploitation need careful consideration in all crop plants irrespective of their breeding systems/modes of pollination.

Heterosis studies provide information about the per cent increase/decrease of F_1 performance over mid parent, better parent or standard check and thus help in identification of the best crosses but do not indicate the possible causes for superiority of the heterotic combinations. In general, the cross-combinations, which exhibit a high magnitude of heterosis for yield and yield-contributing traits but when such combinations are compared with the best parents, very few combinations stand out to be significantly superior and very often these lack in combination of desirable horticultural traits. The basic need is to pre-evaluate the parents for combining ability because the parents, which perform well in cross-combinations are of immense importance to the breeders. Thus, the investigation on general and specific combining ability is very useful in the selection of the parents, hybrid combinations and in the formulation of a successful hybridization programme.

The next crucial step after the identification of suitable crosses is with respect to the adoption of suitable breeding methodology for the purposeful management of generated variability, which largely depends upon the type of gene action in the population for the trait under genetic improvement (Cockerham, 1961 and Sprague, 1966). The diallel mating design not only evaluates parents and crosses for combining ability but also provides information regarding the nature of gene action controlling the inheritance of different horticultural traits.

The analysis of variance for design of experiment revealed significant differences for all the traits studied *viz.*, days to 50% flowering, days to first picking, duration of availability of marketable pods, pod length, pod width, seeds per pod, shelling percentage, pods per plant, branches per plant, plant height, pod yield per plant and total soluble solids (Table 1), which reflected that genotypes evaluated in the present study were genetically diverse. Significant variation among genotypes for different horticultural traits in pea has also been observed earlier by Tyagi and Srivastava (2001 b) and Kaur *et al.* (2003).

The variance due to general combining ability (GCA) and specific combining ability (SCA) were significant for all the characters under investigation (Table 2), indicating the presence of both additive and non-additive gene actions in the manifestation of all the traits. The involvement of both additive and non-additive gene actions in the inheritance of different horticultural traits in pea has also been reported by Sharma *et al.* (1999) and Narayan *et al.* (1999).

1) Days to 50% flowering

The genotypes which flower early are more desirable for getting early produce which fetches better returns to the farmers. All parental lines and their hybrid combinations were genetically diverse with respect to days to 50%

flowering. As many as four crosses over mid parent, one each over better parent and standard check 2 (Pb-89) and seven over standard check 1 (Palam Priya) displayed significant negative heterosis for this trait. Since, the standard heterosis is of great importance to the breeders, the crosses, Azad Pea-1 x Pb-89 (-18.04%), DPP 9418-06 x Pb-89 (-15.05%), Palam Priya x Pb-89 (-13.12%) and Azad Pea-1 x DPP9418-06 (-11.65%), DPP-3 x Pb-89 (-9.04%), Azad Pea-1 x DPP-3 (-8.66%), Lincoln x DPP 9418-06 (-8.45%) and Palam Priya x Azad Pea-1 (-7.23%) exhibited significant negative standard heterosis over Palam Priya (Table 3). However, Azad Pea-1 x Pb-89 had the highest (-9.05%) negative standard heterosis over Pb-89. Significant negative heterosis for days to 50% flowering has also been reported by Moitra and Singh (1986), Mishra *et al.* (1993), Tyagi and Srivastava (2001 b). The genotypes, Pb-89, Azad Pea-1 and DPP 9418-06 were observed to be the good general combiners and the parental *per se* performance for earliness was also better. The best specific combination for early flowering was Azad Pea-1 x Pb-89 as it exhibited the highest significant negative SCA effect (Table 4). This combination involved good general combiners as their parents. Both the general (σ^2gca) and specific (σ^2sca) combining ability variances were significant which indicated the equal involvement of additive and non-additive gene actions in the expression of this trait (Table 33). These results are in agreement with the findings of Gupta and Lodhi (1988), Sarawat *et al.* (1994) and Singh *et al.* (2006).

The component analysis showed that both the additive (D) and non-additive (H_1 and H_2) components were significant but the relative magnitude of non-additive components were more than additive which confirmed the results of combining ability variances. The value of regression coefficient of Wr on Vr was fairly high which clearly indicated the absence of non-allelic interactions. From the graphical analysis and mean degree of dominance, it was further confirmed that the non-additive genetic effects were more pronounced than additive genetic effects in the manifestation of this trait. The parents, Pb-89, DPP9418-06 and Azad Pea-1 possessed more of recessive genes as was evident from negative non-significant 'F' value and it was further confirmed from the ratio of KD/KR and graphical analysis . The importance of non-additive gene action in the inheritance of days to 50% flowering in pea has earlier been reported by Singh *et al.* (1986), Karmakar and Singh (1990) and Sood (2001). The narrow sense heritability was low indicating that non-additive genetic variation constituted the major portion of the phenotypic variation for days to 50% flowering.

The results obtained indicated that the most heterotic crosses *viz.*, Azad Pea-1 x Pb-89, DPP9418-06 x Pb-89 and Palam Priya x Pb-89 can further be exploited and the selection especially in the later filial generations may prove effective in evolving an early flowering genotype of garden pea.

2) Days to first picking

In vegetable crops, early maturing genotypes have an edge over late maturing as early produce fetches better prices in the market. Hence, main emphasis is given towards significant negative heterosis for this trait. Heterosis may be considered either over mid parent, better parent or standard checks. Evidently, the one over standard check would be more useful to the breeders.

Some of the hybrids were earlier in maturity than the standard checks Palam Priya (112.1 days) and Pb-89 (110.63 days). The cross, Azad Pea-1 x Pb-89 displayed -17.07, -16.00, -17.10 and -16.00 per cent significant negative heterosis over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89), respectively. The heterosis for days to first picking has also been reported by Narsinghani and Singh (1979), Mishra *et al.* (1993), Tyagi and Srivastava (2001 b), Kaur *et al.* (2003) and Singh *et al.* (2005).

The early maturing best specific cross combinations were Azad Pea-1 x Pb-89, Azad Pea-1 x DPP 9418-06, DPP 9418-06 x Pb-89, Palam Priya x Azad Pea-1 and Palam Priya x Pb-89. These best specific cross combinations involved either or both the parents with good general combining ability effects. Both GCA and SCA variances were significant for this trait but the relative magnitude of SCA variances was higher than GCA variances which indicated the predominant role of non-additive gene action in the inheritance of this trait. The ratio of general combining ability variances (σ^2gca) to specific combining ability variances (σ^2sca) further confirmed the involvement of dominant gene effects. The results are in confirmity with those obtained by Sharma *et al.* (1999) and Sood (2001).

The graphical analysis revealed that the parameter (H_1) was significant thereby indicating the preponderance of non-additive genes in the expression of this trait. The 'b' value deviated from unity indicating the presence of inter-allelic interactions. The over dominance was observed from the value of mean degree of dominance $(H_1/D)^{1/2}$. The results obtained from graphical and component analysis supported the findings of combining ability variances. The parents possessed more number of recessive genes as reflected from negative non-significant 'F' value and it was further confirmed from the ratio of KD/KR.

