ASSESSMENT OF COMBINING ABILITY AND GENE ACTION FOR ECONOMIC CHARACTERS IN GARDEN PEA (*Pisum sativum* L.)

Dissertation

Submitted to the Punjab Agricultural University
in partial fulfilment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY
IN
VEGETABLE CROPS
(Minor : Plant Breeding)

by
Nirmal Singh
(L-93-A-15-D)

Department of Vegetable Crops
College of Agriculture
PUNJAB AGRICULTURAL UNIVERSITY
LUDHIANA-141 004 (INDIA)
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TO

THE GLORY OF GOD

WHO BLESSED ME WITH

SUCH WONDERFUL PARENTS

AND AN INSPIRING ADVISOR,

DR G.S. DHILLON

CERTIFICATE-I

This is to certify that this dissertation entitled, "Assessment of combining ability and gene action for economic characters in garden pea (*Pisum sativum* L.)" submitted for the degree of Doctor of Philosophy in the subject of Vegetable Crops (Minor subject : Plant Breeding) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by Mr. Nirmal Singh (L-93-A-15-D), under my supervision and that no part of this dissertation has been submitted for any other degree.

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

13.12.96

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CERTIFICATE-II

This is to certify that this dissertation entitled, "Assessment of combining ability and gene action for economic characters in garden pea (*Pisum sativum* L.)" submitted by Mr. Nirmal Singh (L-93-A-15-D), to the Punjab Agricultural University, Ludhiana, in partial fulfilment of the requirements for the degree of Doctor of Philosophy in the subject of Vegetable Crops (Minor subject : Plant Breeding) has been approved by the student's Advisory Committee after an oral examination on the same, in collaboration with an External Examiner.

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Nirmal Singh

NIRMAL SINGH

Dated: 13.12.1996

CONTENTS

CHAPTER-I

INTRODUCTION

Garden pea (*Pisum sativum* L. var. hortense) is one of the most important vegetable crops grown the world over. It is cultivated on about 887,000 hectares in whole of the world and 96,000 hectares in India (Anon., 1990). It is consumed as fresh or after processing in different forms. Among the processed vegetables, pea is only second to tomato and is a leading vegetable amongst frozen foods. Garden pea plays an important role in the balanced diet of human beings, because it is rich source of digestible protein, along with sugars, carbohydrates, minerals and vitamins A, B and C.

Despite a large number of improved varieties developed, the productivity of garden pea leaves much to be desired. The average yield of garden pea in India (Anon., 1990) is very low (2741 kg/ha) as compared to many other advanced countries like Netherlands (16,883 kg/ha), U.K. (11995 kg/ha) and Austria (11786 kg/ha). This shows that there is a considerable scope for improving its yield potential in India. Further, with the enhanced emphasis in the recent years to develop agro-based industries, especially processing industry for horticultural crops both by the central and state governments and creation of separate ministry of food processing industry, the crop needs concerted efforts for its varietal improvement for different qualitative and quantitative traits.

Introduction, selection and hybridization followed by different selection procedures are the main breeding approaches that have been applied for the improvement of garden pea crop. The choice of parents for hybridization is one of the critical and the most difficult task for a plant breeder. The common approach of selecting the parents on the basis of *per se* performance, does not necessarily lead to fruitful results. The ability of parents to nick well depends on the complex interactions among genes which cannot be adjudged by mere yield performance of the parents. The selection of the best parents for hybridization depends upon the knowledge of combining ability of the parental lines as well as the nature of gene effects. Further, it is necessary to know the performance of a cross combination in comparison to the parents involved in the hybrid and magnitude of genetic variation.

Diallel analysis offers means of obtaining useful information on different parental combinations, through an assessment of the overall genetic architecture of the parental lines in relation to the characters studied. Therefore, the present investigation was undertaken with the following objectives:

1. To determine the nature and magnitude of genetic variation among parents and F_1.
2. To determine the extent of heterosis in F_1.
3. To generate information regarding general and specific combining ability effects for different economic characters.

CHAPTER-II

REVIEW OF LITERATURE

The relevant information pertaining to heterosis, combining ability and nature of gene action for economically important characters in peas is presented below:

HETEROSIS

East (1908), Shull (1908), Bruce (1910), Keeble and Pellow (1910), East and Hayes (1912) were probably the first to observe the phenomenon of hybrid vigour. The term 'Hybrid Vigour' was firstly coined by Shull (1914). Pertinent work done on manifestation of hybrid vigour in different economic characters of peas is reviewed as under.

Johnson (1957) reported the presence of heterosis and transgressive segregation for yield and its components in pea. In diallel analysis, Gritton (1969) reported that dry seed weight of F_1 plants exceeded that of better parent by 26 per cent at one location and 37 per cent in another. F_2 yield also exceeded the higher yielding parent. Singh and Jain (1970) observed significant heterosis for pods per plant and days to bloom in pea. Heterosis over better parent was observed for number of branches per plant and seed yield per plant by Srivastava and Sachan (1975) whereas Bhullar *et al.*

(1976) reported heterosis for grain yield up to extent of 32 per cent in pea. Heterosis for other yield components was observed but no clearcut association between heterosis for yield and its components could be established. According to Moitra and Singh (1986); the crosses R 701 x Kinauri, Batri Yellow x T_{163}, T_{10} x T_{163} and Batri Yellow x R 701 showed 91.0, 69.6, 60.3 and 33.8 per cent heterosis, over their parents for seed yield per plant, respectively. They further reported that these crosses also showed heterosis for number of pods per plant and seeds per plant. Ram *et al*. (1986) reported that the highest heterotic response (121.7%) for yield was shown by T_{10} x EC 33866 and pods/plant, pod length and seeds/pod were the major contributors to the increase in heterotic yield.

Srivastava *et al*. (1986) observed significant heterosis over better parent for days to flower, days to maturity, plant height, internode length, primary branches, nodes up to first pod, pod bearing nodes, pods per plant, seeds per pod, 100-seed weight and grain yield per plant. Naumkina (1987) observed that hybrids most often exceeded from their parents in seed number per plant and seed weight per plant and less often in 100-seed weight. He also studied that heterosis was rare for number of pods per plant. Fomin (1987) reported that F_1s outyielded the parents on average over three years by 21.4-53.5 per cent, but the difference between parents and hybrids decreased from the F_2 and reached 2.7-14.1

per cent by the F_6.

In diallel analysis, Singh and Santhoshi (1989) observed significant heterosis for seed yield. They further reported that the crosses T_{163} x BR 12, Rachna x 6113, KLMR 9 x EC 33866 and L 116 x BHU 397 showed heterosis for harvest index, seed yield and protein content. According to Parmar and Godawat (1990), yield and pods per plant showed the greatest heterosis, with heterosis for yield being greatest in the crosses Bonneville x 6587-1 (58.8%) and S_{35} x 6587-1 (54.3%). Pant and Bajpai (1991) observed significant heterosis for yield over the better parent. Lejeune-Henaut *et al.* (1992) observed significant heterosis to the extent of 20 per cent over the better parent for seed yield. Heterosis for yield components was significant for the number of pods per plant and number of seeds per pod per branch. According to Mishra *et al.* (1993), some hybrids showed considerable heterosis over better parent for yield and seven related traits, while all hybrids showed heterosis for earliness. In diallel analysis, Singh *et al.* (1993) observed significant heterosis over better parent for accumulation of nitrogen and seed yield per plant. Similarly, Omprakash *et al.* (1993) reported negative heterosis in the crosses KPSD 1 x Rau 37, KPSD 1 x HFP 4 and Pant P5 x Rau 37 for days to flowering. Heterobeltiosis was recorded for number of seeds per plant. They also observed that heterosis for grain yield was due to increased number of pods per plant. High value of heterosis was observed for yield per plant and number of pods per plant by Parmar (1993). He also observed inbreeding depression in the crosses which showed a high degree of heterosis in F_2 generation.

Katiyar (1994) revealed significant heterobeltiosis for days to 50 per cent flowering, days to maturity, and length of reproductive phase. They further reported that JP 4 x T 163 and Rachna x T 163 showed significant heterosis over the commercial parent and are recommended for yield improvement. According to Kharche and Narsinghani (1994), Arkel x JP 9 and JP 4 x JP 9 showed significant heterosis over better parents for days to maturity, pods per plant and seed yield. Sarawat *et al.* (1994) reported that four F_1 hybrids were significantly higher yielding than the best parent to the extent of 26 per cent. They also revealed that the level of heterosis for yield in a poor yielding environment was higher than that in high yielding one.

Combining Ability Studies

Combining ability studies furnish useful information regarding the selection of suitable genotypes for an effective hybridization programme and at the same time elucidate the nature and magnitude of different types of gene action involved.

Sprague and Tatum (1942) explained that the general combining ability means the overall average performance of a line in hybrid combinations, while specific combining ability refers to those cases in which certain combinations do relatively better or worse than would be expected on the basis of average performance of the lines involved. They also reported that genes with additive effects are more important for general combining ability while specific combining ability is dependent on genes with dominance and epistatic effects. Sprague (1946) reported that genetic diversity is equally important for combining ability in developing high yielding hybrids. Green (1948) reported combining ability as a heritable character.

Hayman (1956) observed that in the presence of epistasis, both general and specific combining ability involves epistatic effect; general combining ability involves average epistasis of array, whereas specific combining ability involves epistasis in a particular cross.

In diallel analysis, Dahiya *et al.* (1977) observed significant general and specific combining ability variances for yield, plant height and number of pods per plant. However, gca variances were larger than sca variances for all the traits except yield. According to Singh *et al.* (1977), specific combining ability was higher than general combining ability for days to flower, pod width and number of seeds per pod. In their studies, Pacucci and Troccoli (1981) reported that general combining ability was important only for seeds per pod and 100-seed weight, whilst specific combining ability was important for nearly all the characters.

Promising donors with high gca for 1000-seed weight, seed number and yield were identified for use in breeding high yielding forms with shattering resistance (Varlakhov *et al.*, 1982). Venkateswaralu and Singh (1983) observed that both general and specific combining ability were influenced by environment (year). It is suggested that both gca and sca should be estimated over a range of environments. Diallel selective crossing among the good general combiners is suggested to release greater genetic variability.

In their studies, Gupta *et al.* (1984) reported that parents EC 109196, EC 109182, EC 21857 and P23 were good general combiners for most of traits. They also recommended the eight hybrids for use in breeding programmes on the basis of specific combining ability effects. In diallel analysis, Csizmadia (1985) observed that general combining ability variances were higher than specific combining ability variances, with a predominance of additive genetic variance for most of characters. He further reported that parents with high gca were generally above average in phenotypic performance, but sca effects were generally not proportional to F_1 performance.

In diallel analysis, Gad and El-Sawah (1985) revealed that cv Television had the highest general combining ability for root nodules/plant, 'Meteor' had the highest gca for root length, plant height and leaves per plant and 'Progress 9' and 'Little Marvel' had the highest gca for branches per plant.

Analysis of data on 100-seed weight and seed yield per plant by Gupta and Lodhi (1985) from a diallel cross grown in 6 environments revealed that both general and specific combining ability were influenced by environment. They concluded that experiments should be performed over a wide range of environments in order to obtain unbiased estimates of combining ability. It is suggested that 2-3 generations of intercrossing to isolate good recombinants from crosses involving varieties with good combining ability, followed by pedigree selection, is suitable means of improving seed yield.

In their studies, Singh *et al.* (1985a) revealed the significance of general and specific combining ability effects for seed yield per plant, seeds per plant and 100-seed weight. On the basis of general combining ability, parental effects and additive gene effects, Singh *et al.* (1985b) revealed that KLMR 9, 6113, Rachna and T 163 were the best parents for tallness; P 209, T 163, and BHU 397 for pods per plant and T 163, 6113 and P 209 for yield per plant. Five promising crosses are identified on the basis of heterosis over the best commercial parent, specific heterotic effects and specific combining ability. They advocated the multiple crossing among suitable hybrids for improving seed yield per plant. Singh *et al.* (1985c) reported that general and specific combining ability variances were significant for most traits in both the generations, but specific combining ability variances predominated for each trait.

According to Gupta *et al.* (1986), both general and specific combining ability variances were influenced by environmental conditions, suggesting that gca and sca should be measured over a wide range of environments. GC 141, P 23, Multifreezer, Boachsel and T 19 showed high gca for most traits and six of their cross combinations showed significant and positive sca for all the traits. Moitra *et al.* (1988) reported the significance of gca and sca for yield, plant height, 100-seed weight, pods per plant, days to flowering and days to maturity. Tewatia *et al.* (1988) observed that gca and the differences among genotypes were highly significant for pod number, node at which 1st fruit appeared, harvest index, height, pod length, protein content, total yield and total solúble sugar content. The varieties Arkel, GC 141, Multifreezer and VL 2 had high estimates of gca for most of characters.

According to Karmakar and Singh (1990), VP 8005 was a good combiner for seeds per pod and Arkel for dwarf stature. Of the hybrids, Gloriosa x JP 169 was the best specific cross for yield and Arkel x VP 8005 was a promising cross for seeds per pod. Singh and Singh (1990a) evaluated a 12-parent diallel cross of pea for eight yield-related characters. The gca and sca variances were highly significant for all the characters. Parents T163, Sel-2, Bonneville and PG 3 had good gca for seed yield and 25-seed weight. The F_1 hybrids 'T 163 x Bonneville' and 'T 163 x Sel-2' were identified as the best combinations for yield per plant. Singh and Singh (1990b) derived the information on combining ability and reported that parental varieties T 163, PG 3, Selection 2 and Bonneville were the good general combiners for yield. Again, Singh and Singh (1990c) reported the significance of gca and sca variances for seed yield and pods per plant in F_1 and F_2 generations.

Singh (1991) reported that 'BR 12' was the best parent, producing high means and highly significant positive values for gca effect, parent effect and additive effect for seeds per pod and weight of 100 seeds in 10 parents and their 45 F_1 progenies. Singh and Singh (1991) found that the performance of the parents was in good agreement with their gca effects. Bonneville was the best general combiner for seed number and seed weight. According to Singh *et al.* (1991), variances due to gca and sca were highly significant for seed yield and other component characters. They also observed that the best general combiners were usually also the best performers.

Pant and Bajpai (1993) observed the good gca for seed yield, days to flowering, pods per plant, pod length, for maturity and 100-seed weight in different varieties. They also listed the promising parents and crosses based on the estimates of gca and sca effects.

Gene Action

The knowledge of the type and magnitude of gene action involved in the expression of a character is essential for appropriate management of available genetic variability and formulation of systematic breeding programme. The literature pertaining to gene effects for the yield, its components and quality characters has been reviewed as under:

Aagae and Davis (1970) reported that seed yield is controlled by additive genes whereas both additive and non additive gene action was important in the control of number of pods per plant. Watts *et al*. (1970) reported an additive system with dominance for late flowering habit. Similarly, Zlmal (1972) observed a high level of genetic variability caused by additive and dominance effects for number of pods per plant. The number of grains per pod also showed genetic variability but the magnitude of dominance was comparatively less pronounced. Nandpuri *et al*. (1973) revealed that yield and number of pods in pea are governed by additive gene effects. Overdominance and epistatic gene effects have a significant role in the expression of these traits. The analysis of generation means of four crosses of pea studied by Sandhu (1973) revealed all the three types of gene action, i.e. additive, dominance and epistasis, for grain yield and its components. Amongst the epistatic gene effects additive x additive and dominance x dominance effects appeared to contribute more to different characters than additive x dominance effects. According to Snoad and Arthur (1973), mean internode length was controlled by a polygenic system plus a major gene while node to first flower was controlled by a similar system without major genes. They also revealed that additive effects were more important.

In diallel analysis, Korrane and Singh (1974) reported that additive and non additive gene effects were important for days to flowering, seeds per pod and yield per plant. Bal (1975) while studying a group of genetically diverse lines of pea reported that both additive and interaction effects were significant for most of the characters. However, epistasis was more pronounced for yield, number of pods per plant and shelling percentage and additive gene effects for number of grains per pod, pod length and days to first flowering. In their studies, Bhullar *et al.* (1975) observed additive gene action for number of days to first flowering, number of primary branches, vine length, pod length and yield while non additive gene effects were found for seeds per pod, pods per plant and 100-seed weight. Kumar and Das (1975) revealed the importance of both additive and dominance gene effects for number of pods per plant. However, days to flowering and maturity were under the control of additive gene action although dominance was also observed for maturity.

Das and Kumar (1976) reported the contribution of both additive and dominance components for plant height in peas. Further, analysis of generation means indicated duplicate gene interactions. From a diallel analysis of F_1 and F_2, Kumar (1976) observed that plant height in pea was influenced by both additive and non-additive gene effects. Sharma *et al.* (1976) observed that epistasis was important in the control of shelling percentage whereas additive gene effects were important for other traits. Sharma *et al.* (1977) observed overdominance for yield, number of pods per plant and partial dominance for days to flowering. Singh *et al.* (1977) reported that both additive and non-additive gene effects were significant for fruit length and pod length. Chandel and Joshi (1978) reported that pod length exhibited the complementary nature of epistasis in majority of the crosses. Seeds per pod showed low additive gene effects and in some crosses complementary epistasis was observed. They emphasised the possibility of utilizing additive gene action in some crosses and complementary gene interaction in majority of the crosses for the improvement of pod length and seeds per pod. Singh and Singh (1979) reported that dominance and epistatic effects were more important than additive effects for seed number per pod. Complementary epistasis for number of sterile nodes and number of pods in the F_1 was observed by Asfandiyarova (1980).

Singh (1980) examined five of intervarietal crosses and observed that additive x additive effects were high for days to flowering, number of primary and secondary branches, pods per plant and seed yield. He further reported that additive x dominance effects were important for pod length, seeds per pod and seed weight while dominance x dominance effects were important for plant height and days to maturity. According to Kumar and Agrawal (1981), the number of pods per plant, pod length, number of seeds per pod and 25-seed weight was predominantly controlled by additive gene action. They further reported that yield per plant and plant height was principally controlled by non-additive gene action. Swiecicki *et al.* (1981) reported dominance in the direction of low protein in the cross of 'Ranger x Stral' while in 'Stral x Paloma' most genetic variation was observed to be additive indicating selection for high protein content would be more in the latter cross.

Kumar and Agrawal (1982) revealed that flowering was predominantly controlled by additive genetic effects in the parental and F_1 generations of the diallel. They also reported that earliness and lateness was due to an accumulation of dominant and recessive genes. Ranalli *et al.* (1982) reported in a diallel cross that the number of days to flowering was controlled by additive effects and to a lesser extent, by dominant effects. Lateness was partially dominant over earliness. In diallel analysis, Rybnikova (1982) found the overdominance for plant height, height of insertion of the first pod, number of fruit-bearing and non-fruiting internodes, pod length, number of seeds per pod and seed weight per plant. Venkateswaralu and Singh (1982) reported the importance of both additive and non additive gene effects for seed number and seed weight and found that *per se* performance of parents was in good agreement with their general combining ability. The cross in which one good and one poor parent was involved, gave the best result. Venkateswaralu (1982) reported, in the analysis of 10x10 non reciprocal diallel involving very early, medium and late cultivars, the importance of both additive and non-additive gene effects for number of days to flowering. However, additive gene effects predominated.

Dubey and Lal (1983) observed that additive genetic variance was greater than dominance variance for seed yield per plant and nine yield related characters. Rastogi *et al.* (1983) conducted a ten parental diallel analysis for soluble protein content of green pea seed in F_1 and F_2. They found that non-additive components (H_1 and H_2) were significantly higher than additive component in both the generations. Mean degree of dominance was in the overdominance range. Venkateswaralu and Singh (1983) recommended the pedigree breeding method for obtaining pure lines with desirable characters since additive genetic effects predominated for seed yield per plant and six yield-related characters. Gupta and Dahiya (1984) studied the inheritance of pod yield and other traits in peas and revealed that additive gene effects were predominant for pod length and width but non-additive effects were predominant for pods per plant. Dominant alleles were predominant for all other characters. According to Gupta *et al.* (1984), the magnitude of non-additive genetic variance was greater than that of additive genetic variance for all the characters studied by them. Mahmood and Gatehouse (1984) observed that vicilin storage protein is controlled by a pair of co-dominant genes at a single locus.

Gad and El-Sawah (1985) reported additive and dominance effects to be significant for various morphological traits. According to Gupta and Lodhi (1985), partial dominance was important for 100-seed weight and overdominance for seed yield per plant. Dominance alleles were in excess for yield and recessive alleles were in excess for 100-seed weight. In diallel analysis, Singh *et al.* (1985b) revealed that both additive and non-additive gene effects were significant for plant height, pods per plant and seed yield per plant. Again Singh *et al.* (1985d) revealed the significance of additive and non-additive gene effects for seed yield per plant and protein content. They also reported that additive component is more important than non-additive component for the above said characters.

According to Gupta *et al.* (1986a), additive gene effects were predominated for pod length and width whereas non-additive gene effects were more important for branches per plant and pods per plant. Gupta *et al.* (1986b) studied the inheritance of seed yield and quality traits in peas and indicated additive as well as non-additive gene effects to be important for the inheritance of seed yield, 100-seed weight and protein content. In a diallel cross of 10 varieties; Singh *et al.* (1986a) revealed that both additive and non additive variances were significant for pods per plant, seeds per pod, seed yield per plant, harvest index and protein content. In a similar study, Singh *et al.* (1986b) reported that additive and dominance components were significant for seed yield, seed number per plant and 100-seed weight. However, Srivastava *et al.* (1986) observed the predominance of additive gene effects in the inheritance of all the traits except days to flower, node upto first pod and grain yield per plant, for which partial dominance were observed.

In a line x tester analysis, Katiyar *et al.* (1987) reported the predominance of non-additive gene action for seed yield, plant height, number of branches per plant and node with the first formed pod. Rastogi (1987) reported in a 10x10 diallel cross that non-additive genetic variance was more important than additive variance for vitamin C content of the seed in the F_1 and F_2. He also revealed that variety 'Bonneville' appeared to have the highest number of dominant genes for high vitamin-C content. Similarly, Singh *et al.* (1987a) reported the significance of additive and non-additive genetic effects for days to flowering, plant height, branches per plant, pods per plant, seeds per pod, pod length, days to maturity, seed yield per plant, harvest index, and protein content in both F_1 and F_2 generations. Singh *et al.* (1987b) reported additive gene action for plant height, internode length and 100-seed weight while the reverse was true for seed yield and harvest index.

Gupta and Lodhi (1988) studied an incomplete diallel analysis for days to pod formation and days to maturity in nine cultivars and reported that additive as well as non-additive gene effects were important for both the traits. There was complete dominance for days to pod formation and overdominance for days to maturity. Srivastava and Singh (1988) revealed the importance of both additive and non-additive effects but non-additive effects were reported to be more prevalent than the additive effects for seeds per pod. The component analysis revealed overdominance in three of the four populations. Singh and Singh (1989a) reported partial dominance for pod length, seeds per pod and test weight in a 12 parent diallel cross. Whereas, Singh and Singh (1989b) revealed the predominance of additive gene effects for flower initiation and days to maturity.

Csizmadia (1990) in a combining ability test for yield and its components reported that additive effects predominated in the control of seed number for pod, pod length and mean seed weight. Similarly, Godawat and Parmar (1990) reported that additive gene effects were predominant in the inheritance of days to flowering and maturity. Singh and Singh (1990c) revealed the importance of both additive and non-additive genetic components of variation for seed yield and pods per plant. They recommended a breeding programme which would focus on biparental mating and mating of selected plants in early segregant generations.

In diallel analysis, Mihailovic and Kraljevic-Balalic (1991) concluded that additive gene action appeared to be more important than non-additive gene action for stem height. Mihailovic *et al.* (1991) reported that additive gene action was more important than dominance and epistasis for seed yield. Singh and Singh (1991) revealed the importance of additive gene effects in the inheritance of seed number and seed weight. Sirohi *et al.* (1993) reported that number of seeds per pod was predominantly controlled by dominant gene action, whereas epistatic gene action was observed for harvest index, number of pods per plant and 100-seed weight.

CHAPTER-III

MATERIAL AND METHODS

The present investigations were carried out at the Vegetable Experimental Farm, Punjab Agricultural University, Ludhiana, during 1994-1996. The experimental material comprised of ten genetically divergent varieties, viz. Bonneville, DPR-3, Arkel, Matar Ageta-6, Early Snap, P-23, Punjab-87, Punjab-88, JP-179 and JP-501-A/2. A brief description of the parent varieties is given below:

Bonneville

It is an introduction from America and is late maturing, sweet, wrinkled seeded and medium tall variety suitable for growing during the main season i.e. middle of October. It takes about 100 days to first picking. It yields on an average 105 quintals of green pods per hectare.

DPR-3

It is an indigenous introduction from IARI, New Delhi. It is a late maturing variety. The plants are medium tall and erect with thick foliage. The pods are borne on 13th or 14th node from the bottom in single as well as in doubles. It takes about 85-90 days to first picking. The pods are small with small, sturdy and round grains. This variety carries resistance to wilt disease.

Arkel

This variety is an introduction from England and is an early maturing, wrinkled seeded and dwarf variety. It takes about 55-60 days to first green pod picking. Being of European origin, it is relatively less tolerant to high temperature and, therefore, can only be planted when the weather cools down considerably i.e. approximately by middle of October. Under cooler climatic conditions, it yields even higher than Harabona and gives, on an average, about 70 quintals per hectare of green pods in three pickings. The peas of this variety are sweet and good for processing (dehydration). Therefore, it can be planted along with main season variety Punjab-87 to extend the availability period of green pods for feeding the processing industry.

Matar Ageta-6

This variety has been developed through pedigree selection from a cross between Massey Gem and Harabona. Matar Ageta-6 is dwarf, quick growing and early in maturity, taking 50 days to first picking, pods medium long, flatish round, well filled and contain six to seven grains on an average, borne singly as well as in pairs; grains bold and green. Its shelling percentage is 44. It is tolerant to high soil temperature, biologically more efficient to give 50 per cent of total green pod yield in the first picking. Grains have high protein and dry matter content. On drying seeds are light green and smooth with slight dimples. Its average yield is 60 q per hectare.

Early Snap

It is an exotic edible podded garden pea variety introduced from U.S.A. and yet not released for general cultivation in Punjab. It is early in maturity and takes about 60-65 days from sowing to marketable green pod stage. Plants are medium tall with dark green foliage. Pods are attractive, small to medium, sweet, well filled 5-6 cm long and each contains 5 or 6 green bold seeds with a shelling percentage of 38. It yields 85-90 quintals of edible pods per hectare.

