COMBINING ABILITY, GENE ACTION AND HETEROSIS FOR SOME SEED QUALITY AND YIELD PARAMETERS IN MAIZE (*Zea mays* L.)

THESIS

By

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Submitted to

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IN

Partial fulfilment of the requirements for the degree

OF

DOCTOR OF PHILOSOPHY IN AGRICULTURE
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(2000)

Dedicated

to

my reverend

grandmother and

parents

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CERTIFICATE - I

This is to certify that the thesis entitled "**Combining ability, gene action and heterosis for some seed quality and yield parameters in maize (*Zea mays* L.)**" submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Plant Breeding** of Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Mr. Gopal Katna** son of **Shri Amar Nath Katna** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

(H. B. Singh)
Chairman
Advisory Committee

Place : Palampur
Dated: the 27th January, 2000.

CERTIFICATE - II

This is to certify that the thesis entitled **"Combining ability, gene action and heterosis for some seed quality and yield parameters in maize (*Zea mays* L.)"** submitted by **Mr. Gopal Katna** son of **Shri Amar Nath Katna** to the Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Plant Breeding**, has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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I owe entire responsibility for all errors and omissions, if any.

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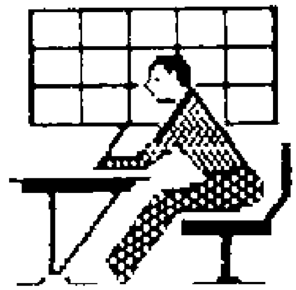


INTRODUCTION

Chapter-I

INTRODUCTION

Maize (*Zea mays* L.), is the third leading cereal in the world and is cultivated widely either for domestic use or commercial purposes on varied climatic conditions up to 3800 m above mean sea level and 58° N to 40° S latitude (Hallauer and Miranda, 1988). Predominantly, it is a crop of tropical and subtropical areas but can be cultivated successfully under temperate climatic conditions. One such example is its cultivation in dry temperate regions of Himachal Pradesh. Maize grains and/or stalk are used for food, feed, fodder and even fuel. Apart from domestic consumption, it also provides raw material for the production of several industrial products.

In India the average yield of maize is very low (17.21 q/ha) in comparison to developed countries like New Zealand and Italy where its average yield is as high as 96 q/ha (Anonymous 1999[a]). Though, several factors contribute to higher yields in developed countries, cultivation of hybrids is one of the most important factors in enhancing the yield per unit area of maize in these countries (Anonymous, 1990).

In Himachal Pradesh, maize is a principal food crop occupying an area of 0.31 million hectare with a total production of 0.62 million tonnes. Although average maize yield in H.P. is higher (19.90 q/ha) than the national average (17.21 q/ha) (Anonymous, 1999[b]), yet there is a considerable scope for yield improvement in this crop keeping in view its yield potential. Major constraint for realization of full yield potential in the state is the lack of the availability of high yielding varieties/hybrids suitable for cultivation in diverse agroclimatic conditions of H.P. Due to availability of large genetic diversity of maize in the state, the farmers are used to cultivate its local composites. Of late, the private companies have initiated cultivation of high yielding and disease resistant hybrids in the state, however, the release of these hybrids for cultivation without adequate testing for their adaptability in its diverse agroclimatic conditions have inhibited the realization of desired high yields. On the other hand the larger use of such hybrids may lead to the depletion of valuable local germplasm available in the state, which represents high genetic variability for different characters. Maize growing areas of the state have their own composites developed naturally since ages and represents separate gene pools. Unfortunately limited efforts have been made to use this germplasm for maize improvement programme and no high yielding hybrid has been developed till date through the exploitation of this local gene pool.

Selection of the parents is the most important factor in the initiation of any hybrid breeding programme aimed at the development of high-yielding hybrids/varieties. Combining ability analysis is one of the most important concepts in quantitative genetics which aids in the selection of desirable inbreds to be used for the development of superior hybrids/varieties. Further, the knowledge of gene action helps in the formulation of an efficient breeding programme aimed at improving yield potential through its components. Extensive utilization of heterosis in maize has resulted in the development of superior hybrids throughout the world, but in H.P., a large part of the locally adapted germplasm remains to be exploited for the development of high yielding hybrids with adaptability to local conditions.

Seed vigour determines the potential level of activity and performance of the seed or seed lot during germination and seedling emergence in the establishment of plant stand. Among many seed vigour tests, accelerated aging and osmotic stress test that determine the capability of seeds to germinate under stress conditions which reflect high field emergence ultimately leading to high yields. However, results on different vigour tests can be combined together to have better prediction of field emergence under varied sowing conditions.

Keeping these factors in view, the present study was proposed to be undertaken with the following objectives:

i) to determine combining ability effects and gene action for some seed quality and yield parameters,

ii) to estimate the extent of heterosis and identify the most promising hybrid combination(s) for commercial exploitation, and;

iii) to determine the association of different seed quality traits with field emergence.

REVIEW OF LITERATURE

Chapter-II

REVIEW OF LITERATURE

The relevant reports pertaining to various aspects of the present study, are briefly reviewed under the following sub heads:

2.1 Combining ability

2.2 Gene action

2.3 Heterosis

2.4 Seed vigour and correlations

2.1 Combining ability

Identification of superior parents is of paramount importance for the development of superior varieties/hybrids. Dhillon (1975) stated that the wrong choice of parents might undo an efficiently planned and well executed programme. In the past quarter century, quantitative genetics and advanced biometrical models like diallel, partial diallel and line X tester have played a leading role in providing basic information regarding the genetic make-up of different polygenic traits.

Sprague and Tatum (1942) were the first to give clear-cut explanation of the concept of combining ability. They defined general combining ability "as the average performance of a line in a number of hybrid combinations" and specific combining ability "as the cases in which certain combinations did relatively better or worse than would be expected on the basis of average performance of the lines involved".

Diallel system provides reliable information on the components of variance, and on gca and sca variances and effects. Thus, it helps in the selection of suitable parents for hybridization as well as in the choice of appropriate breeding procedures. Griffing (1956[a]) has given four different methods for diallel analysis depending upon the material used in the experimentation.

Matzinger and Kempthorne (1956) showed that estimates of general combining ability (gca) include additive genetic variance and portion of the additive based higher order epistatic variance and the estimates of specific combining ability (sca) variance include dominance and other portion of epistatic variance. Estimation of additive and dominance genetic variances can be obtained from a diallel cross only in the absence of epistasis.

The gca and sca have been reported to be important for agronomic and yield characters. Khristova (1975) reported both gca and sca to be high and important for ear length in maize. Dhillon and Singh (1976) and Mason and Zuber (1976) concluded that gca was more important than sca for days to 75 per cent silk, plant height, ear placement height, ear length, ear girth, grains/ ear and leaf area/plant.

Bhalla and Khehra (1977) in a 10 X 10 diallel reported that gca and sca were significant for grain yield, 500-grain weight, ear length, ear girth, ear placement height, plant height and days to 75 per cent silk. All the characters exhibited additive genetic effects.

Singh *et al.* (1979) reported higher gca effects than that of sca for early silking, dwarfness, ear length, 500-grain weight and grain yield/plant. De Loughery and Crookstone (1979) reported both gca and sca effects to be important for harvest index.

Debnath *et al.* (1983[a], 1983[b]) registered inbred B57 Ht (VSA) as the best combiner for yield and yield contributing traits studied followed by line 382 SynB and Aust25. The hybrid A2077 X CM400: Tenn 29 showed desirable significant sca effect for grain yield and days to 75 per cent silk. Qadri *et al.* (1983) observed that gca and sca effects were highly significant for ear length, ear girth, ear placement height and grains/ear under drought conditions.

Nawar and El-Hosary (1984) reported high gca effects for ear girth and sca effects for grain yield per plant, days to 75 per cent silking, ear length, grains per ear, ear height and plant height. Debnath and Sarkar (1987[a]) in a 10 inbreds diallel observed that B49 was the best general combiner for yield and other characters, followed by 382SynB. The crosses, Aust25 X B49 and Kmr25 X 382SynB showed high sca effects for yield.

CM500 was found to be good general combiner for grain yield and other yield components followed by CM105 and CM110, whereas CM500 X CM400 and CM111 X CM400 were good specific combinations (Prasad *et al.*, 1988). Debnath *et al.* (1988) in half diallel found inbred P9 as a good general combiner for most of the characters like grain yield, ear girth, grains/row, ear length except grain rows/ear and 1000-grain weight. The crosses P1 X P7, P2 X P8, P3 X P4 and P8 X P9 showed desirable significant sca effects for grain yield and some other characters viz., ear girth, grains/row and ear length.

Singh *et al.* (1989) reported the parents, R7 and Kanpur 54-79 as the best general combiners for yield and dry leaf weight under two different environmental conditions. Beck *et al.* (1990) in a diallel analysis involving 10 parents found significant gca for grain yield, plant height, ear height and days to silking while sca was significant only for ear height. In another study high sca effects for yield per plant in the hybrids of Rg II with M36, M25 and M30 and K64 with M54 and M36 were observed by El-Hosary and Sedhom (1990).

Perez *et al.* (1991) in a diallel experiment involving a set of crosses concluded that AG103, XL670 and Tucma85 had highest gca for yield, whereas highest sca effects were shown by the hybrids XL670 X GS510s, AG103 X Tropico327, 4F37 X BG012 and BG012 X XL670, indicating the involvement of one high yielding parent with high gca. Ivanov (1991) concluded that the lines Sh14402 and C10302 had high gca for grain yield in a 7 parental diallel cross. Mahajan *et al.* (1991) found parental strains J54, CM202, J617 and B57 as good general combiners for plant growth/day and leaf increase/day. Mustyatsa *et al.* (1991) reported lines viz., MKR30, MKR40, MKR38, MKR46, MKR41 and 1866/80 to be good general combiners for grain yield, green matter yield and low grain moisture in a diallel study.

Dass *et al.* (1992) reported the parents K-719, L-709, K-710 and K-725 to be good general combiners for harvest index. Sharma and Bhalla (1993) in a diallel study reported that parents H98, CM205, V55-B and V57-B were mostly good general combiners for grain yield/plant, leaf area/plant, germination and pollen shed period and best specific combinations found were V50-B X CM205, V20-B X V50-B, V57-B X A-654, V20-B X V57-B and H-98 X CM-205.

Jha (1993) in 12 parental diallel observed Phil DMR Comp4, M12(W), Suwan 2(W) and Jogia Local as the good general combiners for yield. Ferrao *et al.* (1994) evaluated 20 inbred lines in a partial diallel manner (100 hybrids), using a single 10 X 10 lattice design with two replications over three locations. The combined analysis showed significance for the interactions of hybrids and for gca and sca with locations.

Villanueva *et al.* (1994) reported the lines P3288, M355, B810, P507 and B83 as good general combiners and the crosses viz., B83 X P507, P3288 X 0356 and P3288 X HV313 as good combinations for yield. Sedhom (1994a) found that parental line MR4 was the best combiner for grain yield/plant, ear length and silking date. The highest sca effects were recorded in the crosses, K64 X G224D for grain yield/plant and ear diameter; G224 D X MR5 for ear length; G507 X MR5 for number of rows/ear; G251B X MR5 for plant height; G507A X K64 for ear height; and G507A X G251B for silking date. Sedhom (1994b) in a diallel study reported that Moshtohor (M)26 was the best combiner for silking date; M24 for plant height, ear height and number of rows/ear; and M13 for grain yield/plant. The good specific combinations were observed in the crosses M32 X M99 for silking date and plant height; M13 X M24 for ear length, number of grains/row and grain yield/plant; M12 X M26 for ear diameter; M13 X M32 for number of rows/ear; and M12 X M32 for 100-grain weight.

Altinbas (1995) in a half-diallel study involving 6 inbred lines, suggested that the best crosses would be obtained from combinations of parents with negative and high gca effects for days to silking and ear height.

Kalita *et al.* (1995) found good general combiner parents as L1 for days to 50 per cent tasselling and leaf area; E2 for days to 50 per cent silking, ear height and leaf area, and Ageti-76 for days to 50 per cent silking and plant height. Pratap X Ageti-76 was good specific combination for fresh weight of cobs, E2 X Ageti-76 for fresh weight of cobs and days to 50 per cent silking and L19 X Ageti-76 for days to 50 per cent tasselling, leaf area and total number of cobs. Thus parents with high gca estimates did not always give rise to offspring with high sca.

Nagda *et al.* (1995) in a 6 X 6 diallel cross reported that parents SLT-52 and SLT-54 were good general combiners for days to 50 per cent silk, ear length, number of grains/row and 100-grain weight; and SLT-56 for days to 50 per cent silk, number of grains/row and 100-grain weight. Good specific crosses identified were SLT-51 X SLT-52, SLT-51 X SLT-55, SLT-51 X SLT-56 and SLT-52 X SLT-53. Mathur and Bhatnagar (1995) in a partial diallel study involving 20 inbred lines evaluated in 11 X 11 single lattice design reported that inbred I7 had high gca effects for grain yield/plant, ear length, ear girth and 100-kernel weight and was also early in silking. Inbreds I3, I7, I11, I18 and I19 were good general combiners for earliness in silking.

Ismail (1996) while studying combining ability for days to tasselling, days to silking and grain yield/plant revealed differences between genotypes and, genotype X sowing date interaction for all traits like maturity, grain yield, protandrous interval etc. Spaner *et al.* (1996) found that gca was significant for time to silking, plant height, grain yield, ear size and sca was significant for all traits except ear size.

Sinha and Mishra (1997) in a diallel mating design indicated that the crosses Navin X Population 26 showed highest sca effect for ear height, and Suwan1 x Pool 18 for plant height and ear length, and D765 X Kiran for ear height, ear length ear diameter and plant height. Population 26 gave high gca effects for ear height. Dass *et al.* (1997) through diallel analysis in two different situations, viz., winter and summer seasons revealed that K-729 and K-725 were the best general combiners for grain yield and 100-seed weight and K-613 and K-720 for grain yield in both the seasons. Studies on sca effects indicated that most of the superior crosses were between parents with high X low, high X high and high X medium combining parents suggesting that the involvement of one good general combiner appears to be essential to get the better specific combination.

Mathur *et al.* (1998) revealed significant gca variance for days to silking, ear length, ear girth, number of rows/ear, number of kernels/row, shelling per cent and grain yield/plant in normal and stress environments and significant sca variance for ear length and shelling per cent in normal environment and grain yield/plant in stress environment. Singh *et al.* (1998) in a half diallel crosses of 10 X 10 maize inbred lines reported that parents MS1DR-20, TEM-DMR Pool 3-(S7) and CM 400 had high negative gca effects, TEW-DMR Pool C3(S6) X TEW-DMR Pool3-(S7) and MS1DR-30 X TEM-DMR Pool 3-(S7) had high negative sca effects for days to tasselling, silking, husk browning and plant and ear heights. Tulu and Ramachandrappa (1998) based on estimates of gca effects revealed that Abo-Bako and A-511 were best parents for earliness, low ear placement and short plant height, Abo-Bako was also appropriate parent for grain yield. KCB X Abo-Bako and Bako composite X A-511 were best combinations for earliness, low ear placement, short plant height and grain yield. Joshi *et al.* (1998) reported that inbred line X_2W-3232-1-1-1-1 was good general combiner for grain yield, oil content, protein and starch, while inbred Pop. 30-5029 for all except oil content, inbred X_1W-1527-2-2-1-1 for quality and 100-grain weight, and inbreds CD (W)-113-2-1-2-1 and X_2W-3527-2-2-1-1 for oil content along with grain yield and 100-grain weight. Cross Pop. 30-5044-2 X CD(W)-113-2-1-2-1 exhibited significant sca effects for oil content, grain yield and 100-grain weight. Gul *et al.* (1998) on the basis of gca effects, kisan was the best general combiner for earliness and low grain moisture content. Sarhad White X Toxpino C6 was the best combination for grain yield (5927 kg/ha).