The results suggest that the cross combinations namely, Azad Pea-1 x Pb-89, Azad Pea-1 x DPP 9418-06, DPP 9418-06 x Pb-89, Palam Priya x Azad Pea-1 and Palam Priya x Pb-89 can be successfully exploited and selection in the segregating generation would be more beneficial in evolving an early maturing genotype.

3) Duration of availability of marketable pods

Duration of availability of marketable pods has great significance because extended duration of availability of marketable pods will increase marketable yield. Hence, main emphasis is given towards significant positive heterosis for this trait. The heterobeltiosis to the extent of 13.57 per cent and economic heterosis to the tune of 32.50 and 13.57% over standard check 1 (Palam Priya) and standard check 2 (Pb-89), was recorded in the cross Azad Pea-1 x Pb-89. The significant standard heterosis was observed in the crosses, Azad Pea-1 x Pb-89, Palam Priya x Pb-89, Azad Pea-1 x DPP 9418-06, Azad Pea-1 x DPPLMR-41 and DPP 9418-06 x Pb-89, when compared with Palam Priya as a standard check. The heterosis for duration of availability of marketable pods has also been reported by Sarawat *et al.* (1994). The best specific cross combinations were Azad Pea-1 x Pb-89, Palam Priya x Pb-89, Azad Pea-1 x DPPLMR-41, Lincoln x DPP-3 and Azad Pea-1 x DPP 9418-06. These combinations involved one of its parents as good general combiners. The best specific cross combination also displayed significant positive standard heterosis for this trait.

The genetic components, additive (D) and non-additive (H_1 and H_2) were found to be significant but the relative magnitude indicated the active role of non-additive gene action. The estimation of genetic components of variance revealed that specific combining ability variances (σ^2sca) was greater in magnitude, thus depicting that non-additive genetic variance was more important in the genetic control of duration of availability of marketable pods. The graphical analysis indicated the presence of over-dominance which was confirmed from the point of intersection of regression line in Wr, Vr graph. These results are in agreement with the findings of Kumar and Bal (1995).

The presence of substantial heterosis and the involvement of non-additive genetic effects in the expression of this character supported the fact that heterosis breeding can be an important tool in the improvement of this trait.

4) Pod length

In the present investigation, the experimental material used was genetically diverse as was evident from the significant mean squares due to treatment. Based upon superiority of hybrids over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89), considerable heterosis was observed in many crosses in F_1 generation. The best heterotic crosses were DPP-3 x Pb-89 and Azad Pea-1 x Pb-89, when compared with Palam Priya as a standard check. Significant positive heterosis for pod length in pea has also been reported by Singh *et al.* (1975), Mishra (1998) and Pandey *et al.* (2006). From combining ability analysis, it was inferred that the magnitude of specific combining ability variances (σ^2sca), depicted that non-additive genetic variance was more important in the genetic control of pod length. Non-additive gene action controlling the inheritance of pod length in pea has also been reported by Kalia and Sharma (2000) and Singh and Sharma (2001). The parents, Pb-89, DPP-3 and DPPLMR-41 were the good general combiners, whereas the crosses, Azad Pea-1 x DPP 9418-06, Azad Pea-1 x Pb-89 and DPP-3 x Pb-89 were the good specific combinations.

The results of combining ability variances were also confirmed by the low regression value 'b' in the graphical analysis and the higher magnitude of non-additive components (H_1 and H_2) in the component analysis. The position of regression line indicated over-dominance which was confirmed from the estimates of mean degree of dominance $(H_1/D)^{1/2}$. The positive correlation of Yr with Wr + Vr also confirmed that non-additive genes were associated with increased pod length.

The results obtained from all these parameters suggest that either heterosis breeding or selection of superior plants in the segregating generations would be more useful in isolating desirable segregants.

5) Pod width

The considerable variation was observed amongst parents for pod width. The highest pod width of 1.18 cm was observed in the parental line DPP 9418-06 and it ranged from 1.05 (Palam Priya) to 1.18 cm (DPP 9418-06). The highest significant positive heterosis over mid parent and standard check 1 (Palam Priya) was recorded in the cross Palam Priya x Pb-89 to the extent of

7.81 and 13.97%, respectively. Hybrid vigour for pod width has also been reported by Singh *et al.* (1985 a), Sharma *et al.* (1999) and Kumar *et al.* (2002). The combining ability analysis revealed that σ^2sca was greater in magnitude than σ^2gca which indicated the predominant role of non-additive gene action in the inheritance of this trait. The results are in confirmity with the findings of earlier researchers (Kumar *et al.,* 2002 and Chadha *et al.* 2008). The parental genotypes, Azad Pea-1, Pb-89 and DPP 9418-06 were categorized as good general combiners for increased pod width. The best specific cross combination was Palam Priya x Pb-89. Since this cross combination involved one parent with good general combining ability, it can be exploited for obtaining desirable segregants with increased pod width.

The regression of Wr on Vr was low in magnitude which suggested the presence of non-allelic interactions. The component analysis (D, H_1 and H_2) further supported the results obtained from the combining ability variances. The regression line intersected Wr, Vr axis below the origin which indicated over-dominance. The estimates of mean degree of dominance ($H_1/D^{1/2}$ confirmed the involvement of over-dominance in the genetic control of pod width. The ratio of KD/KR, suggested that the frequency of dominant genes was more than recessive ones in the parents for this character. The correlation coefficients of Yr with Wr + Vr indicated that the high expression of character was associated with recessive genes. Fairly high broad sense heritability and medium narrow sense heritability estimates were observed for pod width. The results are in confirmation with findings of many researchers like Kumar *et al.* (2002) and Dixit *et al.* (2006).

The presence of substantial heterosis coupled with the involvement of over-dominance clearly suggested to exploit heterosis breeding. Alternatively, selection in the later generations would be more useful in isolating desirable segregants.

6) Seeds per pod

Wide divergence between parental lines was observed for seeds per pod, which ranged from 5.5 (Azad Pea-1) to 7.1 cm (Pb-89). The maximum average heterosis of 16.80% and standard heterosis of 28.89% was recorded in a cross, Palam Priya x Pb-89. However, the cross, Azad Pea-1 x DPP-3 displayed the maximum heterobeltiosis to the extent of 11.05 per cent. As many as twelve cross combinations over mid parent, four over better parent and twelve over standard check 1 (Palam Priya) possessed significant positive heterosis for seeds per pod. Positive heterosis for seeds per pod has also been reported by Pant and Bajpai, 1993, Lejeune-Henaut *et al.,* 1992, Sarawat, *et al.,* 1994 and Sharma *et al.*, 1998.