P-23

It is a selection from local material collected from Ludhiana and was recommended for general cultivation before 1962. It is suitable for early sowing in September. The plants are dwarf, vigorous with dark green foliage. The pods are small, straight, and borne in pairs. This variety also carries the resistance to wilt and stem fly complex. It yields 50 q of green pods per hectare.

Punjab-87

This variety has been developed through selection from a cross between Morrassis and Pusa 2. It was recommended for cultivation in 1978. It is a main season variety and takes about 100 days for first picking. It is superior to Bonneville in pod colour, pod weight, pod length, number of grains per pod and shelling percentage. It is dwarf, wrinkled seeded, high yielding and gives, on an average, about 130 quintals of green pods per hectare i.e. about 20 per cent more than Bonneville. The grains are sweet, bold and dark green in colour and this is an ideal variety for processing especially because of its colour retention. Keeping in view its processing potentials, the cultivation of this variety can be done on a very large scale to supply green pods to the processing industry during the main season.

Punjab-88

This too is a main season variety and has the same maturity as that of Punjab-87. Plant type and pod characteristics are similar to Punjab-87 except that it is slightly superior in yield (about 135 quintals per hectare). The grains are less sweet. It is suitable for fresh market only. Both these varieties i.e. Punjab-87 and Punjab-88 fetch 25 to 30 per cent higher rates in the fresh market than the conventional varieties because of their attractive pods. Punjab-88 has also been identified at the All India level for general cultivation in northern India. Dried grains are wrinkled and pink coloured.

JP-179

It is an introduction from Jabalpur and is late maturing field pea type variety. Plants are tall (175.00 cm) with thin foliage. It takes about 85-90 days to be ready for first picking. Pods are very small with small round starchy seeds. It is a multiple resistant variety having high resistance to powdery mildew and moderate resistance to Fusarium wilt, rust, downy mildew, leaf miner and Bruchus.

JP-501-A/2

This variety is also an introduction from Jabalpur and is late maturing field pea type. The plants are slightly taller than that of JP-179. Seeds are small, round and starchy. It also carries the resistance to powdery mildew and Fusarium wilt.

PLAN OF WORK

The ten varieties were sown in a crossing block under three different planting dates viz. 17.11.1994, 29.11.1994 and 5.12.1994 in order to achieve flower synchronization for getting sufficient seed from each cross. All the ten varieties were crossed in a diallel mating design (excluding reciprocals) to raise forty five F_1 hybrids. Thus, there were 55 genotypes in all including parents. These 55 genotypes were sown in a randomised block design with three replications on October 27, 1995. Sufficient seeds of each genotype of the experimental material were planted in a single 3 metre long row by providing a distance of 45 cm between rows and 10 cm between plants so as to get a reasonable plant population of each genotype. Further, 10 experimental plants were taken at random in each genotype for recording the observations. Non-experimental rows were planted along the borders to avoid border effects. The crop was raised by following recommended cultural practices.

OBSERVATIONS

Observations were recorded on the following characters:

1. Days to flower initiation

The number of days taken from date of sowing to the day on which the first flower appeared were recorded.

2. Node at which the first pod develops

The number of nodes right from the ground level to the node at which the first pod developed for each experimental plant in each genotype were counted and the average number worked out.

3. Internodal length

An internode just above the node at which the first pod appears was measured in centimetres for each experimental plant in order to work out the average internodal length for each genotype.

4. Number of primary shoots

The number of main branches of each experimental plant were recorded at the time of last picking.

5. Plant height

At the time of last picking, the height of the primary shoot of each experimental plant was measured from ground level to the last growing bud at the tip in centimeters and the average plant height worked out.

6. Number of pods per plant

The number of pods from all the experimental plants of each genotype were counted separately for each picking. At the end of the season, the average number of pods per plant was calculated from the total number of pods harvested from each genotype.

7. Pod weight

Pods harvested at first picking from all experimental plants of each genotype were bulked and thirty pods taken at random from this bulk were used for calculating average pod weight.

8. Number of grains per pod

The thirty pods taken for calculating pod weight were also used for calculating the average number of grains per pod.

9. Yield per plant

All the pods (marketable) were harvested separately for each picking in each genotype and total weight of all the harvested pods in all the pickings were added to work out the average yield per plant for each genotype.

10. Shelling percentage

The same thirty pods from each genotype were used for calculating shelling percentage. The seeds from these pods were shelled and weighed. The shelling percentage was worked out as under:

$$\text{Shelling percentage} = \frac{\text{Weight of shelled seeds}}{\text{Weight of unshelled pods}} \times 100$$

11. Dry matter (%)

Shelled pea grain samples weighing 50 g each were taken in a petri dish and oven-dried at 65±2°C till constant weight was obtained. The per cent dry matter was calculated as below:

$$\text{Dry matter (\%)} = \frac{\text{Final dry weight}}{\text{Initial fresh weight}} \times 100$$

12. Crude protein (%)

Representative 50 g seed samples were taken replication-wise. They were oven-dried, grinded and subjected to chemical analysis. Crude protein content was determined by nitrogen estimation method given by Meknzie and Wallace (1954).

13. Total sugars (%)

0.1 g of dried powdered sample of pea grains was taken and 10 ml of 62.5 per cent methanol was added to it and heated for 15 minutes in the water bath at 55°C. One ml of solution was taken from original extract and diluted to 10 ml. Then 0.1 ml of aliquat was taken to which 0.9 ml of water and 1 ml of phenol reagent was added. After shaking it properly 4 ml of concentrated sulphuric acid was added. The optical density was recorded at 490 nm.

14. Alcohol insoluble matter (%)

30-50 ml of 80 per cent alcohol was added to 10 g of fresh samples of pea grains. It was heated for two hours on boiling water bath, filterated and again washed with hot alcohol (80%). The residue was dried and weighed to calculated the alcohol insoluble matter.

$$\text{Percentage alcohol insoluble matter} = \frac{\text{Weight of residual material}}{10} \times 100$$

15. Reaction to powdery mildew

The observations on the powdery mildew disease reaction were recorded on thirty leaves per genotype. The disease reaction was recorded under 10 categories using 0-9 scale (Anon., 1996) and percentage infested leaf area.

Category number	Powdery mildew infection intensity (Percentage infested leaf area)	Numerical scale
1	Free from infection	0
2	Infection ranging from 1 to 5 per cent of the leaf area	1
3	Infection ranging from 6 to 10 per cent of the leaf area	2

4	Infection ranging from 11 to 15 per cent of the leaf area	3
5	Infection ranging from 16 to 25 per cent of the leaf area	4
6	Infection ranging from 26 to 40 per cent of the leaf area	5
7	Infection ranging from 41 to 50 per cent of the leaf area	6
8	Infection ranging from 51 to 60 per cent of the leaf area	7
9	Infection ranging from 61 to 80 per cent of the leaf area	8
10	Infection ranging from 81 to 100 per cent of the leaf area	9

Further, the Mean Disease Index (MDI) was worked out as follows:

$$MDI = \frac{\Sigma \text{ (Class rating} \times \text{Class frequency)}}{\text{Number of leaves examined}}$$

The MDI from 0-2.0 was considered as highly resistant, 2.1-3.0 as resistant, 3.1-4.0 as moderately resistant and above 4.0 as susceptible. This method helped in estimating the relative degree of resistance in the genotypes tested.

16. Reaction to wilt

For each genotype, the number of infected plants in the population after 40 and 65 days of sowing were counted and per cent infection worked out as per the formula given below:

$$\text{Per cent wilt incidence} = \frac{\text{Number of infected plants}}{\text{Total number of plants}} \times 100$$

STATISTICAL ANALYSIS

The different statistical parameters used are described below:

Analysis of variance

In order to find out differences between parents and F_1's or different characters, the data were analysed on the basis of following model :

$$P_{ijk} = m + g_{ij} + b_k + e_{ijk}$$

Where P_{ijk} = phenotypic value of the ij-th genotype grown in k-th block

m = general population mean

g_{ij} = effect of ij-th genotype

b_k = effect of k-th block

e_{ijk} = environmental effect

The analysis of variance table was set up as under:

Source of variation	d.f.	Sum of squares	Mean squares	
			Observed	Expected
Blocks	(b-1)	$S_b=SB^2/p-(SX)^2/N$	$M_b=S_b/b-1)$	$V_e + pv_b$
Progenies	(p-1)	$S_p=SP^2/b-(SX)^2/N$	$M_p=S_p/p-1)$	$V_e + bv_g$
Error	(b-1)(p-1)	$S_e=S_t-S_b-S_p$	$M_eS_e/(b-1)(p-1)$	V_e

Where

b = Number of blocks

p = Number of progenies

N = Total number of observations

S = Summation

S_e = Error sum of squares

S_t = Total sum of squares

S_x = Grand total of the observations

V_b = Block variance

V_g = Genotypic variance

V_e = Error variance

The progeny variance was tested against error variance by 'F' test for (p-1) and (b-1)(p-1) degrees of freedom. Similarly, the block variance was compared against error variance for (b-1) and (b-1)(p-1) degrees of freedom.

$$\text{Standard error (difference)} = \sqrt{\frac{2\,V_e}{b}}$$

Critical difference (C.D.) = S.E. (difference) x t at error d.f.

Diallel tables were compiled from progeny means, obtained as average over three replications, for parents and their F_1 progenies and these tables were utilized for calculating the general and specific combining ability, variance effects and components analysis.

Estimates of Heterosis

Heterosis was calculated as increase or decrease of hybrid performance over better parent and was expressed in percentage. It is also known as heterobeltiosis.

$$\text{Heterobeltiosis} = \frac{\bar{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

where

$\bar{F}_1$ = mean performance of hybrid, and

$\overline{BP}$ = mean performance of better parent

Standard error of differences for comparing the values of heterobeltiosis, was worked out as follows:

$$SE(d) = \pm(2M_e/b)^{1/2}$$

where

M_e = Error mean square and

b = Number of blocks

The critical differences were computed by multiplying SE(d) by respective 't' value for error degrees of freedom at P = 0.05 and P = 0.01.

Combining ability analysis

The general and specific combining ability analysis were carried out by following Model 1 (fixed effect model) and Method II (parents and their crosses. excluding reciprocals) as described by Griffing (1956).

The analysis of variance for combining ability was based on the following statistical model:

$$P_{ijk} = m + g_i + g_j + s_{ij} + b_k + e_{ijk}$$

where

P_{ijk} = phenotype of ijk-th observation

m = population mean

g_j = general combining ability of j-th parent

g_i = general combining ability of i-th parent

s_{ij} = specific combining ability effect of the cross involving i-th female and j-th male parent

b_k = number of blocks

e_{ijk} = summation error term for ijk-th observation

Analysis of variance for combining ability

Source	d.f.	S.S.	M.S.	Expected mean squares
GCA	$(p-1)$	S_g	M_g	$V_E + p(p+2)\frac{1}{(p-1)}S_{gi}^2$
SCA	$\frac{(p-1)(p)}{2}$	S_s	M_s	$V_E + \frac{2}{p(p-1)}S_{sij}^2$
Error	(b-1(p-1)	M_e	M'_e	V_E

Where

$V_E = M'_e = M_e/b$

Where

M_e is error mean square from ANOVA of experimental design

S = Summation

S_g (sum of squares due to g.c.a.) =

$$\frac{1}{p+2}\left[S(x_i + x_{ii})^2 - \frac{4}{p}x_{..}^2\right]$$

S_m (sum of squares due to s.c.a.) =

$$S_{x}{}^{2}{}_{ij} - \frac{1}{p+2} S(s_i + x_{ii})^2 + \frac{2}{(p+1)(p+2)} x^2..$$

Combining ability estimates

General combining ability effect of the parent

$$g_i = \frac{1}{p+2} [(X_i + X_{ii}) - \frac{2}{p} X..) \text{ and}$$

Specific combining ability estimate =

$$S_{ij} = X_{ij} - \frac{1}{p+2} (X_i + X_{ii}) + (X_{.j} + X_{jj}) + \frac{2X..}{(p+1)(p+2)}$$

Where

P = Number of parents

g_i = General combining ability effect of the i-th parent

S_{ij} = Specific combining ability effect of the cross involving i-th and j-th parent

X_i = Total of the array involving i-th parent

$X_{.j}$ = Total of the array involving j-th parent

X_{ii} = Parental value of the i-th parent

X_{jj} = Parental value of the j-th parent

$X..$ = Total of all p(p+1)/2 items in the diallel table

X_{ij} = Mean value of cross involving i-th and j-th parent

Standard errors to test the significance of general and specific combining ability estimates and the S.E. (difference) between the two estimates were computed from the following formulae:

$$\text{S.E. for g.c.a. effects} = \sqrt{\frac{M'_e(p-1)}{p(p+2)}}$$

$$\text{S.E. for s.c.a. effects} = \sqrt{\frac{M'_e\,(p^2+p+2)}{(p+1)(p+2)}}$$

S.E. $(g_i - g_j)$ = S.E. for difference between two g.c.a. effects =

$$\sqrt{\frac{2\,M'_e}{p+2}}$$

S.E. for difference between two s.c.a. effects in different arrays

$$\text{S.E.}\,(S_{ij} - S_{kl}) = \sqrt{\frac{2p\,M'_e}{p+2}}$$

S.E. for difference between two s.c.a. effects in same arrays

$$\text{S.E.}\,(S_{ij} - S_{ik}) = \sqrt{\frac{2(p-2)\,M_e}{p+2}}$$

Critical differences were calculated by multiplying the corresponding S.E. (difference) with table value of 't' at error degrees of freedom at p=0.05 and p=0.01.

Graphical analysis

The diallel cross technique elaborated by Hayman (1954b) was followed for this aspect. The variance-covariance

(Vr, Wr) graphs were prepared from the following statistics calculated from the data given in diallel tables for different characters.

V_r = Variance of all offsprings in a particular array

W_r = Covariance of the offspring in each parent array with non-recurrent parent.

V_p = Variance of the parents (diagonal of the diallel table)

The regression coefficient of W_r on V_r was calculated using the following formula:

$$b_{Wr/Vr} = \frac{\text{Sum of products, } W_r, V_r}{\text{Sum of squares } V_r}$$

where 'b' denotes the regression coefficient of the above slope of regression line in W_r, V_r graph. The significance of difference of b from unit slope was tested by using the following standard error of the regression coefficient (b)

$$\text{S.E. for } b_{Wr/Vr} = \sqrt{\frac{SSW_r - b \times SP\ (W_r, V_r)}{(n-2)\ SS\ V_r}}$$

Assuming a simple additive-dominance model to be adequate the expected values of W_{ri} are estimated from the following linear regression equation :

$$W_{rei} = \bar{W}_r - b\ \bar{V}_r + b\ V_{ri}$$

where,

Wr_{ei} = expected values of W_r corresponding to V_{ri},

$\bar{V}_r$ and $\bar{W}_r$ are means of V_r and W_r, values for all arrays respectively.

The V_r, W_r graph has the limits, the limiting values of this graph called parabola limit were computed as follows:

$$W_{ri} = \sqrt{V_r . V_p}$$

In V_r, W_r graph, Vr values are taken along the X-axis, while W_r values along the Y axis using the same scale on both the axes.

Estimation of Components of Genetic Variation

Genetic parameters were estimated according to the method suggested by Hayman (1954) which is as under:

$$D = V_p - E$$

$$F = 2V_p - 4\bar{W}_r - 2(n-2)\ E/n$$

$$H_1 = V_p - 4\bar{W}_r + 4\bar{V}_r - (3n-2)\ E/n$$

$$H_2 = 4V_{\bar{r}} - 4\bar{V}_r - 2E$$

$$h^2 = 4(ML_1 - ML_0)^2 - 4(n-1)\ E/n^2$$

Where

$\bar{W}_r$ = Mean of covariance of array value with non-recurrent parent.

ML_1 = Mean of all F_1's

ML_0 = Mean of the parents

$\bar{V}_r$ = Variance of array means

D = Component of variance due to additive effect of genes

H_1 = Component of variance due to dominance effect of genes

H_2 = Component of variance due to non-additive gene effects correlated for gene distribution

F	=	Covariance of additive and non-additive gene effects in all the arrays
$E=M'_e$	=	Environmental or non-heritable variation associated with an individual mean and is calculated by dividing the error mean squares of the design analysis by No. of replications.
h^2	=	Overall dominance effect of the heterozygous loci.

Accuracy of estimates of genetic parameters

In order to estimate the S.E. of these components, the following equations were used :

$$S^{2'} = 1/2 \text{ Var } (W_r - V_r)$$

$$\text{Var D} = \frac{S^2 (n^5 + n^4)}{n^5}$$

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

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

$$\text{Var } H_2 = \frac{S^2}{n^5} (36 n^4)$$

$$\text{Var E} = \frac{S^2(n^4)}{n^5}$$

$$\text{Var } h_2 = \frac{S^2}{n^5} (16 n^4 + 16n^2 - 32n + 16)$$

Where,

n = number of parents involved in the diallel i.e. ten. S.E.'s were calculated by taking the square root of these equations.

The following estimates and ratios were calculated by making use of significant genetic parameters only:

1. $(H_1/D)^{1/2}$ = a weighted measure of degree of dominance at each locus. Its value, when less than one, indicates that genetic control of the character is largely due to additive gene action though some degree of dominance also exists, whereas more than one indicates overdominance.

2. $\overline{u}\overline{v}$ = $H_2/4H_1$ = an estimate of average frequency of negative versus positive alleles at loci exhibiting dominance and has maximum value of 0.25. The value less than 0.25 indicates that positive and negative alleles are not in equal proportion in parents.

Since $u + v = 1$ and $u-v = (1-4\ \overline{u}\overline{v})^{1/2}$

The value of u and v can be found out.

3. Prevalence of dominant and recessive genes in all the parents. It is given by the sign of F. The positive sign indicates dominant genes to be more prevalent and negative sign indicates the prevalence of more recessives.

4. $$\frac{(4\ DH_1)^{1/2} + F}{(4\ DH_1)^{1/2} - F}$$

If the estimates = 1, it suggests equality of dominant and recessive genes.

> 1, suggests excessive of dominant genes, and

< 1, suggests excess of recessive genes

5. h^2/H_2 gives an estimate of number of effective factors operating for a trait and showing some degree of dominance.

6. r = Correlation coefficient between parents means (Yr) and their $(W_r + V_r)$ values was calculated by using formula:

$$r = \frac{SP\ Yr\ (W_r + V_r)}{\sqrt{SS\ Yr \times SS\ (W_r + V_r)}}$$

where,

Yr = mean of each parent

Positive sign of 'r' indicates that maximum expression of the character is governed by recessive genes while negative sign indicates maximum expression of the character is governed by dominant genes.

The general test of the failure of diallel assumptions was obtained by calculating t^2 with the following formula:

$$t^2 = \frac{n-2}{4} \cdot \frac{(Var.V_r - Var.W_r)^2}{Var.V_r \times Var.W_r - Cov^2\ (V_r, W_r)}$$

with n-2 degrees of freedom. Significance of t^2 value through F test at 1 and (n-2) d.f. indicates failure of hypothesis.

CHAPTER-IV

EXPERIMENTAL RESULTS

The results of the present investigation have been described as under:

MEAN PERFORMANCE AND HETEROSIS

The mean squares for genotypes, replications and error from the analysis of variance for the design of the experiment are given in Table 1. The mean squares due to genotypes were highly significant for all the characters. It indicated that the genotypes differ among themselves for all the characters. The mean performance of the parents and F_1's and heterobeltiosis for F_1's are presented in Table 2 and Table 3 respectively.

1. Days to flower initiation

The number of days taken to first flowering among the parents and the hybrids varied from 34.77-60.17 days and 32.93-63.07 days respectively. Matar Ageta-6 was observed to be earliest parent which took 34.77 days to flower initiation followed by Arkel (36.87 days) and Early Snap (48.17 days). Among the hybrids, Arkel x Matar Ageta-6 took the minimum number of days (32.93) to flower initiation which was

Table 1. Analysis of variance for experimental design for different qualitative and quantitative characters

Source of variation	d.f.	Mean squares								
		Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant (g)
Replications	2	10.60	1.70*	0.76	0.16	106.88	2.09	0.48**	6.25**	4.13
Genotypes	54	123.27**	24.72**	24.51**	10.45**	1189.55**	168.19**	4.09**	1.63**	1650.49**
Error	108	5.90	0.51	0.33	0.21	70.50	1.93	0.09	0.51	6.90

Table 1 contd.

Table 1 contd.

Source of variation	d.f.	Shelling percentage	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)	Reaction to powdery mildew	Reaction to wilt (%)
Replications	2	6.68	11.31*	0.03**	0.02**	33.67**	0.14**	0.25
Genotypes	54	229.15**	51.71**	50.07**	37.54**	53.45**	0.50**	20.88**
Error	108	16.15	3.07	0.0005	0.03	3.22	0.02	0.46

**Significant at 1% level
* Significant at 5% level

Table 2. Mean performance of parents and their hybrids for different qualitative and quantitative characters

Genotypes	Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant (g)
(a) Parents									
Bonneville	55.20	15.80	9.00	1.04	145.20	12.48	1.95	4.06	24.34
DPR-3	58.47	13.33	4.07	1.52	83.40	22.20	2.09	5.44	45.42
Arkel	36.87	8.67	3.03	1.91	66.04	4.36	4.93	5.71	21.43
Matar Ageta-6	34.77	7.60	2.64	1.10	38.35	4.84	4.64	6.34	22.39
Early Snap	48.17	8.13	2.88	2.84	74.11	11.93	2.61	5.64	31.09
P-23	52.27	11.77	3.95	4.00	73.15	14.11	1.60	4.61	22.57
Punjab-87	52.33	13.03	4.82	1.73	80.32	12.96	3.54	6.84	45.90
Punjab-88	53.60	13.83	4.87	1.35	86.08	11.13	3.46	6.45	38.51
JP-179	59.20	14.15	10.53	4.62	175.56	7.75	1.18	5.59	9.12
JP-501-A/2	60.17	14.20	8.58	3.55	181.44	13.17	1.26	5.33	16.60
(b) Hybrids									
Bonneville									
x DPR-3	53.10	14.23	7.68	1.44	113.05	22.12	2.45	5.40	54.26
x Arkel	55.80	14.77	9.15	1.53	136.12	27.18	2.40	5.12	65.10
x Matar Ageta-6	48.40	13.07	7.52	1.64	167.44	18.50	2.84	4.83	52.53
x Early Snap	48.33	12.90	6.14	1.35	111.17	16.22	2.91	5.47	47.13
x P-23	51.60	15.10	9.36	1.90	207.60	16.40	2.27	5.05	37.23
x Punjab-87	54.45	14.33	6.20	1.32	118.07	27.83	2.92	4.14	81.78
x Punjab-88	55.93	14.37	9.30	2.04	138.04	25.20	2.95	3.93	74.34
x JP-179	55.27	15.77	8.37	5.36	158.73	14.85	1.28	4.66	19.03
x JP-501-A/2	57.51	17.23	9.07	4.68	176.32	27.04	1.23	3.62	33.33

Table 2 contd.

Table 2 contd.

Genotypes	Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant (g)
DPR-3									
x Arkel	50.77	12.87	3.08	2.31	79.44	16.65	2.80	4.71	46.51
x Matar Ageta-6	47.68	10.51	2.47	1.80	57.07	19.03	2.54	4.70	47.67
x Early Snap	44.50	9.43	2.68	1.55	61.89	17.22	2.75	5.98	47.32
x P-23	51.70	13.07	3.05	2.73	65.91	22.96	2.74	4.61	64.63
x Punjab-87	53.17	13.63	3.90	1.57	75.36	28.48	3.56	6.41	101.45
x Punjab-88	58.39	13.86	3.87	1.33	88.49	34.85	2.64	5.25	91.70
x JP-179	52.93	13.66	7.43	8.92	225.54	32.33	1.42	5.13	46.01
x JP-501-A/2	53.27	14.73	8.62	4.91	149.94	21.82	1.47	4.90	31.49
Arkel									
x Matar Ageta-6	32.93	8.47	2.90	1.22	41.20	12.81	4.57	5.99	58.31
x Early Snap	42.77	9.33	3.60	1.53	73.60	13.28	3.84	5.10	50.88
x P-23	49.90	13.47	5.05	1.23	80.00	21.02	4.15	5.96	87.39
x Punjab-87	46.90	12.97	5.03	1.76	89.54	9.91	4.02	6.27	39.66
x Punjab-88	54.90	13.53	5.14	2.18	102.54	21.55	3.94	5.61	84.38
x JP-179	54.27	13.60	9.93	6.45	158.95	24.68	1.03	4.61	27.00
x JP-501-A/2	52.45	12.97	8.39	5.42	166.14	22.19	1.15	4.21	29.16
Matar Ageta-6									
x Early Snap	40.20	8.73	3.07	1.16	74.31	12.13	4.16	5.73	47.81
x P-23	46.04	10.03	2.82	3.10	77.93	21.93	2.52	4.17	54.70
x Punjab-87	44.10	12.40	4.16	1.04	73.84	9.47	5.02	6.13	44.14
x Punjab-88	45.07	11.80	4.82	1.82	81.64	16.72	3.58	5.65	57.38
x JP-179	48.00	14.87	11.53	2.40	196.75	11.76	1.30	5.38	15.73
x JP-501-A/2	46.13	14.45	11.05	2.52	218.97	19.67	1.23	4.89	24.80

Table 2 contd.

Table 2 contd.

Genotypes	Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant (g)
Early Snap									
x P-23	48.10	9.77	3.05	2.90	83.70	16.74	2.61	5.09	43.69
x Punjab-87	48.30	10.60	3.28	1.30	68.75	13.26	3.49	5.86	45.06
x Punjab-88	47.33	10.00	3.38	1.97	73.37	9.08	4.06	6.16	34.09
x JP-179	47.27	13.69	8.95	4.66	233.48	6.47	2.80	5.54	18.15
x JP-501-A/2	45.90	15.16	10.15	3.95	166.67	13.74	1.30	5.35	19.09
P-23									
x Punjab-87	54.07	13.53	4.42	2.65	86.77	38.60	2.26	4.49	87.28
x Punjab-88	52.33	11.84	4.68	2.05	98.13	31.61	2.96	5.01	93.78
x JP-179	53.62	15.42	8.43	7.99	211.07	17.80	1.06	5.13	18.88
x JP-501-A/2	53.10	17.00	10.63	6.36	221.70	19.55	1.12	4.11	21.90
Punjab-87									
x Punjab-88	52.90	13.33	5.60	1.28	92.45	13.36	4.91	6.61	65.53
x JP-179	60.53	17.62	10.03	3.51	256.73	12.60	1.51	5.56	19.41
x JP-501-A/2	60.57	19.33	9.73	4.24	225.87	13.67	1.84	4.40	25.14
Punjab-88									
x JP-179	63.07	20.10	9.08	4.39	229.50	9.92	1.52	5.13	14.02
x JP-501-A/2	59.57	19.53	9.54	3.30	209.87	13.51	1.94	4.58	26.10
JP-179									
x JP-501-A/2	58.73	18.38	9.03	6.24	203.67	17.99	1.20	5.38	21.62
C.D. at 5%	3.89	1.15	0.92	0.73	13.44	2.22	0.05	1.14	4.20
C.D. at 1%	5.12	1.51	1.21	0.96	17.69	2.93	0.06	1.50	5.53

Table 2 contd.