2.2 Gene action

Knowledge of gene action and relative importance of genes in determining different agromorphological characteristics is important for the success of any breeding programme. Hereditary variance is partitioned into three components viz., additive, dominance and epistatic, which results from average effects of genes and intra and inter-allelic interactions. Wright (1935) defined these three components as additive genetic variance, variance due to dominance and variance due to deviation from the additive which is due to the interaction of non-allelic genes. Johnson (1973) reported that genetic variability for grain yield in single ear plant is attributable to additive and non-additive genetic variances, expressed through yield components. The role of epistasis in controlling grain yield/plant was reported by Pollak *et al.* (1957).

Both additive and non-additive gene action have been reported by different workers for important characters in maize. For example Bhalla and Khehra (1977) for ear circumference; Bonaparte (1977) for days to 50 per cent silking; Krolikowski (1977) for ear placement height and grain yield/plant; Pal *et al.* (1986) and Vedeneev and Zhuzhukin (1986) for 100-seed weight; Ramesha (1988) for days to silking and days to tasselling.

Bhalla and Khehra (1980) reported both additive and non-additive gene action for days to 50 per cent silking and ear length and non-additive for grain yield/plant. Rood and Major (1980) reported additive gene action for days to 50 per cent tasselling; and Verma and Singh (1980) for grain yield/plant. Ahuja (1980) reported non-additive gene action for kernels/row.

Murthy *et al.* (1981) reported additive gene action for days to 50 per cent tasselling and silking, and non-additive for grain yield/plant. Martin (1981) reported both additive and non-additive gene action for grain yield/plant and

Saha (1981) for ear length, ear diameter and epistasis for days to 50 per cent silking.

Sanghi *et al.* (1982) reported additive gene action for number of kernel rows/ear and grain yield/plant. Yang (1982) reported both additive and non-additive gene action for grain yield/plant. Ahuja *et al.* (1983) reported both additive and non-additive gene action for ear diameter and epistasis for days to 50 per cent silking, 100-seed weight, ear length ear diameter, kernel rows/ear, kernels/row and grain yield/plant. Qadri *et al.* (1983) reported additive gene action for ear placement height, ear diameter, number of kernel rows/ear and both additive and non-additive effects for ear length. Singh *et al.* (1983) observed additive type of gene action for plant height.

Non-additive gene action was reported by Genowa (1984), Pinto *et al.* (1985) and Stuber *et al.* (1987) for ear length and 100-seed weight. Kimani (1984) had also observed non-additive gene action for 100 seed weight and significant gca variance but nonsignificant sca variance for graiin yield/plant. Similar results were also reported by Kubecova and Vozda (1985) for grain yield/plant.

Guo *et al.* (1986) reported non-additive gene action for days to 50 per cent tasselling and grain yield/plant. Hemalatha (1986) reported additive gene action for ear placement height and both additive and non-additive gene action for plant height and days to 50 per cent tasselling. Nawar (1986) reported additive type of gene action for plant height, ear placement height, ear length, ear diameter, kernel rows/ear, grain yield/plant. Additive gene action was also reported by Pal *et al.* (1986) for days to 50 per cent silking, ear length, ear diameter, kernel rows/ear and grain yield/plant; and Zambezi *et al.* (1986) for ear placement height.

Genov (1987), Liao *et al.* (1987) and Wu (1987) reported non-additive gene action for grain yield/plant. Complete dominance to over dominance was reported by Debnath and Sarkar (1987) for ear diameter and Kernel rows/ear.

Debnath *et al.* (1988) observed both additive and non-additive gene action for kernel rows/ear and kernels/row. Hallauer and Miranda (1988) reported additive gene action for plant height, ear length, ear diameter and grain yield/ plant.

Jha and Sinha (1989) reported that additive and non-additive gene effects were important for grain yield, germination percentage and leaf yellowing. Leon *et al.* (1989) reported additive gene action for 100-seed weight. Beck *et al.* (1990, 1991) observed additive gene action for plant height and days to 50 per cent tasselling. Crossa *et al.* (1990) reported additive gene action for plant height and non-additive for grain yield/plant. Debnath and Sarkar (1990) reported non-additive gene action for 100-seed weight and additive for grain yield/plant. Additive gene action for ear length, grain yield/plant and additive as well as non-additive gene action for ear diameter were reported by Sanjay Swarup (1990).

Mahajan and Khehra (1991) reported additive gene action for plant height and ear placement height. Cosmin *et al.* (1991) while evaluating 45 single cross hybrids derived from a 10 parents diallel, reported additive gene action for grain yield and grain moisture content at harvest.

Additive type of gene action for plant height, days to 50 per cent tasselling was reported by Vasal *et al.* (1992, 1993a, 1993b). Jha and Khehra (1992) emphasized the role of non-additive genetic variance in the inheritance of grain yield. Damborsky *et al.* (1994) reported that grain yield, grain moisture content and stalk strength were conditioned by additive as well as non-additive gene action.

Kalita *et al.* (1995) reported that gca/sca ratio was 1.48 for days to 50 per cent silking, suggesting additive components were more important, but non-additive components appeared to be more important for days to 50 per cent tasselling, leaf area, ear height, plant height etc. in the lines L1, L19, E1, E2 and Ageti-76. Mathur and Bhatnagar (1995) revealed a major role for additive gene effects for days to tasselling and silking. Magnitudes of additive and dominance variances were nearly equal for days to brown husk and leaves/ plant.

Turgut *et al.* (1995) reported that dominance as well as additive gene effects were important for grain yield, ear diameter, ear length, number of grain rows and 100-grain weight. However, dominance component of genetic variance was more important for all traits studied except 100-grain weight. On the other hand Altinbas (1995) found additive effects to be more important than non-additive ones for days to silking and ear height.

Ismail (1996) reported that lines Rg21, Rg24 and G251B appeared to possess dominant genes for grain yield. Narrow-sense heritability was low for days to tasselling and silking, protandrous interval and grain yield/plant.

Dass *et al.* (1997) through diallel analysis in two different situations, viz., winter and summer seasons revealed that higher magnitude of gca variances in both the seasons indicated the predominance of additive and additive X additive epistatic components, which were fixable.

Mathur *et al.* (1998) reported preponderance of additive gene effects in the expression of days to silking, ear length, ear girth, rows/ear, kernels/row, shelling per cent and grain yield/plant. Tulu and Ramachandrappa (1998) were observed no significant sca effects for ear height and plant height indicating lack of non-additive gene action for these traits. Further, gca variance was higher than sca variance indicating the importance of additive gene action in controlling grain yield, ear height, plant height and days to 50 per cent silking.

Joshi *et al.* (1998) revealed that the ratio of additive/non-additive genetic variance was preponderance of non-additive gene action in the expression of yield per plant, protein and starch content, while for oil content and 100-grain weight there was preponderance of additive gene action.

2.3 Heterosis

Heterosis, usually considered to be synonymous with hybrid vigour, is one of the most important factors for the success of the maize industry. Hybrid vigour is known since the concept of hybridization came into existence. Koelreuter (1766) was the first to describe hybrid vigour in plants. Later on, Beal (1880) made extensive use of controlled cross pollination in breeding corn and gave the concept of "varietal hybrid". East (1909) gave genetic nature of hybridization. Shull (1909) gave genetic explanation of hybrid vigour in maize and laid the foundations for a more comprehensive understanding of heterosis. Bruce (1910) reported that hybrid vigour is due to the presence of dominant genes in the hybrid. Jones (1917) extended this concept of dominant favourable factors to include linkage. The concept of divergent alleles was given by East (1936). Stuber *et al.* (1973) reported that interaction of non alleles may be an important factor in the type of heterosis found in many maize single crosses. Khanna *et al.* (1993) reported that for yield, heterosis is dependent on the environment and hybrid vigour help in efficient utilization of environmental factor. Heterosis in maize has been described extensively for several agromorphological characters such as yield, grain weight, flowering, tasselling, ear length etc. Literature available on heterosis for various characters is reviewed as under:

High heterosis for early tasselling was reported by Hassaballa *et al.* (1980); for ear length, 100-grain weight and grain yield by Verma and Singh (1980); for ear placement height and plant height by Paterniani (1980); for ear length and plant height by Moreno-Gongalez and Dudley (1981); and for plant height and biological yield by Simeonov (1983).

Akhtar and Singh (1981) reported average heterotic response over better parent was 8 per cent for grain yield with the extent of 40.93 per cent, whereas, 3 per cent with a range of -4 to11 per cent for days to silk. Todorov (1981) reported 137 to 157 per cent heterosis for plant height.

It has also been concluded that heterosis for dry matter production usually associate with corresponding positive heterosis for plant height (Dolstra, 1984). Cohen and Galint (1984) observed both positive and negative heterosis for kernel rows/ear (-30 to 45.64 %), plant height and ear length. Mukherjee and Saha (1984) had reported 1.4 to 10.1 per cent heterosis for ear length over better parent and 0.82 to 17.27 per cent heterosis for kernels/row. Further, low heterosis for plant height was found by Miranda Filho and Vencovsky (1984); whereas, positive heterosis for kernel rows/ear and plant height was observed by Kimani (1984). Gupta *et al.* (1986) reported high heterosis for ear length and kernel rows/ear.

Debnath (1987) reported highest heterosis for grains/row followed by ear length and 1000-grain weight. Prasad (1987) reported -16.16 to 28.23 per cent heterosis for harvest index, 25.0 to 30.0 per cent for 100-grain weight, -18.58 to 31.71 per cent for ear length and -35.2 to 62.7 per cent for grain yield per plant over the better parent. Abdul Shakoor (1988) had reported heterosis range from -12.5 to 27.4 per cent for plant height.

Ganguli *et al.* (1989) reported high heterosis for ear height and grain yield over check variety. The extent of heterosis over better parent for ear height was 33.8 to 42.5 per cent and for grain yield 23.8 to 27.5 per cent. Tomov *et al.* (1990) reported high heterosis for ear length, grain yield/unit area and grain rows/ear. Beck *et al.* (1990) reported low heterosis over better parent for yield, plant height, ear height and days to silking.

Walter *et al.* (1991) observed high heterosis for grain yield in a cross $C_3 X C_9$. Alvarez *et al.* (1993) observed positive heterosis for internode number, plant height, ear height, kernels/rows and grain weight and negative heterosis for days to silking and tasselling. Gomes e Gama *et al.* (1993) reported high heterosis for grain yield in a number of crosses.

Altinbas (1995) reported high heterosis for grain yield and days to silking. However, the heterosis was positive for grain yield and negative for days to silking. The range of heterosis was 72 to 140.7 per cent for grain yield and -2.4 to -18 per cent for days to silking. In another study mean heterotic effects were highest for grain yield/plant followed by 100-grain weight, ear length, ear thickness and kernel rows/ear (Chen-Ling *et al.*, 1996). Ismail (1996) observed 16.2 per cent increase in grain yield in F_1 hybrid. The hybrid showed earliness for silking and protandrous interval than that of F_1 mean. The earliness was -3.45 per cent for silking and -3.13 per cent for protandrous interval.

Aguerre *et al.* (1997) reported significant heterosis for grain yield in twelve crosses. The best cross combinations were CDB X P29, CDB X C85P and M17 X P89. Sinha and Mishra (1997) reported that the cross Navin X Population 26 gave the highest grain yield (about 15 per cent more) than the best yield among varieties. This cross had the highest BP heterosis and therefore, the most heterotic combination. Dass *et al.* (1997) through diallel analysis revealed that the cross K-725 X K-644 in summer and K-725 X K-622 in winter produced the highest yielding hybrids.

Tulu and Ramachandrappa (1998) observed that the Abo-Bako was the ideal parent for initiating intra-population interline hybrid programme due to its good general combining ability for grain yield.

2.4 Correlation coefficient

Correlation coefficient is a measure of the degree of association between the two traits worked out at the same time (Hays *et al.*, 1995). It is a well known fact that majority of the traits of economic importance are complex in nature and involve several related traits. Therefore, the knowledge of degree of phenotypic and genotypic correlation between the traits is important for increasing the yield potential through direct or indirect selection as these traits give estimates of performance of lines/hybrids in field (Robinson *et al.*, 1951).

In maize vigour test like accelerated aging test, osmotić stress test and germination percentage have been standardised for prediction of field emergence.

Seedling vigour in corn, is measured either by cold test (Funk *et al.*, 1962 and Burris and Navratil, 1979) or seedling dry weight (Burris, 1975). Both the tests are considered to provide prior information about vigour differences among seed lots. Burris (1975), however, concluded that the correlation between corn seedling emergence and vigour of plant was not consistent in conventional planting system. Johnson and Wax (1981) reported that high vigour seed lots showed faster emergence and increased final stands compared to low-vigour seed lots.

The accelerated aging test has also been correlated with field emergence. The test gave accurate estimates of emergence of genotypes of sugary (su) sweet corn (Kulik and Schoen, 1982). The soil cold test have also been reported to correlate with field emergence of dent corn genotypes (Hunter *et al.*, 1987 and Martin *et al.*, 1988).

Garcia and Lasa (1989) analysed different viability tests and reported that germination in saline solutions at osmotic potentials of -2 or -6 bar were the best predictor of field emergence. Wang *et al.* (1989) found cold test to be the best indicator of field emergence performance. Bohlmann (1989) reported that major discrepancies for germination between paper roll and cold test indicated low seed vigour and low field emergence.

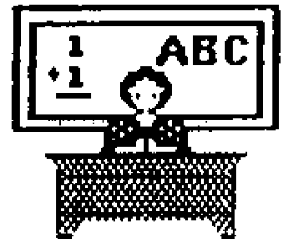
Odiemah (1991) reported the correlation of all seed traits viz., seedling emergence, seed vigour, grain yield/plant and concluded that these were good predictors of field performance. Venter and Lock (1991) studied relationship between vigour tests and field emergence under 4 different environmental conditions. He concluded that high correlation between seed traits and emergence could not be established under very hot and dry climatic conditions.

Dronavalli and Kang (1992) found that physical parameters such as weight of seed influence the performance of a variety under field conditions. He found significant correlations between seed weight and dry matter (0.89); seed weight and vigour index (0.84); and dry matter and vigour index (0.90). The results highlight the importance of heavier seed in obtaining improved seedling vigour. Wilson *et al.* (1992) reported that seed vigour tests have high correlation with final stand count.

Mazur (1994) observed high variability in seedling emergence from seeds having variable shape, size and sowing dates. Early hybrids showed better field emergence. It was suggested to grade seeds each within the same lot for consistency in emergence of seeds. Milosevic *et al.* (1994) reported that field emergence was most closely correlated with the results of the cold test (r=0.94 to 0.95) and the accelerated aging test (r = 0.89 to 0.90).

Kurdikeri *et al.* (1995) reported that seed soaking treatments such as soaking in water or PEG 6000 etc. enhanced field emergence and grain yield compared to dry seed. Highest yield has been observed from seeds soaked in water prior to sowing.

Lovato and Balboni (1997) questioned the use of standard germination tests for estimation of emergence. He was of the view that standard germination test was not a good indicator of field emergence, except for standard sowing date.



MATERIAL AND METHODS

MATERIAL AND METHODS

3.1 Experimental material

The experimental material consisted of 12 maize inbred lines which were derived from local germplasm collected from different parts of Himachal Pradesh and developed composite varieties, Early Composit, Parvati and Naveen through sib mating (Table 3.1). The lines were selected on the basis of their combining ability through top crosses.