The estimates of genetic components of variance revealed the presence of both additive and dominant gene action but comparatively higher magnitude of specific combining ability variances (σ^2sca) and the ratio of σ^2gca to σ^2sca clearly indicated the involvement of non-additive genetic effects in the manifestation of this trait. These results are in line with those of Koranne and Singh (1974), Rybnikova (1982), Singh and Sharma (2001), Sood (2001) and Dixit *et al.* (2006). The genotype, Pb-89 was observed as the good general combiner for seeds per pod. The best specific cross combinations were Azad Pea-1 x DPP-3, Palam Priya x Pb-89, Azad Pea-1 x DPP 9418-06, Palam Priya x

DPP-3 and Palam Priya x DPPLMR-41. The presence of sufficient heterosis coupled with high estimates of specific combining ability effects confirmed the involvement of non-additive genetic effects. The variance component analysis further supported the findings that non-additive genetic components were more predominant in the expression of this trait. The regression line intersected Wr axis below the origin which suggested the presence of over-dominance. The mean degree of dominance $(H_1/D)^{1/2}$ further confirmed the presence of over-dominance in the manifestation of seeds per pod.

The parents, DPP 9418-06, Pb-89 and DPP-3 contained more of dominant genes with increased effect on seeds per pod. These parents can successfully be exploited for obtaining desirable segregants in later generations for getting more number of seeds per pod. The low narrow sense heritability estimates coupled with the presence of substantial heterosis and non-additive gene action clearly suggest that heterosis breeding may be opted for bringing desirable improvement in seeds per pod.

7) Shelling percentage

Sufficient genetic variability existed amongst the parental lines which varied from 52.67 (DPPLMR-41) to 61% (DPP-3). Significant heterosis to the maximum extent of 11.93, 10.91, 12.96 and 10.91% over mid parent, better parent standard check 1 (Palam Priya) and standard check 2 (Pb-89) was noticed in the cross, Palam Priya x Pb-89. Other cross combinations exhibiting significant positive standard heterosis were Palam Priya x Lincoln, Azad Pea-1 x Pb-89, DPP-3 x DPPLMR-41 and DPPLMR-41 x Pb-89. Heterosis for shelling percentage was reported earlier by Abdou *et al.* (1999), Sood (2001) and Bhardwaj and Vikram (2002). The parental liens Pb-89 and DPP-3 were observed as the good general combiners for this trait. The crosses, Palam Priya x Pb-89, Palam Priya x Lincoln, DPP-3 x DPPLMR-41, Azad Pea-1 x Pb-89 and DPPLMR-4 x Pb-89 had the highest significant positive SCA effects and these best cross combinations involved average x good, average x average, good x poor, poor x good and poor x good general combiners which clearly suggested utilization of these crosses following biparental mating design.

The combining ability analysis indicated that higher magnitude of non-additive components appeared to play a major role in the inheritance of this trait. The components of genetic variation (D, H_1 and H_2) further supported that non-additive genetic components were more pronounced in the manifestation of this trait. Gupta (1982), Sharma *et al.* (1999) and Sood (2001) have also reported dominant gene action in the inheritance of shelling percentage. The graphical analysis showed the presence of over-dominance in the expression of the trait. The over-dominance was also confirmed from the value of mean degree of dominance. Further, positive and non-significant 'F' value indicated that the parents contained more of dominant genes controlling this trait.

The narrow sense heritability was medium, which suggested that either biparental mating or heterosis breeding can be successfully exploited for bringing considerable improvement in shelling percentage. Alternatively, selection in later generations may be carried out for advancing generations.

8) Pods per plant

Pods per plant is a direct component which contributes towards higher pod yield in pea. The analysis of variance and further the mean squares due to treatments indicated that the genotypes used in the present investigation were genetically diverse. Two cross combinations namely, Palam Priya x Azad Pea-1 and Azad Pea-1 x Pb-89 displayed the highest significant positive heterosis to the extent of 35.57, 31.75, 53.64 and 13.38 per cent over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89). Heterosis was also observed in the other cross combinations but of lesser magnitude. Heterosis for pods per plant has also been reported earlier by many researchers (Parmar and Godawat, 1990; Lejeune-Henaut *et al.,* 1992; Sharma *et al.,* 1998; Mishra, 1998; Abdou *et al.,* 1999; Kaur *et al.*, 2003 and Pandey *et al.,* 2006). The combining ability analysis revealed the presence of both additive and non-additive types of gene effects but their comparative magnitude hinted towards the involvement of dominant gene action in the expression of this trait. These results are analogous with those of Venkateswarlu and Singh (1982) and Sarawat *et al.* (1994).

The parent, Pb-89 appeared to be a good general combiner followed by Azad Pea-1. Cross combinations, Palam Priya x Azad Pea-1, Azad Pea-1 x Pb-89, Azad Pea-1 x DPP 9418-06, Azad Pea-1 x DPPLMR-41 and DPP-3 x Pb-89 exhibited significant positive specific combining ability effects. These results strongly favour that either heterosis breeding or delayed selection can be undertaken for the improvement of pods per plant. Similar results have also been reported earlier by Kumar and Tewatia (2003) and Singh and Dhillon (2004). The cross, Azad Pea-1 x Pb-89 exhibited the highest estimates of specific combining ability effects and it involved good x good general combiners as its parents. Significant general and specific combining ability effects for number of pods per plant have also been observed by Dubey and Lal (1983).

Standardized deviation graph suggested that Pb-89 possessed dominant and Azad Pea-1 contained recessive genes with positive effects for increased number of pods per plant. The genetic component of variation revealed the presence of non-allelic interactions with over-dominance, which corroborates the findings of Kalia (1982). Estimates of dominance components also confirmed the predominant role of non-additive gene action for this trait. The results are in agreement with the findings of Sood (2001), who has reported non-additive genetic effects with over-dominance for pods per plant. High broad sense and low narrow sense heritability estimates further supported the results of both variance component and combining ability analysis. Korrane and Singh (1974) have also observed high heritability estimates for pods per plant.

The higher magnitude of exploitable heterosis and predominant role of specific combining ability variances, it is concluded that either heterosis breeding or delayed selection may be opted for evolving an ideal genotype having more number of pods per plant.

9) Branches per plant

The number of branches is a direct component for getting more number of pods, which ultimately leads to higher pod yield in pea. The maximum heterosis upto 88.52% was observed in a cross DPP 9418-06 x Pb-89. As many as seven crosses over mid parent, six over better parent and sixteen over standard check 1 (Palam Priya) showed significant positive heterosis for branches per plant, thus affording opportunity for heterosis breeding. Significant heterosis for this trait has also been reported by Singh *et al.* (1978) and Venkateswarlu and Singh (1982). Both the GCA and SCA variances were equally important but comparatively higher estimates of σ^2sca over σ^2gca indicated that non-additive genetic effects played a major role in the manifestation of number of branches per plant. The results are analogous with findings of Dubey and Lal (1983) and Katiyar *et al.* (1987). The lines, Pb-89, DPPLMR-41 and DPP 9418-06 showed positive general combining ability effects for this trait. The cross combinations which showed good SCA effects were Azad Pea-1 x Lincoln, Palam Priya x DPP 9418-06, Palam Priya x Azad Pea-1, Azad Pea-1 x DPP 9418-06, Palam Priya x DPP-3, Lincoln x DPP 9418-06 and DPP 9418-06 x Pb-89.