Table 2 contd.

Genotypes	Shelling percentage	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)	Reaction to powdery mildew	Reaction to wilt (%)
(a) Parents							
Bonneville	42.40	25.24	15.14	19.50	22.40	7.51	4.52
DPR-3	55.49	31.97	25.20	15.40	26.61	7.73	0.00
Arkel	42.65	20.48	24.76	24.26	13.51	7.17	8.53
Matar Ageta-6	45.00	22.47	20.17	19.95	17.50	7.24	5.00
Early Snap	37.76	24.37	17.76	20.31	13.24	6.48	5.89
P-23	39.03	28.86	18.64	17.82	25.45	6.54	0.00
Punjab-87	46.89	26.14	18.42	18.61	19.34	7.28	4.21
Punjab-88	46.76	25.91	23.67	19.86	20.35	6.33	5.31
JP-179	67.97	26.02	27.17	12.62	24.00	0.00	0.00
JP-501-A/2	54.33	25.30	24.54	10.75	24.70	0.00	0.00
(b) Hybrids							
Bonneville							
x DPR-3	60.99	33.80	25.42	17.21	27.32	5.24	0.00
x Arkel	45.85	25.40	18.64	26.03	18.00	6.33	6.00
x Matar Ageta-6	54.11	33.14	18.42	21.23	23.34	6.34	4.86
x Early Snap	50.42	27.26	19.73	19.84	21.17	6.19	5.20
x P-23	44.45	26.80	22.36	18.81	27.00	5.34	0.00
x Punjab-87	50.23	26.00	22.36	19.31	23.22	6.91	4.30
x Punjab-88	43.82	27.00	21.25	23.04	23.57	5.78	4.62
x JP-179	61.27	31.61	21.70	18.21	26.33	7.19	0.00
x JP-501-A/2	48.89	25.78	17.98	16.32	26.94	6.57	0.00

Table 2 contd.

Table 2 contd.

Genotypes	Shelling percentage	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)	Reaction to powdery mildew	Reaction to wilt (%)
DPR-3							
x Arkel	43.30	32.98	24.76	20.24	29.00	7.51	0.00
x Matar Ageta-6	48.89	34.47	19.73	23.43	26.51	6.93	0.00
x Early Snap	50.00	29.43	24.98	19.04	23.40	6.61	0.00
x P-23	53.33	33.35	23.67	16.86	22.37	5.88	0.00
x Punjab-87	43.46	30.30	15.58	18.22	28.67	6.27	0.00
x Punjab-88	51.67	33.37	12.51	19.31	20.95	6.36	0.00
x JP-179	54.60	34.30	24.98	14.21	23.00	5.47	0.00
x JP-501-A/2	55.34	35.27	22.79	13.26	30.73	4.57	0.00
Arkel							
x Matar Ageta-6	43.49	22.23	31.98	27.48	12.84	5.71	5.85
x Early Snap	44.35	25.64	26.51	22.53	19.94	6.28	5.55
x P-23	48.86	26.83	28.04	19.34	22.61	7.22	0.00
x Punjab-87	44.40	26.59	22.36	21.47	24.26	7.34	5.67
x Punjab-88	51.66	21.97	19.95	23.62	17.74	6.96	6.12
x JP-179	63.05	35.85	28.48	20.31	26.33	6.90	0.00
x JP-501-A/2	58.52	28.01	23.23	20.79	30.98	5.91	0.00
Matar Ageta-6							
x Early Snap	46.49	27.77	24.54	22.45	24.97	5.51	5.10
x P-23	37.78	27.57	20.83	18.68	24.70	6.57	0.00
x Punjab-87	35.25	25.97	29.14	19.00	23.78	6.20	4.31
x Punjab-88	32.03	22.90	21.26	23.20	27.75	5.97	3.99
x JP-179	54.76	29.51	29.36	14.31	25.30	6.34	0.00
x JP-501-A/2	61.72	36.77	29.58	13.34	32.05	5.94	0.00

Table 2 contd.

Table 2 contd.

Genotypes	Shelling percentage	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)	Reaction to powdery mildew	Reaction to wilt (%)
Early Snap							
x P-23	36.72	24.20	23.67	19.21	24.81	6.45	0.00
x Punjab-87	35.71	24.00	20.61	22.61	19.98	6.35	5.22
x Punjab-88	46.67	22.67	19.29	24.00	25.82	5.57	5.41
x JP-179	54.05	28.13	24.33	19.65	25.94	5.34	0.00
x JP-501-A/2	58.33	31.51	24.54	18.31	25.05	5.52	0.00
P-23							
x Punjab-87	40.83	29.43	17.33	21.00	23.50	5.25	0.00
x Punjab-88	48.22	30.90	20.83	23.65	19.33	5.75	0.00
x JP-179	61.66	34.10	23.67	15.01	29.60	5.28	0.00
x JP-501-A/2	53.38	32.10	29.36	13.83	25.86	5.51	0.00
Punjab-87							
x Punjab-88	35.60	20.28	23.01	23.22	18.99	7.18	4.37
x JP-179	60.48	26.80	26.73	18.73	28.77	4.92	0.00
x JP-501-A/2	66.41	31.00	18.86	16.35	24.27	5.46	0.00
Punjab-88							
x JP-179	59.19	32.13	19.08	17.82	25.00	5.53	0.00
x JP-501-A/2	57.42	28.62	27.83	19.65	24.33	5.47	0.00
JP-179							
x JP-501-A/2	63.05	26.13	20.61	14.04	20.60	0.00	0.00
C.D. at 5%	6.43	2.80	0.04	0.03	2.87	1.09	0.54
C.D. at 1%	8.47	3.69	0.05	0.04	3.78	1.43	0.71

Table 3. Per cent heterotic effects over the better parent

Hybrids	Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant (g)
Bonneville									
x DPR-3	-3.80	-	-	-	-	-	17.22**	-	19.46**
x Arkel	-	-	-	-	-	117.79**	-	-	167.46**
x Matar Ageta-6	-	-	-	49.09	15.32**	48.24**	-	-	115.82**
x Early Snap	-	-	-	-	-	29.97**	11.49**	-	51.59**
x P-23	-1.28	-	-	-	42.98**	16.23*	16.41**	9.54	52.96**
x Punjab-87	-	-	-	-	-	114.74**	-	-	78.17**
x Punjab-88	-	-	-	51.11	-	101.92**	-	-	93.04**
x JP-179	-	-	-7.00	16.02*	-	18.99*	-	-	-
x JP-501-A/2	-	-	-	1.83**	-	105.32**	-	-	36.94**
DPR-3									
x Arkel	-	-	-	20.94	-	-	-	-	2.40
x Matar Ageta-6	-	-	-6.44	18.42	-	-	-	-	4.95
x Early Snap	-7.62	-	-6.94	-	-	-	5.36**	6.03	4.18
x P-23	-1.09	-	-22.78	-	-	3.42	31.10**	-	42.29**
x Punjab-87	-	-	-4.18	-	-	28.29**	0.56	-	121.02**
x Punjab-88	-	-	-4.91	-	2.80	56.98**	-	-	102.89**
x JP-179	-9.47**	-	-	93.07**	28.47**	45.63**	-	-	1.30
x JP-501-A/2	-8.89**	-	-	38.31**	-	-	-	-	-

Table 3 contd.

Table 3 contd.

Hybrids	Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant (g)
Arkel									
x Matar Ageta-6	-5.29	-	-	-	-	164.67**	-	-	160.43**
x Early Snap	-	-	-	-	-	11.32	-	-	63.65**
x P-23	-	-	-	-	9.36	48.97**	-	4.38	287.20**
x Punjab-87	-	-	-	-	11.48	- *	-	-	-
x Punjab-88	-	-	-	14.14	19.12*	93.62**	-	-	119.11**
x JP-179	-	-	-	39.61**	-	218.45**	-	-	25.99**
x JP-501-A/2	-	-	-	52.68**	-	68.49**	-	-	36.07**
Matar Ageta-6									
x Early Snap	-	-	-	-	0.27	1.68	-	-	53.78**
x P-23	-	-	-	-	6.53	55.42**	-	-	142.36**
x Punjab-87	-	-	-	-	-	-	8.19**	-	-
x Punjab-88	-	-	-	34.81	-	50.22**	-	-	49.00**
x JP-179	-	-	-	-	12.07**	51.74**	-	-	-
x JP-501-A/2	-	-	-	-	20.68**	49.35**	-	-	10.76
Early Snap									
x P-23	-0.15	-	-	-	12.94	18.64*	-	-	40.53**
x Punjab-87	-	-	-	-	-	2.31	-	-	-
x Punjab-88	-1.74	-	-	-	-	-	17.34**	-	-
x JP-179	-1.87	-	-	0.87	32.99**	-	7.28**	-	-
x JP-501-A/2	-4.71	-	-	11.27	-	4.33	-	-	-

Table 3 contd.

Table 3 contd.

Hybrids	Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant
P-23									
x Punjab-87	-	-	-	-	8.03	173.56**	-	-	90.15**
x Punjab-88	-	-	-	-	14.00	124.03**	-	-	143.52**
x JP-179	-	-	-	72.94**	20.23**	26.15**	-	-	-
x JP-501-A/2	-	-	-	59.00**	22.19**	38.55**	-	-	-
Punjab-87									
x Punjab-88	-	-	-	-	7.40	3.09	38.70**	-	42.77**
x JP-179	-	-	-	-	46.23**	-	-	-	-
x JP-501-A/2	-	-	-	19.44	24.49**	3.80	-	-	-
Punjab-88									
x JP-179	-	-	-	-	30.72**	-	-	-	-
x JP-501-A/2	-	-	-	-	15.67**	2.58	-	-	-
JP-179									
x JP-501-A/2	-0.79	-	-	35.06**	12.25**	36.60**	-	-	30.24*
C.D. at 5%	3.89	-	0.92	0.73	13.44	2.22	0.05	1.14	4.20
C.D. at 1%	5.12	-	1.21	0.96	17.69	2.93	0.06	1.50	5.53

Table 3 contd.

Hybrids	Shelling percentage	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)	Reaction to powdery mildew
Bonneville						
x DPR-3	9.91	5.72	0.87**	-	-	-14.43**
x Arkel	7.50	0.63	-	7.30**	-	-5.26
x Matar Ageta-6	20.24**	31.30**	-	6.42**	-	-5.59
x Early Snap	18.92*	8.00	11.09**	-	-	-2.20
x P-23	4.83	-	19.96**	-	-	-8.06*
x Punjab-87	7.12		21.39**	-	-	-2.09
x Punjab-88	-	4.21	-	16.01**	-	-4.07
x JP-179	-	21.48**	-	-	-	-
x JP-501-A/2	-	1.90	-	-	-	-
DPR-3						
x Arkel	-	3.16	-	-	-	-
x Matar Ageta-6	-	7.82	-	17.44**	-	-1.75
x Early Snap	-	-	-	-	-	-
x P-23	-	4.32	-	-	-12.10*	-4.40
x Punjab-87	-	-	-	-	-	-6.27
x Punjab-88	-	4.38	-	-	-	-
x JP-179	-	7.29	-	-	-4.17	-
x JP-501-A/2	-	10.32*	-		-	-

Table 3 contd.

Table 3 contd.

Hybrids	Shelling percentage	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)	Reaction to powdery mildew
Arkel						
x Matar Ageta-6	-	-	29.16**	13.27**	-4.96	-9.47*
x Early Snap	-	5.21	7.07**	-	-	-1.47
x P-23	14.56	-	13.25**	-	-	-
x Punjab-87	-	1.72	-	-	-	-
x Punjab-88	10.48	-	-	-	-	-
x JP-179	-	37.78**	4.82**	-	-	-
x JP-501-A/2	7.71	10.71	-	-	-	-
Matar Ageta-6						
x Early Snap	3.31	13.95*	21.67**	10.54**	-	-6.96
x P-23	-	-	3.27**	-	-	-
x Punjab-87	-	-	44.47**	-	-	-6.29
x Punjab-88	-	-	-	16.29**	-	-2.59
x JP-179	-	13.41*	8.06**	-	-	-
x JP-501-A/2	13.60*	45.34**	20.54**	-	-	-
Early Snap						
x P-23	-	-	26.98**	-	-	-0.37
x Punjab-87	-	-	11.89**	11.32**	-	-1.10
x Punjab-88	-	-	-	18.17**	-	-5.93
x JP-179	-	8.11	-	-	-	-
x JP-501-A/2	7.36	24.55**	-	-	-	-

Table 3 contd.

Table 3 contd.

Hybrids	Shelling percentage	Dry matter (%)	Crude protein	Total sugars	Alcohol insoluble matter	Reaction to powdery mildew
P-23						
x Punjab-87	-	1.98	-	12.84**	-	-8.79*
x Punjab-88	3.12	7.07	-	19.08**	-5.01	-4.07
x JP-179	-	18.16**	-	-	-	-
x JP-501-A/2	-	11.23*	19.64**	-	-	-
Punjab-87						
x Punjab-88	-	-	-	16.92**	-1.81	-
x JP-179	-	2.52	-	0.64**	-	-
x JP-501-A/2	22.23**	18.59**	-	-	-	-
Punjab-88						
x JP-179	-	23.48**	-	-	-	-
x JP-501-A/2	5.69	10.46	13.41**	-	-	-
JP-179						
x JP-501-A/2	-	0.42	-	11.25**	-14.17*	-
C.D. at 5%	6.43	2.80	0.04	0.03	2.87	0.21
C.D. at 1%	8.47	3.69	0.05	0.04	3.78	0.28

statistically on a par with the better parent Matar Ageta-6. The other hybrids with minimum number of days to flower initiation were Matar Ageta-6 x Early Snap (40.20), Arkel x Early Snap (42.77), and Matar Ageta-6 x Punjab-87 (44.10). However, all these three hybrids were not significantly different from each other for this character.

The heterobeltiosis range for days to flower initiation varied from -0.15 to -9.47 per cent. Only two cross combinations viz. DPR-3 x JP-179 and DPR-3 x JP 501-A/2 showed highly significant desirable heterobeltiosis of -9.47 and -8.89 per cent respectively.

2. Node at which the first pod develops

The parental range for number of nodes varied from 7.60 to 15.80 and that of hybrids from 8.47 to 20.10. The node at which the first pod develops was lowest (7.60) in Matar Ageta-6 followed by Early Snap (8.13) and Arkel (8.67) which were statistically on a par with each other. Among the hybrids, Arkel x Matar Ageta-6 produced the pod at the lower node (8.47) which was followed by Matar Ageta-6 x Early Snap (8.73), Arkel x Early Snap (9.33), and DPR-3 x Early Snap (9.43). However, all these hybrids were not significantly different from each other.

The hybrids did not show any desirable heterobeltiosis for this character.

3. Internodal length

The internodal length varied from 2.64 to 10.53 cm and 2.47 to 11.53 cm in the parents and hybrids, respectively. Matar Ageta-6 was found to have the shortest internodal length (2.64 cm) closely followed by Early Snap (2.88 cm) and Arkel (3.03 cm). The internodal length in these three early maturing varieties was on a par with each other. Among the hybrids, DPR-3 x Matar Ageta-6 was the best hybrid with short internodal length (2.47 cm) and it was statistically significant from rest of the hybrids. The other hybrids having better internodal length (short) were DPR-3 x Early Snap (2.68 cm), Matar Ageta-6 x P-23 (2.82 cm) and Arkel x Matar Ageta-6 (2.90 cm) which were statistically on a par with each other.

The heterobeltiosis range was observed to vary from -4.18 to -22.78 per cent. The cross DPR-3 x P-23 showed the maximum desirable heterobeltiosis (-22.78 per cent). The hybrids, however, did not show any significant desirable heterobeltiosis for this character.

4. Number of primary shoots

The parental range for number of primary shoots varied from 1.04 to 4.62 and that of hybrids from 1.04 to 8.92. The parent JP-179 gave more number of primary shoots (4.62) and was significantly superior than rest of the genotypes except P-23. The other parents which gave more number of primary shoots were P-23 (4.00), JP-501-A/2 (3.55) and Early Snap (2.84). Among the hybrids, the cross DPR-3 x JP-179 gave the maximum number of primary shoots (8.92) followed by P-23 x JP-179 (7.99), Arkel x JP-179 (6.45) and P-23 x JP-501-A/2 (6.36). These cross combinations proved to be significantly better than the best parent JP-179.

Nine cross combinations showed highly significant desirable heterobeltiosis for number of primary shoots. The heterobeltiosis range for number of primary shoots was observed to be from 0.87 to 93.07 per cent. The highly significant desirable heterobeltiosis (93.07%) was manifested in the cross DPR-3 x JP-179, followed by P-23 x JP-179 (72.94%), P-23 x JP-501-A/2 (59.00%) and Arkel x JP-501-A/2 (52.68%).

5. Plant height

The plant height of the parents and hybrids ranged from 38.35 to 181.44 cm and 41.20 to 256.73 cm respectively. The parent JP-501-A/2 gave maximum plant height (181.44 cm) followed by JP-179 (175.56 cm), Bonneville (145.20 cm), and Punjab-88 (86.08 cm) which indicated that JP-501-A/2 was the tallest variety among the parent varieties. The maximum plant height (256.73 cm) was found in the cross combination, Punjab-87 x JP-179 and was significantly superior to all other cross combinations. It was followed by Early Snap x JP-179 (233.48 cm), Punjab-88 x JP-179 (229.50 cm) and Punjab-87 x JP-501-A/2

(225.87 cm). These cross combinations proved to be significantly better than the best parent JP-501-A/2.

Fourteen cross combinations showed significant desirable heterobeltiosis for plant height. The heterobeltiosis range for plant height was observed to be from 0.27 to 46.23 per cent. The highly significant desirable heterobeltiosis (46.23%) was manifested in the cross Punjab-87 x JP-179, followed by Bonneville x P-23 (42.98%), Early Snap x JP-179 (32.99%) and Punjab-88 x JP-179 (30.72%).

6. Number of pods per plant

Number of pods per plant for the parents and hybrids ranged from 4.36 to 22.20 and 6.47 to 38.60 respectively. DPR-3 gave maximum number of pods (22.20) per plant and was significantly superior than all the varieties. The other parents having more pods per plant were P-23 (14.11), JP-501-A/2 (13.17) and Punjab-87 (12.96). Among the various cross combinations the maximum number of pods per plant (38.60) were found in P-23 x Punjab-87 which was also significantly superior to all other cross combinations as well as the best parent DPR-3. The other cross combinations viz. DPR-3 x Punjab-88 (34.85), DPR-3 x JP-179 (32.33) and P-23 x Punjab-88 (31.61) also proved to be significantly superior than the best parent DPR-3.

Twenty six cross combinations showed significant desirable heterobeltiosis for number of pods per plant. The per cent heterobeltiosis for number of pods ranged from 1.68 to 218.45. The highly significant desirable heterobeltiosis (218.45%) for this character was expressed in the hybrids Arkel x JP-179 followed by P-23 x Punjab-87 (173.56%); Arkel x Matar Ageta-6 (164.67%) and P-23 x Punjab-88 (124.03%).

7. Pod weight

The range of pod weight was 1.18 to 4.93 g and 1.03 to 5.02 g among the parents and the hybrids, respectively. The maximum pod weight (4.93 g) was obtained in Arkel followed by Matar Ageta-6 (4.64 g), Punjab-87 (3.54 g) and Punjab-88 (3.46 g) which were significantly different among themselves. Amongst various crosses the maximum pod weight (5.02 g) was found to be in Matar Ageta-6 x Punjab-87 which was significantly superior to all other cross combinations as well as the best parent Arkel. The other cross combinations which exhibited highly significant differences among themselves for this character were Punjab-87 x Punjab-88 (4.91 g), Arkel x Matar Ageta-6 (4.57 g) and Matar Ageta-6 x Early Snap (4.16 g).

Nine cross combinations showed significant desirable heterobeltiosis for pod weight. The heterobeltiosis range for pod weight was observed to be from 0.56 to 38.70 per cent. Highly significant desirable heterobeltiosis (38.70%) was manifested in the cross Punjab-87 x Punjab-88, followed by DPR-3 x P-23 (31.10%), Early Snap x Punjab-88 (17.34%) and

Bonneville x DPR-3 (17.22%) which were statistically different among themselves.

8. Number of grains per pod

The parental range for number of grains per pod varied from 4.06 to 6.84 and that of hybrids from 3.62 to 6.61. Punjab-87 was the best parent with more number of grains per pod (6.84), followed by Punjab-88 (6.45), Matar Ageta-6 (6.34) and Arkel (5.71). Among the hybrids, Punjab-87 x Punjab-88 was the best hybrid with highest number of grains per pod (6.61), followed by DPR-3 x Punjab-87 (6.41), Arkel x Punjab-87 (6.27) and Early Snap x Punjab-88 (6.16). However, all these hybrids were not significantly different from each other.

The hybrids did not show any significant desirable heterobeltiosis for this character. However, it ranged from 4.38 to 9.54 per cent. The cross Bonneville x P-23 showed the maximum desirable heterobeltiosis (9.54%) followed by DPR-3 x Early Snap (6.03%) and Arkel x P-23 (4.38%).

9. Yield per plant

The yield per plant in parents varied from 9.12 to 45.90 g, whereas in hybrids it ranged from 14.02 to 101.45 g per plant. The maximum yield was observed in Punjab-87 (45.90 g) and DPR-3 (45.42 g) which were statistically on a par with each other. These were followed by Punjab-88 and Early Snap which gave 38.51 g and 31.09 g yield per plant respectively. Among the hybrids, the cross DPR-3 x Punjab-87 gave the maximum yield (101.45 g) followed by P-23 x Punjab-88 (93.78 g), DPR-3 x Punjab-88 (91.70 g) and Arkel x P-23 (87.39 g). These cross combinations proved to be significantly better than the best parent Punjab-87.

Twenty five cross combinations showed significant desirable heterobeltiosis for yield. The heterobeltiosis range for yield was observed to be from 1.30 to 287.20 per cent. The highly significant desirable heterobeltiosis (287.20%) was manifested in the cross Arkel x P-23 followed by Bonneville x Arkel (167.46%), Arkel x Matar Ageta-6 (160.43%) and P-23 x Punjab-88 (143.52%).

10. Shelling percentage

The shelling percentage in parents ranged from 37.76 to 67.97 per cent and among the hybrids, it varied from 32.03 to 66.41 per cent. The maximum shelling percentage (67.97) was obtained in JP-179, followed by DPR-3 (55.49%), JP-501-A/2 (54.33%) and Punjab-87 (46.89%) which indicated that JP-179 was the best variety among parents for this character. The maximum shelling percentage (66.41) was observed in the cross Punjab-87 x JP-501-A/2 followed by JP-179 x JP-501-A/2 (63.05%), Arkel x JP-179 (63.05%) and Matar Ageta-6 x JP-501-A/2 (61.72%). However, they were statistically on a par with each other.

The heterobeltiosis range for shelling percentage was observed to be from 3.12 to 22.23 per cent. Out of forty five hybrids, four showed significant desirable heterobeltiosis for shelling percentage. Highly significant desirable heterotic response (22.23%) was manifested in the hybrid Punjab-87 x JP-501-A/2, followed by Bonneville x Matar Ageta-6 (20.24%), Bonneville x Early Snap (18.92%) and Matar Ageta-6 x JP-501-A/2 (13.60%).

11. Dry matter

The range of dry matter varied from 20.48 to 31.97 per cent and 20.28 to 36.77 per cent among the parents and hybrids, respectively. The parent DPR-3 contains more dry matter (31.97%), followed by P-23 (28.86%), Punjab-87 (26.14%) and JP-179 (26.02%) which indicated that DPR-3 was the best parent among the parental varieties for this character. Among the hybrids, the cross Matar Ageta-6 x JP-501-A/2 gave more dry matter (36.77%), followed by Arkel x JP-179 (35.85%), DPR-3 x JP-501-A/2 (35.27%) and DPR-3 x Matar Ageta-6 (34.47%). However, the hybrids did not differ significantly among themselves for dry matter.

The heterobeltiosis range for dry matter varied from 0.42 to 45.34 per cent. Twelve hybrids showed significant desirable heterobeltiosis for this character. Highly significant desirable heterobeltiosis (45.34%) was manifested in the hybrid Matar Ageta-6 x JP-501-A/2, followed by Arkel x

JP-179 (37.78%), Bonneville x Matar Ageta-6 (31.30%) and Early Snap x JP-501-A/2 (24.55%).

12. Crude protein

The parental values of crude protein varied from 15.14 to 27.17 per cent and that of hybrids from 12.51 to 31.98 per cent. The maximum crude protein (27.17%) was found to be in the parent JP-179 followed by DPR-3 (25.20%), Arkel (24.76%), and JP-501-A/2 (24.54%). All these parents were statistically different among themselves. Whereas the maximum amount of crude protein (31.98%) was found in the cross combination, Arkel x Matar Ageta-6 which was significantly superior to all other cross combinations. The other crosses having considerable amount of crude protein in order of decreasing merit were Matar Ageta-6 x JP-501-A/2 (29.58%), Matar Ageta-6 x JP-179, and P-23 x JP-501-A/2 (29.36%). These cross combinations also proved to be significantly better than the best parent JP-179.

Seventeen cross combinations showed significant desirable heterobeltiosis for crude protein. The heterobeltiosis range for crude protein was observed to be from 0.87 to 44.47 per cent. The highly significant desirable heterobeltiosis (44.47%) was manifested in the cross Matar Ageta-6 x Punjab-87 followed by Arkel x Matar Ageta-6 (29.16%), Early Snap x P-23 (26.98%) and Matar Ageta-6 x Early Snap (21.67%).