Table 3.1 Pedigree and source of maize inbred lines

Inbred Code No.	Pedigree	Source
P_1	HPMS-91-Chd S_2-4-2-3-2-#-#	Chadhiar Local
P_2	HPMS-91-Kum S_9-2-8-3-5-#-#	Kumarsen Local
P_3	HPMS-91-Mal S_{10}-3-5-3-4-#-#	Malan Local
P_4	HPMS-91-Nav S_3-2-5-4-1-#-#	Naveen composite
P_5	HPMS-91-Hat S_5-3-5-4-1-#-#	Hatwas Local
P_6	HPMS-91-Eco S_{10}-3-5-3-3-#-#	Early Composite
P_7	HPMS-91-Par S_1-1-3-4-2-#-#	Parvati composite
P_8	HPMS-91-Par S_5-8-3-5-2-#-#	Parvati composite
P_9	HPMS-91-Ber S_1-1-4-3-2-#-#	Berthin Local
P_{10}	HPMS-91 -Par S_4-3-4-3-2-#-#	Parvati composite
P_{11}	HPMS-91-Sal S_{12}-4-4-5-2-#-#	Saliana Local
P_{12}	HPMS-91-Eco S_5-5-4-5-4-#-#	Early Composite

3.2 Field experimentation

These lines were crossed in diallel mating system excluding reciprocals during *kharif* 1997 at the experimental farm of Seed Production Unit, Palampur. The experimental material consisting of 66 crosses, 12 inbred parents and three hybrids as checks viz., EHB-1520, KH-101, PSCL-3436, was evaluated in a 9 X 9 simple lattice design replicated twice at 2 locations representing different agroclimatic and ecological conditions i.e. HPKV, Palampur, environment I (EI) and RRS, Bajaura, environment II (EII) during *kharif* 1998. The details of environmental conditions of these two locations are given in Appendix-I. Inter and intra-row distances were kept 75 and 20cm, respectively. Each plot comprised 5 rows of 5m length.

3.3 Recording of observations

The data were recorded on plot basis for days to silking, maturity and pollen shed, whereas, for the remaining phenological and yield traits the data were recorded from ten tagged plants in each plot.

3.3.1 Phenological and structural traits

i) Days to silking

Days to silking were recorded as days taken from sowing to silk emergence in 75 per cent plants in the plot.

ii) Days to pollen shedding

Days to pollen shedding were recorded as days taken from sowing to 75 per cent pollen shedding in a plot.

iii) Days to maturity

The number of days from sowing date to the stage when 75 per cent plants had brown husk, were counted.

iv) Plant height (cm)

For 10 plants tagged at random, the height in cm from the base of the plant above the ground to the point where the tassel starts to branch was recorded using a measuring rod and averaged.

v) Ear height (cm)

The height from the plant base to the node bearing the upper ear was determined for recording ear height.

vi) Leaf area/plant (cm^2)

Leaf area for the 10 tagged plants was determined from the leaves subtending top ear (ELA) as per the method suggested by Montgomery (1911).

ELA = 0.75 X length X maximum width

Leaf area per plant was estimated as suggested by Perce *et al.* (1975).

Leaf area/plant = ELA X 9.39.

3.3.2 Yield and yield components

i) Grain yield (g)

Fresh ear weight was recorded at the time of harvest. The moisture was determined in grains using "Universal Moisture Meter". The ear weight was first converted into grain weight assuming shelling percentage as 80 per cent. This grain weight was adjusted at 15 per cent moisture content and grain yield per plant was calculated.

ii) Biological yield (g)

After sun drying the plants, total weight of the tagged plants was calculated and biological yield per plant was measured by dividing total biological yield by number of tagged plants.

iii) Shelling percentage

Shelling prcentage was calculated as the ratio of grain weight over ear weight and multiplied by hundred.

iv) Harvest index (%)

This was calculated by expressing grain yield as per unit of biological yield by following below given formula :

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

v) Kernel rows per ear

The number of kernel rows in each ear of ten plants were counted and the average was worked out.

vi) Kernels per row

The number of kernels in one row of an ear were counted and the average of ten plants was worked out.

vii) Ear length (cm)

The ear length of 10 plants was measured from butt to tip of the ear and average was worked out.

viii) Ear circumference (cm)

Ear circumference was measured from the centre of each ear for the tagged plants and the average was worked out.

3.3.3 Seed quality traits

i) 100-seed weight (g)

From the composited sample of 10 plants, 100-seeds were counted, sun dried and weight was recorded.

ii) 100-seed volume (ml)

In the measured volume of spirit solution, 100-seeds which were weighed earlier, immersed. The amount of solution displaced was equal to the 100-seed volume.

iii) Seed density (g/ml)

It was calculated as weight per unit volume based upon 100-seed weight. The 100-seed weight was divided by 100-seed volume to give seed density.

iv) Seed vigour indices

a) Accelerated aging test : The test was conducted as suggested by Byrd and Delouche (1971). One hundred seeds of each genotype in 2 replications were wrapped in muslin cloth and kept in desiccator having water in the bottom. The desiccator was sealed to maintain 95±5 per cent relative humidity and kept in incubator at 40±1°C temperature for 96 hours. Thereafter, the seeds were dried to normal moisture conditions and then usual germination test was performed. Germination count was recorded after five days.

b) Osmotic stress test : This test was performed as per the method suggested by Langer-Werff (1961) using polyethylene glycol (PEG). The solution was prepared by dissolving 19.6 g PEG in 100 ml of water to create - 5.0 bar pressure.

c) Germination percentage : Standard germination test was carried out using top of paper method in seed germinator at 25±1°C temperature and 85±5 per cent RH, as per the method of ISTA (1985). Final count was recorded on 5th day.

d) **Field emergence :** Counted number of seeds were sown in plots and the number of seedlings emerged on plot basis were counted and the per cent emergence was worked out.

e) **Coleoptile length** : The coleoptile length was measured in cm upto the base of first leaflet from the seedlings emerged of normal germination test.

f) **Seedling vigour index** : Seedling vigour index was calculated by following formula:

$$\text{Seedling vigour index} = \frac{\text{Coleoptile length} \times \text{Standard germination}}{100}$$

3.3.4 Reaction to leaf blight

The incidence of leaf blights (*Helminthosporium maydis* and *H. turcicum*) and brown spot (*Physoderma zeae maydis*) was observed under field conditions. The observation were recorded as 0 (no), 1 (slight), 2 (light), 3 (moderate), 4 (heavy) and 5 (very heavy) infection (Chenulu and Hora, 1962).

3.4 Statistical analysis

The experimental data were subjected to the following analyses:

3.4.1 Analysis of variance for the experimental design

3.4.2 Diallel analysis

3.4.2.1 Combining ability analysis for individual environment

3.4.2.2 Combining ability analysis pooled over environments

3.4.2.3 Estimation of components of genetic variance

3.4.3 Estimation of heterosis over standard check

3.4.4 Estimation of correlation coefficients

3.4.1 Analysis of variance for the experimental design

Analysis of variance for simple lattice design was done using method given by Federer (1963). The simple lattice design is applicable when the number of varieties, 'v' is a perfect square. Simple lattices are unlikely to be more accurate than randomized blocks unless the variation among incomplete blocks is greater than the variation within incomplete blocks. The mathematical model of analysis of variance leads to the following break-up of the variance components.

Analysis of variance table

Source of variation	df	MS	Expected MS
Replication	(r-1)		
Treatments	(K^2-1)		
Block (Rep.)	r(K-1)	Eb	$\sigma^2_e + \frac{r-1}{r} K\sigma^2\beta$
Intra block-Error	(K-1) (rK-K-1)	Ee	σ^2_e
Total	rk^2-1		

Where r = Number of replication,

K = Number of blocks,

σ^2_e= Population variance associated with the random error deviations.

$\sigma^2\beta$=Population variance associated with the incomplete block deviations

If Eb is greater than Ee, proceed to calculate μ, ' the weighting factor' to be used for adjusting the varietal totals for the block effects.

$$\mu = \frac{Eb - Ee}{K\ (r-1)\ Eb}$$

Where, Eb and Ee are, respectively, the mean squares for blocks and intra-block error. If Eb is less than Ee, the factor is taken as zero and no adjustments are made for block effects, the experiment being analysed as in randomized blocks.

3.4.2 Diallel cross analysis

A set of all possible matings among a set of genotypes is designated as a diallel mating system and analysis of such a crossing programme is known as diallel analysis. The analysis provides information on general and specific combining ability of parents and their crosses and also on the nature and magnitude of genetic parameters. The diallel analysis is based on the validity of the following assumptions :

i) Normal diploid segregation.

ii) No differences between reciprocal crosses, i.e., no maternal effects.

iii) Independent action of non-allelic genes.

iv) No multiple allelism.

v) Homozygous parents.

vi) Genes independently distributed between the parents.

vii) No genotype - environment interactions.

The validity of various assumptions was tested by applying t^2 test as follow :

$$t^2 = \frac{n-2}{4} \left[\frac{(\text{Var Vr} - \text{Var Wr})^2}{\text{Var Vr} \times \text{Var Wr} - \text{Cov}^2 (\text{Vr}, \text{Wr})} \right]$$

Where,

n = number of parents

It is a simple 'F' test with n-2 degrees of freedom. The nonsignificant values of t^2 confirms the validity of the hypothesis postulated.

The regression coefficient (b) provides another test for testing the hypothesis. Here, the regression of covariance on the variance is calculated as:

$$b = \text{Cov (Wr, Vr)}/\text{Var Vr}.$$

Standard error of regression coefficient [SE(b)] :

$$SE\ (b) = \pm \sqrt{[(\text{Var Wr-b Cov Wr, Vr})/\text{Var Vr}(n-2)]}.$$

The significance of 'b' from zero and unity was tested as follows:

$$Ho : b = O = (b-0)/SE(b)$$

$$Ho : b = 1 = (1-b)/SE(b)$$

The significance of regression coefficient against tabulated value (t) for n-2 degrees of freedom indicates the failure of hypothesis.

3.4.2.1 Combining ability analysis for individual environment

The data obtained from F_1 population was subjected to combining ability analysis Griffing's (1956b) experimental method 2 model I was considered to be the most appropriate for the material under study. Method 2 (half diallel) was applicable to the present investigation as parents and one set of F_1's were included without reciprocals. Model I is the fixed model i.e. it assumes that the variety and block effects are constant but the environmental effect (error) is a random variable such that e_{ijkl} are normally and independently distributed with mean zero and variance one.

When the 'F' test for genotypes revealed significant differences among the genotypes, combining ability analysis was done. A linear mathematical model for an observation made of ij^{th} genotype could be expressed as :

$$Y_{ij} = \mu + g_i + g_j + s_{ij} + \frac{1}{bc} \Sigma_k \Sigma_l e_{ijkl}$$

$i,j = 1, \text{------}, P,$

$k = 1, \text{-----}, b,$

$l = 1, \text{------}, c.$

Where,

μ = population mean,

g_i = general combining ability effect of i^{th} parent,

g_j = general combining ability effect of j^{th} parent,

s_{ij} = specific combining ability effect of the cross between the i^{th} parent such that $s_{ij} = s_{ji}$, and

e_{ijkl} = environmental effect associated with $ijkl^{th}$ observation.

The restrictions $\Sigma_i\ g_i = 0$, and $\Sigma_j\ S_{ij} + S_{ii} = 0$ (for each i)

are imposed. The structure of the ANOVA for combining ability is given in the table below :

ANOVA for combining ability:

Source	df	SS	MS	Expectation	F-ratio
General combining ability (gca)	(p-1)	s_g	M_g	$\sigma^2_e + \frac{(p+2)}{(p-1)} \Sigma_i\ g_i^2$	Mg/Me'
Specific cmobining ability (sca)	$\frac{p(p-1)}{2}$	s_s	M_s	$\sigma^2_e + \frac{2}{p(p-1)} \Sigma_i\Sigma_j\ S_{ij}^2$	Ms/Me'
Error	m	s_e	M_e' (=Me/r)	σ^2_e	

Where,

$$S_g = \frac{1}{p+2} \left[\Sigma_i\ (Y_{i.} + Y_{ii})^2 - \frac{4}{p} Y^2..\right], \text{ and}$$

$$S_s = \sum_{i \le j}\sum Y^2_{ij} - \frac{1}{p+2} \Sigma_i\ (Y_{i.} + Y_{ii})^2 + \frac{2}{(p+1)\ (p+2)} Y^2..$$

$$m = p(p-1) / 2+p-1(r-1)$$

Where the mean squares for gca and sca were found siognificant their respective effects and standard errors were calculated. Thus, $\hat{g}_i$ the estimates of gca effects of i[th] inbred line was as:

$$g_i = \frac{1}{p+2} [(Y_{i.} + Y_{ii}) - \frac{2}{p} Y..]$$

Standard errors required to test significance of gca effects and difference between gca effects were obtained as:

$$S.E.\ g_i = \left[\frac{p-1}{p(p+2)} \sigma^2_e \right]^{1/2}$$; and

$$SE\ (g_i - g_j) = \left[\frac{2}{p+2} \sigma^2_e \right]^{1/2}$$

Estimates of S_{ij}, the specific combining ability effect of ij[th] cross is computed as:

$$\hat{S}_{ij} = Y_{ij} - \frac{1}{(p+2)} [Y_{i.} + Y_{ii} + Y_{j.} + Y_{jj} + \frac{2}{(p+1)(p+2)} Y..]$$

Various standard errors required to test the significance of gca effects and differences between sca effects, are calculated as:

$$S.E.\ s_{ij} = \left[\frac{p^2+p+2}{(p+1)\ (p+2)} \sigma^2_e \right]^{1/2}$$

$$S.E.\ (S_{ij} - S_{ik}) = \left[\frac{2(p+1)}{p+2} \sigma^2_e \right]^{1/2}$$; and

$$S.E.\ (S_{ij} - S_{kl}) = \left[\frac{2p}{p+2} \sigma^2_e \right]^{1/2}$$

Critical differences were calculated by multiplying the corresponding standard error of difference SE(d) with 't' value at error degrees of freedom.

Each gca and sca value was tested against zero for its significance by 't' test,

$$t = \frac{g_i - o}{SE\ (g_i)} \quad \text{and} \quad t = \frac{S_{ij} - o}{SE(s_{ij})}$$

The 't' value obtained was tested against tabulated value at P≤0.05 at error degrees of freedom.

3.4.2.2 Combining ability analysis pooled over environments

The pooled analysis over environments for combining ability for experimental Method 2 Model I (Griffing, 1956,a) was carried out by following method of Singh (1973) and notations used by him are:

P(number of parents), b (number of blocks), c(number of observations for each of the plot) and l(number of environments).

The summation notations followed by Griffing (1956a) method 2 were as follows:

$$X_{ij} = S_k\ S_{ijk}\ ;\ X_{i.k} = S_j\ X_{ijk}$$

where, $X_{ijk} = X_{jik}$;

$$X_i = S_j\ X_{ij} = S_k\ X_{i.k}$$

Where, $X_{ij} = X_{ji}$,

$X_{..k} = S_i \leq S_j\ X_{ijk}$;

$X_{...} = S_k\ X_{..k}$

The model used is:

$$X_{ijk} = \mu + g_i + g_j + S_{ij} + l_k + (gl)_{ik} + (gl)_{jk} + (sl)_{ijk} + H + 1/bc\ S_m\ S_r\ L_{ijkmr}$$

Where,

μ= population mean,

$g_i(g_j)$ = gca effect of $i^{th}(j^{th})$ parent,

S_{ij} = sca effect of the crosses between the i^{th} and j^{th} parents,

l_k = effect of k^{th} environments,

$(gl)_{ik}$ or $(gl)_{jk}$ = interaction between gca effects of the i^{th} and j^{th} parent with k^{th} environment,

$(Sl)_{ijk}$ = inatraction between sca effects of the ij^{th} cross and the k^{th} environment,

H = O for fixed effect model (Model I).