The indication of over-dominance from the value of mean degree of dominance $(H_1/D)^{1/2}$ was in confirmity with combining ability variances and component analysis. The results are in confirmation with the findings of Singh and Sharma (2001). The standardized deviation graph showed that the recessive genes in the parents DPPLMR-41 and Pb-89 were associated with more number of branches per plant.

The heritability estimates both in narrow and broad sense were fairly high which showed that simple selection procedures could be employed for getting more number of branches.

10) Plant height

The experimental material used in the present investigation was genetically variable as evident from highly significant differences among parents, which ranged from 67.8 (Lincoln) to 94.93cm (DPP-3). To make commercial pea growing a remunerative venture, dwarf and medium genotypes are preferred as these can be grown successfully without staking. Significant desirable negative heterosis to the extent of -25.90% over standard check 2 (Pb-89) was observed in the cross, Azad Pea-1 x DPPLMR-41. However, the cross, DPP-3 x Pb-89 displayed the maximum heterobeltiosis to the extent of -24.37 per cent. These results are in confirmity with those of Mendel (1866), Narsinghani and Singh (1979), Sarawat *et al.* (1994), Tyagi and Srivastava (2001 b) and Singh *et al.* (2005). The combining ability analysis revealed that the parent Lincoln was good general combiner for decreased plant height and the parent DPP-3 for increased plant height. The cross combinations, DPP-3 x Pb-89, Azad Pea-1 x DPPLMR-41, DPP 9418-06 x DPP-3 and Palam Priya x Pb-89 exhibited significant negative SCA effects, whereas Azad Pea-1 x DPP-3, Azad Pea-1 x Lincoln, Azad Pea-1 x DPP 9418-06, Palam Priya x DPP-3 and Palam Priya x Lincoln had significant positive SCA effects, thereby providing an opportunity to explore the possibility of heterosis breeding.

The graphical analysis showed over-dominance. Both additive (D) and non-additive (H_1 and H_2) components were significant, but the comparative magnitude of non-additive components of variation appeared to play an important role in the inheritance of this trait. These results are in the line with those of

Singh and Sharma (2001). The mean degree of dominance confirmed the involvement of non-additive genes in the expression of this trait.

The estimates of heritability both in narrow sense and broad sense were fairly high indicating that simple selection could be employed for evolving an ideal plant height of pea.

11) Pod yield per plant

Yield being a complex trait is depend upon the other horticultural traits and its improvement is easier if progress is made through its component characters like pod length, pod width, seeds per pod, pod weight and pods per plant. Increase in yield has always been the first and foremost objective in any crop improvement programme. Significant differences for pod yield were observed among the treatments which was evident from their significant mean squares. As many as six crosses over mid parent, four over better parent, seven over standard check 1 (Palam Priya) and one over standard check 2 (Pb-89) displayed significant positive heterosis. The hybrid combination, Azad Pea-1 x Pb-89 displayed the highest heterotic response to the extent of 59.37, 41.39, 86.22 and 41.39% over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89), respectively (Table 28). Significant desirable heterosis has also been reported earlier by many workers (Putincev, 1965; Gritton, 1975; Singh *et al.*, 1978; Parmar and Godawat, 1990; Singh *et al.*, 1994; Singh and Mishra, 1996 and Narayan *et al.*, 1999). Highest heterotic response favours the development of hybrids but it is not economically feasible in pea due to cleistogamous flowers, where male and female organs are covered by keel which need manual emasculation for hybridization, few seeds per pollination and more seed rate, thereby making hybrid breeding uneconomical. The result of combining ability analysis revealed that the parents, Pb-89 and Azad Pea-1 were the good general combiners for increased pod yield, whereas the parents, Lincoln, DPPLMR-41, DPP-3 and Palam Priya were the poor general combiners for this trait. The best specific cross combinations were Azad Pea-1 x Pb-89, Palam Priya x Azad Pea-1, Palam Priya x Pb-89 and DPP-3 x DPPLMR-41 for pod yield. The results are in agreement with the findings of earlier workers (Srivastava *et al.,* 1986; Sharma *et al.,* 2000; Singh and Dhillon, 2004; Singh *et al.,* 2005 and Pandey *et al.,* 2006).

Both the combining ability analysis and the components of genetic variation suggested the importance of both additive and dominance gene action but comparatively the higher magnitude of non-additive components clearly indicated the predominant role of non-additive genetic effects in the inheritance of this trait. In literature, the role of non-additive gene action was reported to govern the inheritance of pod yield per plant in pea by Dhaliwal *et al.* (1971), Nandpuri *et al.* (1973), Kumar and Bal (1995), Sharma *et al.* (1999), Singh and Sharma (2001) and Sood (2001). The importance of both additive and non-additive gene effects in the inheritance of this trait has also been reported by Narayan *et al.* (1999), Tyagi and Srivastava (2001a), Narayan (2006) and Singh *et al.* (2006).

Graphical analysis revealed the presence of over-dominance which was probably due to the predominant role of non-additive genetic variance. The mean degree of dominance $(H_1/D)^{1/2}$ further confirmed over-dominance. These findings are in confirmity with those of Koranne and Singh (1974). The value of regression coefficient (b) deviated from unity which further confirmed the presence of non-allelic interactions in the inheritance of this trait. The parents possessed more for recessive genes for increased pod yield which was reflected from negative non-significant 'F' value. The ratio of dominant to recessive genes further confirmed the involvement of more of recessive genes in the parents for enhanced pod yield. The influence of recessive genes in increasing pod yield was further confirmed from the positive correlation coefficient between parental order of dominance (Yr) and parental measurements (Wr + Vr). Low narrow sense heritability estimates suggested the involvement of non-additive genes in the manifestation of pod yield per plant. The results are in confirmity with the findings of Abdou *et al.* (1999) who observed low narrow sense heritability estimates. However Gupta *et al.* (1998), Shinde (2000) and Chadha *et al.* (2008) recorded high heritability estimates for pod yield per plant.

The findings reveal that either heterosis breeding or delayed selection of desirable segregants in later filial generations may be carried out for effecting improvement in marketable pod yield.

The trait-wise list of the hybrids exhibiting maximum heterosis over better parent, standard check 1(Palam Priya) and standard check 2 (Pb-89) is presented in Table 34.