13. Total sugars

The total sugars in the parents varied from 10.75 to 24.26 per cent. The range among the hybrids was from 13.26 to 27.48 per cent. The maximum amount of total sugars (24.26%) was found in the parent Arkel followed by Early Snap (20.31%), Matar Ageta-6 (19.95%), and Punjab-88 (19.86%) which indicated that Arkel is the sweetest variety among the parental varieties. These varieties also exhibited highly significant difference among themselves for this character. Among the hybrids, Arkel x Matar Ageta-6 and Bonneville x Arkel contained 27.48 and 26.03 per cent of total sugars and were observed to be significantly better than all other cross combinations as well as the best parent Arkel. These were followed by Early Snap x Punjab-88 and P-23 x Punjab-88 which contained 24.00 and 23.65 per cent of total sugars. However, these cross combinations were significantly inferior than the best parent Arkel.

The heterobeltiosis range for total sugars varied from 0.64 to 19.08 per cent. Fourteen hybrids showed significant desirable heterobeltiosis for this character. Highly significant desirable heterobeltiosis (19.08%) was manifested in the hybrid P-23 x Punjab-88 followed by Early Snap x Punjab-88 (18.17%), DPR-3 x Matar Ageta-6 (17.44%) and Punjab-87 x Punjab-88 (16.92%).

14. Alcohol insoluble matter (%)

The parental range for alcohol insdluble matter varied from 13.24 to 26.61 per cent and that of hybrids from 12.84 to 32.05 per cent. Early Snap was the best parent with less amount of alcohol-insoluble matter (13.24%), followed by Arkel (13.51%), Matar Ageta-6 (17.50%), and Punjab-87 (19.34%). However, Early Snap and Arkel were statistically on a par with each other for this character. Among the hybrids, Arkel x Matar Ageta-6 contained less amount of alcohol insoluble matter (12.84%) which was statistically on a par with the better parent. The other hybrids with less amount of alcohol insoluble matter were Arkel x Punjab-88 (17.74%), Bonneville x Arkel (18.00%), and Punjab-87 x Punjab-88 (18.99%). However, these three hybrids did not differ significantly from each other.

The heterobeltiosis range for alcohol insoluble matter was observed to be from -1.81 to -14.17 per cent. Only two cross combinations viz. JP-179 x JP-501-A/2 and DPR-3 x P-23 showed significant desirable heterobeltiosis of -14.17 and -12.10 per cent respectively for this trait.

15. Reaction to powdery mildew

The mean disease index for reaction to powdery mildew amongst the parents and the hybrids ranged from 0.00 to 7.73 and 0.00 to 7.51 respectively. The parents JP-179 and JP-501-A/2 were found to be having the lowest MDI for reaction to powdery mildew whereas for other parents the MDI ranged from 6.33 to 7.73. Among the hybrids, the cross JP-179 x JP-501-A/2 showed the lowest MDI for reaction to powdery mildew and was significantly less than all other cross combinations. The other crosses viz. DPR-3 x JP-501-A/2, Punjab-87 x JP-179 and Bonneville x DPR-3 respectively were having a MDI of 4.57, 4.92 and 5.24 for reaction to powdery mildew disease. The heterbeltiosis range for reaction to powdery mildew varied from -0.37 to -14.43 per cent. Four hybrids showed significant desirable heterobeltiosis for this character. Highly significant desirable heterobeltiosis was manifested in the hybrid Bonneville x DPR-3, followed by Arkel x Matar Ageta-6, P-23 x Punjab-87 and Bonneville x P-23.

16. Reaction to wilt

The parental range for reaction to wilt incidence varied from 0.00 to 8.53 per cent and that of hybrids from 0.00 to 6.12 per cent. The parent DPR-3, P-23, JP-179 and JP-501-A/2 were the best among the parental varieties as they did not show any reaction to wilt. Out of forty five hybrids, thirty were found to be free from wilt disease thereby indicating their superiority so far as their resistance to wilt disease is concerned.

COMBINING ABILITY ANALYSIS AND GENETIC COMPONENTS OF VARIANCE

The mean squares due to general and specific combining ability were highly significant for all the characters studied (Table 4). The components of variation for gca and sca revealed the predominance of additive gene action for days to flower initiation, node at which the first pod develops, internodal length, number of primary shoots, plant height, shelling percentage and total sugars. On the other hand, predominance of non additive gene action was observed for number of pods per plant, yield per plant, dry matter, crude protein and alcohol insoluble matter. Further, both additive and non additive genetic variances were equally important for pod weight and number of grains per pod.

The estimates of g.c.a. and s.c.a. effects are presented in Table 5 and 6 respectively. The W_r/V_r graphs where-ever pertinent were drawn and are presented in Figs. 1-13. The components of the genetic and environmental variances of the diallel cross have been presented in Table 7 and various ratios of these parameters in Table 8.

The results for different characters are presented as below:

1. Days to flower initiation

Only three parents exhibited the highly significant desirable general combining ability effects for this character, the highest being in Matar Ageta-6 followed by

Table 4. Analysis of variance for combining ability for different characters

		Mean squares								
Source of variation	d.f.	Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant (g)
g.c.a.	9	196.67**	36.80**	37.00*	14.34**	15669.47**	114.55**	6.23**	1.63**	1693.82**
s.c.a.	45	9.97**	2.53**	2.40**	1.31**	1341.92**	44.37**	0.39**	0.33**	321.43**
Error	108	1.97	0.17	0.11	0.07	23.50	0.64	0.0003	0.17	2.30
$\sigma^2 A$		31.12	5.71	5.77	2.17	2387.93	11.70	0.97	0.22	228.73
$\sigma^2 D$		8.00	2.36	2.29	1.24	1318.42	43.72	0.39	0.16	319.13

Table 4 contd.

Table 4 contd.

		Mean squares				
		Shelling percentage	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)
g.c.a.	9	289.97**	47.19**	29.72**	57.58**	35.16**
s.c.a.	45	33.67**	11.25**	14.08**	3.50**	14.35**
Error	108	5.38	1.02	0.0002	0.00009	1.07
$\sigma^2 A$		42.72	5.99	2.61	9.01	3.47
$\sigma^2 D$		28.29	10.22	14.08	3.50	13.27

**Significant at 1% level

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

Parents	Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant (g)
Bonneville	2.35**	1.35**	1.74**	-0.70**	17.56**	2.21**	-0.30**	-0.61**	2.88**
DPR-3	1.65**	-0.38**	-1.59**	-0.18*	-26.89**	5.51**	-0.18**	0.03	11.92**
Arkel	-4.01**	-1.49**	-0.97**	-0.36**	-28.88**	-1.31**	0.75**	0.12	4.37**
Matar Ageta-6	-7.87**	-2.31**	-1.19**	-1.07**	-28.36**	-3.50**	0.69**	0.21	-2.58**
Early Snap	-4.46**	-2.61**	-1.66**	-0.47**	-25.92**	-4.31**	0.37**	0.33**	-5.28**
P-23	0.20	-0.37**	-0.88**	0.60**	-10.59**	3.43**	-0.32**	-0.40**	6.32**
Punjab-87	1.42**	0.55**	-0.66**	-0.80**	-13.18**	-0.05	0.66**	0.49**	10.21**
Punjab-88	2.84**	0.74**	-0.40**	-0.72**	-10.00**	0.36	0.56**	0.27*	11.63**
JP-179	4.13**	2.02**	2.83**	2.28**	68.28**	-2.49**	-1.10**	0.01	-21.73**
JP-501-A/2	3.75**	2.50**	2.79**	1.41**	57.99**	0.15	-1.14**	-0.46**	-17.75**
C.D.(gi)									
at 5%	0.75	0.22	0.18	0.14	2.60	0.43	0.009	0.22	0.81
at 1%	0.99	0.29	0.23	0.19	3.43	0.57	0.012	0.29	1.07
C.D.(gi-gj)									
at 5%	1.12	0.33	0.27	0.21	3.88	0.64	0.01	0.33	1.21
at 1%	1.48	0.44	0.35	0.28	5.11	0.85	0.02	0.43	1.60

Table 5 contd.

Parents	Shelling percentage	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)
Bonneville	-0.25	-0.34	-2.61**	0.63**	0.08
DPR-3	2.06**	4.16**	-0.39**	-1.57**	2.03**
Arkel	-1.58*	-2.07**	2.00**	3.24**	-2.67**
Matar Ageta-6	-3.61**	-0.51	1.31**	0.96**	-0.37
Early Snap	-4.13**	-1.83**	-0.48**	1.40**	-1.93**
P-23	-3.71**	0.97**	-0.20**	-0.79**	0.81**
Punjab-87	-3.47**	-1.56**	-1.39**	0.47**	-0.55
Punjab-88	-2.33**	-1.64**	-1.43**	2.15**	-1.38**
JP-179	10.02**	1.61**	1.98**	-2.83**	1.51**
JP-501-A/2	6.99**	1.21**	1.20**	-3.67**	2.46**
C.D. (gi)					
at 5%	1.25	0.54	0.007	0.005	0.56
1%	1.64	0.71	0.009	0.007	0.73
C.D. (gi-gj)					
at 5%	1.86	0.81	0.008	0.008	0.83
1%	2.44	1.07	0.01	0.01	1.09

Table 6. Specific combining ability effects of the hybrids for different characters

Hybrids	Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant (g)
Bonneville									
x DPR-3	-2.05	-0.12	1.17**	-0.57**	-5.46	-3.22**	0.32**	0.73*	-4.07**
x Arkel	6.32**	1.53**	2.02**	-0.30	19.60**	8.67**	-0.67**	0.37	14.32**
x Matar Ageta-6	2.78*	0.64	0.62*	0.52*	50.40**	2.18**	-0.17**	-0.01	8.70**
x Early Snap	-0.70	0.78*	-0.30	-0.36	-8.31*	0.70	0.22**	0.51	6.00**
x P-23	-2.10	0.74*	2.14**	-0.89**	72.80**	-6.85**	0.28**	0.81*	-15.50**
x Punjab-87	-0.47	-0.95**	-1.23**	-0.07	-14.15**	8.05**	-0.05**	-0.98**	25.17**
x Punjab-88	-0.40	-1.10**	1.61**	0.58**	2.64	5.02**	0.07**	-0.97**	16.30**
x JP-179	-2.35*	-0.98**	-2.55**	0.89**	-54.95**	-2.49**	0.07**	0.02	-5.66**
x JP-501-A/2	0.27	0.01	-1.81**	1.08**	-27.07**	7.06**	0.06**	-0.55	4.67**
DPR-3									
x Arkel	1.98	1.35**	-0.72**	-0.04	7.38	-5.16**	-0.39**	-0.67*	-13.31**
x Matar Ageta-6	2.76*	-0.19	-1.11**	0.16	-15.51**	-0.59	-0.59**	-0.78*	-5.20**
x Early Snap	-3.84**	-0.96**	-0.43	-0.68**	-13.14**	-1.59*	-0.04**	0.38	-2.85**
x P-23	-1.30	0.43	-0.84**	-0.57**	-24.44**	-3.59**	0.62**	-0.26	2.86*
x Punjab-87	-1.05	0.08	-0.21	-0.33	-12.40**	5.41**	0.47**	0.64	35.79**
x Punjab-88	2.75*	0.12	-0.51	-0.65**	-2.45	11.37**	-0.35**	-0.28	24.63**
x JP-179	-3.99**	-1.36**	-0.16	3.92**	56.32**	11.69**	0.09**	-0.15	12.28**
x JP-501-A/2	-3.28**	-0.77*	1.06**	0.78**	-8.99*	-1.45*	0.18**	0.09	-6.22**

Table 6 contd.

Table 6 contd.

Hybrids	Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant (g)
Arkel									
x Matar Ageta-6	-6.32**	-1.12**	-1.30**	-0.24	-29.39**	0.01	0.51**	0.43	12.99**
x Early Snap	0.10	0.05	-0.14	-0.52*	0.57	1.29	0.10**	-0.58	8.26**
x P-23	2.57*	1.95**	0.54**	-1.90**	-8.36*	1.29	1.10**	1.00**	33.17**
x Punjab-87	-1.65	0.52	0.30	0.03	3.77	-6.34**	-0.003	0.42	-18.44**
x Punjab-88	4.93**	0.91**	0.15	0.37	13.58**	4.89**	0.02	-0.01	24.85**
x JP-179	3.01**	-0.31	1.71**	1.64**	-8.28**	10.87**	-1.23**	-0.75*	0.83
x JP-501-A/2	1.57	-1.42**	0.22	1.47**	9.20*	5.74**	-1.07**	-0.68*	-0.99
Matar Ageta-6									
x Early Snap	1.39	0.27	-0.44	-0.18	0.76	2.33**	0.49**	-0.05	12.14**
x P-23	2.57*	-0.67*	-1.47**	0.69**	-10.96**	4.40**	-0.46**	-0.88**	7.43**
x Punjab-87	-0.59	0.77*	-0.34	0.02	-12.45**	-4.59**	1.05**	0.19	-7.02**
x Punjab-88	-1.05	-0.01	0.05	0.72**	-7.83	2.25**	-0.28**	-0.06	4.80**
x JP-179	0.60	1.77**	3.54**	-1.70**	29.00**	0.14	-0.90**	-0.07	-3.49**
x JP-501-A/2	-0.89	0.87*	3.10**	-0.71**	61.51**	5.41**	-0.93**	-0.10	1.60
Early Snap									
x P-23	1.22	-0.64	-0.77**	-0.11	-7.63	0.02	-0.05**	-0.08	-0.87
x Punjab-87	0.20	-0.72*	-0.76**	-0.31	-19.98**	0.01	-0.15**	-0.20	-3.39**
x Punjab-88	-2.19	-1.51**	-0.92**	0.28	-18.55**	-4.59**	0.52**	0.33	-15.79**
x JP-179	-3.54**	0.90**	1.42**	-0.04	63.29**	-4.35**	0.93**	-0.04	1.63
x JP-501-A/2	-4.53**	1.89**	2.66**	0.13	6.76	0.29	-0.54**	0.24	-1.41

Table 6 contd.

Table 6 contd.

Hybrids	Days to flower initiation	Node at which the first pod develops	Inter-nodal length (cm)	No. of primary shoots	Plant height (cm)	No. of pods per plant	Pod weight (g)	No. of grains per pod	Yield per plant (g)
P-23									
x Punjab-87	1.30	-0.03	-0.40	-0.03	-17.30**	17.62**	-0.69**	-0.84*	27.23**
x Punjab-88	-1.85	-1.91**	-0.40	-0.71**	-9.11*	10.21**	0.11**	-0.10	32.31**
x JP-179	-1.85	0.39	0.13	2.22**	25.54**	-0.75	-0.13**	0.28	-9.24**
x JP-501-A/2	-1.99	1.49**	2.37**	1.46**	46.47**	-1.64*	-0.03*	-0.27	-10.20**
Punjab-87									
x Punjab-88	-2.51*	-1.34**	0.30	-0.08	-12.21**	-4.56**	1.08**	0.61	0.17
x JP-179	3.84**	1.67**	1.51**	-0.86**	73.80**	-2.48**	-0.66**	-0.18	-12.60**
x JP-501-A/2	4.25**	2.90**	1.25**	0.74**	53.23**	-4.04**	-0.29**	-0.87**	-10.85**
Punjab-88									
x JP-179	4.95**	3.97**	0.30	-0.06	43.39**	-5.57**	-0.55**	-0.38	-19.41**
x JP-501-A/2	1.83	2.92**	0.79**	-0.28	34.05**	-4.61**	-0.09**	-0.47	-11.31**
JP-179									
x JP-501-A/2	-0.29	0.48	-2.94**	-0.35	-50.43**	2.72**	0.84**	0.60	17.57**
C.D.(Sij) at 5%	2.27	0.67	0.54	0.43	7.85	1.30	0.03	0.66	2.45
1%	2.99	0.88	0.71	0.56	10.33	1.71	0.04	0.87	3.23
C.D.(Sij-Sik) at 5%	3.72	1.10	0.88	0.70	12.87	2.13	0.04	1.09	4.02
1%	4.90	1.45	1.16	0.92	16.94	2.80	0.06	1.43	5.30
C.D.(Sij-Skl) at 5%	3.55	1.05	0.84	0.67	12.27	2.03	0.04	1.04	3.84
1%	4.67	1.38	1.10	0.88	16.15	2.67	0.06	1.37	5.05

Table 6 contd.

Hybrids	Shelling percentage	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)
Bonneville					
x DPR-3	9.37**	1.68*	5.74**	-1.07**	1.50
x Arkel	-2.12	-0.49	-3.43**	2.94**	-3.11**
x Matar Ageta-6	8.16**	5.68**	-2.96**	0.41**	-0.06
x Early Snap	5.00**	1.13	0.14**	-1.41**	-0.68
x P-23	-1.39	-2.14*	2.49**	-0.26**	2.39**
x Punjab-87	4.15*	-0.41	3.68**	-1.02**	-0.01
x Punjab-88	-3.40	0.67	2.61**	1.04**	1.17
x JP-179	1.69	2.04*	-0.35**	1.18**	1.04
x JP-501-A/2	-7.66**	-3.39**	-3.29**	0.14**	0.70
DPR-3					
x Arkel	-6.98**	2.59**	0.47**	-0.65**	5.93**
x Matar Ageta-6	0.63	2.52**	-3.87**	4.82**	1.15
x Early Snap	2.26	-1.20	3.17**	-0.01	-0.40
x P-23	5.18**	-0.09	1.58**	-0.01	-4.20**
x Punjab-87	-4.93*	-0.60	-5.32**	0.10**	3.48**
x Punjab-88	2.14	2.55**	-8.36**	-0.49**	-3.41**
x JP-179	-7.28**	0.24	0.70**	-0.61**	-4.25**
x JP-501-A/2	-3.51	1.60	-0.70**	-0.72**	2.53**

Table 6 contd.

Table 6 contd.

Hybrids	Shelling percentage	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)
Arkel					
x Matar Ageta-6	-1.12	-3.49**	5.99**	4.05**	-7.82**
x Early Snap	0.27	1.24	2.31**	-1.33**	0.84
x P-23	4.36*	-0.37	3.56**	-2.34**	0.75
x Punjab-87	-0.34	1.92*	-0.93**	-1.47**	3.78**
x Punjab-88	5.78**	-2.62**	-3.30**	-0.99**	-1.91*
x JP-179	4.82*	8.02**	1.82**	0.67**	3.79**
x JP-501-A/2	3.31	0.57	-2.65**	2.00**	7.48**
Matar Ageta-6					
x Early Snap	4.42*	1.80*	1.03**	0.86**	3.57**
x P-23	-4.71*	-1.20	-2.96**	-0.72**	0.54
x Punjab-87	-7.47**	-0.27	6.54**	-1.66**	1.00
x Punjab-88	-11.83**	-3.26**	-1.30**	0.86**	5.80**
x JP-179	-1.45	0.11	3.39**	-3.05**	0.46
x JP-501-A/2	8.53**	7.77**	4.39**	-3.18**	6.26**
Early Snap					
x P-23	-5.24**	-3.24**	1.67**	-0.63**	2.21**
x Punjab-87	-6.49**	-0.91	-0.20**	1.51**	-1.24
x Punjab-88	3.33	-2.16**	-1.48**	1.23**	5.43**
x JP-179	-1.65	0.06	0.15**	1.85**	2.66**
x JP-501-A/2	5.66**	3.83**	1.14**	1.36**	0.82

Table 6 contd.

Table 6 contd.

Hybrids	Shelling percentage	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)
P-23					
x Punjab-87	-1.79	1.71*	-3.78**	2.09**	-0.48
x Punjab-88	4.46*	3.26**	-0.22**	3.06**	-3.82**
x JP-179	5.55**	3.22**	-0.79**	-0.60**	3.56**
x JP-501-A/2	0.29	1.62	5.68**	-0.94**	-1.13
Punjab-87					
x Punjab-88	-8.40**	-4.82**	3.14**	1.38**	-2.78**
x JP-179	4.13*	-1.55	3.45**	1.86**	4.11**
x JP-501-A/2	13.09**	3.05**	-3.63**	0.33**	-1.34
Punjab-88					
x JP-179	1.70	3.86**	-4.16**	-0.72**	1.16
x JP-501-A/2	2.96	0.75	5.38**	1.95**	-0.45
JP-179					
x JP-501-A/2	-3.76*	-4.98**	-5.25**	1.32**	-7.07**
C.D. (Sij) at 5%	3.75	1.64	0.02	0.02	1.68
at 1%	4.94	2.16	0.03	0.02	2.21
C.D.(Sij-Sik) at 5%	6.16	2.69	0.03	0.03	2.75
at 1%	8.10	3.53	0.04	0.03	3.62
C.D.(Sij-Skl) at 5%	5.87	2.56	0.03	0.03	2.62
at 1%	7.73	3.37	0.04	0.03	3.45

Table 7. Genetic components of variation

Character	D	H_1	H_2	F	E
Days to flower initiation	76.47**±4.22	45.84**±8.99	30.22**±7.64	26.64* ±9.75	1.97 ±1.27
Node at which the first pod develops	8.22**±1.35	10.83**±2.87	7.87**±2.44	-2.34 ±3.11	0.17 ±0.41
Internodal length (cm)	8.05**±0.93	10.07**±1.68	8.39**±1.97	-3.71 ±2.14	0.11 ±0.28
Number of primary shoots	1.61 ±1.01	6.25**±2.16	4.31* ±1.84	-2.18 ±2.34	0.07 ±0.30
Plant height (cm)	2374.92**±424.47	5762.18**±903.51	4537.13**±767.89	-2390.74* ±979.37	23.50 ±127.98
Number of pods per plant	25.68 ±15.48	172.24**±32.95	150.44**±28.00	3.34 ±35.72	0.64 ±4.67
Pod weight (g)	1.84**±0.14	1.91**±0.33	1.38**±0.28	0.16 ±0.35	0.0003±0.04
Number of grains per pod	0.53**±0.10	0.91**±0.26	0.84**±0.22	0.08 ±0.28	0.17**±0.03
Yield per plant (g)	147.37±184.52	1395.32**±392.77	1040.30**±333.81	-204.23 ±425.75	2.30 ±55.64
Shelling percentage	78.16**±13.77	135.87**±29.30	112.93**±24.90	-1.63±31.76	5.38 ±4.15
Dry matter (%)	8.93* ±3.30	44.95**±7.02	36.45**±5.97	-0.81±7.61	1.02 ±0.99
Crude protein (%)	16.03**±4.71	64.23**±10.03	51.45**±8.53	17.99±10.87	0.0002±1.42
Total sugars (%)	15.85**±1.23	14.08**±2.63	12.70**±2.23	-2.87 ±2.85	0.00009±0.37
Alcohol insoluble matter (%)	21.92**±5.14	54.74**±10.94	48.49**±9.30	17.74 ±11.86	1.08 ±1.55

Table 8. Ratios of components of genetic variance

Character	$\sqrt{H_1/D}$	$H_2/4H_1$	$[\sqrt{4DH_1}+F]/[\sqrt{4DH_1}-F]$	h^2/H_2	r	t^2	b±SE(b)
Days to flower initiation	0.77	0.16	1.58	-0.02	-0.58	0.01	0.92±0.12
Node at which the first pod develops	1.15	0.18	0.78	0.89	-0.45	1.22	0.35±0.16
Internodal length (cm)	1.12	0.21	0.66	0.40	-0.94**	0.01	0.96±0.12
Number of primary shoots	1.97	0.17	0.49	0.24	0.26	6.30*	0.26±0.09
Plant height (cm)	1.56	0.20	0.51	0.66	-0.90**	0.02	0.88±0.13
Number of pods per plant	2.59	0.22	1.05	0.99	-0.14	4.75	0.30±0.09
Pod weight (g)	1.02	0.18	1.09	0.04	0.94**	0.43	0.83±0.09
Number of grains per pod	1.31	0.23	1.12	0.56	0.80**	0.01	0.80±0.22
Yield per plant (g)	3.08	0.19	0.63	0.96	0.57	22.29**	0.18±0.05
Shelling percentage	1.32	0.21	0.98	0.12	-0.66*	0.99	0.51±0.14
Dry matter (%)	2.24	0.20	0.96	0.75	-0.73*	3.64	0.46±0.09
Crude protein (%)	2.00	0.20	1.78	0.09	-0.09	0.25	0.01±0.25
Total sugars (%)	0.94	0.23	0.82	0.54	-0.19	4.19	0.64±0.07
Alcohol insoluble matter (%)	1.58	0.22	1.69	0.73	-0.81**	0.06	0.67±0.21

Early Snap and Arkel. The other parents were poor combiners. The highly significant desirable specific combining ability effect for early flowering was observed in the cross combination Arkel x Matar Ageta-6 followed by Early Snap x JP-501-A/2, DPR-3 x JP-179, DPR-3 x Early Snap and Early Snap x JP-179. However, all these crosses were statistically on par with each other.

The regression of W_r on V_r (b = 0.92±0.12, Fig. 1) did not differ from unity indicating the absence of non-allelic interctions. The non-significant t^2 value also indicated the absence of epistasis. Since the regression line intersected the W_r axis above the origin so only partial dominance was observed from the graph. The parent Arkel (P_2) carried the maximum recessive genes. A relatively higher concentration of dominant genes was shown by Early Snap (P_5), Bonneville (P_1) and P-23 (P_6). The correlation of W_r+V_r with parents (Y_r) was non-significant indicating that both dominants as well as recessives contributed towards early flowering.