Least square estimates of effects and their interaction with environment/year:

The estimates are:

$$\hat{\mu} = 2\ X\ ...\ /p(p+1)l.$$

$$\hat{g}_i = [X_{i}..+X_{ii}.\ -\ (2/p)X...]\ /\ (p+2)l.$$

$$\hat{S}_{ij} = (X_{ij}./l)\ -\ [X_{i}..+X_{ii}.+X_{j}..+X_{jj}.)/(p+2)l]\ +2\ X\ /(p+1)(p+2)l.$$

$$\hat{l}_k = [2X.._k/p\ (p+1)]-2X.../p(p+1)l.$$

$$\hat{gl} = \{[X_{i\cdot k}+X_{iik}-(2/p)X.._k]/(p+2)\}\ -\ \{X_{i}\ \ -(2/p)X\ \}/(p+2)l.$$

$$\hat{Sl} = X_{ijk}\ -\ (X_{i\cdot k}+X_{iik}+X_{j\cdot k}+X_{jjk})/(p+2)\ +[2X.._k/(p+1)(p+2)]\ -X_{ij}./l\ +[(X_{i}..$$

$$+X_{ii}+X_{j}\ +X_{jj})/(p+2)l]\ +\ [2X\ /(p+1)(p+2)l]$$

The sum of squares were calculated as follows:

$$SS(\hat{\mu}) = 2X^2\ /p(p+1)l$$

$$SS(\hat{g}) = [S_i(X_{i}..+X_{ii}.)^2/(p+2)l]\ -[4X^2\ /p(p+2)l]$$

$$SS(\hat{s}) = S_i \leq S_j\ (X^2_{ij}./l)\ -[S_i\ (X_{i}..+X_{ii})^2/(p+2)l)]\ +\ [2X^2.../(p+1)(p+2)l]$$

$$SS(\hat{l}) = [2\ S_k\ X^2.._k/p(p+1)]\ -\ [2X^2.../p(p+1)l]$$

$$SS(\hat{gl}) = [S_kS_i\ (X_{i\cdot k}+X_{iik})^2/(p+2)]-[4S_kX^2\ _k/p(p+2)]-[S_i(X_{i}..+X_{ii}.)^2/(p+2)l]+4X^2.../p(p+2)l].$$

$$SS(\hat{sl}) = S_k\ S_i\ \leq\ S_j\ X_{ijk}^2\ -[S_k\ S_i\ (X_{i\cdot k}+X_{iik})^2/(p+2)]\ +\ [2\ S_k\ X^2.._k/(p+1)(p+2)]$$

$$-[S_i \leq S_j\ x^2_{ij}./l]\ +\ [S_i\ (X_{i}..+X_{ii}.)^2/(p+2)l]\ -\ [2X^2.../(p+1)(p+2)l]$$

Where.

$SS(\hat{g})$ = Sum of squares due to gca

$SS(\hat{s})$ = Sum of squares due to sca

$SS(\hat{l})$ = Sum of squares due to location

$SS(\hat{gl})$ = Sum of squares due to gca X location

$SS(\hat{sl})$ = Sum of squares due to sca X location

X_{i} = Arrays total of i^{th} parent

X_{ii} = Mean values of the i^{th} parent

$X_{..}$ = Grand total of p(p-1) progenies and parental values.

Analysis of variance for the design of experiment

Source	df	MS	Expectation of MS
gca	p-1	M_g	$\sigma^2_e + \frac{(p+2)l}{(p-1)} S_i\ g^2_i$
sca	p(p-1)/2	M_s	$\sigma^2_e + \frac{2l}{p(p-1)} S_i \leq S_j\ S^2_{ij}$
Location	(l-1)	M_l	$\sigma^2_e + \frac{p(p+1)}{2(l-1)} S_k\ l_k^2$
gca X location	(p-1)(l-1)	M_{gl}	$\sigma^2_e + \frac{p+2}{(p-1)(l-1)} S_k S_i (gl)^2_{ik}$
sca X location	p(p-1)(l-1)/2	M_{sl}	$\sigma^2_e + \frac{2}{p(p-1)(l-1)} S_k S_i \leq S_j (Sl)^2_{il}$
Eerror	l(p-1)(b-1)	M_e	σ^2_e

Variance of the difference between any two mean values is :

$$Var.\ (X_{ij} - X_{km}) = 2\sigma^2_e/l$$

Variance of effects and their difference

i) Var. (μ) = $[2/p(p+1)I]\ \sigma^2_e$

ii) Var (g) = $[(p-1)/p(p+2)I]\ \sigma^2_e$

iii) Var $(g-g)$ = $[2/(p+2)I]\ \sigma^2_e$ $(i \neq j)$

iv) Var (S) = $[(p^2+p+2)/(p+1)(p+2)I]\ \sigma^2_e$ $(i \neq j)$

v) Var. $(S_{ij}-S_{ik})$ = $[2(p+1)/(p+2)I]\ \sigma^2_e$ $(i \neq j,k)$

vi) Var. $(S_{ij}-S_{km})$ = $[2p/(p+2)I]\ \sigma^2_e$ $(i \neq j,k,m)$

Where,

$\hat{\sigma}^2_e$ is the estimate of σ^2_e and is given by σ^2_e = Me

SE of an estimate: SE = (Var. of that estimate)$^{1/2}$

CD of the estimates: Applicable to differences between any two mean values and to the differences between estimates involved in (ii) to (vi):

CD = SE X 't'; where t is the tabulated value at error degree of freedom at $p \leq 0.05$.

Estimation of genetic parameters : According to model as suggested by Griffing (1956b) :

$X_{ij} = \mu + g_i + g_j + s_{ij}$ + error

Where,

X = phenotypic value of the ijth observation and i, j = 1, 2 .... p, (i<j)

μ = population mean

g_i (g) = gca effect of the ith (jth) inbred line

s = sca effect associate with the cross of the ith and jth inbreds and such that $s = s$

error = environmental error effects associated with the ijth observation.

The estimation of the components of variance is accomplished by equating the observed to the expected mean square and solving. Thus, For individual analysis gca components of variance : $\sigma^2_g = \dfrac{Mg - Ms}{p-2}$

Additve variance $(\sigma^2_A) = 4\sigma^2_{gca}$

sca component of variance $(\sigma^2_s) = \dfrac{2Si\ Sj\ Sij^2}{p(p-1)} = Ms - Me'$

and dominance variance $(\sigma^2_D) = 4\sigma^2_{sca}$

(For open pollinated crops)

For pooled analysis: $\sigma^2_g = \dfrac{Mg - Ms}{(p-2)l}$ and $\sigma^2_s = \dfrac{Ms - Me'}{l}$

Where,

l = number of locations

Mean degree of dominance = $\left[\dfrac{\sigma^2_D}{\sigma^2_A}\right]^{1/2}$

3.4.2.3 Estimation of components of genetic variance

The following genetic components of variation were calculated as per the method proposed by Hayman (1954):

$D = V_0L_0 - E$

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

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

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

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

$F_r = 2(V_0L_0 - W_0L_{01} + V_1L_1 - W_r - V_r) - 2(p-2)E/p$

Where,

D = measure of additive genetic variance

F = the mean of 'F_r' over the arrays

H_1 = measure of dominance variance

H_2 = measure of non-additive effects for gene distribution,

= H_1 $[1-(u-v)^2]$ where, 'u' is the proportion of positive genes in the parents, 'v' is the proportion of negative genes in the parents and u+v =1,

h^2 = dominance effect (as the algebraic sum over all loci in heterozygous phase in all crosses)

E = the expected environmental component of variation which is same as observed in the analysis of variance for the design.

To test each of these components standard error for each is calculated. For this first of all common multiplier of variance (=s^2) is calculated.

$$S^2 = [Var\ (Wr - Vr)]/2$$

$$SE\ (D) = \left[\frac{p^5 + p^4}{p^5} S^2 \right]^{1/2}$$

$$SE\ (H_1) = \left[\frac{p^5 + 41p^4 - 12p^3 + 4p^2}{p^5} S^2 \right]^{1/2}$$

$$SE\ (H_2) = \left[\frac{36p^4}{p^5} S^2 \right]^{1/2}$$

$$SE\ (h^2) = \left[\frac{16p^4 + 16p^2 - 32p + 16}{p^5} S^2 \right]^{1/2}$$

$$SE\ (F) = \left[\frac{4p^5 + 20p^4 - 16p^3 + 16p^2}{p^5} S^2 \right]^{1/2}$$

$$SE\ (E) = \left[\frac{p^4}{p^5} S^2 \right]^{1/2}$$

Where p is the number of inbred lines. When the estimates of D, H_1, H_2, F, h^2 and E were found to be significant, the following ratios were obtained, which furnish useful information on various aspects of inheritance pattern of the metric traits being investigated :

1. $(H_1/D)^{1/2}$ provided information regarding average degree of dominance involved in the action of genes.
2. $H_2/4H_1$ determined the proportion of genes with positive and negative effects in the parents.
3. $\frac{(4DH_1)^{1/2} + F}{(4DH_1)^{1/2} - F} = K_D/K_R$ gave information regarding the proportion of dominant and recessive genes in the parents.
4. h^2/H_2 gave information about the number of gene groups exhibiting dominance
5. The coefficient of correlation (r) between the parental order of dominance (Wr +Vr) and parental measurement (Yr) was calculated to get an idea about the dominance of genes with positive and negative effects.

3.4.3 Estimation of heterosis over best check

The magnitude of heterosis was estimated over the best check (BC) as follow:

$$\text{Heterosis over best check (\%)} = \frac{\overline{F}_1 - \overline{BC}}{\overline{BC}} \times 100$$

Calculation of standard error [SE(d)]

S.E. (d) for testing heterosis over BC = $\pm \sqrt{2Me/r}$

Test of significance for heterosis :

$$\text{Calculated 't'} = \frac{\overline{F}_1 - \overline{BC}}{\overline{SE}}$$

Calculated value of 't' was compared with 't' tabulated at error degrees of freedom at $P \leq 0.05$.

3.4.4 Estimation of correlation coefficients

Phenotypic (r_p), genotypic (r_g) and environmental (r_e) correlation coefficients were calculated by analysis of variance-covariance technique, as suggested by Al-Jibouri *et al.* (1958).

Phenotypic coefficient of correlation

$$rp_{xy} = \frac{\sigma p_{xy}}{(\sigma^2 p_x \times \sigma^2 p_y)^{1/2}}$$

Where,

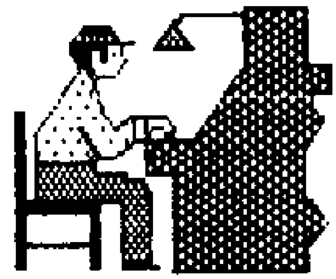
σp_{xy} = Phenotypic covariance between two characters x and y,

$\sigma^2 p_x$ = Phenotypic variance of character x, and

$\sigma^2 p_y$ = Phenotypic variance of character y.

Similarly, correlation coefficients at genotypic and environmental levels were worked out using the respective covariance and variance.

The significance of phenotypic coefficients of correlation was tested against 'r' values as given by Fisher and Yates (1963) at n-2 degrees of freedom.



EXPERIMENTAL RESULTS

Chapter-IV

RESULTS

Data collected on various traits in the present investigation were subjected to the following analyses:

4.1 Analysis of variance for the experimental design

4.2 Diallel analysis

4.2.1 Combining ability analysis

4.2.2 Genetic component analysis

4.3 Heterosis on the best check, and

4.4 Correlation coefficient analysis

4.1 Analysis of variance for the experimental design

Data obtained from the experiments conducted, were subjected to the analysis of variance. Separate analysis was done for the data from Palampur and Bajaura locations and pooled over both the locations. Perusal of results revealed significant differences among the genotypes for all the traits under study except, days to maturity at Palampur (Table 4.1 and 4.2). The trait had been excluded from the further statistical analysis. Whereas, in case of Bajaura, analysis of variance revealed significant differences among the genotypes for all the traits under study.

The pooled analysis over the locations was also found to have significant genotype X environment interaction for all the traits under study except, days to maturity. The mean values for yield and different yield

Table 4.1 Analysis of variance for experimental design for yield and yield components at Palampur (E_1) and Bajaura (E_2)

Character	Source :	Mean squares due to							
		Reps.		Block (Rep)		Treatment		Error	
	df:	1		16		80		64	
		E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Days to 75% silking		0.89	5.19*	4.63*	1.31*	3.19*	1.57*	1.13	0.66
Days to 75% pollen shedding		0.03	0.75	4.14*	1.719*	2.79*	2.04*	1.08	0.77
Leaf area/plant		97.04	1367271.81*	338821.68*	131623.99*	386179.89*	244466.30*	162137.09	104708.47
Plant height		21.48	25.44	195.68*	88.68*	243.05*	187.32*	57.87	43.77
Ear height		0.07	9.49	108.05*	48.80	144.02*	88.42*	33.36	30.25
Days to 75% maturity		4.84	0.15	6.75*	1.46	3.29	1.87*	2.66	0.86
Ear length		1.56	2.85	1.31	1.05	1.85*	1.94*	0.93	0.75
Ear circumference		0.001	1.26*	0.34	0.40	0.61*	0.76*	0.22	0.24
Kernel rows/ear		0.05	0.05	0.18	0.32	1.67*	1.73*	0.28	0.35
Kernels/row		3.37	0.68	4.08	3.61	10.15*	9.85*	3.74	3.61
Shelling percentage		8.52	6.99	2.84	4.72*	6.86*	7.18*	3.76	2.49
100-seed weight		0.38	6.06	3.94*	2.64	5.37*	6.26*	2.05	2.21
Grain yield		1.01	7.14	17.10	16.52	324.51*	187.98*	14.08	13.99
Biological yield		25.06	15.51	114.44	84.94	944.40*	977.29*	101.86	89.39
Harvest index		1.80	0.70	1.02*	0.46	17.54*	15.50*	0.49	0.38

* Significant at $P \leq 0.05$

Table 4.2 Analysis of variance for yield and yield components in maize pooled over 2 environments

Character	Source : df:	Loc 1	Rep 1	Blk (Rep) 16	Trt 80	Loc X Trt 80	Error 145
		Mean squares due to					
Days to 75% silking		233.34*	0.89	1.83	3.35*	1.77*	1.28
Days to 75% pollen shedding		388.97*	0.52	2.68*	3.18*	1.99*	1.17
Leaf area/plant		732883949.47*	672165.86*	166470.91	389561.32*	347134.76*	156116.65
Plant height		182351.30*	46.84	139.13*	302.46*	173.65*	60.89
Ear height		28749.27*	5.60	33.29	169.05*	88.12*	41.74
Days to 75% maturity		124.69*	1.63	3.30	3.07*	2.43	2.12
Ear length		228.21*	0.10	1.63*	2.36*	1.82*	0.85
Ear circumference		4.54*	0.60	0.51*	1.06*	0.42*	0.23
Kernel rows/ear		82.12*	0.10	0.16	2.74*	0.69*	0.32
Kernels/row		7085.15*	3.54	3.81	12.93*	8.46*	3.68
Shelling percentage		2391.86*	15.47*	3.41	9.47*	5.19*	3.66
100-seed weight		53.44*	4.75	2.27	8.81*	3.88*	2.37
Grain yield		30532.71*	6.75	20.95	433.89*	107.83*	13.80
Biological yield		160910.18*	0.57	104.40	1486.37*	551.66*	95.17
Harvest index		6.09*	2.37*	0.88*	31.45*	1.97*	0.45

* Significant at $P \leq 0.05$

components obtained in the two environments and their pooled means are presented in Appendix- II. Analysis of variance for seed quality traits is presented in (Table 4.3). The differences among the treatments were significant for all the traits studied. The mean values for different seed quality traits are presented in Appendix-III.

4.2 Diallel analysis

4.2.1 Combining ability analysis

The analysis of variance for combining ability at Palampur and Bajaura for different characters is presented in Table 4.4 and for pooled over the environments in Table 4.5 and for seed quality trairs in Table 4.6.

The mean sum of squares due to general combining ability (gca) were significant for days to silking, days to pollen shedding, leaf area/plant, plant height, ear height, ear length, ear circumference, kernel rows/ear, kernels/ row, shelling percentage, 100-seed weight, grain yield, biological yield and harvest index in both the environments as well as pooled basis and for days to maturity at Bajaura only.

The mean sum of squares due to specific combining ability (sca) were found to be significant for all the traits studied at Palampur, Bajaura as well as on pooled basis except for days to maturity in both the environments.