Table 34: Best cross combinations and per cent heterotic response for different traits

Trait	Crosses with highest heterosis over		
	Standard check 1	Standard check 2	Better parent
Days to 50% flowering	Azad Pea-1× Pb-89 (-18.04), DPP 9418-06 × Pb-89 (-15.05), Palam Priya × Pb-89 (-13.12)	Azad Pea-1× Pb-89 (-9.05)	Azad Pea-1× Pb-89 (-9.05)
Days to first picking	Azad Pea-1× Pb-89 (-17.10), Azad Pea-1 × DPP 9418-06 (-14.15), DPP 9418-06 × Pb-89 (-13.92)	Azad Pea-1× Pb-89 (-16.00), Azad Pea-1 × DPP 9418-06 (-13.02), DPP 9418-06 × Pb-89 (-12.77)	Azad Pea-1× Pb-89 (-16.00), Azad Pea-1 × DPP 9418-06 (-14.69), DPP 9418-06 × Pb-89 (-14.45)
Duration of availability of marketable pods	Azad Pea-1× Pb-89(32.50), Palam Priya × Pb-89 (22.50), Azad Pea-1 × DPP 9418-06 (17.50)	Azad Pea-1× Pb-89 (13.57)	Azad Pea-1× Pb-89 (13.57), Azad Pea-1 × DPP 9418-06 (10.16)
Pod length	DPP-3 × Pb-89 (14.95), Azad Pea-1× Pb-89 (12.10)	-	Azad Pea-1 × DPP 9418-06(13.06)
Pod width	Palam Priya × Pb-89 (13.97), Azad Pea-1× Pb-89 (10.79), Palam Priya x Azad Pea-1 (8.89)	-	-
Seeds per pod	Palam Priya × Pb-89 (29.89), Azad Pea-1× Pb-89 (24.14), DPP 9418-06 × Pb-89 (22.99)	-	Azad Pea-1 × DPP-3 (11.05), Palam Priya × DPPLMR-41 (9.60), Palam Priya × Azad Pea-1(8.62)

Shelling percentage	Palam Priya × Pb-89 (12.96), Palam Priya × Lincoln (8.64), Azad Pea-1× Pb-89 (7.41)	Palam Priya × Pb-89 (10.91), Palam Priya × Lincoln (6.67)	Palam Priya × Pb-89 (10.91), Palam Priya × Lincoln (8.64),
Pods per plant	Azad Pea-1× Pb-89 (53.64), DPP-3 x Pb-89 (40.37), Palam Priya × Azad Pea-1(39.63), DPP 9418-06 × Pb-89 (39.44)	Azad Pea-1× Pb-89 (13.38),	Palam Priya × Azad Pea-1(31.75), Azad Pea-1× DPP 9418-06 (27.51), Azad Pea-1× DPPLMR-41 (21.87)
Branches per plant	DPP 9418-06 × Pb-89 (88.52), Palam Priya × DPP 9418-06 (65.57), Palam Priya × Pb-89 (65.57)	-	Palam Priya × DPP 9418-06 (60.32), Azad Pea-1 × Lincoln (57.89), Azad Pea-1 × DPP 9418-06 (53.97)
Plant height	**Dwarf:** Azad Pea-1 × DPPLMR-41 (-14.23), Lincoln × DPP 9418-06 (-11.84), DPP-3 × Pb-89 (-11.18) **Tall:** Azad Pea-1 x DPP-3 (15.38) Palam Priya x DPP-3 (8.37)	**Dwarf:**Azad Pea-1 × DPPLMR-41 (-25.90), Lincoln × DPP 9418-06 (-23.83), DPP-3 × Pb-89 (-23.26)	**Dwarf:**DPP-3 × Pb-89 (-24.37), Palam Priya × Pb-89 (-22.02), Azad Pea-1 × DPPLMR-41 (-21.95) **Tall:** Azad Pea-1 x Lincoln (18.82)
Pod yield per plant	Azad Pea-1× Pb-89 (86.22), Palam Priya × Pb-89 (43.28), DPP-3 × Pb-89 (36.72)	Azad Pea-1× Pb-89 (41.39)	Azad Pea-1× Pb-89 (41.39), Palam Priya × Azad Pea-1(31.96), Azad Pea-1× DPPLMR-41 (22.93)
Total soluble solids	DPP-3 × Pb-89 (12.08), Azad Pea-1× DPP-3 (6.73), Azad Pea-1 × Pb-89 (6.09)	DPP-3 × Pb-89 (12.50), Azad Pea-1× DPP-3 (7.13), Azad Pea-1 × Pb-89 (6.48)	DPP-3 × Pb-89 (10.25), DPP 9418-06 × Pb-89 (6.02), Palam Priya × DPP 9418-06 (4.43)

*Values in parenthesis indicate per cent heterotic response

12) Total soluble solids (TSS)

Increased amount of TSS is a desirable quality attribute from the consumers view point. In the present set of material, TSS in parents ranged from 17.5 (DPPLMR-41) to 18.48 °brix (Azad Pea-1), whereas in F_1s, it varied from 17.42 (Lincoln x DPPLMR-41) to 20.25 °brix (DPP-3 x Pb-89). Favourable heterosis to the extent of 12.08 and 12.50% was recorded in the cross combination DPP-3 x Pb-89. The results are in agreement with the findings of Tyagi and Srivastava (1999), who observed significant positive heterosis for TSS. The estimates of genetic components of variance reflected the preponderance of non-additive genetic effects in the control of this trait. The combining ability analysis revealed that the parents Pb-89 and DPP-3 were the good general combiners and cross combinations *viz.,* DPP-3 x Pb-89, Palam Priya x DPP 9418-06, DPP-3 x DPPLMR-41, Azad Pea-1 x DPP-3, Palam Priya x Lincoln and DPP 9418-06 x Pb-89 showed significant positive specific combining ability effects for increased TSS.

The trait-wise list of best general combiners, best specific cross combinations and nature of gene action involved in the inheritance of different horticultural traits is given in Table 35.

The standardized deviation graph suggested that the higher TSS in the parents DPP-3 and Pb-89 was controlled by the recessive genes, whereas in parents, Palam Priya and Azad Pea-1, higher TSS was under the control of dominant genes. It will therefore, be desirable to involve the parents like DPP-3, Pb-89, Palam Priya and Azad Pea-1 in hybridization programme for increasing

Table 35: Best general, specific combiners and nature of gene action in the inheritance of different horticultural traits

Trait	Best general combiner	Best specific combination	Nature of gene action
Days to 50% flowering	Pb-89, Azad Pea-1, DPP 9418-06	Azad Pea-1 × Pb-89, Lincoln × DPPLMR-41, Palam Priya × Pb-89	Additive and non-additive
Days to first picking	Pb-89, Azad Pea-1	Azad Pea-1 × Pb-89, Azad Pea-1 × DPP 9418-06, DPP 9418-06 × Pb-89	Non-additive
Duration of availability of marketable pods	Pb-89, Azad Pea-1	Azad Pea-1 × Pb-89, Palam Priya × Pb-89, Azad Pea-1 × DPPLMR-41	Non-additive
Pod length	Pb-89, DPP-3, DPPLMR-41	Azad Pea-1 × DPP 9418-06, Azad Pea-1 × Pb-89, DPP-3 × Pb-89	Non-additive
Pod width	Pb-89, Azad Pea-1, DPP 9418-06	Palam Priya × Pb-89	Non-additive
Seeds per pod	Pb-89	Azad Pea-1 × DPP-3, Palam Priya × Pb-89, Azad Pea-1 × DPP 9418-06	Non-additive
Shelling percentage	Pb-89, DPP-3	Palam Priya × Pb-89, Palam Priya × Lincoln, DPP-3 × DPPLMR-41	Non-additive
Pods per plant	Pb-89, Azad Pea-1	Palam Priya x Azad Pea-1, Azad Pea-1 × Pb-89, Azad Pea-1 × DPP 9418-06	Non-additive
Branches per plant	Pb-89, DPPLMR-41, DPP 9418-06	Azad Pea-1 × Lincoln, Palam Priya × DPP 9418-06, Palam Priya × Azad Pea-1	Non-additive
Plant height	**Dwarf** : Lincoln **Tall** : DPP-3	**Dwarf:** DPP-3 × Pb-89, Azad Pea-1 × DPPLMR-41, DPP 9418-06 × DPP-3 **Tall:** Azad Pea-1 x DPP-3, Azad Pea-1 x Lincoln	Non-additive
Pod yield per plant	Pb-89, Azad Pea-1	Azad Pea-1 × Pb-89, Palam Priya × Azad Pea-1, Palam Priya × Pb-89,	Non-additive
Total soluble solids	Pb-89, DPP-3	DPP-3 × Pb-89, Palam Priya × DPP 9418-06, DPP-3 × DPPLMR-41	Non-additive