The estimates of components of variance and the statistics derived from these showed that the additive genetic component for days to flower initiation was more important than dominant one. The significant and positive F value indicated the presence of more dominant genes in the parents. The mean degree of dominance $(H_1/D)^{1/2}$ was less than one which indicates that genetic control of the character is largely due

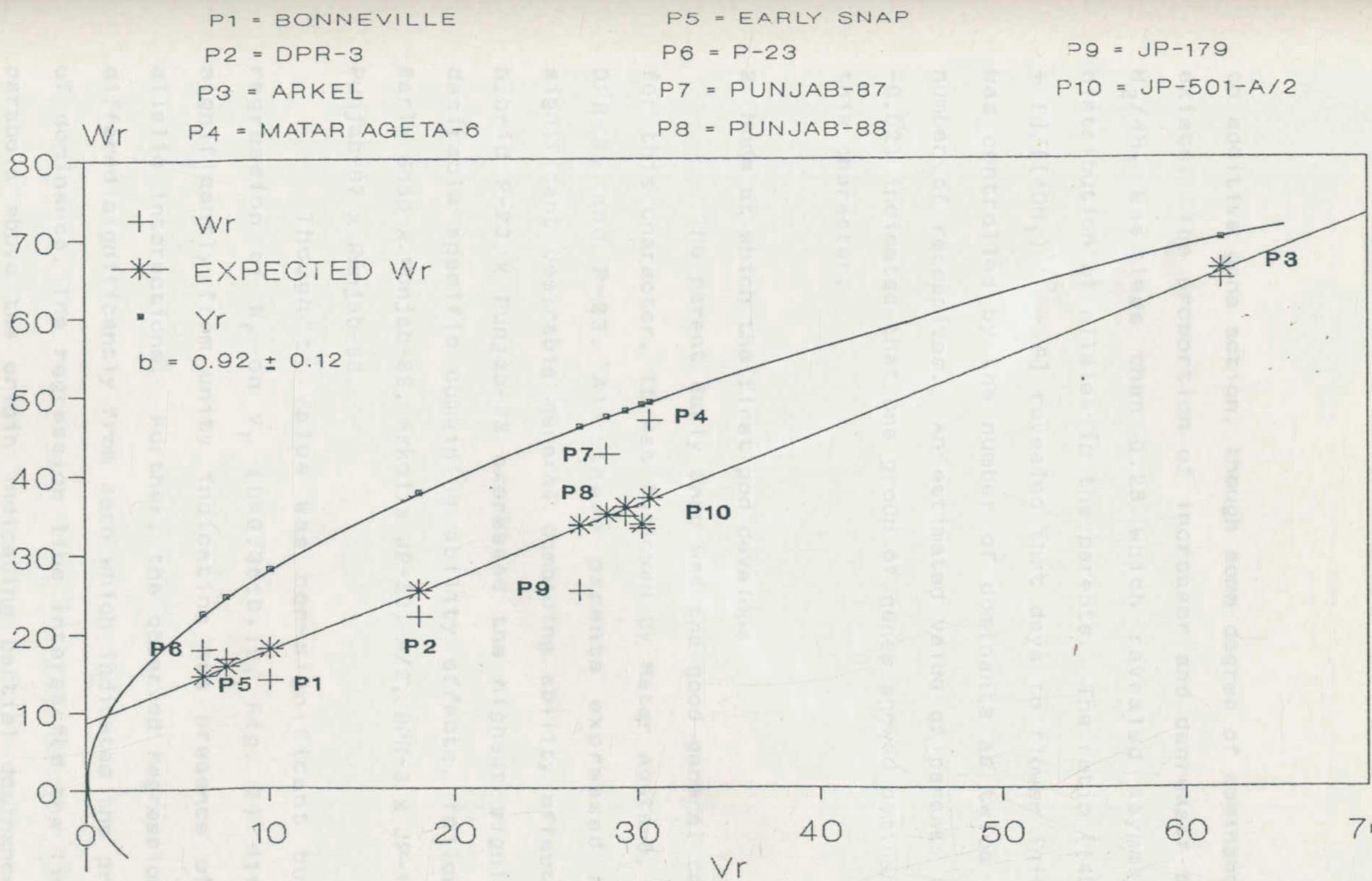

FIG. 1:Wr/ Vr GRAPH FOR DAYS TO FLOWER INITIATION

to additive gene action, though some degree of dominance also exists. The proportion of increaser and decreaser alleles $H_2/4H_1$ was less than 0.25 which revealed asymmetrical distribution of alleles in the parents. The ratio $[(4DH_1)^{1/2} + F]/[(4DH_1)^{1/2} - F]$ revealed that days to flower initiation was controlled by the number of dominants as twice as the number of recessives. An estimated value of parents (h^2/H_2; -0.02) indicated that one group of genes showed dominance for this character.

2. Node at which the first pod develops

The parent Early Snap was the good general combiner for this character. It was followed by Matar Ageta-6, Arkel, DPR-3, and P-23. All these parents expressed highly significant desirable general combining ability effects. The hybrid P-23 x Punjab-88 expressed the highest significant desirable specific combining ability effects, followed by Early Snap x Punjab-88, Arkel x JP-501-A/2, DPR-3 x JP-179 and Punjab-87 x Punjab-88.

Though t^2 value was non-significant but the regression of W_r on V_r (b=0.35±0.16, Fig. 2) differed significantly from unity indicating the presence of non-allelic interactions. Further, the observed regression line differed significantly from zero which indicates the presence of dominance. The regression line intersected the limiting parabola above the origin indicating partial dominance. The

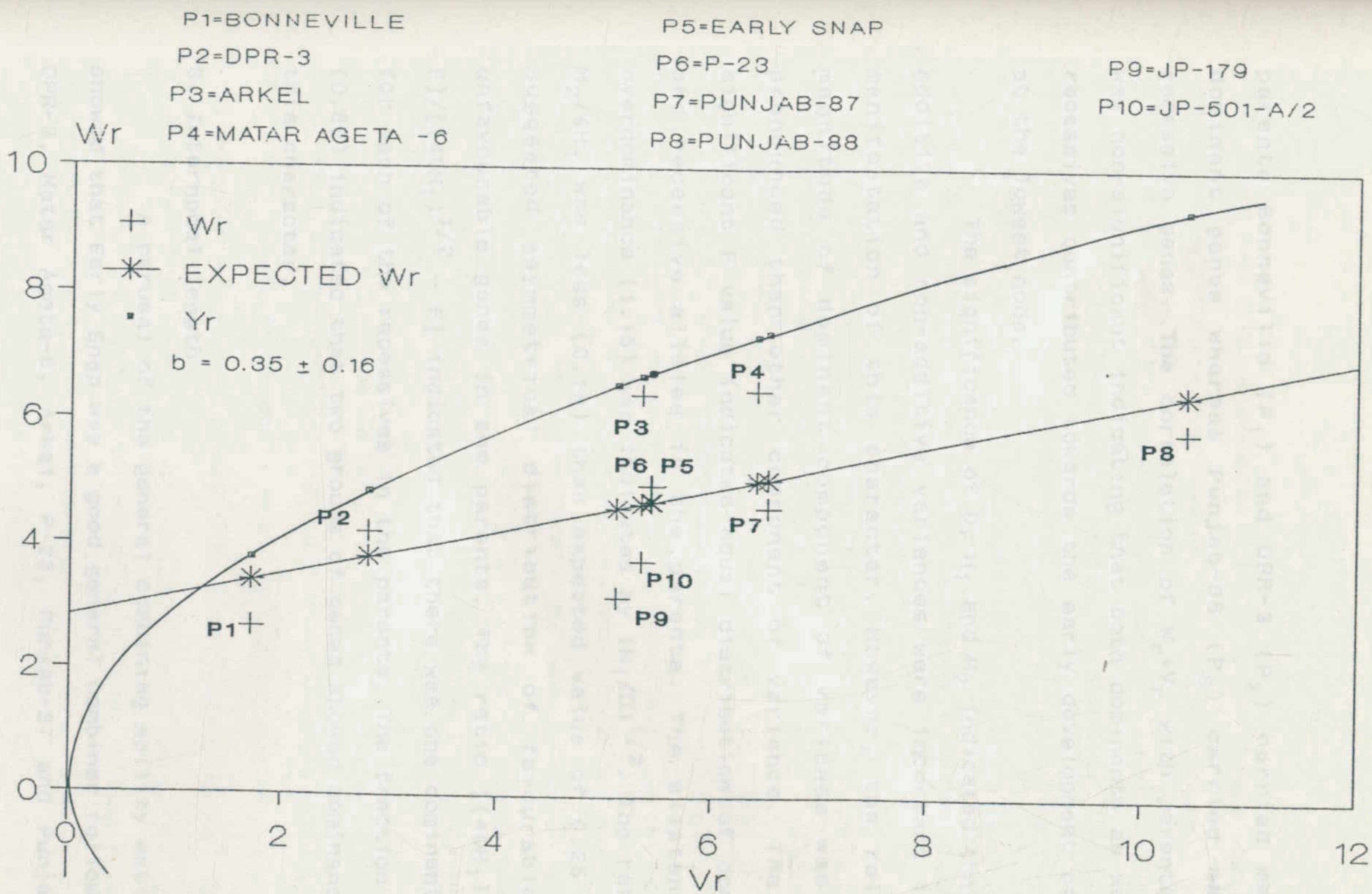

FIG. 2:Wr/ Vr GRAPH FOR NODE AT WHICH THE FIRST POD DEVELOPS

parents Bonneville (P_1) and DPR-3 (P_2) carried maximum dominant genes whereas Punjab-88 (P_8) carried maximum recessive genes. The correlation of W_r+V_r with parents (Y_r) was non-significant indicating that both dominants as well as recessives contributed towards the early development of pods at the lowest node.

The significance of D, H_1 and H_2 indicated that both additive and non-additive variances were important in the manifestation of this character. However, the relative magnitude of dominant component of variance was more pronounced than other component of variance. The non-significant F value indicated equal distribution of dominant and recessive alleles in the parents. The existence of overdominance (1.15) was indicated by $(H_1/D)^{1/2}$. The ratio of $H_2/4H_1$ was less (0.18) than expected value of 0.25 which suggested asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio $[(4DH_1)^{1/2} + F]/[(4DH_1)^{1/2} - F]$ indicated that there was one dominant gene for each of the recessives in the parents. The fraction h^2/H_2 (0.89) indicated that two groups of genes showed dominance for this character.

3. Internodal length

A perusal of the general combining ability estimates showed that Early Snap was a good general combiner followed by DPR-3, Matar Ageta-6, Arkel, P-23, Punjab-87 and Punjab-88.

All these parents expressed highly significant desirable general combining ability effects. The cross JP-179 x JP-501-A/2 revealed the highly significant specific combining ability effects for short internodal length followed by Bonneville x JP-179, Bonneville x JP-501-A/2, Matar Ageta-6 x P-23 and Arkel x Matar Ageta-6. In addition to these, seven other hybrids also showed significant desirable specific combining ability effects for this character.

The regression of W_r on V_r (b=0.96±0.12, Fig. 3) of unit slope indicated the absence of non-allelic interaction. The possibility of epistasis was also excluded by non-significant t^2 value. The regression line intersected the parabola near the origin indicating complete dominance. The parent Bonneville (P_1) carried maximum dominant genes while Matar Ageta-6 (P_4) had more recessive genes. The correlation of W_r+V_r with parents (Y_r) was significant with negative sign showing that recessive genes were important to reduce the internodal length.

The significance of D, H_1 and H_2 indicated that both additive and non-additive variances were important in the manifestation of internodal length but the relative magnitude of dominance variance was more than additive variances. The F-value was negative and non-significant showing equal distribution of dominant and recessive alleles in the parents. The ratio of $(H_1/D)^{1/2}$ being greater than one, suggested the existence of overdominance. Unequal gene frequencies were

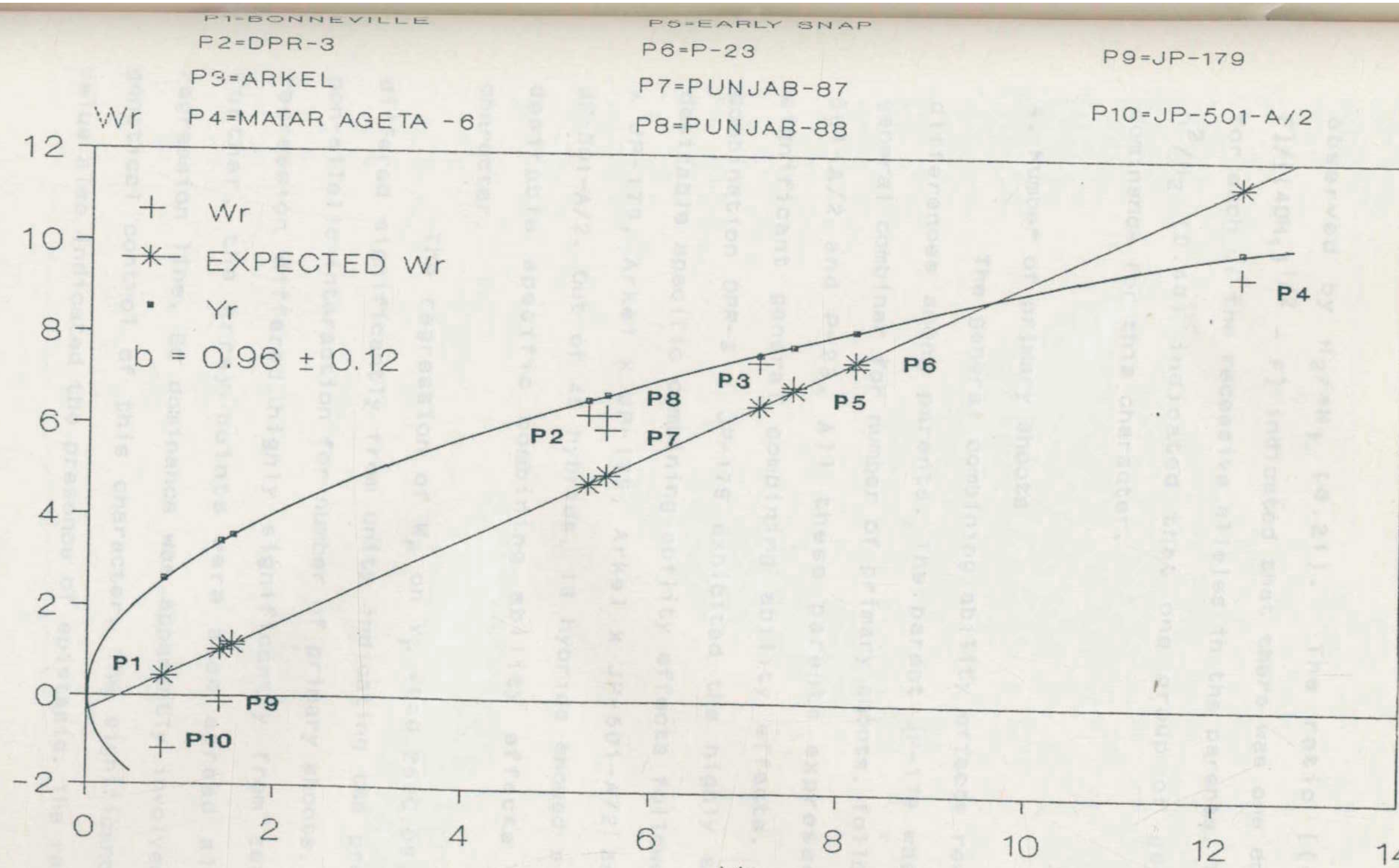

FIG. 3:Wr/ Vr GRAPH FOR INTERNODAL LENGTH

observed by $H_2/4H_1$ (0.21). The ratio $[(4DH_1)^{1/2} + F]/[(4DH_1)^{1/2} - F]$ indicated that there was one dominant gene for each of the recessive alleles in the parents. The value of h^2/H_2 (0.40) indicated that one group of genes showed dominance for this character.

4. Number of primary shoots

The general combining ability effects revealed wide differences among parents. The parent JP-179 was the good general combiner for number of primary shoots, followed by JP-501-A/2 and P-23. All these parents expressed highly significant general combining ability effects. The cross combination DPR-3 x JP-179 exhibited the highly significant desirable specific combining ability effects followed by P-23 x JP-179, Arkel x JP-179, Arkel x JP-501-A/2 and P-23 x JP-501-A/2. Out of 45 hybrids, 13 hybrids showed significant desirable specific combining ability effects for this character.

The regression of W_r on V_r (b=0.26±0.09, Fig. 4) differed significantly from unity indicating the presence of non-allelic interaction for number of primary shoots. But this regression differed highly significantly from zero also. Further, the array points were also spread along the regression line. So dominance was apparently involved in the genetical control of this character. The significance of t^2 value also indicated the presence of epistasis. The regression

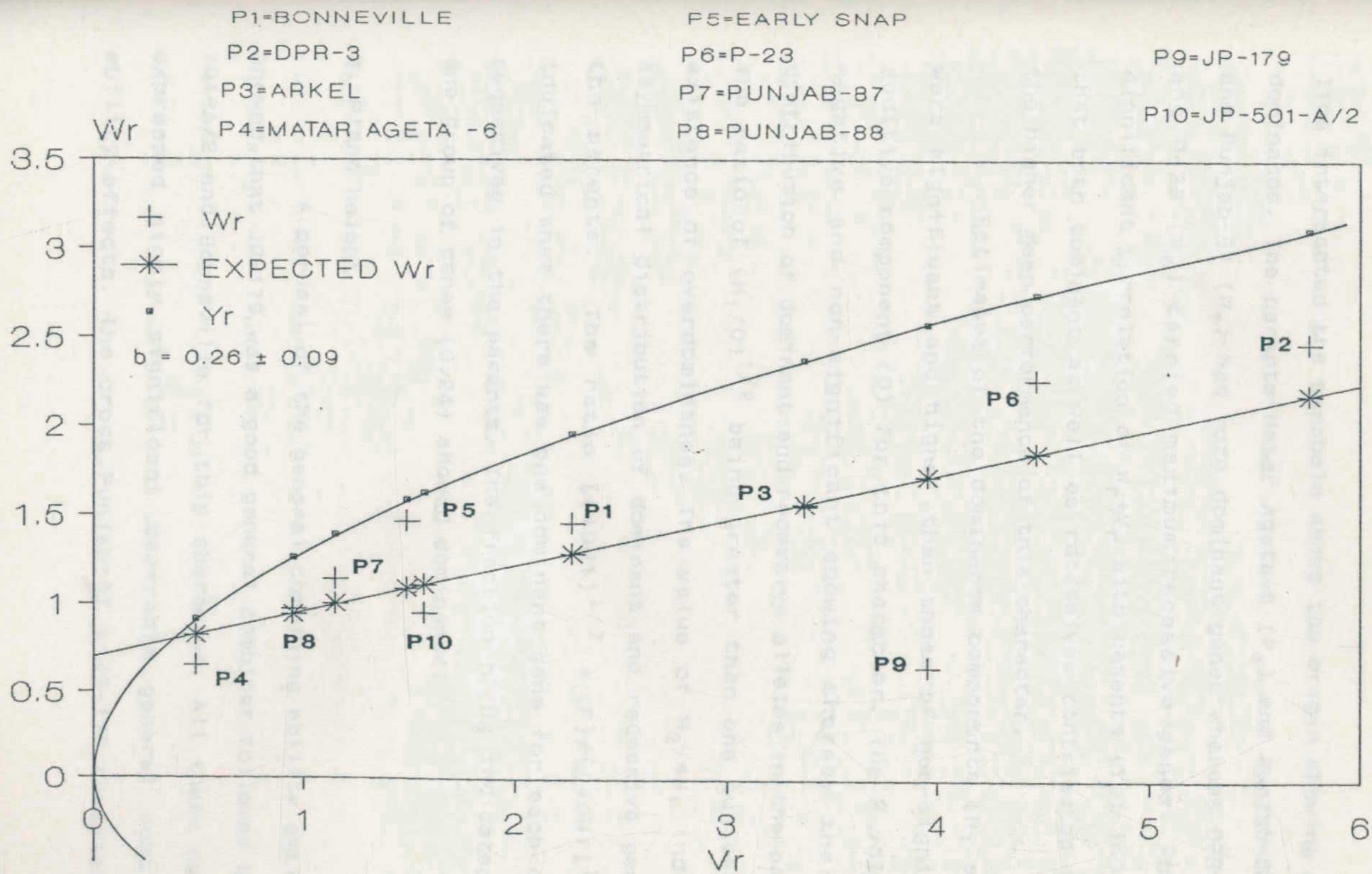

FIG. 4:Wr/ Vr GRAPH FOR NUMBER OF PRIMARY SHOOTS

line intersected the parabola above the origin showing partial dominance. The parents Matar Ageta-6 (P_4) and Punjab-88 (P_8), and Punjab-87 (P_7) had more dominant genes whereas DPR-3 (P_2) and P-23 (P_6) carried maximum recessive genes. The non-significant correlation of W_r+V_r with parents (Y_r) indicating that both dominant as well as recessives contributed towards the higher mean performance of this character.

Estimates of the dominance components (H_1 and H_2) were significant and higher than those of non-significant additive component (D) for this character. The F value was negative and non-significant showing thereby the equal distribution of dominant and recessive alleles in the parents. The ratio of $(H_1/D)^{1/2}$ being greater than one suggests the existence of overdominance. The value of $H_2/4H_1$ indicated asymmetrical distribution of dominant and recessive genes in the parents. The ratio $[(4DH1)^{1/2} + F]/[(4DH1)^{1/2} - F]$ indicated that there was one dominant gene for each of the recessives in the parents. The fraction h^2/H_2 indicated that one group of genes (0.24) showed dominance.

5. Plant height

A perusal of the general combining ability estimates showed that JP-179 was a good general combiner followed by JP-501-A/2 and Bonneville for this character. All these parents expressed highly significant desirable general combining ability effects. The cross Punjab-87 x JP-179 revealed the highly significant specific combining ability effect for maximum plant height followed by the hybrids Bonneville x P-23, Early Snap x JP-179, Matar Ageta-6 x JP-501-A/2, and DPR-3 x JP-179. As many as 15 out of 45 crosses showed significant desirable specific combining ability effects for plant height.

The regression W_r on V_r was 0.88±0.13 (Fig. 5) which indicated the absence of non-allelic interaction and/or other disturbances. The possibility of epistasis was also excluded by non-significant t^2 value. Since the regression line intersected the W_r axis below the origin so overdominance was observed from the graph. The parents showed considerable diversity for the number of dominant and recessive genes. Bonneville (P_1), JP-501-A/2 (P_{10}) and JP-179 (P_9) carried more dominant genes whereas Matar Ageta-6 (P_4), P-23 (P_6) and Punjab-87 (P_7) had relatively more recessive genes. The correlation of W_r+V_r with parents (Y_r) was significant with negative sign showing that dominant genes were desirable for increasing the plant height.

The estimates of components of variance and the statistics derived from these showed that the additive genetic component for plant height was less important than dominant one. The significant negative F value indicated presence of more number of recessive genes in the parents. The existence of overdominance (1.56) was confirmed by $(H_1/D)^{1/2}$. The value of $H_2/4H_1$ was less (0.20) than the expected value of 0.25 which suggested asymmetrical distribution of favourable and

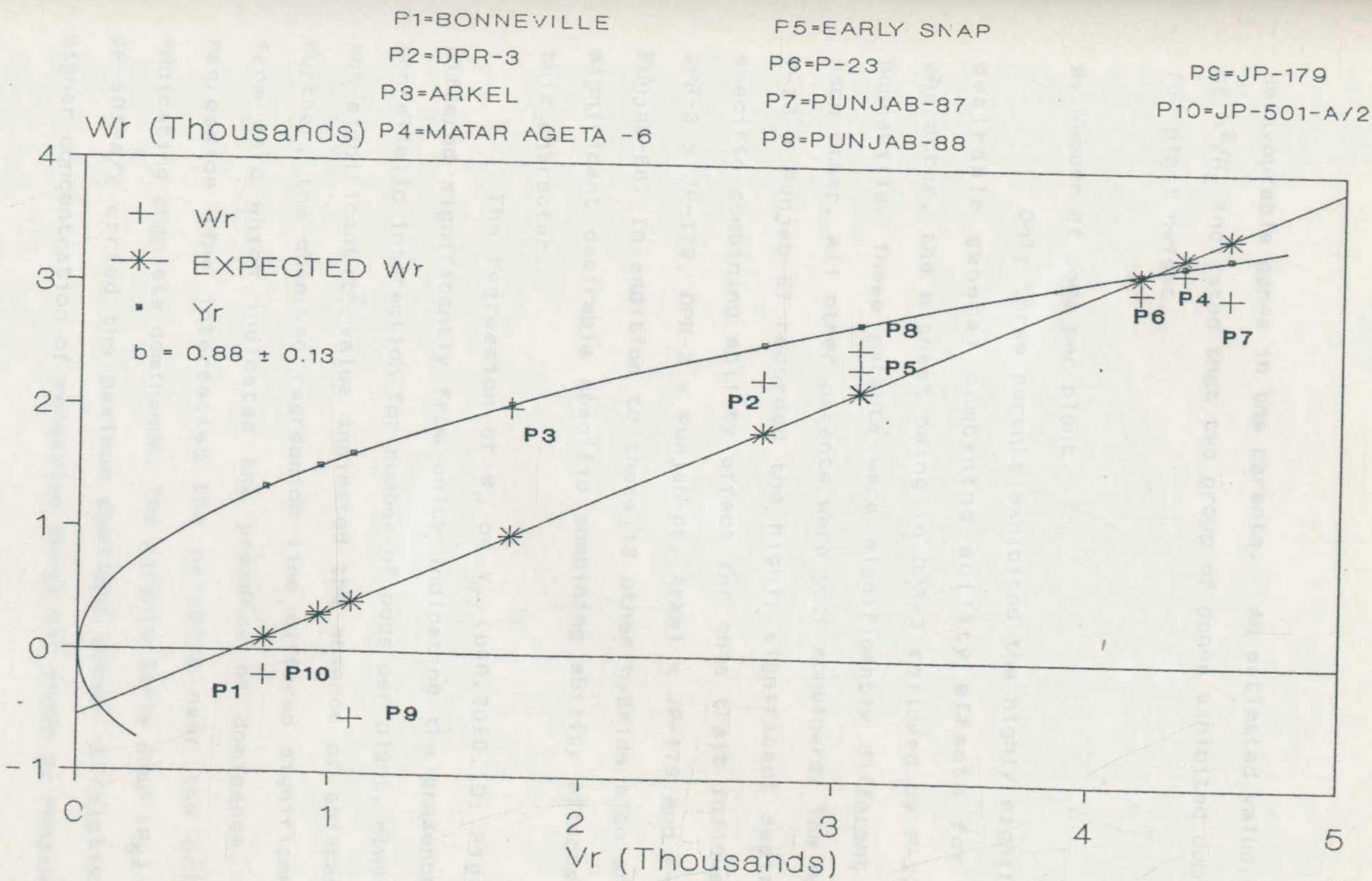

FIG. 5: Wr/ Vr GRAPH FOR PLANT HEIGHT(cm)

unfavourable genes in the parents. An estimated value (0.66) of h^2/H_2 indicated that two group of genes exhibited dominance for plant height.