The magnitude of gca variance was higher than the corresponding sca variance for all the traits in both the environments as well as on pooled basis except for grain yield, harvest index and biological yield at Palampur; for grain yield, harvest index and kernels/row at Bajaura; and for grain yield and harvest index on pooled basis. The gca X e interaction in pooled analysis was significant for days to silking, days to pollen shedding, days to maturity, plant

Table 4.3 Analysis of variance for experimental design for seed quality traits

Character	Source : df:	Mean squares due to Rep. 1	Blk (Rep) 16	Trt 80	Error 64
100-seed weight		11.16*	3.14*	4.46*	1.64
100-seed volume		2.47	1.37	2.96*	0.82
Seed density		0.003*	0.0004	0.002*	0.0005
Accelerated aging test		0.01	9.22	51.25*	9.91
Osmotic stress test		4.17	10.94	57.49*	15.11
Germination percentage		26.08*	5.91	12.44*	6.28
Seed vigour index		82.76*	4.14	7.12*	4.79
Field emergence		5.56	14.36	74.31*	16.98

* Significant at $P \leq 0.05$

Table 4.4 Analysis of variance for combining ability for yield and yield components at Palampur (E_1) and Bajaura (E_2)

Character	Source : df:	Mean squares due to GCA 11		SCA 66		Error 77	
		E_1	E_2	E_1	E_2	E_1	E_2
Days to 75% silking		2.34*	1.69*	1.88*	0.66*	0.93	0.41
Days to 75% pollen shedding		1.96*	1.80*	1.55*	0.98*	0.86	0.50
Leaf area/plant		337878.49*	376000.20*	227457.42*	118827.14*	100889.82	54286.68
Plant height		281.41*	156.48*	145.54*	97.61*	42.92	27.29
Ear height		268.66*	92.55*	76.86*	47.05*	24.01	17.11
Days to 75% maturity		2.23	2.77*	1.69	0.48	1.74	0.51
Ear length		0.98*	1.58*	0.97*	1.04*	0.50	0.42
Ear circumference		0.44*	0.40*	0.29*	0.27*	0.13	0.13
Kernel rows/ear		3.08*	2.04*	0.47*	0.66*	0.13	0.18
Kernels/row		6.30*	3.66*	5.91*	6.31*	1.89	1.76
Shelling percentage		5.19*	10.25*	4.08*	3.95*	2.15	1.48
100-seed weight		6.56*	4.67*	3.35*	3.40*	1.21	1.13
Grain yield		185.32*	129.71*	285.64*	141.44*	7.37	7.39
Biological yield		524.91*	944.46*	629.23*	524.14*	51.12	45.23
Harvest index		7.99*	6.40*	15.23*	12.58*	0.29	0.20

* Significant at $P \leq 0.05$

Table 4.5 Analysis of variance for combining ability for yield and yield components for pooled over 2 environments

Character	Source : df:	Mean squares due to GCA 11	SCA 66	Location 1	GCA X Location 11	SCA X Location 66	Error 154
Days to 75% silking		2.66*	1.75*	100.96*	1.37*	0.79	0.67
Days to 75% pollen shedding		1.86*	1.67*	182.00*	1.90*	0.86	0.68
Leaf area/plant		637561.37*	158879.99*	358235630.00*	76317.32	187404.58*	77592.18
Plant height		240.85*	170.83*	87827.75*	197.03*	73.32*	35.07
Ear height		275.40*	85.65*	13891.34*	85.81*	38.26*	20.56
Days to 75% maturity		2.68*	2.27*	56.64*	3.32*	0.90	1.12
Ear length		2.01*	0.98*	114.05*	0.54	0.97*	0.46
Ear circumference		0.76*	0.33*	2.58*	0.09	0.23*	0.13
Kernel rows/ear		4.83*	0.77*	39.37*	0.29*	0.36*	0.15
Kernels/row		8.73*	7.47*	3350.75*	1.23	4.75	1.83
Shelling percentage		12.63*	4.44*	1172.33*	2.81	2.58*	1.82
100-seed weight		9.81*	4.70*	29.42*	1.43	2.05*	1.17
Grain yield		260.80*	371.60*	14376.65*	54.23*	55.48*	7.38
Biological yield		1080.71*	889.99*	75761.35*	388.66*	263.38*	48.20
Harvest index		13.02*	26.86*	3.19*	1.38*	0.95*	0.25

* Significant at $P \leq 0.05$

Table 4.6 Analysis of variance for combining ability for seed quality traits

		Mean squares due to		
	Source :	GCA	SCA	Error
Character	df:	11	66	77
100-seed weight		4.78*	2.44*	0.99
100-seed volume		4.15*	1.45*	0.46
Seed density		0.0009*	0.0009*	0.0002
Accelerated aging test		22.18*	23.01*	4.98
Osmotic stress test		44.01*	28.49*	6.47
Germination percentage		8.82*	5.57*	3.17
Seed vigour index		4.71*	3.56*	2.35
Field emergence		74.98*	32.97*	8.21

* Significant at $P \leq 0.05$

height, ear height, kernel rows/ear, grain yield, biological yield and harvest index. Further sca X e interaction was significant for leaf area/plant, plant height, ear height, ear length, ear circumference, kernel rows/ear, kernels/row, shelling percentage, 100-seed weight, grain yield, biological yield and harvest index.

In case of seed quality traits, the mean sum of squares due to general and specific combining abilities were found to be significant for 100-seed weight, 100-seed volume seed density, accelerated aging test, osmotic stress test, germination percentage, seed vigour index and field emergence.

4.2.1.1 Estimation of mean degree of dominance

Overdominance was recorded for all the yield components at both the locations and in pooled analysis. The mean degree of dominance was greater the unity for days to silking, pollen shedding, leaf area per plant, plant height, ear height, ear length, ear circumference, kernel rows per ear, shelling percentage and 100-seed weight. In addition to these traits overdominance was also reported for kernels per row at Palampur; biological yield at Bajaura; and days to maturity, kernels per row and biological yield in pooled analysis (Table 4.7).

Overdominance was exhibited for seed quality traits viz., 100-seed weight, 100-seed volume, osmotic stress test, seed vigour index and field emergence (Table 4.8).

4.2.1.2 Estimates of general combining ability (gca) effects

The estimates of gca effects associated with parental lines for different characters in both the environments as well as pooled over the environments were significant (Table 4.9, 4.10 and 4.11) and are described below:

Table 4.7 Estimates of mean degree of domiance along with variance component of gca and sca for yield and yield contributing traits for Palampur (E_1), Bajaura (E_2) and pooled over two environments

Character	Palampur			Bajaura			Pooled		
	$\sigma^2 g$	$\sigma^2 s$	$\sqrt{\frac{\sigma^2 s}{\sigma^2 g}}$	$\sigma^2 g$	$\sigma^2 s$	$\sqrt{\frac{\sigma^2 s}{\sigma^2 g}}$	$\sigma^2 g$	$\sigma^2 S$	$\sqrt{\frac{\sigma^2 s}{\sigma^2 g}}$
Days to 75% silking	0.05	0.94	4.53	0.10	0.25	1.60	0.05	0.54	3.46
Days to 75% pollen shedding	0.04	0.70	4.12	0.08	0.48	2.39	0.10	0.49	7.10
Leaf area/plant	11042.11	126567.60	3.39	25717.30	0 64540 50	1.58	23934.06	40643 91	1.30
Plant height	13.17	102.62	2.79	5.88	70.33	3.46	3.50	67.88	4.40
Ear height	19.18	52.84	1.66	4.55	29.94	2.57	9.49	32.54	1.85
Days to 75% maturity	0.05	-	-	0.22	-	-	0.02	0.08	1.94
Ear length	0.01	0.41	7.61	0.06	0.62	3.33	0.05	0.26	2.23
Ear circumference	0.001	0.16	12.73	0.01	0.14	3.28	0.02	0.10	2.20
Kernel rows/ear	0.26	0.34	1.14	0.14	0.49	1.87	0.20	0.31	1.23
Kernels/row	0.04	4.01	10.15	-	4.55	-	0.06	2.82	6.69
Shelling percentage	0.21	0.93	2.10	0.63	2.47	1.98	0.41	1.31	1.79
100-seed weight	0.32	2.14	2.58	0.13	2.27	4.24	0.26	1.76	2.63
Grain yield	-	278.27	-	-	134.05	-	-	182.11	-
Biological yield	-	578.11	-	42.03	478.91	3.38	9.54	420.90	6.64
Harvest index	-	14.94	-	-	12.38	-	-	13.31	-

- Not calculated.

Table 4.8 Estimates of mean degree of dominance along with variance component of gca and sca for seed quality traits

Character	$\sigma^2 g$	$\sigma^2 s$	$\sqrt{\frac{\sigma^2 D}{\sigma^2 A}} = \sqrt{\frac{\sigma^2 s}{\sigma^2 g}}$
100-seed weight	0.23	1.45	2.49
100-seed volume	0.27	0.99	1.91
Seed density	-	0.001	-
Accelerated aging test	-	18.03	-
Osmotic stress test	1.55	22.03	3.77
Germination percentage	0.33	2.41	2.72
Seed vigour index	0.12	1.21	3.24
Field emergence	4.20	24.76	2.43

- Not calculated

Days to silking

Negative gca effects for days to silking were exhibited by the parents P_2, P_6 and P_5 at Bajaura; and by P_4 and P_8 at Palampur and on pooled basis. Positive gca effects were observed for P_7 at Palampur; P_1 and P_9 at Bajaura; and P_1 and P_7 on pooled basis.

Days to pollen shedding

Negative gca effects were observed for P_4 at Palampur; P_2 and P_6 at Bajaura; and P_4 and P_2 on pooled basis. Positive effects were exhibited by P_7 and P_{12} at Palampur; P_1, P_9 and P_3 at Bajaura; and P_7 on pool basis.

Leaf area per plant

GCA effects were positive for the parents P_2 and P_7 at Palampur; for P_2, P_7, P_8 and P_9 at Bajaura; and P_2 and P_7 on pooled basis. Negative gca effects were observed for P_5 at Palampur; and P_3 and P_5 at Bajaura and on pooled basis.

Plant height

Combined analysis over the two environments showed negative gca effects for P_3, P_4, P_5 and P_8 whereas, these effects were positive for P_9 and P_{11}. Negative gca effects were observed for parents P_5, P_8 at Palampur; and for P_1, P_3, P_5, P_8 at Bajaura, however, positive gca effects were also observed in P_1, P_{10} at Palampur; and P_6, P_7, P_9, P_{11} and P_{12} at Bajaura.

Ear height

Analysis of pooled data from the two environments revealed negative gca effects for the parents P_4, P_5, P_7, P_8 and P_9 and positive for P_1, P_3, P_{10}

Table 4.9 Estimates of general combining ability effects for yield and yield components at Palampur (E_1)

Parental Line	Characters													
	Days to 75% silking	Days to 75% pollen shedding	Leaf area/ plant	Plant height	Ear height	Ear length	Ear circum-ference	Kernel rows/ ear	Kernels/ row	Shelling percentage	100- seed weight	Grain yield	Biological yield	Harvest index
P_1	0.21	-0.13	118.60	7.53*	7.95*	-0.29	0.03	0.49*	0.46	-1.23*	-0.04	-5.83*	-3.02	-1.57*
P_2	0.29	0.12	185.77*	1.62	2.20	-0.01	0.12	0.40*	0.27	-0.79*	-0.54	-1.61	-7.06*	0.44*
P_3	-0.04	0.01	-138.84	-0.91	4.16*	-0.68*	0.13	0.35*	-1.39*	-0.04	-0.28	0.70	-2.21	0.52*
P_4	-0.96*	-0.88*	11.45	1.25	-1.05	0.36*	-0.03	0.22*	0.37	0.24	0.37	1.82*	-0.48	1.01*
P_5	-0.04	-0.06	-253.22*	-4.97*	-6.78*	0.14	-0.07	-0.45*	0.18	0.46	0.12	-2.85*	-6.05*	-0.13
P_6	0.00	0.15	-139.87	-1.80	-2.58*	0.01	-0.21*	-0.30*	1.02*	0.87*	-1.11*	-4.41*	-3.85*	-0.87*
P_7	0.57*	0.58*	290.24*	0.96	-0.47	0.14	0.12	0.61*	-0.29	0.70	-0.96*	5.60*	14.41*	-0.14
P_8	-0.50*	-0.06	25.55	-10.55*	-6.83*	0.16	0.09	0.09	0.34	-0.15	0.36	-1.31	0.32	-0.54*
P_9	-0.14	-0.13	61.00	2.17	-2.35	0.01	-0.24*	-0.87*	-0.19	-0.35	0.88*	0.64	1.63	-0.20
P_{10}	0.29	0.05	49.76	3.35*	4.15*	0.20	0.32*	-0.06	-0.73*	-0.27	1.22*	6.53*	8.16*	1.02*
P_{11}	0.00	-0.20	-120.31	1.80	0.01	-0.13	0.04	0.12	-0.63	0.14	0.21	1.11	2.10	0.05
P_{12}	0.32	0.55*	-90.14	-0.45	1.59	0.36*	-0.29*	-0.63*	0.60	0.43	-0.23	-0.39	-3.96*	0.37*
SE(gi)	0.25	0.24	81.28	1.68	1.25	0.18	0.09	0.10	0.35	0.38	0.28	0.70	1.83	0.14
SE(gi-gj)	0.37	0.35	120.05	2.48	1.85	0.27	0.13	0.14	0.52	0.55	0.42	1.03	2.70	0.20
CD(gi) at 5%	0.49	0.47	161.74	3.34	2.50	0.36	0.18	0.19	0.70	0.75	0.56	1.38	3.64	0.28

* Significant at $P \leq 0.05$

Table 4.10 Estimates of general combining ability effects for yield and yield components at Bajaura (E_2)

Parental Line	Characters														
	Days to 75% silking	Days to 75% pollen shedding	Leaf area/ plant	Plant height	Ear height	Days to 75% maturity	Ear length	Ear circum-ference	Kernel rows/ ear	Kernels/ row	Shelling percentage	100-seed weigh	Grain yield	Biological yield	Harvest index
P_1	0.67*	0.66*	71.31	-4.65*	0.49	1.05*	-0.19	0.01	0.09	-0.14	-1.28*	-0.41	-2.27*	4.36*	-1.65*
P_2	-0.40*	-0.55*	138.52*	-2.53	0.04	0.12	-0.08	-0.03	0.25*	0.15	-0.92*	-0.77*	-2.05*	-5.81*	0.08
P_3	0.14	0.38*	-130.16*	-3.11*	1.78	-0.13	-0.56*	0.06	0.57*	-0.90*	0.81*	-0.45	1.12	-2.07	0.83*
P_4	-0.26	-0.20	-117.22	-1.85	-3.47*	-0.10	0.41*	-0.01	0.16	0.65	0.42	0.14	5.41*	14.08*	-0.03
P_5	-0.18	-0.05	-413.05*	-2.78*	-2.59*	-0.77*	-0.56*	-0.29*	-0.33*	-0.15	0.33	-0.55*	-5.52*	-15.08*	0.31*
P_6	-0.36*	-0.38*	25.90	3.82*	0.87	-0.13	0.20	-0.19*	-0.13	0.86*	1.23*	-0.44	-2.45*	-4.83*	-0.11
P_7	0.14	0.05	164.36*	2.82*	-3.03*	0.01	0.54*	0.17	0.52*	-0.32	-0.73*	-0.05	4.59*	12.51*	-0.27*
P_8	-0.33*	-0.27	123.92*	-2.98*	-2.34*	-0.31	0.09	0.17	0.28*	0.13	-0.16	0.54*	-0.91	-0.02	-0.35*
P_9	0.49*	0.41*	131.94*	3.00*	-1.12	0.15	-0.08	-0.06	-0.60*	0.68*	0.01	0.50	-0.48	-0.69	-0.15
P_{10}	0.28	0.23	70.46	0.32	4.56*	0.33	0.26	0.33*	-0.18	-0.69*	-1.17*	1.17*	-0.05	-7.03*	1.03*
P_{11}	-0.11	-0.23	0.90	4.91*	1.54	0.19	-0.05	0.00	-0.07	-0.20	0.99*	0.49	1.48*	5.41*	-0.17
P_{12}	-0.08	-0.05	-66.88	3.05*	3.26*	-0.42*	0.01	-0.15	-0.57*	0.01	0.46	-0.16	1.12	-0.84	0.47*
SE(gi)	0.16	0.18	59.62	1.34	1.06	0.18	0.16	0.10	0.11	0.34	0.31	0.27	0.70	1.72	0.11
SE(gi-gj)	0.24	0.27	88.06	1.97	1.56	0.27	0.25	0.14	0.16	0.50	0.46	0.40	1.03	2.54	0.17
CD(gi) at 5%	0.33	0.36	118.64	2.66	2.11	0.36	0.33	0.19	0.22	0.68	0.62	0.54	1.39	3.43	0.22