TSS content. The component of genetic variation confirmed the predominant role of non-additive genes in the expression of this trait. The dominant gene control for total soluble solids in pea has also been reported by Narayan *et al.* (1999), Bhardwaj and Vikram (2002) and Singh *et al.* (2006). The presence of over-dominance was confirmed from the estimates of mean degree of dominance and the point of intersection of regression line in Wr, Vr graph. The KD/KR ratio indicated that the frequency of recessive genes was more than dominant genes in the parents. The deviation of regression coefficient value (b) from unity and low narrow sense heritability estimates further supported the presence of non-allelic interaction influencing the expression of this trait.

The value of all these parameters clearly suggests that heterosis breeding may be taken up for the improvement of total soluble solids in pea.

CONCLUSION

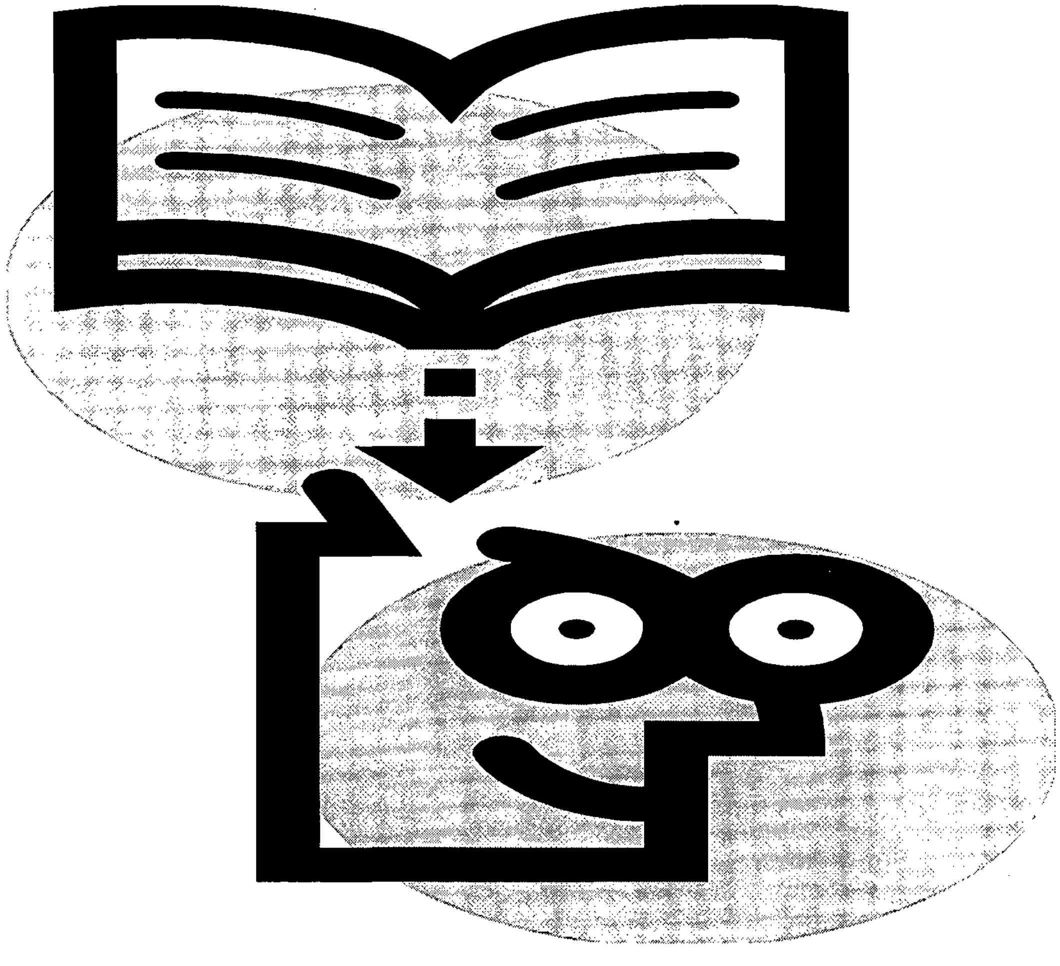
The knowledge of genetic architecture of quantitative characters is essential for systematic handling of the breeding material for achieving the maximum possible genetic gain. The proposed research work was based on three biometrical approaches *viz.*, combining ability analysis, graphical analysis and component analysis to understand the gene action involved in the inheritance of different horticultural traits in garden pea (*Pisum sativum* L.).

Hybridization employing diallel mating of parental genotypes generated sufficient variability. The cross combination Azad Pea-1 x Pb-89 exhibited the highest favourable heterosis over mid parent, better parent, standard check 1 (Palam Priya) and standard check 2 (Pb-89) for days to 50% flowering, days to first picking, duration of availability of marketable pods, pods per plant and pod yield per plant. Other cross combinations namely, Palam Priya x Azad Pea-1, Azad Pea-1 x DPPLMR-41 and Azad Pea-1 x DPP 9418-06 exhibited desirable heterosis over mid parent, better parent and standard check 1 (Palam Priya) for pod yield per plant.

Combining ability analysis construed the predominant role of non-additive genetic effects in the inheritance of all the traits studied except for days to 50% flowering where both the additive and non-additive genetic effects were equally important. The genotype Pb-89 was found to be good general combiner for all the traits studied except for plant height. However, the genotype Azad Pea-1 was rated as good general combiner for days to 50% flowering, days to first picking, duration of availability of marketable pods, pod width, pods per plant and pod yield per plant. The cross combinations, Azad Pea-1 x Pb-89 and Palam Priya x Pb-89 displayed significant SCA effects for most of the traits studied *viz.,* days to 50% flowering, days to first picking, duration of availability of marketable pods, pod length, seeds per pod, shelling percentage and pod yield per plant, thereby providing enough scope for getting genetic gain through exploitation of heterosis breeding.