6. Number of pods per plant

Only three parents exhibited the highly significant desirable general combining ability effects for this character, the highest being in DPR-3 followed by P-23 and Bonneville. These parents were significantly different from each other. All other parents were poor combiners. The hybrid P-23 x Punjab-87 recorded the highly significant desirable specific combining ability effect for this trait followed by DPR-3 x JP-179, DPR-3 x Punjab-88, Arkel x JP-179 and P-23 x Punjab-88. In addition to these 13 other hybrids also showed significant desirable specific combining ability effects for this character.

The regression of W_r on V_r (b=0.30±0.10; Fig. 6) differed significantly from unity indicating the presence of non-allelic interaction for number of pods per plant. However, non-significant t^2 value indicated the absence of epistasis. Further, the observed regression line differed significantly from zero which indicates the presence of dominance. The regression line intersected the parabola near the origin indicating complete dominance. The parents Early Snap (P_5) and JP-501-A/2 crried the maximum dominant genes. A relatively higher concentration of recessive genes was shown by Punjab-87

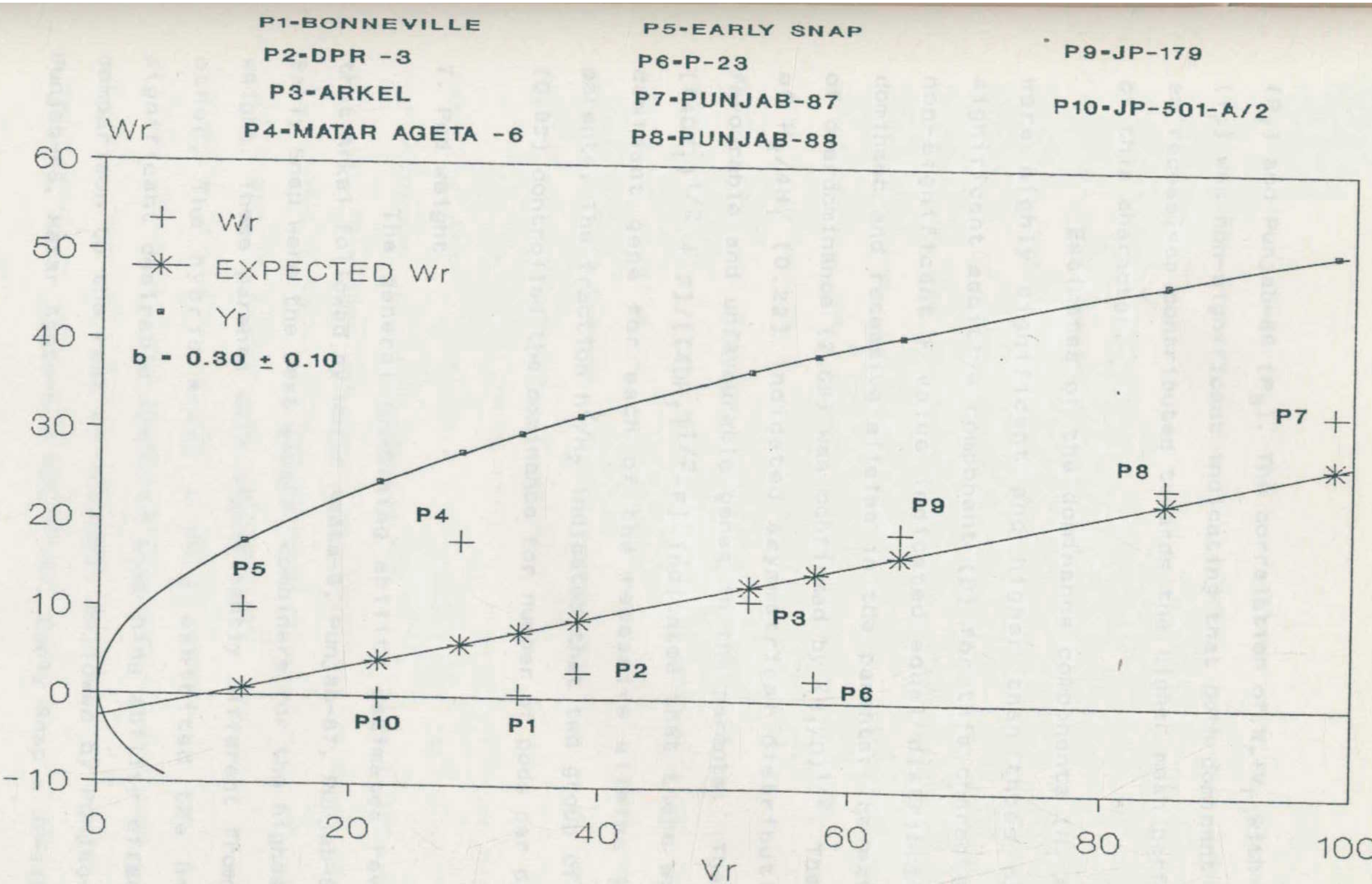

FIG. 6:Wr/ Vr GRAPH FOR NUMBER OF PODS PER PLANT

(P_7) and Punjab-88 (P_8). The correlation of W_r+V_r with parents (Y_r) was non-significant indicating that both dominant as well as recessives contributed towards the higher mean performance of this character.

Estimates of the dominance components (H_1 and H_2) were highly significant and higher than those of non-significant additive component (D) for this character. The non-significant F value indicated equal distribution of dominant and recessive alleles in the parents. The existence of overdominance (2.59) was confirmed by $(H_1/D)^{1/2}$. The value of $H_2/4H_1$ (0.22) indicated asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio $[(4DH_1)^{1/2} + F]/[(4DH_1)^{1/2}-F]$ indicated that there was one dominant gene for each of the recessive alleles in the parents. The fraction h^2/H_2 indicated that two group of genes (0.99) controlled the dominance for number of pods per plant.

7. Pod weight

The general combining ability estimates revealed that Arkel followed by Matar Ageta-6, Punjab-87, Punjab-88 and Early Snap were the best general combiners for the highest pod weight. These parents were significantly different from each other. The hybrid Arkel x P-23 exhibited the highly significant desirable specific combining ability effect in comparison to the rest of crosses, followed by Punjab-87 x Punjab-88, Matar Ageta-6 x Punjab-87, Early Snap x JP-179 and

JP-179 x JP-501-A/2. Twenty out of forty five crosses showed significant desirable specific combining ability effects for pod weight.

The regression of W_r on V_r (b=0.83±0.09; Fig. 7) of unit slope indicated the absence of non-allelic interaction. The possibility of epistasis was also excluded by non-significnt t^2 value. Since the regression line intersected the W_r axis above the origin so only partial dominance was observed from the graph. The parents showed considerable diversity for the number of dominant and recessive alleles. Matar Ageta-6 (P_4), Arkel (P_3), and Punjab-87 (P_7) carried more recessive alleles whereas JP-501-A/2 (P_{10}), JP-179 (P_9) and DPR-3 (P_2) had relatively more dominant alleles. The correlation of W_r+V_r with parents (Y_r) was significnt with positive sign showing that recessive genes played an important role in increasing the pod weight.

The significance of D, H_1 and H_2 indicated that both additive and non-additive variances were important in the manifestation of pod weight but the relative magnitude of non-additive variances was more than additive variance. The non-significant F value indicated equal distribution of dominant and recessive alleles in the parents. The mean degree of dominance $(H_1/D)^{1/2}$, suggested the existence of overdominance (1.02). The proportion of favourable and unfavourable alleles $(H_2/4H_1)$ was less than 0.25 which revealed asymmetrical distribution of genes in the parents. The ratio $[(4DH_1)^{1/2}$ +

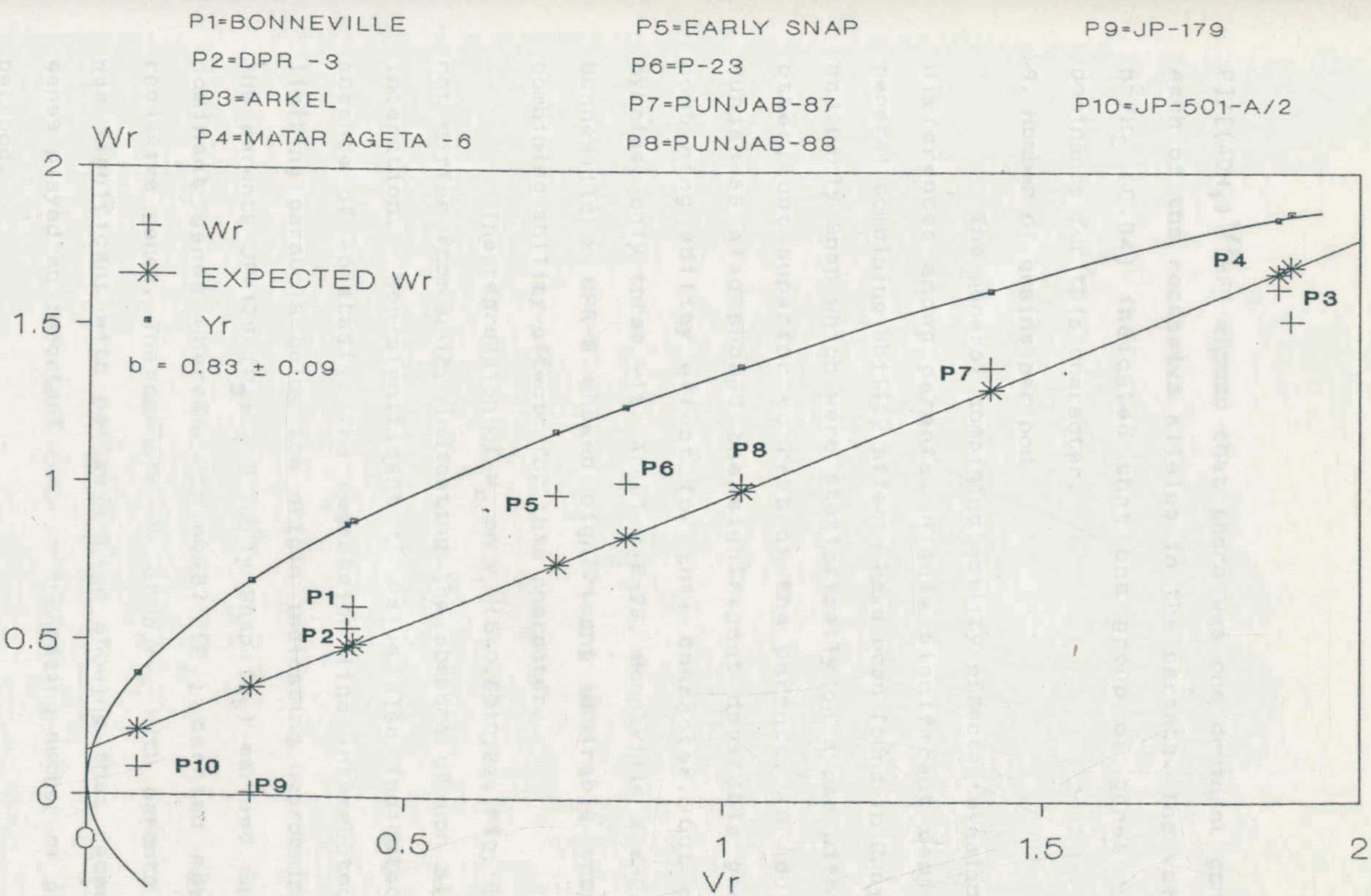

FIG. 7:Wr/ Vr GRAPH FOR POD WEIGHT (gm)

$F]/[(4DH_1)^{1/2}-F]$ showed that there was one dominant gene for each of the recessive alleles in the parents. The value of h^2/H_2 (0.04) indicated that one group of genes showed dominance for this character.

8. Number of grains per pod

The general combining ability effects revealed wide differences among parents. Highly significant desirable general combining ability effects have been found in Punjab-87 and Early Snap which were statistically on a par with each other, but superior to rest of the parents. In addition Punjab-88 also showed the significant desirable general combining ability effect for this character. Out of 45 hybrids, only three viz. Arkel x P-23, Bonneville x P-23 and Bonneville x DPR-3 showed significant desirable specific combining ability effects for this character.

The regression of W_r on V_r (b=0.80±0.22, Fig. 8) did not differ from unity indicating the absence of non allelic interction. Non-significant t^2 value also indicated the absence of epistasis. The regression line intersected the limiting parabola below the origin indicating overdominance. The parents JP-179 (P_9) and Early Snap (P_5) carried maximum dominant genes whereas Punjab-87 (P_7) carried maximum recessive genes. The correlation of W_r+V_r with parents (Y_r) was significant with positive sign showing that recessive genes played an important role in increasing number of grains per pod.

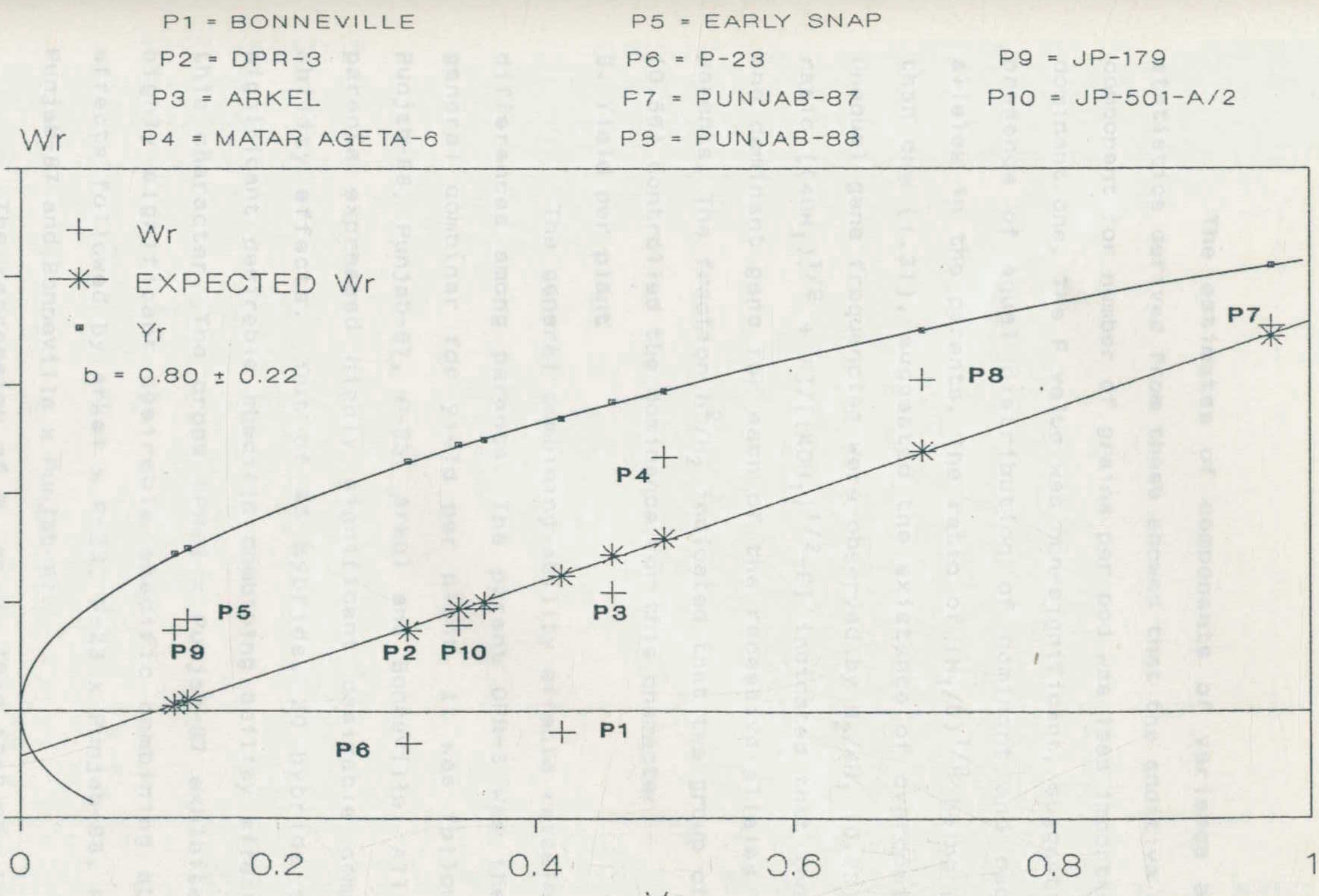

FIG. 8: Wr/ Vr GRAPH FOR NUMBER OF GRAINS PER POD

The estimates of components of variance and the statistics derived from these showed that the additive genetic component for number of grains per pod was less important than dominant one. The F value was non-significant, suggesting the presence of equal distribution of dominant and recessive alleles in the parents. The ratio of $(H_1/D)^{1/2}$ being greater than one (1.31), suggested the existence of overdominance. Unequal gene frequencies were observed by $H_2/4H_1$ (0.23). The ratio $[(4DH_1)^{1/2} + F]/[(4DH_1)^{1/2} - F]$ indicated that there was one dominant gene for each of the recessive alleles in the parents. The fraction h^2/H_2 indicated that two group of genes (0.56) controlled the dominance for this character.

9. Yield per plant

The general combining ability effects revealed wide differences among parents. The parent DPR-3 was the good general combiner for yield per plant. It was followed by Punjab-88, Punjab-87, P-23, Arkel and Bonneville. All these parents expressed highly significant desirable combining ability effects. Out of 45 hybrids, 20 hybrids showed significant desirable specific combining ability effects for this character. The cross DPR-3 x Punjab-87 exhibited the highly significant desirable specific combining ability effects followed by Arkel x P-23, P-23 x Punjab-88, P-23 x Punjab-87 and Bonneville x Punjab-87.

The regression of W_r on V_r (b=0.18±0.05, Fig. 9) differed significantly from unity, indicating the presence of

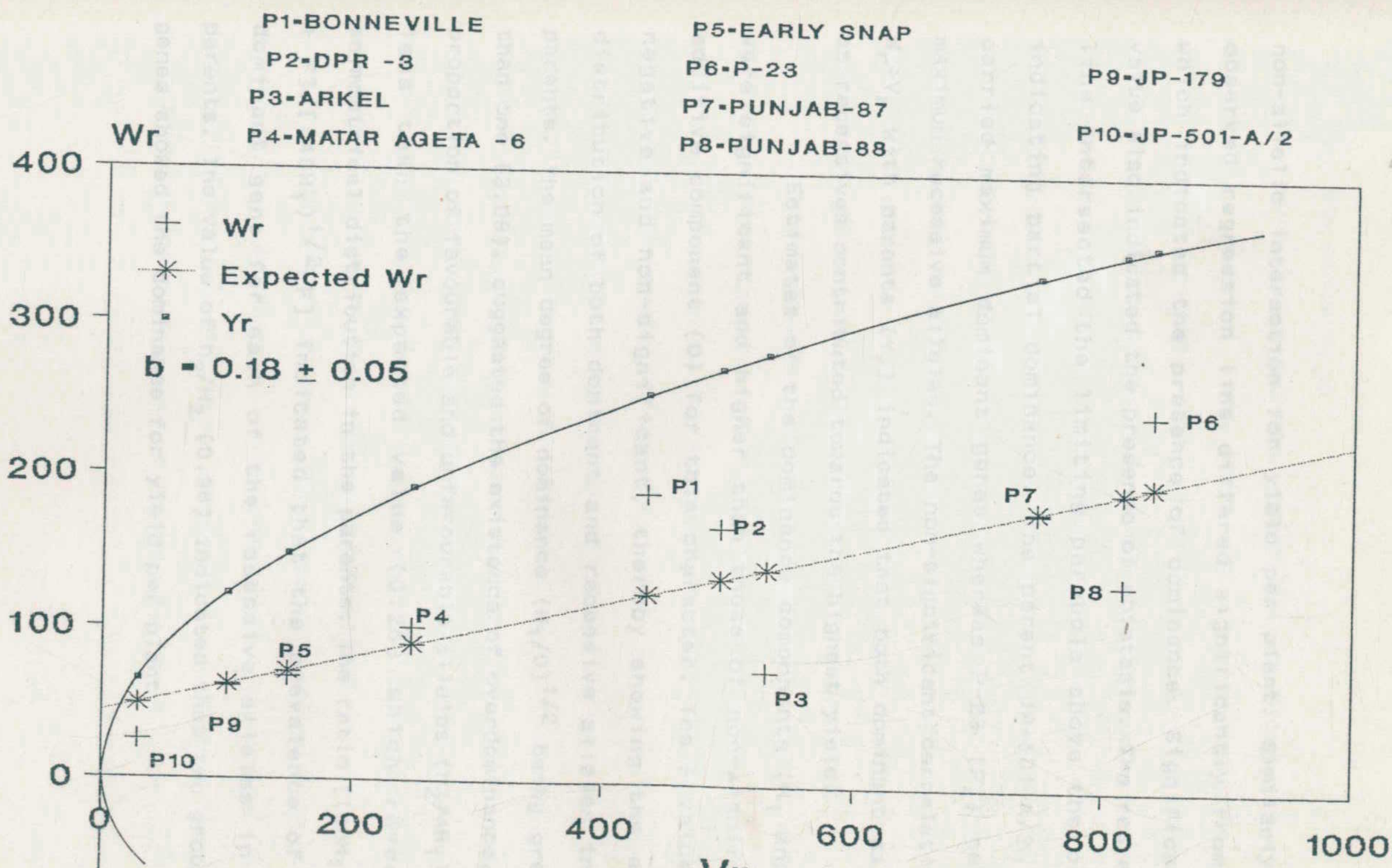

FIG. 9:Wr/ Vr GRAPH FOR YIELD PER PLANT (gm)

non-allelic interaction for yield per plant. Similarly, the observed regression line differed significantly from zero which indicates the presence of dominance. Significant t^2 value also indicated the presence of epistasis. The regression line intersected the limiting parabola above the origin indicating partial dominance. The parent JP-501-A/2 (P_{10}) carried maximum dominant genes whereas P-23 (P_4) carried maximum recessive alleles. The non-significant correlation of W_r+V_r with parents (Y_r) indicated that both dominant as well as recessives contributed towards the highest yield.

Estimates of the dominance components (H_1 and H_2) were significant and higher than those of non-significant additive component (D) for this character. The F value was negative and non-significant, thereby showing the equal distribution of both dominant and recessive alleles in the parents. The mean degree of dominance $(H_1/D)^{1/2}$ being greater than one (3.08), suggested the existence of overdominance. The proportion of favourable and unfavourable alleles ($H_2/4H_1$) was less than the expected value (0.25) which revealed asymmetrical distribution in the parents. The ratio $[(4DH_1)^{1/2} + F]/[(4DH_1)^{1/2}-F]$ indicated that the prevalence of one dominant gene for each of the recessive alleles in the parents. The value of h_2/H_2 (0.96) indicated that two group of genes showed the dominance for yield per plant.

10. Shelling percentage

Only three parents exhibited the highly significant desirable general combining ability effects for this character, the highest being in JP-179 followed by JP-501-A/2 and DPR-3. The other parents were poor combiners. The hybrid Punjab-87 x JP-501-A/2 expressed the highly significant desirable specific combining ability effects, followed by Bonneville x DPR-3, Matar Ageta-6 x JP-501-A/2, Bonneville x Matar Ageta-6, and Arkel x Punjab-88. In addition to these, 10 other hybrids also showed the significant desirable specific combining ability effects for this character.

The regression of W_r on V_r (b=0.51±0.14, Fig. 10) differed significantly from unity indicating the presence of non-allelic interactions. Non-significant t^2 value indicated the absence of epistasis. The regression line intersected the limiting parabòla above the origin indicating partial dominance. The parents JP-179 (P_9) and JP-501-A/2 (P_{10}) carried maximum dominant genes wheres Punjab-87 (P_7) carried recessive genes. The correlation of W_r+V_r with parents (Y_r) was significant with negative sign showing that dominant genes had greater role for high shelling percentage.

The significance of D, H_1 and H_2 indicated that both additive and non-additive variances were important in the manifestation of shelling percentage but the relative magnitude of non-additive variance was more than additive variance. The F value was negative and non-significant,

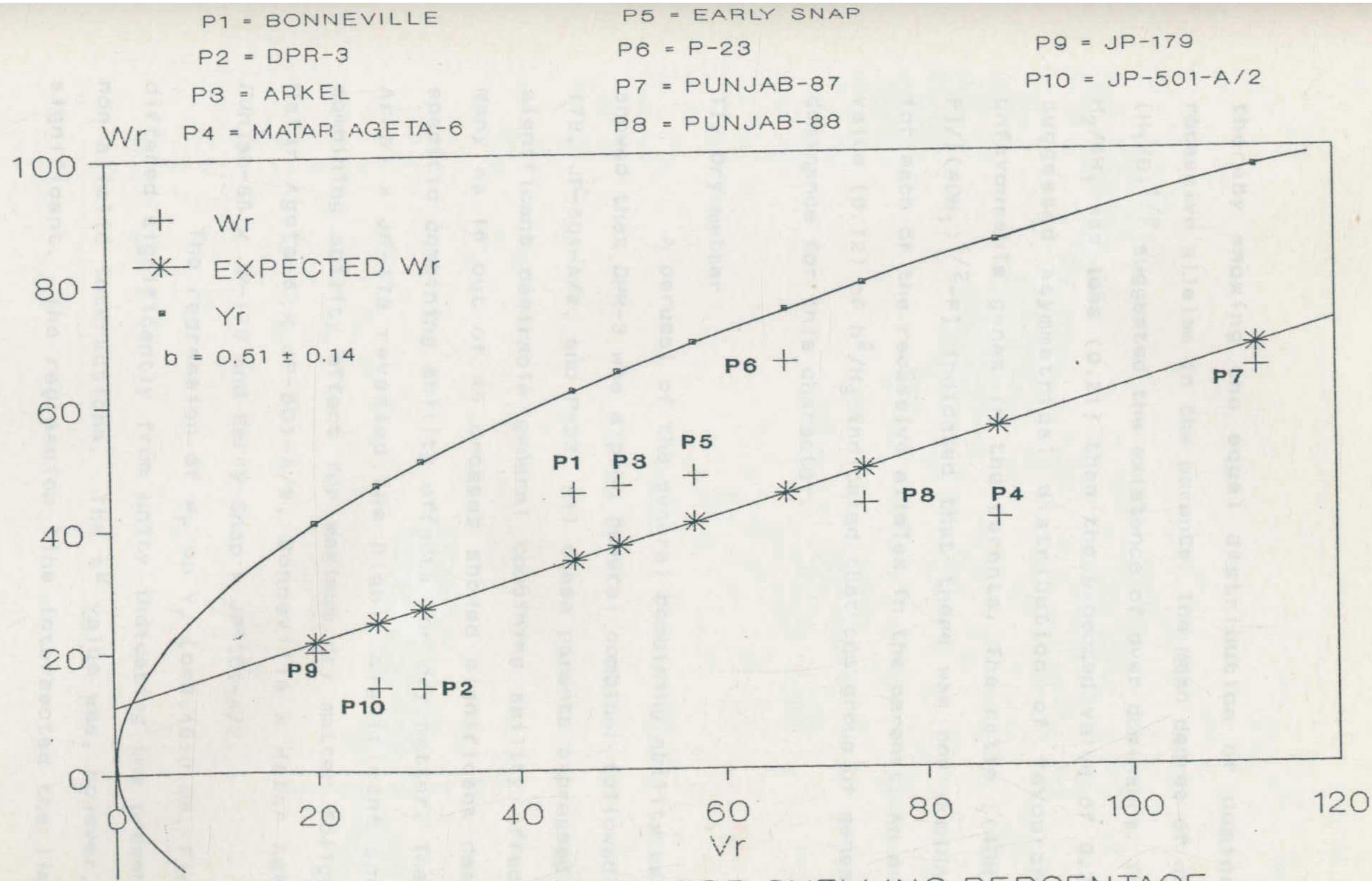

FIG. 10: Wr/ Vr GRAPH FOR SHELLING PERCENTAGE

thereby showing the equal distribution of dominant and recessive alleles in the parents. The mean degree of dominance $(H_1/D)^{1/2}$ suggested the existence of over dominance. The ratio $H_2/4H_1$ was less (0.21) than the expected value of 0.25 which suggested asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio $[(4DH_1)^{1/2} + F]/[(4DH_1)^{1/2}-F]$ indicated that there was one dominant gene for each of the recessive alleles in the parents. An estimated value (0.12) of h^2/H_2 indicated that one group of genes showed dominance for this character.