* Significant at $P \leq 0.05$

Table 4.11 Estimates of general combining ability effects for yield and yield components at pooled over 2 environments

Parental Line	Characters													
	Days to 75% silking	Days to 75% pollen shedding	Leaf area/ plant	Plant height	Ear height	Ear length	Ear circum-ference	Kernel rows/ ear	Kernels/ row	Shelling percentage	100- seed weight	Grain yield	Biological yield	Harvest index
P_1	0.44*	0.26	94.96	1.44	4.22*	-0.24*	0.02	0.29*	0.16	-1.25*	-0.23	-4.05*	0.67	-1.61*
P_2	-0.06	-0.29*	162.15*	-0.46	1.12	-0.04	0.05	0.32*	0.21	-0.85*	-0.66*	-1.83*	-6.44*	0.26*
P_3	0.05	0.19	-134.50*	-2.09*	2.97*	-0.62*	0.10	0.46*	-1.14*	0.38	-0.37	0.91	-2.14	0.69*
P_4	-0.61*	-0.54*	-52.88	-3.30*	-2.26*	0.29*	-0.02	0.19*	0.51*	0.33	0.26	3.62*	6.80*	0.49*
P_5	-0.11	-0.06	-333.13*	-3.87*	-4.68*	-0.21	-0.18*	-0.39*	0.02	0.39	-0.22	-4.18*	-10.56*	0.09
P_6	-0.18	-0.11	-56.98	1.01	-0.85	0.10	-0.20*	-0.21*	0.94*	1.05*	-0.78*	-3.43*	-4.34*	-0.49*
P_7	0.35*	0.32*	227.30*	1.89	-1.75*	0.34*	0.14*	0.57*	-0.31	-0.01	-0.50*	5.10*	13.46*	-0.21*
P_8	-0.41*	-0.16	74.74	-6.77*	-4.59*	0.13	0.13*	0.19*	0.23	-0.15	0.45*	-1.11*	0.15	-0.44*
P_9	0.18	0.14	96.47	2.58*	-1.74*	-0.03	-0.15*	-0.73*	0.17	-0.17	0.69*	0.08	0.47	-0.17
P_{10}	0.28	0.14	60.11	1.84	4.36*	0.23	0.32*	-0.12	-0.68*	-0.72*	1.20*	3.24*	0.57	1.02*
P_{11}	-0.06	-0.22	-59.71	3.36*	0.78	-0.09	0.02	0.03	-0.42	0.56*	0.35	1.30*	3.76*	-0.06
P_{12}	0.12	0.25	-78.51	1.30	2.43*	0.13	-0.22*	-0.60*	0.31	0.45	-0.20	0.37	-2.40	0.42*
SE(gi)	0.15	0.15	50.40	1.07	0.82	0.12	0.06	0.07	0.25	0.24	0.20	0.49	1.26	0.09
SE(gi-gj)	0.22	0.22	74.45	1.58	1.21	0.18	0.10	0.11	0.36	0.36	0.17	0.73	1.86	0.13
CD(gi) at 5%	0.29	0.29	98.79	2.10	1.61	0.24	0.12	0.14	0.48	0.48	0.38	0.96	2.46	0.17

* Significant at $P \leq 0.05$

and P_{12}. The effects for the parents P_5, P_6 and P_8 at Palampur; and P_4, P_5, P_7 and P_8 at Bajaura were found to be negative. However, positive gca in P_1, P_3 and P_{10} at Palampur; and P_{10} and P_{12} at Bajaura were also observed.

Days to maturity

At Bajaura, negative gca effects were observed for the parents P_5 and P_{12}; and positive for P_1 only. Pooled analysis for the trait could not be carried out due to non-significant variance at Palampur.

Ear length

Positive gca effects were observed for P_4 and P_{12}; and negative for P_3 at Palampur. Whereas, at Bajaura, positive effects for P_4 and P_7; and negative for P_3 and P_5 were observed. In pooled analysis also P_4 and P_7 exhibited positive; and P_1 and P_3 negative gca effects for this trait.

Ear circumference

Positive gca effects were found for P_{10} in both the environments, and for P_7, P_8 and P_{10} in pooled analysis. The effects were negative for P_6, P_9 and P_{12} at Palampur; P_5 and P_6 at Bajaura; and P_5, P_6, P_9 and P_{12} in pooled analysis.

Kernel rows/ear

For this trait, positive gca effects were observed for P_1, P_2, P_3, P_4 and P_7 at Palampur, P_2, P_3, P_7 and P_8 at Bajaura; and P_1, P_2, P_3, P_4, P_7 and P_8 in pooled analysis. Negative gca effects were observed for P_5, P_6, P_9 and P_{12} at Palampur and on pooled basis, and P_5, P_9 and P_{12} at Bajaura.

Kernels/row

At Palampur parent P_6; at Bajaura P_6 and P_9; and on pooled basis P_4 and P_6 exhibited positive gca, whereas, P_3 and P_{10} showed negative gca in both the environments.

Shelling percentage

Positive gca effects were found for the inbred P_6 at Palampur; P_3, P_6 and P_{11} at Bajaura; and P_6 and P_{11} in pooled analysis. Negative gca effects were observed for parents P_1 and P_2 at Palampur; P_1, P_2, P_7 and P_{10} at Bajaura; and P_1, P_2 and P_{10} in pooled analysis.

100-seed weight

GCA was positive for P_9 and P_{10} at Palampur; P_8 and P_{10} at Bajaura; and P_8, P_9 and P_{10} on pooled basis. Negative effects were observed for P_6 and P_7 at Palampur; P_2 and P_5 at Bajaura; and P_2, P_6 and P_7 on pooled basis.

Grain yield/plant

At Palampur, parents P_{10}, P_7, P_4 were good general combiners, whereas P_1, P_6, P_5 and P_2 were poor general combiners. Similarly, at Bajaura, P_4, P_7 and P_{11} were good general combiners, and P_5, P_6, P_1 and P_2 poor general combiners. In pooled over analysis P_7, P_4, P_{10} and P_{11} were good general combiners; and P_5, P_1, P_6, P_2 and P_8 poor general combiners. The rest of the parents at each of the location were found to be average combiners.

Biological yield

In pooled analysis, the parents P_4, P_7 and P_{11} showed positive gca effects, whereas, P_2, P_5 and P_6 had negative effects. At Palampur, parents P_7 and P_{10} exhibited positive and P_2, P_5, P_6 and P_{12} showed negative gca effects.

At Bajaura, parents P_1, P_4, P_7 and P_{11} showed positive and P_2, P_5, P_6 and P_{10} negative gca effects.

Harvest index

Positive gca effects were found for the parents P_2, P_3, P_4, P_{10} and P_{12} at Palampur; for P_3, P_5, P_{10} and P_{12} at Bajaura; and for P_2, P_3, P_4, P_{10} and P_{12} on pooled basis. Negative gca effects were found for parents P_1, P_6 and P_8 at Palampur; for P_1, P_7 and P_8 at Bajaura; and for P_1, P_6, P_7 and P_8 on pooled basis.

Estimates of general combining ability (gca) effects for seed quality traits have been presented in Table 4.12 and only significant results are described below :

100-seed weight

Positive gca effects were obtained for parents P_{11} and P_{12}. However, significant negative effects were observed for P_2, P_4 and P_7 for this trait.

100-seed volume

Positive gca effects were obtained for parents P_{11} and P_{12}, and negative effects were observed for P_2, P_3, P_4 and P_7 for 100-seed volume.

Seed density

Positive gca effects were obtained for the inbreds P_2, P_3 and P_4. Negative effects were observed for P_6, P_7, P_9 and P_{12} inbreds.

Accelerated aging test

Positive gca effects were observed for P_4 and P_6 whereas, gca effects were negative for inbreds P_2, P_{10} and P_{12}.

Table 4.12 Estimates of general combining ability effects for seed quality traits

Parental Line	Characters							
	100-seed weight	100-seed volume	Seed density	Accelerated aging test	Osmotic stress test	Germination percentage	Seed vigour index	Field emergence
P_1	-0.40	-0.29	0.00	0.12	-0.79	0.39	-0.07	-2.95*
P_2	-0.63*	-0.75*	0.01*	-1.20*	-2.93*	-0.33	-0.31	1.55*
P_3	-0.39	-0.46*	0.01*	0.94	0.61	0.49	-0.10	3.33*
P_4	-0.56*	-0.64*	0.01*	1.30*	-0.25	1.39*	-0.80*	3.76*
P_5	0.27	0.21	0.00	0.33	1.39*	-0.83	0.43	0.48
P_6	-0.10	0.00	-0.01*	1.87*	1.50*	0.89	-0.34	0.98
P_7	-0.82*	-0.54*	-0.01*	-0.60	2.36*	-1.26*	0.63	-2.38*
P_8	0.18	0.18	0.00	1.05	3.00*	0.10	0.40	0.76
P_9	0.12	0.29	-0.01*	-0.38	-0.82	0.17	0.32	-3.52*
P_{10}	0.48	0.32	0.00	-1.95*	-1.46*	-0.33	-1.07*	-0.95
P_{11}	0.87*	0.71*	0.00	0.55	-1.32*	0.39	0.91*	0.26
P_{12}	0.97*	0.96*	-0.01*	-2.02*	-1.29	-1.08*	-0.01	-1.31
SE(gi)	0.25	0.17	0.004	0.57	0.65	0.46	0.39	0.73
SE(gi-gj)	0.38	0.26	0.005	0.84	0.96	0.67	0.58	1.08
CD(gi) at 5%	0.50	0.34	0.008	1.14	1.29	0.91	0.78	1.46

* Significant at $P \leq 0.05$

Osmotic stress test

Positive gca effects were displayed by P_5, P_6, P_7 and P_8 on the contrary negative gca effects were observed for P_2, P_{10} and P_{11}.

Germination percentage

Positive gca effects were observed for P_4 and negative for P_7 and P_{12}.

Seed vigour index

Positive gca effects were observed for P_{11} and negative for P_4 and P_{10}.

Field emergence

Parents P_2, P_3 and P_4 had positive gca effects, whereas, negative gca effects were observed for P_1, P_7 and P_9.

4.2.1.3 Estimates of specific combining ability (sca) effects

The estimates of specific combining ability (sca) effects for different yield and yield components at Palampur, Bajaura and in pooled analysis are presented in Tables 4.13, 4.14, and 4.15, respectively. The significant sca effects obtained for different characters are described below:

Days to silking

The cross combinations $P_2 \times P_8$, $P_2 \times P_{12}$, $P_3 \times P_6$, $P_4 \times P_8$, $P \times P_9$ and $P_5 \times P_{10}$ at Palampur; $P_2 \times P_7$, $P_4 \times P_{10}$ and $P_5 \times P_{10}$ at Bajaura; and $P_2 \times P_{12}$, $P_4 \times P_{12}$, $P_5 \times P_{10}$ and $P_8 \times P_{11}$ in pooled analysis exhibited negative sca effects. However, positive sca effects were also observed for $P_2 \times P_5$, $P_4 \times P_6$, $P_8 \times P_{10}$, $P_8 \times P_{12}$ and $P_{11} \times P_{12}$ at Palampur; $P_{10} \times P_{12}$ at Bajaura; and $P_2 \times P_5$, $P_4 \times P_6$, $P_8 \times P_{10}$, $P_{10} \times P_{11}$ and $P_{11} \times P_{12}$ in pooled analysis.

Table 4.13 Estimates of specific combining ability (sca) effects for yield and yield components at Palampur (E_1)

Parental combination	Characters												
	Days to 75% silking	Days to 75% pollen shedding	Leaf area/ plant	Plant height	Ear height	Ear length	Ear circumference	Kernel rows/ ear	Kernels/ row	100-seed weight	Grain yield	Biological yield	Harvest index
1	2	3	4	5	6	7	8	9	10	11	12	13	14
$P_1 X P_2$	-1.58	-1.51	181.09	5.44	5.24	0.14	0.96	0.86*	1.57	0.76	-0.73	6.55	-1.19*
$P_1 X P_3$	-0.26	-0.41	139.63	-5.23	-0.81	1.49*	0.10	-0.09	2.48	1.09	4.17	-16.86*	0.98
$P_1 X P_4$	-0.33	-0.01	39.47	8.93	5.96	-0.49	0.11	0.04	-1.27	0.64	-2.29	-34.34*	4.34*
$P_1 X P_5$	0.74	0.66	98.44	3.12	-0.66	-0.02	-0.54	-0.29	-3.72*	1.37	-3.56	9.04	-2.49*
$P_1 X P_6$	-0.79	-1.05	188.29	8.54	-0.89	0.33	0.14	-0.03	0.77	-0.67	3.07	30.28*	-2.78*
$P_1 X P_7$	-0.86	-0.98	67.59	2.68	2.63	0.45	-0.10	-0.88*	0.57	0.48	-0.76	-4.46	0.48
$P_1 X P_8$	-0.79	-0.34	-87.99	6.47	11.14*	0.43	-0.05	0.30	-0.56	-0.10	4.34	-1.46	1.78*
$P_1 X P_9$	0.85	0.74	154.31	-2.81	6.35	0.33	0.57	0.26	-0.53	1.38	4.21	-4.87	2.37*
$P_1 X P_{10}$	-0.08	-0.44	267.53	15.95*	10.45*	0.90	-0.02	-0.18	-1.49	1.65	11.13*	18.83*	1.27*
$P_1 X P_{11}$	0.21	-0.19	-786.36*	6.69	-0.95	-0.28	0.21	0.14	-0.52	-0.13	24.04*	39.26*	2.66*
$P_1 X P_{12}$	0.89	1.06	312.08	6.94	-1.50	1.46*	0.45	1.01*	2.99*	-0.89	5.24*	-9.05	3.31*
$P_2 X P_3$	0.17	-1.16	-234.09	0.37	-8.35	0.33	0.38	0.63	1.67	-0.02	13.36*	40.20*	-1.04*
$P_2 X P_4$	1.60	1.24	-199.54	-4.19	-6.05	-0.68	0.14	0.04	-1.40	2.72*	-4.36	-9.98	-0.27
$P_2 X P_5$	2.17*	1.91*	40.05	1.96	10.12*	-0.18	0.08	0.18	2.98*	-2.05*	2.81	0.46	1.03*
$P_2 X P_6$	0.14	0.20	73.74	9.95	11.74*	1.34*	0.13	-0.35	0.89	1.68	-0.89	-12.86	1.57*
$P_2 X P_7$	0.07	0.77	368.92	-3.28	-7.10	1.48*	0.59	0.74*	1.95	1.41	16.59*	6.68	4.66*

Contd......