The graphical analysis revealed the involvement of over-dominance in the expression of all the traits studied. The parental lines, Lincoln and DPPLMR-41 possessed excess of dominant genes, whereas Palam Priya, Azad Pea-1 and Pb-89 contained excess of recessive genes for most of the traits studied. The dominant and recessive genes were asymmetrically distributed in the parents for days to 50% flowering, duration of availability of marketable pods, pod length, pod width, seeds per pod, shelling percentage, pods per plant, branches per plant, plant height, pod yield per plant, whereas. symmetrical distribution was observed for days to 50 per cent flowering and total soluble solids. The high narrow sense heritability estimates were found for pod length, branches per plant, plant height, whereas medium to low for days to 50 per cent flowering, days to first picking, duration of availability of marketable pods, pod width, seeds per pod, shelling percentage, pods per plant, pod yield per plant and total soluble solids.

SUMMARY



Chapter -VI

SUMMARY

The present investigation entitled **"Genetic analysis of some horticultural traits in Garden Pea (*Pisum sativum* L.)"** was designed and executed to obtain information pertaining to the nature and extent of heterosis, combining abilities, genetic architecture and inheritance pattern of yield and its contributing traits in seven genetically diverse pea genotypes and their crosses developed through diallel mating design (excluding reciprocals). The F_1 population of 21 crosses alongwith parents were evaluated in a Randomized Block Design with three replications at the Experimental Farm, Department of Vegetable Science and Floriculture, CSK HPKV, Palampur during Rabi 2008-09. The observations were recorded on different horticultural traits *viz.,* days to 50% flowering, days to first picking, duration of availability of marketable pods, pod length, pod width, seeds per pod, shelling percentage, pods per plant, branches per plant, plant height, pod yield per plant and total soluble solids.

The analysis of variance revealed significant differences for all the characters studied. Considerable heterosis over mid parent, better parent and standard checks (Palam Priya and Pb-89) was observed for all the traits studied. Out of 21 hybrid combinations, six over mid parent, four over better parent, seven over standard check 1 (Palam Priya) and one over standard check 2 (Pb-89) displayed significant desirable heterosis for pod yield per plant. The range of heterosis for pod yield per plant was -22.12 (Palam Priya × DPP-3) to 59.37%

(Azad Pea 1 × Pb-89) over mid parent, -30.11 (Lincoln × DPP-3) to 41.39% (Azad Pea 1 × Pb-89) over better parent, -25.78 (Lincoln × DPP-3) to 86.22% (Azad Pea 1 × Pb-89) over standard check 1 (Palam Priya) and -43.65 (Lincoln × DPP-3) to 41.39% (Azad Pea 1 × Pb-89) over standard check 2 (Pb-89). The cross combination, Azad Pea-1 × Pb-89 (168.53 g/plant) was observed to be the best as it exhibited 86.22 and 41.36% heterosis over both the standard checks Palam Priya and Pb-89, respectively. None of the remaining cross-combinations could surpass Pb-89. The other heterotic combinations which out yielded Palam Priya (standard check 1) were Palam Priya × Pb-89, DPP-3 × Pb-89, Palam Priya × Azad Pea-1, DPP 9418-06 × Pb-89, Azad Pea-1 × DPPLMR-41 and Azad Pea-1 × DPP 9418-06 as they exhibited standard heterosis for pod yield per plant. The cross Azad Pea-1 × Pb-89 also showed significant desirable heterosis over both the standard checks (Palam Priya and Pb-89) for days to 50 % flowering (-18.04%, -9.05%), days to first picking (-17.10%, -16.0%), duration of availability of marketable pods (32.5%, 13.57%) and pods per plant (53.64%, 13.38%). The other cross-combinations which exhibited significant desirable heterosis over Palam Priya (standard check 1) were DPP-3 × Pb-89 (14.95%) for pod length, Palam Priya × Pb-89 (29.98%) for both seeds per pod and shelling percentage (12.96%), Azad Pea- 1 × Pb-89 (53.64%) for pods per plant and Azad Pea- 1 × DPPLMR-41 for plant height (-14.23%).

The variances due to general and specific combining ability were significant for all the characters, there by indicating the presence of both additive and non-additive gene actions in the inheritance of these traits. However, the relative magnitude of SCA variances was higher than the GCA variances for days to first picking, duration of availability of marketable pods, pod length, pod width, seeds per pod, shelling percentage, pods per plant, branches per plant, plant height, pod yield per plant and total soluble solids indicating the preponderance of non-additive gene action in the inheritance of these traits. Both the additive and non-additive genetic variances played a major role in the manifestation of days to 50% flowering.

The high estimates of general combining ability effects were exhibited by the parents, Pb-89 and Azad Pea-1 for pod yield per plant, days to 50% flowering, days to first picking, duration of availability of marketable pods, pod width and pods per plant; Pb-89 for pod length, seeds per pod, shelling percentage, branches per plant and total soluble solids and DPP-3 for plant height. Most of the crosses exhibiting significant SCA effects for a particular trait involved at least one of the parents as good general combiner. The crosses, Azad Pea-1 × Pb-89, Palam Priya × Azad Pea-1, Palam Priya × Pb-89 were observed to be the good specific combinations for pod yield per plant, Azad Pea-1 × Pb-89, Palam Priya × Azad Pea-1 and Palam Priya × Pb-89 for earliness (days to 50% flowering and days to first picking).In addition, the cross, Azad Pea-1 × Pb-89 exhibited the highest specific combining ability effects for duration of availability of marketable pods, pods per plant and pod yield per plant. The other best specific cross combinations were Azad Pea-1 × DPP 9418-06 for pod length, Azad Pea-1 × DPP-3 for seeds per pod, Palam Priya × Pb-89 for pod width and shelling percentage and DPP-3 × Pb-89 for plant height and total soluble solids.

Both the graphical and component analyses indicated the importance of over-dominance in the expression of all the traits studied. The parents, Azad Pea-1 and Pb-89 possessed excess of recessive genes for increased pod yield per plant; Pb-89, Azad Pea-1 and DPP 9418-06 for earliness (days to 50% flowering and days to first picking). The parental genotype, Pb-89 contained more of dominant genes for increased duration of availability of marketable pods, pod length, seeds per plant, shelling percentage and pods per plant. The asymmetrical distribution of dominant and recessive genes was observed for all the traits studied except for days to 50% flowering and total soluble solids. The value of regression coefficient 'b' was low and deviated from the unity for most of the characters namely, days to first picking, duration of availability of marketable pods, pod length, pod width, shelling percentage, pods per plant, plant height, pod yield per plant and total soluble solids, which indicated the involvement of inter-allelic interactions in the expression of these traits.