11. Dry matter

A perusal of the general combining ability estimates showed that DPR-3 was a good general combiner followed by JP-179, JP-501-A/2, and P-23. All these parents expressed highly significant desirable general combining ability effects. As many as 16 out of 45 crosses showed significant desirable specific combining ability effects for dry matter. The cross Arkel x JP-179 revealed the highly significant specific combining ability effect for maximum dry matter followed by Matar Ageta-6 x JP-501-A/2, Bonneville x Matar Ageta-6, Punjab-88 x JP-179 and Early Snap x JP-501-A/2.

The regression of W_r on V_r (b=0.46±0.09, Fig. 11) differed significantly from unity indicating the presence of non-allelic interactions. The t^2 value was, however, non-significant. The regression line intersected the limiting

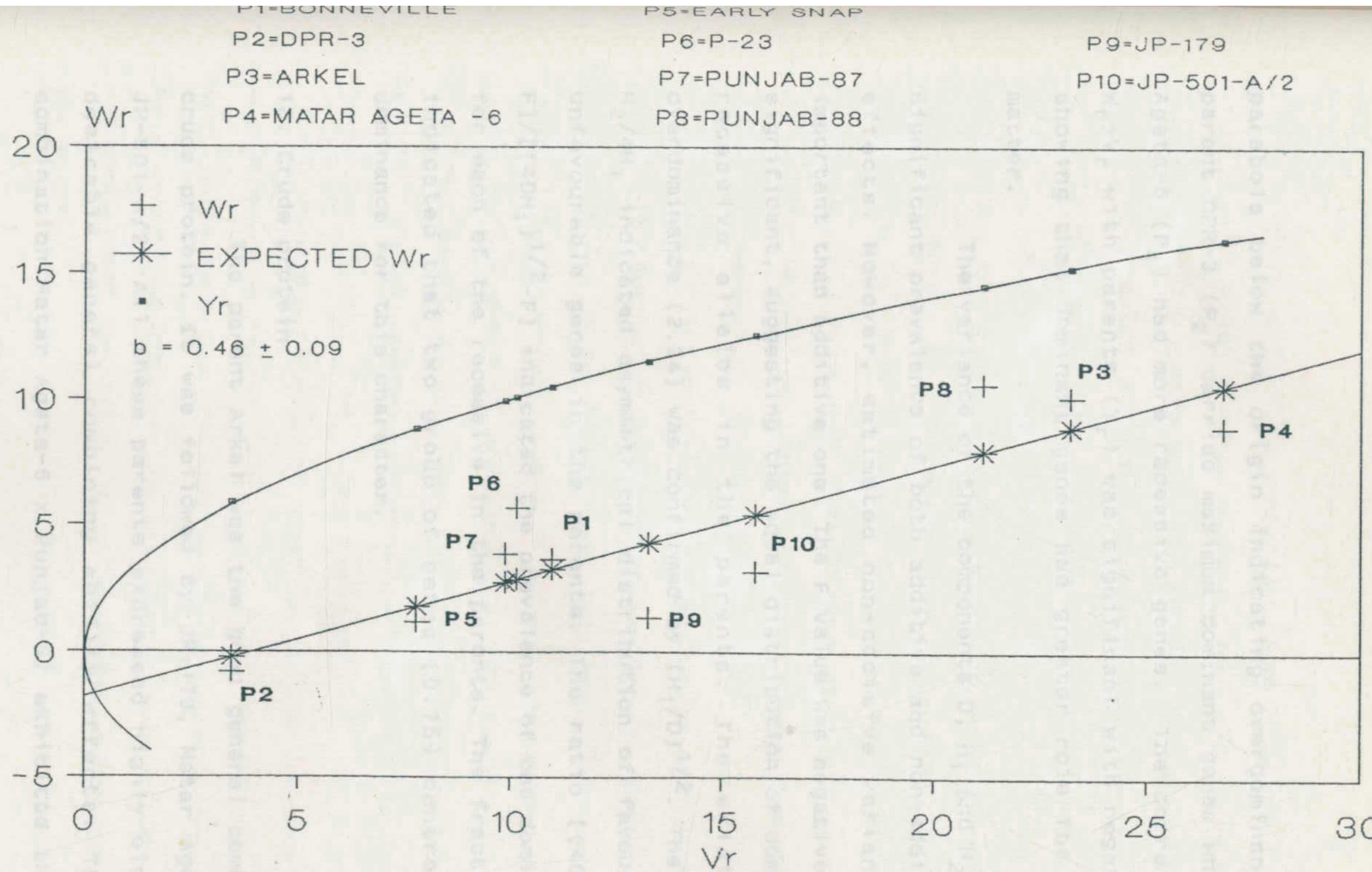

FIG. 11: Wr/ Vr GRAPH FOR DRY MATTER (%)

parabola below the origin indicating overdominance. The parent DPR-3 (P_2) carried maximum dominant genes while Matar Ageta-6 (P_4) had more recessive genes. The correlation of W_r+V_r with parents (Y_r) was significant with negative sign showing that dominant genes had greater role for high dry matter.

The variance of the components D, H_1 and H_2 revealed significant prevalence of both additive and non-additive gene effects. However, estimated non-additive variances were important than additive one. The F value was negative and non-significant, suggesting the equal distribution of dominant and recessive alleles in the parents. The existence of overdominance (2.24) was confirmed by $(H_1/D)^{1/2}$. The value of $H_2/4H_1$ indicated asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio $[(4DH_1)^{1/2}+F]/[(4DH_1)^{1/2}-F]$ indicated the prevalence of one dominant gene for each of the recessive in the parents. The fraction h^2/H_2 indicated that two group of genes (0.75) controlled the dominance for this character.

12. Crude protein

The parent Arkel was the good general combiner for crude protein. It was followed by JP-179, Matar Ageta-6 and JP-501-A/2. All these parents expressed highly significant desirable general combining ability effects. The cross combination Matar Ageta-6 x Punjab-87 exhibited the highly significant desirable specific combining ability effect followed by Arkel x Matar Ageta-6, Bonneville x DPR-3, P-23 x JP-501-A/2 and Punjab-88 x JP-501-A/2. In addition to these, 19 other hybrids also showed significant specific combining ability effects for maximum crude protein.

A non-significant regression of W_r on V_r (b=0.01±0.25) due to high standard error was observed for this character. As a consequence of which the V_r/W_r graph was not drawn for this character. The correlation of W_r+V_r with parents (Y_r) was non-significant indicating that both dominants as well as recessives contributed towards the high mean performance of this character.

The estimates of components of variance and the statistics derived from these showed that the additive genetic component for crude protein was less important than dominant one. The non-significant F value indicated the equal distribution dominant and recessive alleles in the parents. The mean degree of dominance $(H_1/D)^{1/2}$ being greater than one (2.00), thereby suggested the presence of overdominance. The value of $H_2/4H_1$ indicated asymmetrical distribution of favourable and unfavourable genes in the parents for this character. The ratio $[(4DH_1)^{1/2} + F]/[(4DH_1)^{1/2}-F]$ indicated that there were two dominant genes for each of the recessive alleles in the parents. An estimated value (0.09) of h^2/H_2 indicated that one group of genes showed dominance for this character.

13. Total sugars

A perusal of the general combining ability estimates showed that Arkel was a good general combiner followed by Punjab-88, Early Snap, Matar Ageta-6, Bonneville, and Punjab-87. All these parents expressed highly significant desirable general combining ability effects. The hybrid DPR-3 x Matar Ageta-6 exhibited the highly significant desirable specific combining ability effect in comparison to the rest of crosses, followed by Arkel x Matar Ageta-6, P-23 x Punjab-88, Bonneville x Arkel, and P-23 x Punjab-87. Twenty three out of 45 crosses showed significant desirable specific combining ability effects for total sugars.

The regression of W_r on V_r (b=0.64±0.07, Fig. 12) differed significantly from unity indicating the presence of non-allelic interaction for total sugars. But this regression differed significantly from zero also. The array points were also spread along the regression line. So dominance was apparently involved in the genetical control of this character. But the interaction of regression on W_r axis showed only partial dominance. However, the non-significant t^2 value indicated the absence of epistasis. The parent Matar Ageta-6 (P_4) carried the maximum recessive genes. A relatively higher concentration of dominant genes was shown by Early Snap (P_5), Punjab-87 (P_7) and Punjab-88 (P_8). The correlation of W_r+V_r with parents (Y_r) was non-significant indicating that both dominants as well as recessives contributed towards the

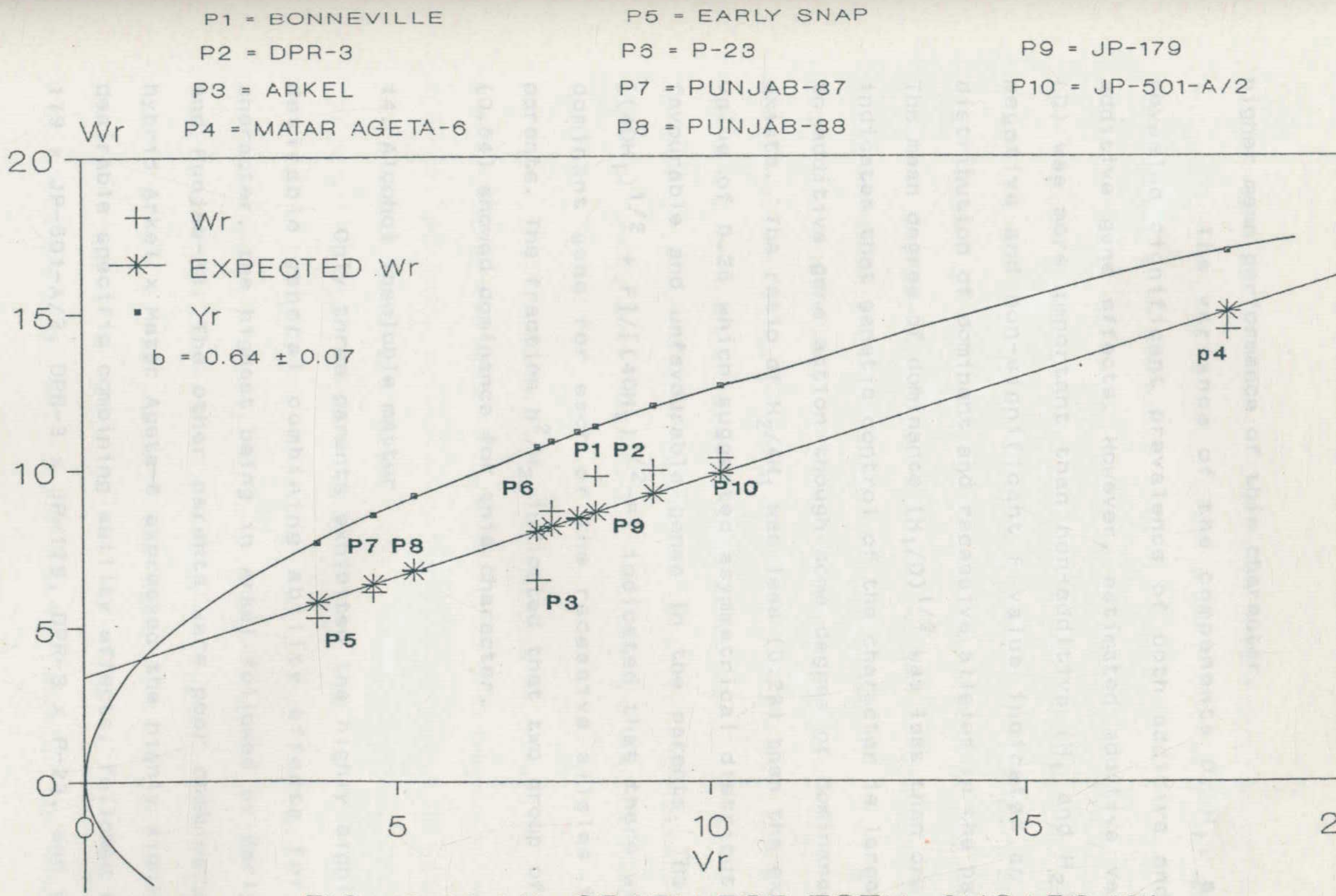

FIG. 12:Wr/ Vr GRAPH FOR TOTAL SUGARS (%)

higher mean performance of this character.

The variance of the components D, H_1, and H_2 revealed significant prevalence of both additive and non-additive gene effects. However, estimated additive variance (D) was more important than non-additive (H_1 and H_2). The negative and non-significant F value indicated an equal distribution of dominant and recessive alleles in the parents. The mean degree of dominance $(H_1/D)^{1/2}$ was less than one which indicates that genetic control of the character is largely due to additive gene action though some degree of dominance also exists. The ratio of $H_2/4H_1$ was less (0.23) than the expected value of 0.25 which suggested asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio $[(4DH_1)^{1/2} + F]/[(4DH_1)^{1/2} - F]$ indicated that there was one dominant gene for each of the recessive alleles in the parents. The fraction h^2/H_2 indicated that two group of genes (0.54) showed dominance for this character.

14. Alcohol insoluble matter

Only three parents exhibited the highly significant desirable general combining ability effects for this character, the highest being in Arkel followed by Early Snap and Punjab-88. The other parents were poor combiners. The hybrid Arkel x Matar Ageta-6 expressed the highly significant desirable specific combining ability effects, followed by JP-179 x JP-501-A/2, DPR-3 x JP-179, DPR-3 x P-23, and P-23 x

Punjab-88. In addition to these, four other hybrids also showed significant desirable specific combining ability effects for this character.

The regression of W_r on V_r (b=0.67±0.21, Fig. 13) of unit slope indicated the absence of non-allelic interaction. The possibility of epistasis was also excluded by non-significant t^2 value. The regression line intersected the parabola below the origin showing overdominance. The parents showed considerable diversity for number of dominant and recessive genes. P-23 (P_6), JP-179 (P_9) and DPR-3 (P_2) carried more dominant genes whereas Arkel (P_3) and Matar Ageta-6 (P_4) had more recessive genes. The correlation of W_r+V_r with parents (Y_r) was significant with negative sign showing that recessiv genes were important to reduce the alcohol insoluble matter.

The variance of the components D, H_1 and H_2 revealed significant prevalence of both additive and non-additive gene effects. However, estimated non-additive variances were more pronounced than additive. The non-significant F value indicated an equal distribution of both dominant and recessive alleles in the parents. The existence of overdominance (1.58) was confirmed by $(H_1/D)^{1/2}$. The ratio $H_2/4H_1$ was less (0.22) than expected value of 0.25 which suggested asymmetrical distribution of favourable and unfavourable genes in the parents. The ratio $[(4DH_1)^{1/2} + F]/[(4DH_1)^{1/2} - F]$ indicated that there were two dominant genes for each of the recessive

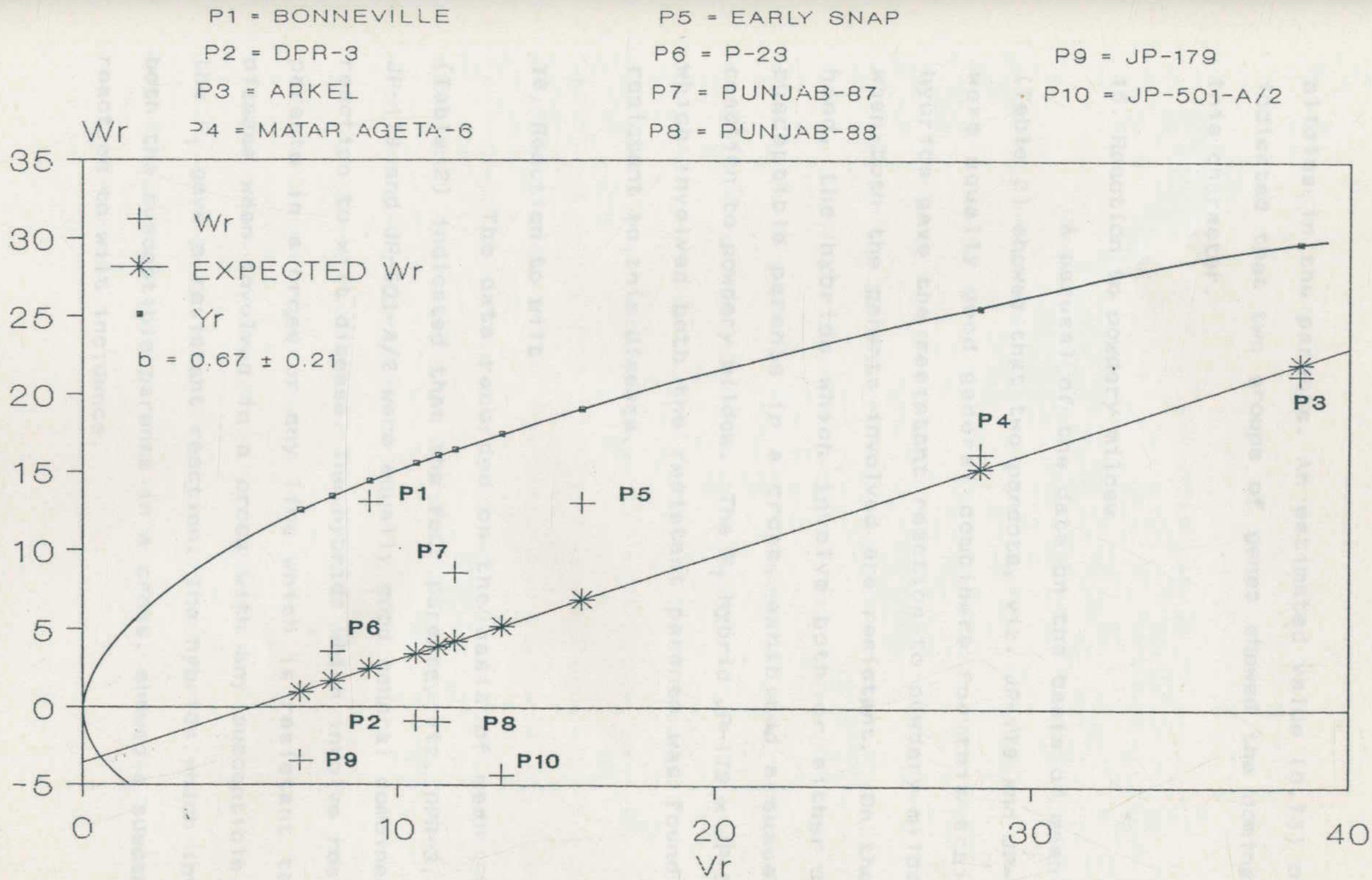

FIG. 13:Wr/ Vr GRAPH FOR ALCOHOL INSOLUBLE MATTER (%)

alleles in the parents. An estimated value (0.73) of h^2/H_2 indicated that two groups of genes showed the dominance for this character.

15. Reaction to powdery mildew

A perusal of the data on the basis of mean values (Table 2) showed that two parents, viz. JP-179 and JP-501-A/2 were equally good general combiners for this trait. The hybrids gave the resistant reaction to powdery mildew only when both the parents involved are resistant. On the other hand, the hybrids which involve both or either of the susceptible parents in a cross, exhibited a susceptible reaction to powdery mildew. The F_1 hybrid JP-179 x JP-501-A/2 which involved both the resistant parents was found to be resistant to this disease.

16. Reaction to wilt

The data recorded on the basis of mean values (Table 2) indicated that the four parents, viz. DPR-3, P-23, JP-179 and JP-501-A/2 were equally good general combiners for reaction to wilt disease. The hybrids which involve resistant parents in a cross or any line which is resistant to this disease when involved in a cross with any susceptible line, the F_1 gave a resistant reaction. The hybrids which involves both the susceptible parents in a cross, showed a susceptible reaction to wilt incidence.

CHAPTER-V

DISCUSSION

The combining ability studies is a prelude to any breeding programme as it gives useful information regarding the selection of suitable genotypes for improving upon any crop species through hybridization. Besides, it also elucidates the nature and magnitude of different types of gene action involved. The knowledge of the type and magnitude of gene action involved in the expression of a character is essential for appropriate management of available genetic variability and formulation of a systematic breeding programme. Although substantial information on these genetic parameters exists today, but has limited applicability because such information is specific to the material used and environmental conditions under which the studies are conducted. Therefore, the present investigation was undertaken with the following objectives:

1. To determine the nature and magnitude of genetic variation among parents and F_1.
2. To determine the extent of heterosis in F_1.
3. To generate information regarding general and specific combining ability effects for different economic characters.

Keeping in view the above objectives, the various biometrical aspects viz. heterosis, combining ability analysis, graphic analysis and genetic components of variance were analysed by evaluating a diallel mating design (excluding reciprocals) for different economic characters. The findings related to these biometrical aspects in the light of the available literature are discussed below:

Heterosis

In the present investigation, significant desirable heterosis over the better parent was observed for days to flower initiation, number of primary shoots, plant height, number of pods per plant, pod weight, yield per plant, shelling percentage, dry matter, crude protein, total sugars, alcohol insoluble matter and reaction to powdery mildew. On the other hand, significant desirable heterobeltiosis was not observed for node at which the first pod develops, internodal length, number of grains per pod and wilt incidence. These findings corroborate the views of different research workers viz. Srivastava *et al.* (1986), Parmar and Godawat (1990), Pant and Bajpai (1991), Mishra *et al.* (1993), Katiyar (1994) and Sarawat *et al.* (1994) who observed heterosis for yield over the better parent. The manifestation of heterobeltiosis for pods per plant was observed by Srivastava *et al.* (1986), Parmar and Godawat (1990), Mishra *et al.* (1993) and Kharche and Narsinghani (1994). Srivastava and Sachan (1975) and

Srivastava *et al.* (1986) observed heterobeltiosis for number of primary branches whereas for days to flowering it was observed by Srivastava *et al.* (1986), Mishra *et al.* (1993), Kharche and Narsinghani (1994) and Katiyar (1994). Further significant desirable heterosis over the better parent for plant height was observed by Srivastava *et al.* (1986) and Mishra *et al.* (1993).

The failure of most of high yielding crosses to have high heterobeltiosis may be attributed to the fact that higher performing crosses involved high yielding parents. Since heterosis have been worked out as the difference between the mean performance of the F_1 and that of the best parent of a cross, therefore, per cent superiority is likely to be relatively small. The manifestation of heterobeltiosis for days to flower initiation, number of primary shoots, plant height, number of pods per plant, pod weight, yield per plant, shelling percentage, dry matter, crude protein, total sugars, alcohol insoluble matter, and reaction to powdery mildew suggested the exploitation of heterosis by developing F_1 hybrids. However, economic production of hybrid seed on commercial scale particularly in pea has its own limitations.

Combining ability analysis

The main objective of this analysis is to identify the best parents and crosses on the basis of general and specific combining ability effects. The analysis of variance for combining ability revealed that the mean squares for gca and sca were highly significant for all the characters studied in the present investigation. The relative magnitude of general and specific combining ability variances showed that additive effects were predominant for days to flower initiation, node at which the first pod develops, internodal length, plant height, number of primary shoots, shelling percentage and total sugars. On the other hand, predominance of non-additive effects was observed to be important in the inheritance of number of pods per plant, yield per plant, dry matter, crude protein and alcohol insoluble matter. Further, both additive and non-additive gene effects were equally important for pod weight and number of grains per pod. Dahiya *et al.* (1977), Csizmadia (1985), Moitra *et al.* (1988), Singh and Singh (1990a), Singh and Singh (1990c) and Singh *et al.* (1991) also reported that both additive and non-additive type of gene effects are important for most of the garden pea characters either alone or in combination. Their studies further revealed that there would be a good response to selection for identifying plants superior with regard to characters showing high gca and those with high gca and sca effects.

The capacity of a parent to transmit gene complexes for a trait to its progeny is known from the status of its general combining ability effects for that trait. In the present study, none of the parents was found to be a good general combiner for all the characters. However, parents Arkel and Matar Ageta-6 were found to be the best general combiners for six important traits namely days to flower initiation, node at which the first pod develops, internodal length, pod weight, crude protein and total sugars. Further, Arkel was also good general combiner for alcohol insoluble matter. The parent DPR-3 was considered to be the best general combiner for number of pods per plant, internodal length, yield per plant, node at which the first pod develops, shelling percentage, dry matter and resistance to wilt. Similarly, Punjab-87 and Punjab-88 were considered to be the best combiners for number of grains per pod, pod weight and yield per plant. Further, Punjab-88 was the best general combiner for total sugars and alcohol insoluble matter. The parents JP-179 and JP-501-A/2 were observed to be the best general combiners for reaction to powdery mildew and wilt incidence.