1	2	3	4	5	6	7	8	9	10	11	12	13	14
$P_2 X P_8$	-2.36*	-1.09	493.24	1.39	8.54	-0.11	0.41	-0.26	-0.25	1.62	11.62*	33.90*	-0.64
$P_2 X P_9$	-1.22	-0.51	1038.89*	9.92	8.32	2.02*	-0.46	-0.71*	1.91	1.39	10.81*	23.03*	0.65
$P_2 X P_{10}$	-0.65	-0.69	-213.94	14.52*	3.52	-1.80*	0.54	1.16*	-3.92*	-0.67	3.10	2.31	0.86
$P_2 X P_{11}$	1.64	1.56	-3.82	-2.46	5.39	0.66	-0.64	-1.02*	0.36	-1.70	-4.55	-8.82	-0.18
$P_2 X P_{12}$	-2.68*	-2.19*	-222.14	-2.11	-7.40	-0.60	-0.36	-0.52	-2.51	0.14	1.65	-8.70	2.14*
$P_3 X P_4$	-0.08	-0.16	-128.08	-2.85	-8.66	-0.48	0.07	-0.32	-0.30	-1.46	-6.32*	-1.64	-2.22*
$P_3 X P_5$	0.99	0.52	-84.37	21.90*	13.44*	-0.15	-0.79*	-1.02*	-1.83	-0.58	-1.68	15.02*	-2.62*
$P_3 X P_6$	-2.04*	-1.19	561.79	10.98	10.06*	0.93	0.72*	-0.07	2.10	1.21	7.10*	-9.59	4.00*
$P_3 X P_7$	-1.11	-1.62	223.33	9.03	8.20	0.43	-0.11	0.52	1.23	-0.47	6.46*	-10.17	3.76*
$P_3 X P_8$	-1.54	-1.48	380.01	8.29	15.27*	0.68	0.41	0.47	1.67	1.44	12.75*	0.30	4.51*
$P_3 X P_9$	1.10	1.09	165.46	12.63*	4.80	-0.82	0.28	-1.28*	-3.83*	1.60	2.42	-10.83	2.75*
$P_3 X P_{10}$	0.67	0.41	460.26	7.51	3.86	0.34	0.00	0.21	1.23	1.52	11.41*	6.28	3.02*
$P_3 X P_{11}$	-0.04	0.16	15.14	6.37	3.03	-0.77	0.43	2.03*	-1.49	0.72	13.76*	3.52	4.31*
$P_3 X P_{12}$	0.14	-0.09	106.31	0.01	1.89	0.23	-0.25	-0.44	1.55	0.68	6.56*	5.10	1.67*
$P_4 X P_5$	-0.58	-0.59	-83.63	-12.38*	-7.41	0.89	0.49	0.98*	1.19	0.71	11.79*	8.14	2.66*
$P_4 X P_6$	1.89*	1.70	512.56	10.60	3.01	0.71	-0.34	0.34	0.70	-0.79	20.40*	40.12*	0.86
$P_4 X P_7$	-1.18	-0.73	294.07	3.19	4.69	-0.51	0.05	0.15	2.36	-1.12	10.05*	10.82	1.51*
$P_4 X P_8$	-2.11*	-1.09	214.33	10.63	7.26	0.15	0.64	1.07*	-0.65	0.73	6.88*	2.32	1.82*
$P_4 X P_9$	-0.47	-0.51	553.66	12.67*	2.19	1.76*	0.56	1.05*	4.11*	-1.17	11.46*	10.79	2.24*
$P_4 X P_{10}$	-0.40	-0.19	-265.27	-9.14	-1.06	-0.23	0.16	-0.69*	-1.15	0.95	11.67*	9.49	2.27*

Contd..

1	2	3	4	5	6	7	8	9	10	11	12	13	14
$P_4 \times P_{11}$	-0.61	-0.94	-273.99	3.16	3.64	-0.49	-0.13	-0.70*	-1.06	0.70	4.71	-6.64	2.42*
$P_4 \times P_{12}$	-1.43	-0.19	-28.22	8.60	1.31	0.24	-0.27	-0.34	1.21	0.92	6.90*	-10.96	4.07*
$P_5 \times P_6$	0.96	0.38	-341.41	1.42	4.15	-0.10	-0.15	-0.37	0.41	-1.80	-11.85*	-20.49*	-1.50*
$P_5 \times P_7$	1.39	1.45	1055.92*	-0.50	1.70	-0.34	0.10	-0.30	3.27*	-0.20	10.72*	29.45*	-0.34
$P_5 \times P_8$	-1.54	-1.91*	770.88*	5.91	7.49	0.62	0.49	0.24	0.53	0.00	6.73*	4.76	1.74*
$P_5 \times P_9$	-1.90*	-1.84*	658.01*	20.63*	5.20	1.57*	0.70*	0.73*	2.07	1.67	19.66*	28.45*	2.81*
$P_5 \times P_{10}$	-3.83*	-2.01*	6.60	6.38	4.98	0.68	0.46	0.39	0.91	2.67*	-2.55	-13.70*	1.31*
$P_5 \times P_{11}$	-1.54	-0.76	-9.87	14.25*	4.31	1.00	0.76*	0.83*	2.50	3.68*	11.06*	50.36*	-2.80*
$P_5 \times P_{12}$	-0.86	-1.01	300.27	-4.37	-4.74	0.56	1.10*	1.13*	1.27	4.00*	20.33*	30.44*	2.62*
$P_6 \times P_7$	0.35	-0.26	48.02	3.67	6.53	-0.40	1.19*	-0.44	-1.87	3.56*	12.26*	11.91	3.32*
$P_6 \times P_8$	1.42	1.88*	-234.29	-6.63	-2.77	0.51	-0.68*	-0.79*	1.57	-0.62	5.05*	-25.24*	6.69*
$P_6 \times P_9$	0.57	1.95*	-311.26	-9.91	-4.37	-0.41	-0.33	-0.31	2.21	0.86	7.57*	-2.85	3.21*
$P_6 \times P_{10}$	0.14	0.77	52.64	-2.66	-0.84	0.15	-0.17	0.07	-1.98	1.13	11.46*	31.88*	-0.51
$P_6 \times P_{11}$	-1.08	-0.98	-80.51	-14.29*	-5.83	-0.42	-0.52	-0.06	1.37	-2.29*	-6.94*	-22.96*	0.85
$P_6 \times P_{12}$	-1.40	-0.73	295.50	0.08	-7.00	0.41	-0.41	-0.20	0.05	-2.21*	-2.93	-11.19	0.58
$P_7 \times P_8$	-0.15	-0.05	-23.01	7.79	2.28	-0.25	-0.10	-0.58	-0.25	-0.66	5.85*	-0.58	2.16*
$P_7 \times P_9$	-1.01	0.02	154.81	5.48	-3.29	-0.85	0.23	0.51	-1.65	2.63*	7.58*	4.24	2.18*
$P_7 \times P_{10}$	0.07	-0.66	-255.95	3.52	1.71	-0.35	-0.01	-0.68*	-0.80	-0.21	6.57*	-8.54	3.47*
$P_7 \times P_{11}$	0.35	1.09	138.13	4.63	7.82	0.47	0.04	0.89*	2.60*	-1.36	0.05	-4.91	0.81
$P_7 \times P_{12}$	0.53	0.34	-759.38*	5.23	4.17	0.28	-0.16	0.52	3.17*	-1.03	8.05*	29.58*	-1.17*

Contd..

1	2	3	4	5	6	7	8	9	10	11	12	13	14
$P_8 \times P_9$	0.57	0.16	217.79	2.12	-1.65	-0.28	-0.33	-0.32	2.18	-0.59	9.88*	21.81*	0.59
$P_8 \times P_{10}$	2.14*	2.99*	-108.59	-9.91	-4.40	-0.16	0.26	-0.16	1.44	-1.00	9.67*	28.99*	-0.61
$P_8 \times P_{11}$	-1.58	-2.26*	419.72	4.51	-4.89	0.12	0.04	0.20	1.46	-0.03	1.26	5.85	-0.26
$P_8 \times P_{12}$	2.10*	1.99*	382.77	10.02	7.78	-0.68	0.44	0.23	-2.74*	1.95	-0.10	8.79	-1.13*
$P_9 \times P_{10}$	0.28	-0.94	154.88	2.43	3.56	1.03	-0.15	0.30	4.80*	0.49	7.66*	7.37	1.77*
$P_9 \times P_{11}$	0.07	-0.19	288.19	-12.83*	-2.87	0.72	0.28	-0.12	1.36	0.69	3.45	9.41	0.12
$P_9 \times P_{12}$	-0.26	-0.44	-285.86	-13.45*	-15.50*	1.32*	-0.15	-0.13	-2.79*	-2.56*	-0.60	6.92	-0.89
$P_{10} \times P_{11}$	1.64	1.63	67.87	-7.01	0.98	-0.54	0.09	-0.22	-2.04	-0.57	1.54	-2.25	0.97
$P_{10} \times P_{12}$	0.32	0.38	97.42	2.43	-0.14	0.94	0.20	-0.19	4.36*	0.88	6.44*	20.77*	-0.61
$P_{11} \times P_{12}$	2.10*	2.13*	347.90	13.17*	7.84	-0.46	-0.43	-0.99*	-3.03*	0.76	14.48*	28.77*	0.93
SE(sij)	0.90	0.86	295.95	6.10	4.57	0.66	0.33	0.34	1.28	1.03	2.53	6.66	0.50
SE(sij-sik)	1.32	1.26	433.32	8.93	6.68	0.97	0.48	0.49	1.87	1.50	3.70	9.74	0.73
SE(sij-skl)	1.27	1.21	415.88	8.58	6.42	0.93	0.46	0.47	1.80	1.44	3.55	9.36	0.70
CD(sij) at 5%	1.79	1.72	588.94	12.15	9.09	1.31	0.66	0.67	2.55	2.04	5.03	13.26	1.00

* Significant at $P \leq 0.05$

Days to pollen shedding

Negative sca effects were observed for the cross combinations P_2 x P_{12}, P_5 x P_8, P_5 x P_9, P_5 x P_{10} and P_8 x P_{11} at Palampur; P_1 x P_3, P_3 x P_{11}, P_4 x P_{10} and P_5 x P_{10} at Bajaura; and P_1 x P_2, P_1 x P_3, P_2 x P_{12}, P_5 x P_8, P_5 x P_{10}, P_5 x P_{12} and P_8 x P_{11} in pooled analysis for this trait. Positive sca effects were found for P_2 x P_5, P_6 x P_8, P_6 x P_9, P_8 x P_{10}, P_8 x P_{12} and P_{11} x P_{12} at Palampur; for P_{10} x P_{12} at Bajaura; and for P_2 x P_5, P_4 x P_6, P_8 x P_{10}, P_{10} x P_{11} and P_{11} x P_{12} on pooled basis.

Leaf area/plant

Positive sca effects were observed for P_2 x P_9, P_5 x P_7, P_5 x P_8 and P_5 x P_9 at Palampur; for P_1 x P_4, P_7 x P_{11}, P_8 x P_9 and P_8 x P_{12} at Bajaura; and for P_2 x P_9, P_5 x P_7 and P_8 x P_{12} on pooled basis. Negative sca effects were observed for P_1 x P_{11} at Palampur; for P_1 x P_7, P_1 x P_8, P_2 x P_{11}, P_2 x P_{12}, P_4 x P_{11} and P_5 x P_9 at Bajaura; and for P_1 x P_{11} and P_4 x P_{11} in pooled analysis.

Plant height

Combined analysis over the two environments showed negative sca effects for P_1 x P_7 and P_6 x P_{11} whereas, these effects were positive for P_1 x P_4, P_1 x P_8, P_2 x P_5, P_3 x P_5, P_3 x P_6, P_3 x P_8, P_3 x P_9, P_3 x P_{11}, P_5 x P_9, P_8 x P_{12} and P_{11} x P_{12}. Negative sca effects were exhibited by the cross combinations P_4 x P_5, P_6 x P_{11}, P_9 x P_{11} and P_9 x P_{12} at Palampur and by P_1 x P_7, P_3 x P_7, P_4 x P_8 and P_6 x P_{12} at Bajaura, however, positive sca in P_1 x P_{10}, P_2 x P_{10}, P_3 x P_5, P_3 x P_9, P_4 x P_9, P_5 x P_9, P_5 x P_{11} and P_{11} x P_{12} at Palampur and in P_1 x P_8, P_2 x P_5, P_3 x P_4, P_3 x P_8, P_3 x P_9, P_3 x P_{11}, P_4 x P_7, P_5 x P_6 an P_8 x P_{12} at Bajaura were also observed.

Table 4.14 Estimates of specific combining ability (sca) effects for yield and yield contributing traits at Bajaura (E_2)

Parental comb-nation	Characters													
	Days to 75% silking	Days to 75% pollen shedding	Leaf area/ plant	Plant height	Ear height	Ear length	Ear circum-ference	Kernel rows/ ear	Kernels/ row	Shelling percentage	100- seed weight	Grain yield	Biological yield	Harvest index
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$P_1 X P_2$	-0.24	-0.97	-290.47	-9.24	4.34	-0.09	-0.17	-0.13	0.34	0.68	-1.03	9.03*	45.50*	-3.13*
$P_1 X P_3$	-0.78	-1.90*	-363.34	3.54	-2.10	-0.21	-0.36	-0.85*	0.79	0.20	0.51	2.85	3.25	0.51
$P_1 X P_4$	0.62	0.67	486.32*	8.48	7.86*	1.58*	0.46	-0.64	-0.16	-0.65	5.47*	0.57	-29.90*	5.20*
$P_1 X P_5$	-0.96	-0.97	370.90	2.80	-1.43	-1.11	0.34	1.05*	0.74	-0.57	-0.02	4.00	13.26*	-0.71
$P_1 X P_6$	-0.78	-0.65	-231.65	-0.49	-5.59	-0.06	0.20	-0.35	0.72	-1.67	1.33	6.93*	25.01*	-1.26*
$P_1 X P_7$	0.72	0.92	-557.16*	-18.29*	-8.49*	-1.35*	-0.52	-0.80*	-2.09	-0.82	-0.17	-19.61*	-47.83*	-0.39
$P_1 X P_8$	-0.81	-0.76	-484.68*	11.01*	10.93*	-0.21	-0.27	1.24*	1.06	3.06*	-0.72	8.89*	-5.30	4.42*
$P_1 X P_9$	0.87	1.06	205.00	4.53	6.31	2.11*	0.46	-0.88*	3.06*	-2.30*	1.95	5.96*	9.87	0.81
$P_1 X P_{10}$	0.08	0.74	240.21	-6.30	-3.18	1.52*	-0.28	0.10	4.92*	-0.50	-1.27	5.53*	9.21	0.74
$P_1 X P_{11}$	0.47	0.71	-178.62	-3.88	-10.76*	-0.71	0.65	0.19	-0.71	2.20	1.94	12.00*	16.77*	1.89*
$P_1 X P_{12}$	0.44	0.53	-377.46	-4.93	-3.88	-0.82	-0.10	1.61*	-4.92*	-2.16	-1.92	-8.65*	-29.98*	1.55*
$P_2 X P_3$	-0.21	-0.19	4.32	2.02	-9.15*	-0.57	0.93*	0.00	-2.60*	-1.36	-0.47	-0.36	0.43	-0.25
$P_2 X P_4$	-0.81	-0.62	115.05	6.46	-2.89	-0.73	0.25	1.33*	-3.25*	3.08*	1.07	-3.65	-15.22*	0.94*
$P_2 X P_5$	1.12	1.24	-251.19	22.68*	7.92*	0.93	-0.22	-0.71	0.55	-1.34	-0.73	3.28	-3.06	2.01*
$P_2 X P_6$	-0.21	0.06	78.54	4.39	2.06	0.58	1.18*	1.89*	1.44	0.54	1.22	5.21*	13.19*	-0.19
$P_2 X P_7$	-1.21*	-0.87	235.52	4.79	-0.44	0.94	0.22	0.45	2.32	1.91	0.14	9.18*	-3.15	4.25*