The non-significance of 't^2' value indicated that Wr, Vr values were homogeneous and satisfied the assumptions of diallel analysis. Both the additive component (D) and non-additive component (H_1 and H_2) were significant for days to 50% flowering, duration of availability of marketable pods, pod length, pod width, seeds per pod, pods per plant, branches per plant and plant height, whereas non-additive components were significant for the remaining traits. The relative magnitude of non-additive components was more in comparison to additive components for all the traits studied except for days to 50% flowering which reflected the predominant role of non-additive genes in the expression of this trait. The mean degree of dominance $(H_1/D)^{1/2}$ and position of regression line further confirmed the involvement of over dominance in the expression of all the traits studied. The negative non-significant 'F' value for days to 50% flowering, days to first picking, duration of availability of marketable pods, pod length, pod width, seeds per pod, shelling percentage, pods per plant, pod yield per plant and total soluble solids indicated that majority of the parents contained excess of the recessive genes. The asymmetrical distributions of dominant and recessive genes was observed for all the traits studied except for days to 50% flowering and total soluble solids. The KD/KR ratio suggested the presence of more number of dominant genes in the parental population for manifestation of traits like pod length, pod width, shelling percentage, branches per plant and plant height, whereas the parents contained excess of recessive genes for earliness (days to 50% flowering and days to first picking), duration of availability of marketable pods, seeds per pod, pods per plant, pod yield per plant and total soluble solids. The high narrow sense heritability estimates were observed for pod length, branches per plant and plant height, which advocated that simple progeny selection can be effective in bringing desirable improvement for these traits. However, medium to low narrow sense heritability estimates coupled with non-additive genetic effects for days to 50% flowering, days to first picking, duration of availability of marketable pods, seeds per pod, shelling percentage, pods per plant, pod yield per plant and total soluble solids which clearly suggested that either heterosis breeding or selection of desirable segregants in later filial generations can be taken up for bringing desirable improvement.

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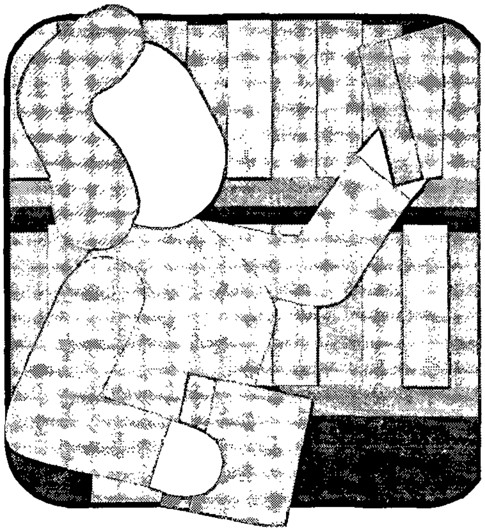

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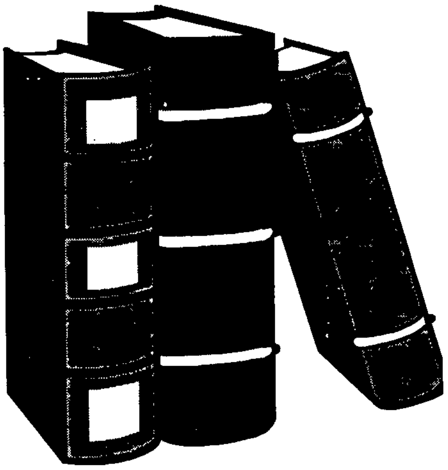
*original not seen

Appendices



Appendix-I

Mean fortnightly meteorological data (Nov-2008 to May-2009)

Interval	Maximum Temp. (°C)	Minimum Temp. (°C)	Rainfall (mm)	Relative Humidity (%)	Wind Speed (Kmph)	Evaporation (mm)	Sunshine Hours	Soil Temp. 5cm depth (°C)
3-17 Nov.	22.42	10.01	0	53.81	21.84	2.79	9.34	18.48
18-2 Nov-Dec.	20.25	7.47	0	48.19	5.54	2.53	8.68	15.48
3-17 Dec.	19.33	7.53	0	45.97	8.38	2.57	7.49	15.2
18-1 Dec.-Jan.	17.13	6.19	0.66	58.11	5.95	2.23	7.11	12.61
2-16 Jan.	15.38	5.18	1.6	66.37	5.87	2.05	6	10.98
17-31 Jan.	16.6	6.42	1.88	64.5	5.59	2.36	4.64	12.34
1-15 Feb.	16.78	6.45	1.69	57.7	6.15	2.44	5.12	12.5
16-2 Feb.- March	18.51	7.13	0.21	52.1	6.44	3.04	8.22	15.97
3-17 March	19.1	12.19	0	43.33	6.19	4.19	7.01	19.36
18-1 March- April	21.29	10.44	5.95	53.8	6.91	3.26	5.5	17.05
2-16 April	24.05	12.63	4.17	52.97	7.07	3.92	7.25	18.98
17-1 April-May	27.97	15.69	0.05	46.87	7.17	5.97	8.94	25.97
2-10 May	28.3	16.24	1.75	47.94	7.12	5.36	6.39	23.75

Appendix II

Combined analysis of variance for different traits

Mean squares

Source of variation	Replication	Treatments	Parents	Hybrids	Parent vs. Hybrids	Error
Character df	2	27	6	20	1	54
Days to 50% flowering	9.705	48.224*	50.126*	44.859*	104.143*	12.208
Days to first picking	8.958	147.784*	16.780	182.574*	238.00*	25.141
Duration of availability of marketable pod	0.035	67.687*	46.110*	77.421*	2.480	6.431
Pod length	0.003	1.714*	2.022*	1.651*	1.138*	0.139
Pod width	0.001	0.005*	0.010*	0.005*	0.002*	0.0001
Seeds per pod	0.125	1.063*	0.847*	1.103*	1.571*	0.078
Shelling percentage	3.726	27.492*	22.825*	30.009*	5.143	3.541
Pods per plant	12.520*	30.381*	20.097*	32.881*	42.099*	3.432
Branches per plant	0.005	1.714*	4.996*	0.815*	0.004	0.0433
Plant height	61.466*	168.247*	355.812*	108.860*	350.507*	17.583
Pod yield per plant	309.625	1327.565*	562.195*	1565.311*	1164.870*	99.212
Total soluble solids	0.193	1.234	0.347	1.396*	3.314*	0.202

*Significant at 5% level of significance

Appendix III

Mean performance of the parents for different horticultural traits

Parents character	Palam Priya	Azad Pea-1	Lincoln	DPP 9418-06	DPP-3	DPPLMR-41	Pb-89
Days to 50% flowering	79.27	74.6	80.47	71.7	78.73	**80.97**	**71.43**
Days to first picking	112.1	113.5	116.3	112.8	115.9	**116.83**	**110.63**
Duration of availability of marketable pods	40	42.67	**33.67**	41.67	40.67	39.33	**46.67**
Pod length	8.65	**7.57**	7.92	7.86	9.44	9.33	**9.45**
Pod width	**1.05**	1.15	**1.05**	**1.18**	1.06	1.1	1.17
Seeds per pod	5.8	**5.5**	5.63	6.23	6.03	5.9	**7.1**
Shelling percentage	54	53.67	54	54.33	**61**	**52.67**	55
Pods per plant	17.83	18.9	**15.87**	18.8	19.57	17.6	**24.17**
Branches per plant	2.03	**1.9**	1.87	2.1	2.27	3.97	**5.17**
Plant height	80.83	70.83	**67.8**	82.67	**94.93**	88.83	93.57
Pod yield per plant	90.5	92.3	**75.03**	92.87	96.1	83.03	**119.2**
Total soluble solids	18.07	**18.48**	17.82	17.8	18.37	**17.5**	18