The comparison of best general combining parents with mean performance (Table 9) in the present study revealed that, in general, the premise that mean performance is good index of general combining ability of the parental lines held good for all the characters. It indicated that the mean performance of the parents may serve as a useful index for identifying potential parents for hybridization. The present findings, therefore, suggested that the preliminary screening of the voluminous germplasm could be made on the basis of mean

Table 9. Desirable parents for different characters

Criteria	Days to flower initiation	Node at which the first pod develops	Internodal length (cm)	Number of primary shoots	Plant height (cm)
Mean performance	Matar Ageta-6 Arkel Early Snap P-23	Matar Ageta-6 Early Snap Arkel P-23	Matar Ageta-6 Early Snap Arkel P-23	JP-179 P-23 JP-501-A/2 Early Snap	JP-501-A/2 JP-179 Boneville Punjab-88
g.c.a.	Matar Ageta-6 Early Snap Arkel	Early Snap Matar Ageta-6 Arkel DPR-3	Early Snap DPR-3 Matar Ageta-6 Arkel	JP-179 JP-501-A/2 P-23	JP-179 JP-501-A/2 Bonneville

	Number of pods per plant	Pod weight (g)	Number of grains per pod	Yield per plant (g)	Shelling percentage
Mean performance	DPR-3 P-23 JP-501-A/2 Punjab-87	Arkel Matar Ageta-6 Punjab-87 Punjab-88	Punjab-87 Punjab-88 Matar Ageta-6 Arkel	Punjab-87 DPR-3 Punjab-88 Early Snap	JP-179 DPR-3 JP-501-A/2 Punjab-87
g.c.a.	DPR-3 P-23 Boneville	Arkel Matar Ageta-6 Punjab-87 Punjab-88	Punjab-87 Early Snap Punjab-88	DPR-3 Punjab-88 Punjab-87 P-23	JP-179 JP-501-A/2 DPR-3

Table 9 contd.

Table 9 contd.

	Dry matter (%)	Crude protein (%)	Total sugars (%)	Alcohol insoluble matter (%)
Mean performance	DPR-3 P-23 Punjab-87 JP-179	JP-179 DPR-3 Arkel JP-501-A/2	Arkel Early Snap Matar Ageta-6 Punjab-88	Early Snap Arkel Matar Ageta-6 Punjab-87
g.c.a.	DPR-3 JP-179 JP-501-A/2 P-23	Arkel JP-179 Matar Ageta-6 JP-501-A/2	Arkel Punjab-88 Early Snap Matar Ageta-6	Arkel Early Snap Punjab-88

performance and the material selected on the basis of this preliminary screening might be tested for combining ability by adopting suitable mating design. Findings in support of the positive relationship between the mean performance and general combining ability of the parents have been reported by Venkateshwarlu and Singh (1982), Singh and Singh (1991) and Singh *et el.* (1991). In view of this, it may be suggested that an elite population, involving good general combiners viz. DPR-3, Punjab-87, Punjab-88, Arkel, Matar Ageta-6, JP-179 and JP-501-A/2 may be developed by using three way or multiple crossing systems for isolating high yielding lines having good quality, earliness, resistance to wilt and powdery mildew.

The relative ranking of the top four crosses having high specific combining ability effects and mean performance with respect to various characters have been given in Table 10. On comparing specific combining ability effects with mean performance for all the characters, three crosses viz. DPR-3 x Punjab-87, Arkel x P-23, and P-23 x Punjab-88 were found to be common and promising for yield per plant. Similarly, Punjab-87 x Punjab-88 and Matar Ageta-6 x Punjab-87 for pod weight; P-23 x Punjab-87, DPR-3 x JP-179, DPR-3 x Punjab-88 for number of pods per plant; DPR-3 x JP-179, P-23 x JP-179 and Arkel x JP-179 for number of primary shoots; Punjab-87 x JP-179 and Early Snap x JP-179 for plant height; Matar Ageta-6 x P-23 for internodal length; Arkel x Matar Ageta-6 for days to flower initiation, total sugars, crude protein and alcohol insoluble

Table 10. Desirable hybrids for different characters

Criteria	Days to flower initiation	Node at which the first pod develops	Internodal length (cm)	Number of primary shoots
Mean performance	Arkel x Matar Ageta-6	Arkel x Matar Ageta-6	DPR-3 x Matar Ageta-6	DPR-3 x JP-179
	Matar Ageta x Early Snap	Matar Ageta-6 x Early Snap	DPR-3 x Early Snap	P-23 x JP-179
	Arkel x Early Snap	Arkel x Early Snap	Matar Ageta-6 x P-23	Arkel x JP-179
	Matar Ageta-6 x Punjab-87	DPR-3 x Early Snap	Arkel x Matar Ageta-6	P-23 x JP-501-A/2
Hetero-beltiosis	DPR-3 x JP-179	-	-	DPR-3 x JP-179
	DPR-3 x JP-501-A/2			P-23 x JP-179
				P-23 x JP-501-A/2
				Arkel x JP-501-A/2
s.c.a.	Arkel x Matar Ageta-6	P-23 x Punjab-88	JP-179 x JP-501-A/2	DPR-3 x JP-179
	Early Snap x JP-501-A/2	Early Snap x Punjab-88	Boneville x JP-179	P-23 x JP-179
	DPR-3 x JP-179	Arkel x JP-501-A/2	Bonneville x JP-501-A/2	Arkel x JP-179
	DPR-3 x Early Snap	DPR-3 x JP-179	Matar Ageta-6 x P-23	Arkel x JP-501-A/2

Table 10 contd.

Table 10 contd.

Criteria	Plant height (cm)	Number of pods per plant	Pod weight (g)	Number of grains per pod
Mean performance	Punjab-87 x JP-179	P-23 x Punjab-87	Matar Ageta-6 x Punjab-87	Punjab-87 x Punjab-88
	Early Snap x JP-179	DPR-3 x Punjab-88	Punjab-87 x Punjab-88	DPR-3 x Punjab-87
	Punjab-88 x JP-179	DPR-3 x JP-179	Arkel x Matar Ageta-6	Arkel x Punjab-87
	Punjab-88 x JP-501-A/2	P-23 x Punjab-88	Matar Ageta-6 x Early Snap	Early Snap x Punjab-88
Hetero-beltiosis	Punjab-87 x JP-179	Arkel x JP-179	Punjab-87 x Punjab-88	-
	Bonneville x P-23	P-23 x Punjab-87	DPR-3 x P-23	
	Early Snap x JP-179	Arkel x Matar Ageta-6	Early Snap x Punjab-88	
	Punjab-88 x JP-179	P-23 x Punjab-88	Bonneville x DPR-3	
s.c.a.	Punjab-87 x JP-179	P-23 x Punjab-87	Arkel x P-23	Arkel x P-23
	Bonneville x P-23	DPR-3 x JP-179	Punjab-87 x Punjab-88	Bonneville x P-23
	Early Snap x JP-179	DPR-3 x Punjab-88	Matar Ageta-6 x Punjab-87	Boneville x DPR-3
	Matar Ageta-6 x JP-501-A/2	Arkel x JP-179	Early Snap x JP-179	

Table 10 contd.

Table 10 contd.

Criteria	Yield per plant (g)	Shelling percentage	Dry matter (%)	Crude protein (%)
Mean performance	DPR-3 x Punjab-87	Punjab-87 x JP-501-A/2	Matar Ageta x JP-501-A/2	Arkel x Matar Ageta-6
	P-23 x Punjab-88	JP-179 x JP-501-A/2	Arkel x JP-179	Matar Ageta-6 x JP-501-A/2
	DPR-3 x Punjab-88	Arkel x JP-179	DPR-3 x JP-501-A/2	Matar Ageta-6 x JP-179
	Arkel x P-23	Matar Ageta-6 x JP-501-A/2	DPR-3 x Matar Ageta-6	P-23 x JP-501-A/2
Hetero-beltiosis	Arkel x P-23	Punjab-87 x JP-501-A/2	Matar Ageta-6 x JP-501-A/2	Matar Ageta-6 x Punjab-87
	Bonneville x Arkel	Bonneville x Matar Ageta-6	Arkel x JP-179	Arkel x Matar Ageta-6
	Arkel x Matar Ageta-6	Bonneville x Early Snap	Bonneville x Matar Ageta-6	Early Snap x P-23
	P-23 x Punjab-88	Matar Ageta-6 x JP-501-A/2	Early Snap x JP-501-A/2	Matar Ageta-6 x Early Snap
s.c.a.	DPR-3 x Punjab-87	Punjab-87 x JP-501-A/2	Arkel x JP-179	Matar Ageta-6 x Punjab-87
	Arkel x P-23	Bonneville x DPR-3	Matar Ageta-6 x JP-501-A/2	Arkel x Matar Ageta-6
	P-23 x Punjab-88	Matar Ageta-6 x JP-501-A/2	Bonneville x Matar Ageta-6	Boneville x DPR-3
	P-23 x Punjab-87	Bonneville x Matar Ageta-6	Punjab-88 x JP-179	P-23 x JP-501-A/2

Table 10 contd.

Table 10 contd.

Criteria	Total sugars (%)	Alcohol insoluble matter (%)
Mean performance	Arkel x Matar Ageta-6 Bonneville x Arkel Early Snap x Punjab-88 P-23 x Punjab-88	Arkel x Matar Ageta-6 Arkel x Punjab-88 Bonneville x Arkel Punjab-87 x Punjab-88
Heterobeltiosis	P-23 x Punjab-88 Early Snap x Punjab-88 DPR-3 x Matar Ageta-6 Punjab-87 x Punjab-88	JP-179 x JP-501-A/2 DPR-3 x P-23
s.c.a.	DPR-3 x Matar Ageta-6 Arkel x Matar Ageta-6 P-23 x Punjab-88 Bonneville x Arkel	Arkel x Matar Ageta-6 JP-179 x JP-501-A/2 DPR-3 x JP-179 DPR-3 x P-23

matter; Punjab-87 x JP-501-A/2 and Matar Ageta-6 x JP-501-A/2 for shelling percentage; Arkel x JP-179 and Matar Ageta-6 x JP-501-A/2 for dry matter; were found to be common and promising.

This comparison revealed that there was not a close parallelism between mean performance of crosses and their specific combining ability effects for most of traits. This clearly indicated that both the specific combining ability effects and actual cross performance should be considered while evaluating the superiority of a cross. Csizmadia (1985) also observed that specific combining ability effects were generally not proportional to F_1 performance.

Graphic analysis

The validity of the estimates and the inferences from diallel analysis are dependent to a large extent upon the fulfilment of underlying assumptions:

1. Diploid segregation
2. Parents are homozygous for all loci
3. No reciprocal differences
4. No epistasis
5. Genes independently distributed among the parents
6. No multiple alleles

Garden pea is a diploid and strictly self-pollinated crop. The reciprocal differences for the characters studied in the present investigations could be assumed to be absent on the basis of earlier findings reported by Gritton (1975). He did not find any reciprocal differences in garden pea in a diallel cross analysis. To test the rest of three assumptions, Hayman's t^2 (1954) was applied. The t^2 values were non-significant for all the characters except for number of primary shoots and yield per plant indicating that these two characters did not fulfill these three assumptions. The significant t^2 values for number of primary shoots and yield per plant were due to the presence of epistasis or linkage disequilibrium as regression coefficient of W_r on V_r significantly deviated from unity. Hayman (1954) suggested that even when a trait exhibits a partial failure of assumptions, analysis could be carried out for such characters, though the results would not be as reliable as they would have been had all the assumptions been fulfilled. The earlier studies have also revealed the failure of these assumptions for plant height, number of primary branches and seeds per pod (Singh and Singh, 1989a).

Considering the significance of regression coefficient, the W_r/V_r graphs were prepared for days to flower initiation, node at which the first pod develops, internodal length, number of primary shoots, plant height, number of pods per plant, pod weight, number of grains per pod, yield per plant, shelling percentage, dry matter, total sugars and alcohol insoluble matter. From the perusal of the graphs, it is evident that the regression line intersected the W_r axis above the origin point for days to flower initiation, node at which first pod develops, number of primary shoots, pod weight, yield per plant, shelling percentage, total sugars and near the origin for internodal length, number of pods per plant; indicating the presence of partial dominance and complete dominance, respectively. Singh and Singh (1989a) also observed partial dominance for seeds per pod. Similarly, Srivastava and Singh (1988) observed the partial dominance for seeds per pod. Overdominance was observed for plant height, number of grains per pod, dry matter and alcohol insoluble matter. Non-allelic interaction is usually associated with overdominance (Jinks, 1955). Similarly, Singh and Singh (1989a) reported the preponderance of overdominance for plant height.

Further perusal of the W_r/V_r graphs revealed that the regression line had a slope which differed significantly from unity for most of characters viz. node at which the first pod develops, number of primary shoots, number of pods per plant, yield per plant, shelling percentage, dry matter, and total sugars. This showed inadequacy of simple additive-dominance model suggesting that a non-allelic interaction was operative.

The non-significant correlation coefficient (r) of W_r+V_r with parents (Y_r) further indicating that both dominant as well as recessives contributed towards the higher mean performance of most of characters viz. days to flower initiation, node at which the first pod develops, number of primary shoots, number of pods per plant, yield per plant, crude protein and total sugars. Similarly, Singh and Singh (1989a) also observed the non-significant correlation (r) of either sign for number of primary branches, pods per plant and yield per plant which further indicated that both dominants and recessives contributed towards the higher mean performance of these traits.

Parents Early Snap, Bonneville and P-23 had more dominant genes for days to flower initiation than Arkel which had recessive genes. For node at which the first pod develops, parents Bonneville and DPR-3 had the preponderance of dominant genes whereas Punjab-88 had the recessive genes. The preponderance of dominant genes was shown by Matar Ageta-6, Punjab-88 and Punjab-87 and recessive genes by DPR-3 and P-23 for number of primary shoots. The parent JP-501-A/2 contained excess of dominant genes for yield per plant while P-23 carried excess of recessive genes. The most dominant parents for number pods per plant were Early Snap and JP-501-A/2 and the most recessive were Punjab-87 and Punjab-88. For total sugars, parents Early Snap, Punjab-87 and Punjab-88 had the preponderance of dominant genes whereas Matar Ageta-6 had the recessive genes.

The correlation of W_r/V_r with parents (Y_r) for internodal length and alcohol insoluble matter was significantly negative. This suggested that recessive genes played an important role in reducing internodal length and alcohol insoluble matter. The parents Matar Ageta-6 and Arkel contained excess of recessive genes for internodal length and alcohol insoluble matter.

Further, significantly negative correlation of W_r+V_r with parents (Y_r) was observed for shelling percentage and dry matter. This suggested that the dominant genes governed high shelling percentage, and dry matter. The parents DPR-3 contained the excess of dominant genes for dry matter while JP-179, and JP-501-A/2 carried the excess of dominant genes for shelling percentage. For plant height, all tall parents viz. Bonneville, JP-501-A/2 and JP-179 contained high proportion of dominant genes whereas, rest of the parents (medium to dwarf) had comparatively higher concentration of recessive genes. The negatively significant value of correlation coefficient (r) between parental measurement (Y_r) and parental order of dominance (W_r+V_r), further indicated the positive direction of dominant genes in the expression of this trait. Singh and Singh (1989a) also reported the positive direction of dominance in the expression of plant height.

The correlation of W_r+V_r with parents (Y_r) for pod weight and number of grains per pod were significantly positive. This suggested that recessive genes played an important role in increasing the pod weight as well as number of grains per pod. However, Srivastava and Singh (1988) observed an equal importance of both dominant aas well as recessives in the higher mean performance of seeds per pod. The preponderance of recessive genes was shown by Matar Ageta-6, Arkel and Punjab-87 for pod weight. The most recessive parent for number of grains per pod was Punjab-87 while JP-179 and Early Snap carried the excess of dominant genes for this trait.

Genetic Components of Variance

The genetic components of variance revealed that both additive and non-additive components were significantly important for most of the characters viz. days to flower initiation, node at which the first pod develops, internodal length, plant height, pod weight, number of grains per pod, shelling percentage, dry matter, crude protein, total sugars and alcohol insoluble matter. However, additive component of variance was non-significant for three characters viz. number of primary shoots, number of pods per plant, and yield per plant. These estimates more or less confirmed the prediction of the combining ability analysis. Further, the comparison of D and H_1 components revealed the preponderance of dominance gene effects for most of characters except days to flower initiation, number of grains per pod, pod weight and total sugars. In case of days to flower initiation and total sugars, additive genetic variances was in preponderance. Further, the additive component of variance appeared to play an equally important role as non-additive components in the inheritance of number of grains per pod and pod weight. Both additive and non-additive gene effects have also been observed to be important for days to flowering (Korrane and Singh, 1974), for plant height (Das and Kumar, 1976; Kumar, 1976), for seeds per pod (Venkateshwarlu and Singh, 1982; Singh *et al.*, 1987a) and for seed yield and protein content (Singh *et al.*, 1985b; Gupta *et al.*, 1986b). The preponderance of dominant effects were also reported for number of pods per plant (Bhullar *et al.*, 1975), for yield per plant (Kumar and Agrawal, 1981; Singh *et al.*, 1987b), for plant height (Kumar and Agrawal, 1981; Katiyar *et al.*, 1987; Singh and Singh, 1989a), for number of primary branches (Gupta *et al.*, 1986a; Katiyar *et al.*, 1987), for node upto first pod (Srivastava *et al.*, 1986; Katiyar *et al.*, 1987), for protein content (Rastogi *et al.*, 1983; Gupta *et al.*, 1986b). In the earlier studies, Bhullar *et al.* (1975), Kumar and Das (1975), Kumar and Agrawal (1982) and Godawat and Parmar (1990), revealed that days to flower initiation was predominantly controlled by additive genetic effects.

The mean degree of dominance $(H_1/D)^{1/2}$ was less than unity for days to flower initiation and total sugars, indicating partial dominance. However, the mean degree of dominance was more than unity for the remaining characters viz. node at which the first pod develops, internodal length, number of primary shoots, plant height, number of pods per plant, pod weight, number of grains per pod, yield per plant, shelling percentage, dry matter, crude protein and alcohol insoluble matter. This suggested the overdominance for these characters. The graphic analysis depicted partial dominance for most of these characters. The discrepancy observed in the graphic and component analysis could be due to epistasis which might have inflated the estimates of overdominance in the component analysis. In the earlier studies, Sharma *et al.* (1977) observed overdominance for yield, number of pods per plant and partial dominance for days to flowering. Similarly, Rybnikova (1982) found the overdominance for plant height, height of insertion of the first pod and number of seeds per pod. Further, Rastogi *et al.* (1983) observed overdominance range for soluble protein.

The estimates of F were significantly positive for days to flower initiation suggesting the preponderance of dominant genes in the parents. However, the negative significant F-value for plant height indicated a tendency of presence of more of recessive genes in the parents. For the remaining characters, the F was non-significant, thus indicating equal distribution of dominant and recessive genes among parents. Negative significant F value was also observed by Singh and Singh (1989a) for plant height.

The value of ratio $[(4\ DH_1)^{1/2} + F]/[(4\ DH_1)^{1/2} - F]$ indicated the prevalence of two dominant genes for each of the recessives in the parents for days to flower initiattion, crude protein and alcohol insoluble matter. On the other hand, one dominant gene for each of the recessives in the parents was observed for the remaining characters.

The value of $H_2/4H_1$ was less than the expected value of 0.25 for all the characters studied in the present investigation which suggested asymmetrical gene distribution of favourable and unfavourable genes in the parents. Singh and Singh (1989a) though observed symmetrical gene distribution for seeds per pod but observed asymmetrical gene distribution for plant height, number of primary branches, pods per plant and yield per plant. Srivastava and Singh (1988) observed asymmetrical gene distribution in the parents for seeds per pod. The h^2/H_2 estimates detected one effective factor for days to flower initiation, internodal length, number of primary shoots, pod weight, shelling percentage, and crude protein. Further, two effective factors were detected for node at which the first pod develops, plant height, number of pods per plant, yield per plant, number of grains per pod, dry matter, total sugars and alcohol insoluble matter.

Implication in garden pea breeding

The present investigation revealed the predominance of non-additive gene effects for yield per plant, number of pods per plant, dry matter, crude protein, total sugars, and alcohol insoluble matter. The breeding method with progeny testing such as pedigree method would be more reliable for the improvement of these traits.

The predominance of additive gene effects was observed to be more important for days to flower initiation, node at which the first pod develops, internodal length, number of primary shoots, plant height, and shelling percentage. The predominance of additive gene effects for these traits can be efficiently utilized by any conventional breeding programme, which involve hybridization and selection. It mainly involves crossing of two or more diverse genotypes and then selection in the segregating generations to fix the additive genetic variance.

The capacity of a parent to transmit gene complexes for a trait to its progeny is known from the status of its general combining ability effects for that trait. In the present study, the parents DPR-3, Punjab-87, Punjab-88, Arkel, and Matar Ageta-6 are identified as superior general combiners for yield coupled with yield contributing characters, earliness, quality and resistance to wilt. Hence, the said parents could be rated as of high potentials for including these in any hybridization programme. Certain crosses viz. Arkel x Matar Ageta-6, P-23 x Punjab-88, DPR-3 x Punjab-87, Arkel x P-23, Matar Ageta-6 x JP-501-A/2 exhibited high sca effects for almost all the traits studied in the present investigation. Therefore, these crosses can be involved in multiple crossing programme as well. The best approach would be to cross a number of F_1's showing highest sca effects for each type of character with a view to combine good features in one genotype.

CHAPTER-VI

SUMMARY

The present investigation entitled, "Assessment of combining ability and gene action for economic characters in garden pea (*Pisum sativum* L.)" was carried out at the Vegetable Experimental Farm, Punjab Agricultural University, Ludhiana during 1994-1996. The study was undertaken to determine the nature and magnitude of genetic variation among parents and F_1, extent of heterosis in F_1 and to generate information regarding general and specific combining ability effects for different economic characters. The experimental material for the studies comprised of ten genetically divergent varieties viz. Bonneville, DPR-3, Arkel, Matar Ageta-6, Early Snap, P-23, Punjab-87, Punjab-88, JP-179 and JP-501-A/2. During the year 1994, all the ten varieties were crossed in a diallel mating design (excluding reciprocals) to raise forty five F_1 hybrids. Thus, there were 55 genotypes in all including parents. These 55 genotypes were sown in a randomised block design with three replications on October 27, 1995. Observations were recorded for days to flower initiation, node at which the first pod develops, internodal length, number of primary shoots, plant height, number of pods per plant, pod weight, number of grains per pod, yield per

plant, shelling percentage, dry matter, crude protein, total sugars, alcohol insoluble matter, reaction to powdery mildew and wilt.

The analysis of variance for the design of the experiment revealed highly significant differences among genotypes for all the characters.

In the present study, significant desirable heterosis over the better parent was observed for days to flower initiation, number of primary shoots, plant height, number of pods per plant, pod weight, yield per plant, shelling percentage, dry matter, crude protein, total sugars, alcohol insoluble matter and reaction to powdery mildew. On the other hand, significant desirable heterobeltiosis was not observed for node at which the first pod develops, internodal length, number of grains per pod and wilt incidence.

The analysis of variance for combining ability revealed that mean squares due to gca and sca were highly significant for all the characters studied in the present investigation. The best parents were identified through general combining ability analysis for various characters. The parents Arkel and Matar Ageta-6 were observed to be the best general combiners for days to flower initiation, node at which the first pod develops, internodal length, pod weight, crude protein and total sugars. Further, Arkel was also good general combiner for alcohol insoluble matter. The parent DPR-3 was considered to be the best general combiner for yield per plant, number of pods per plant, internodal length, node at which the first pod develops, shelling percentage, dry matter and reaction to wilt. Similarly, Punjab-87 and Punjab-88 were considered to be the best general combiners for yield per plant, pod weight, and number of grains per pod. Further, Punjab-88 was the best combiner for total sugars and alcohol insoluble matter. The parents JP-179 and JP-501-A/2 were observed to be the best general combiners for reaction to powdery mildew and wilt.

In general, there was a close agreement between general combining ability values and mean performance of parents for all the characters studied in the present investigation. However, there was not a close parallelism between mean performance of crosses and their specific combining ability effects for most of the traits.

The studies with regard to graphic analysis revealed partial dominance for days to flower initiation, node at which the first pod develops, number of primary shoots, pod weight, yield per plant, shelling percentage, and total sugars. On the other hand, complete dominance was observed for internodal length and number of pods per plant. Overdominance prevailed for plant height, number of grains per pod, dry matter and alcohol insoluble matter. Partial dominance for days to flower initiation, total sugars and overdominance for plant height, number of grains per pod, dry matter and alcohol insoluble matter was also revealed by analysis of genetic components of variance.

The graphic analysis detected the presence of non-allelic interaction for node at which the first pod develops, number of primary shoots, number of pods per plant, yield per plant, shelling percentage, dry matter, and total sugars, while for other traits, the interaction was absent.

The graphic analysis also revealed the importance of recessive genes in reducing internodal length, alcohol insoluble matter; while these played an important role in increasing pod weight as well as number of grains per pod. On the other hand, contribution of dominant genes was found to be more important for improving shelling percentage, dry matter, and plant height. Further, an equal importance of both dominant as well as recessive genes was observed for the remaining traits.

Parents were also identified for containing maximum dominant genes for various traits which include Bonneville for days to flower initiation, node at which the first pod develops and plant height; DPR-3 for node at which the first pod develops and dry matter; Early Snap for days to flower initiation, number of pods per plant and total sugars; JP-501-A/2 for yield, number of pods per plant, plant height and shelling percentage; Punjab-87 and Punjab-88 for number of primary shoots and total sugars. On the other hand, the parents Arkel and Matar Ageta-6 contained maximum recessive genes for internodal length, alcohol insoluble matter and pod weight.

Nature of gene effects was studied through combining ability and genetic components of variance analysis. These analyses revealed the preponderance of non-additive gene effects for yield per plant, number of pods per plant, dry matter, crude protein, total sugars and alcohol insoluble matter. On the other hand, predominance of additive gene effects was observed for days to flower initiation, while both additive and non-additive gene effects were equally important for pod weight and number of grains per pod. The combining ability analysis revealed the predominance of additive gene effect for node at which the first pod develops, internodal length, number of primary shoots, plant height and shelling percentage, while components of variance analysis revealed that non-additive gene effects were more important. The components of variance analysis also revealed the asymmetrical distribution of favourable and unfavourable genes in the parents for all the characters studied in the present investigation.

The implication of the nature of gene action involved have been discussed and the suitable breeding procedures to bring about improvement in various characters of garden pea have been suggested.

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*Original not seen