Contd....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$P_2 X P_8$	0.26	0.46	-311.53	4.19	3.48	0.18	-0.03	-0.52	1.37	1.38	2.11*	14.68*	32.38*	0.49
$P_2 X P_9$	-0.06	0.28	176.80	3.31	-1.04	0.05	0.24*	-0.04	-0.93	-1.87	1.08	5.25*	1.55	1.95*
$P_2 X P_{10}$	0.15	-0.04	-156.73	-5.42	-3.33	-1.84*	0.16	0.54	-0.47	1.68	-0.03	-4.68	0.39	-1.92*
$P_2 X P_{11}$	0.04	0.42	-670.35*	-2.80	0.09	-0.48	-0.91*	-0.97*	2.40	1.41	-2.00*	-5.22*	-19.55*	1.03*
$P_2 X P_{12}$	-0.49	-0.26	-451.23*	3.95	-3.23	0.77	-0.16	-0.67	3.70*	0.68	1.25	-2.36	-11.80	1.25*
$P_3 X P_4$	-0.35	-0.54	-17.90	13.74*	12.46*	-0.55	-0.09	0.68	0.10	3.15*	-1.34	-4.32	-2.46	-1.54*
$P_3 X P_5$	0.58	0.31	184.75	5.06	2.98	1.16	0.94*	0.07	2.90*	-0.06	2.02*	-0.40	18.69*	-3.36*
$P_3 X P_6$	0.26	0.13	-298.28	9.47	1.92	-1.09	0.05	-1.23*	-0.81	0.56	-0.98	-5.97*	-24.56*	1.81*
$P_3 X P_7$	-0.24	-0.29	-41.59	-10.43*	-0.18	-1.33*	-0.22	0.53	-0.83	-0.30	-1.29	2.00	-14.39*	3.25*
$P_3 X P_8$	0.22	0.03	244.49	11.07*	8.44*	1.66*	0.18	-0.84*	3.42*	0.09	0.90	5.50*	-8.86	3.80*
$P_3 X P_9$	0.40	0.35	210.28	11.69*	6.31	1.53*	0.61	-0.96*	3.42*	-0.28	0.74	6.57*	-3.69	3.38*
$P_3 X P_{10}$	0.12	-0.47	150.77	-1.84	3.53	-1.21*	-0.63	0.82*	-2.72*	3.14*	0.38	15.14*	17.40*	3.15*
$P_3 X P_{11}$	-0.99	-1.51*	98.63	12.27*	7.35	1.11	0.25	2.23*	1.95	0.33	2.18*	13.10*	5.71	4.01*
$P_3 X P_{12}$	-0.53	-0.69	12.04	2.83	-1.97	-0.80	-0.15	-0.61	-2.35	0.58	-0.01	-2.04	-18.89*	2.72*
$P_4 X P_5$	-0.03	-0.62	-72.57	8.90	12.64*	0.95	0.36	1.18*	3.15*	1.46	-0.80	12.82*	5.04	4.09*
$P_4 X P_6$	0.65	0.71	86.82	-5.19	-1.92	0.39	0.32	-0.82*	2.24	-1.00	0.50	13.25*	17.04*	1.01*
$P_4 X P_7$	-0.35	-0.22	-110.73	9.91*	8.78*	-0.09	0.45	0.73	1.02	0.19	-0.40	4.21	15.46*	-0.82
$P_4 X P_8$	0.12	0.10	30.84	-12.39*	-12.01*	0.30	0.20	0.57	-0.63	-1.13	-1.27	10.21*	32.99*	-1.25*
$P_4 X P_9$	-0.21	-0.08	32.54	2.33	-0.83	-0.53	0.28	0.05	3.17*	0.31	-1.82	21.28*	52.91*	-0.18
$P_4 X P_{10}$	-1.49*	-1.40*	-196.84	4.80	-4.61	0.58	0.05	0.02	0.23	-1.21	0.15	3.85	-4.50	2.26*

Contd....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$P_4 \times P_{11}$	-1.10	-0.94	-679.54*	-8.18	-2.59	-2.11*	-0.58	-0.48	-2.40	0.14	0.04	-11.68*	-10.44	-0.86*
$P_4 \times P_{12}$	-1.13	-1.12	101.79	2.37	-1.91	0.34	0.12	0.42	3.20*	0.46	-0.67	12.68*	2.31	4.44*
$P_5 \times P_6$	0.58	0.56	234.11	11.73*	6.79	0.46	0.40	-0.34	1.64	-0.50	0.22	-1.32	10.79	-2.69*
$P_5 \times P_7$	-0.92	-0.87	-136.47	1.03	-0.31	0.92	-0.02	0.02	1.72	0.61	2.62*	0.64	15.11*	-2.25*
$P_5 \times P_8$	-0.46	-0.54	-235.40	-1.37	2.41	-2.19*	-0.12	0.25	-3.93*	-0.22	2.88*	-16.36*	-44.86*	0.84*
$P_5 \times P_9$	0.22	0.28	-496.81*	6.05	2.19	-0.97	-0.84*	-0.27	-1.33	0.35	-2.18*	-9.29*	-39.19*	3.52*
$P_5 \times P_{10}$	-2.06*	-2.04*	-76.79	-2.98	-6.90	1.24*	0.07	0.11	3.53*	1.33	-0.61	6.28*	11.15	0.78
$P_5 \times P_{11}$	-0.17	-0.58	-422.81	-5.96	0.32	-1.19	0.20	0.80*	-1.30	2.36*	0.54	6.25*	37.96*	-3.68*
$P_5 \times P_{12}$	0.71	-1.26	-202.35	-6.80	-2.70	-0.40	-0.70*	-1.10*	-1.00	3.12*	-0.75	21.60*	42.71*	1.45*
$P_6 \times P_7$	-0.24	-0.04	-130.89	5.84	1.04	-0.74	-0.07	-0.58	-2.09	2.93*	3.63*	15.07*	17.86*	2.82*
$P_6 \times P_8$	-0.28	-0.72	-395.82	-5.06	-3.65	-0.44	-0.17	-0.55	1.06	1.47	-2.36*	1.07	-33.36*	6.84*
$P_6 \times P_9$	-1.10	-0.90	-61.15	-2.14	-0.57	0.18	-0.99*	1.13*	1.16	5.82*	-1.38	2.64	-11.94	3.18*
$P_6 \times P_{10}$	-0.30	-0.22	-431.23	2.53	6.04	-1.01	0.68*	-0.49	-2.68*	-0.18	2.74*	-2.29	-0.10	-0.97*
$P_6 \times P_{11}$	0.01	0.24	-10.39	-4.75	0.06	-0.30	-0.24	0.00	1.79	-0.83	-3.17*	-5.32*	-23.54*	1.57*
$P_6 \times P_{12}$	-0.03	0.06	-196.56	-15.20*	-10.26*	0.54	-0.34	0.60	0.68	-4.03*	-2.18*	-11.47*	-32.79*	0.97*
$P_7 \times P_8$	0.22	0.35	371.81	5.14	4.25	0.52	-0.18	-0.59	-0.15	0.29	-0.28	10.03*	9.06	2.39*
$P_7 \times P_9$	-0.10	-0.83	-146.22	0.16	0.33	0.14	-0.05	-0.11	-1.15	-0.23	-0.03	4.60	-2.52	2.27*
$P_7 \times P_{10}$	-0.38	-0.65	176.81	8.93	-1.76	0.85	0.66	0.57	-0.90	-0.73	0.52	7.68*	0.57	3.06*
$P_7 \times P_{11}$	0.51	-0.19	456.11*	5.65	-3.34	-0.24	0.74*	0.16	1.37	-3.07*	0.52	5.64*	3.63	1.46*
$P_7 \times P_{12}$	-0.53	-0.37	130.63	7.40	10.64*	0.36	0.44	0.46	2.77*	2.11	-0.63	9.50*	28.13*	-0.65

Contd....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$P_8 X P_9$	-0.13	-0.01	453.25*	-2.44	2.94	0.98	-0.05	1.23*	0.80	-0.43	0.29	2.60	5.00	0.20
$P_8 X P_{10}$	0.08	0.17	-315.87	1.43	7.76*	-0.96	0.71*	1.03*	0.35	0.18	0.22	3.68	13.09*	-0.67
$P_8 X P_{11}$	-1.03	-0.87	276.39	-0.15	-3.42	-1.29*	0.54	-0.40	-2.38	0.89	-0.46	-5.36*	-18.20*	0.61
$P_8 X P_{12}$	-0.56	-0.54	493.76*	17.10*	12.56*	0.55	0.34	-0.70	0.22	-2.42*	2.30*	6.00*	20.90*	-0.95*
$P_9 X P_{10}$	-0.24	-1.01	160.77	-0.65	2.44	-1.19	-0.21	-0.22	-1.25	-0.27	-0.92	3.25	-3.24	2.11*
$P_9 X P_{11}$	0.15	-0.54	-293.19	-0.23	-6.04	0.48	-0.33	-0.52	3.42*	3.60*	1.66	4.21	3.82	0.91*
$P_9 X P_{12}$	-0.88	-1.22	186.92	5.42	4.34	-0.28	0.47	-0.22	1.02	0.16	3.07*	3.57	16.57*	-1.15*
$P_{10} X P_{11}$	0.87	1.13	-61.70	8.04	5.07	1.59*	0.13	-0.95*	1.58	-1.49	2.25*	-3.22	-11.59	0.60
$P_{10} X P_{12}$	1.33*	1.46*	409.47	0.60	4.05	1.38*	-0.27	-0.05	2.77*	-0.09	-0.38	3.14	14.41*	-0.95*
$P_{11} X P_{12}$	0.72	0.92	331.98	6.51	3.67	-0.01	1.01*	0.05	1.55	-0.28	2.79*	13.10*	25.97*	0.80
SE(sij)	0.60	0.66	217.09	4.87	3.85	0.60	0.34	0.39	1.24	1.13	0.99	2.53	6.27	0.42
SE(sij-sik)	0.87	0.96	317.52	7.12	5.64	0.88	0.49	0.57	1.81	1.66	1.45	3.71	9.17	0.62
SE(sij-skl)	0.84	0.92	305.06	6.84	5.42	0.85	0.47	0.56	1.74	1.59	1.39	3.56	8.81	0.59
CD(sij) at 5%	1.19	1.31	432.01	9.69	7.67	1.20	0.67	0.78	2.46	2.26	1.97	5.04	12.47	0.84

* Significant at $P \leq 0.05$

Ear height

The cross combinations $P_9 \times P_{12}$ at Palampur; $P_1 \times P_7$, $P_1 \times P_{11}$, $P_2 \times P_3$, $P_4 \times P_8$ and $P_6 \times P_{12}$ at Bajaura; and $P_2 \times P_3$ and $P_8 \times P_{12}$ in pooled analysis were found to have negative sca effects for this trait. However, positive sca effects for $P_1 \times P_8$, $P_1 \times P_{10}$, $P_2 \times P_5$, $P_2 \times P_6$, $P_3 \times P_5$, $P_3 \times P_6$ and $P_3 \times P_8$ at Palampur; for $P_1 \times P_4$, $P_1 \times P_8$, $P_2 \times P_5$, $P_3 \times P_4$, $P_3 \times P_8$, $P_4 \times P_5$, $P_4 \times P_7$, $P_7 \times P_{12}$, $P_8 \times P_{10}$ and $P_8 \times P_{12}$ at Bajaura; and for $P_1 \times P_4$, $P_1 \times P_8$, $P_1 \times P_9$, $P_2 \times P_5$, $P_2 \times P_6$, $P_2 \times P_8$, $P_3 \times P_5$, $P_3 \times P_6$, $P_3 \times P_8$, $P_4 \times P_7$, $P_7 \times P_{12}$ and $P_8 \times P_{12}$ in pooled analysis were also observed.

Ear length

Positive sca effects were observed for $P_1 \times P_3$, $P_1 \times P_{12}$, $P_2 \times P_6$, $P_2 \times P_7$, $P_2 \times P_9$, $P_4 \times P_9$, $P_5 \times P_9$ and $P_9 \times P_{12}$ and negative for $P_2 \times P_{10}$ at Palampur. Whereas, at Bajaura positive sca effects for $P_1 \times P_4$, $P_1 \times P_9$, $P_1 \times P_{10}$, $P_3 \times P_8$, $P_3 \times P_9$, $P_5 \times P_{10}$, $P_{10} \times P_{11}$ and $P_{10} \times P_{12}$, and negative effects for $P_1 \times P_7$, $P_2 \times P_{10}$, $P_3 \times P_7$, $P_3 \times P_{10}$, $P_4 \times P_{11}$, $P_5 \times P_8$ and $P_8 \times P_{11}$ were observed. In pooled analysis $P_1 \times P_9$, $P_1 \times P_{10}$, $P_2 \times P_6$, $P_2 \times P_7$, $P_2 \times P_9$, $P_3 \times P_8$, $P_4 \times P_5$, $P_5 \times P_{10}$ and $P_{10} \times P_{12}$ showed positive and $P_2 \times P_{10}$ and $P_4 \times P_{11}$ negative sca effects.

Ear circumference

Positive sca effects for ear circumference were exhibited by the cross combinations $P_1 \times P_2$, $P_3 \times P_6$, $P_5 \times P_9$, $P_5 \times P_{11}$, $P_5 \times P_{12}$ and $P_6 \times P_7$ at Palampur; by $P_2 \times P_3$, $P_2 \times P_6$, $P_3 \times P_5$, $P_6 \times P_{10}$, $P_7 \times P_{11}$, $P_8 \times P_{10}$ and $P_{11} \times P_{12}$ at Bajaura; and by $P_1 \times P_9$, $P_2 \times P_3$, $P_2 \times P_6$, $P_5 \times P_{11}$, $P_6 \times P_7$ and $P_8 \times P_{10}$ on pooled basis. Negative sca effects were observed for $P_3 \times P_5$ and P_6

$\times P_8$ at Palampur; $P_2 \times P_{11}$, $P_5 \times P_9$, $P_5 \times P_{12}$ and $P_6 \times P_9$ at Bajaura; and $P_2 \times P_{11}$ and $P_6 \times P_9$ on pooled basis.

Kernel rows/ear

Positive sca effects were observed for $P_1 \times P_2$, $P_1 \times P_{12}$, $P_2 \times P_7$, $P_2 \times P_{10}$, $P_3 \times P_{11}$, $P_4 \times P_5$, $P_4 \times P_8$, $P_4 \times P_9$, $P_5 \times P_9$, $P_5 \times P_{11}$, $P_5 \times P_{12}$ and $P_7 \times P_{11}$ cross combinations at Palampur; for $P_1 \times P_5$, $P_1 \times P_8$, $P_1 \times P_{12}$, $P_2 \times P_4$, $P_2 \times P_6$, $P_3 \times P_{10}$, $P_3 \times P_{11}$, $P_4 \times P_5$, $P_5 \times P_{11}$, $P_6 \times P_9$, $P_8 \times P_9$ and $P_8 \times P_{10}$ at Bajaura; and for $P_1 \times P_8$, $P_1 \times P_{12}$, $P_2 \times P_4$, $P_2 \times P_6$, $P_2 \times P_7$, $P_2 \times P_{10}$, $P_3 \times P_7$, $P_3 \times P_{10}$, $P_3 \times P_{11}$, $P_4 \times P_5$, $P_4 \times P_8$, $P_4 \times P_9$, $P_5 \times P_{11}$ and $P_7 \times P_{11}$ in pooled analysis. 10 cross combinations each at Palampur, Bajaura and in pooled analysis exhibited negative sca effects.

Kernels/row

Analysis of pooled data from the two environments revealed positive sca effects for $P_2 \times P_5$, $P_2 \times P_7$, $P_3 \times P_8$, $P_4 \times P_5$, $P_4 \times P_9$, $P_4 \times P_{12}$, $P_5 \times P_7$, $P_5 \times P_{10}$, $P_7 \times P_{11}$, $P_7 \times P_{12}$, $P_9 \times P_{10}$, $P_9 \times P_{11}$ and $P_{10} \times P_{12}$ and negative for $P_2 \times P_4$, $P_2 \times P_{10}$, $P_6 \times P_7$ and $P_6 \times P_{10}$. The effects for the cross combinations $P_1 \times P_{12}$, $P_2 \times P_5$, $P_4 \times P_9$, $P_5 \times P_7$, $P_7 \times P_{11}$, $P_7 \times P_{12}$, $P_9 \times P_{10}$ and $P_{10} \times P_{12}$ at Palampur and for $P_1 \times P_9$, $P_1 \times P_{10}$, $P_2 \times P_{12}$, $P_3 \times P_5$, $P_3 \times P_8$, $P_3 \times P_9$, $P_4 \times P_5$, $P_4 \times P_9$, $P_4 \times P_{12}$, $P_5 \times P_{10}$, $P_7 \times P_{12}$, $P_9 \times P_{11}$ and $P_{10} \times P_{12}$ at Bajaura were found to be positive. However, negative sca in $P_1 \times P_5$, $P_2 \times P_{10}$, $P_3 \times P_9$, $P_8 \times P_{12}$, $P_9 \times P_{12}$ and $P_{11} \times P_{12}$ at Palampur and in $P_1 \times P_{12}$, $P_2 \times P_3$, $P_2 \times P_4$, $P_3 \times P_{10}$, $P_5 \times P_8$ and $P_6 \times P_{10}$ at Bajaura were also observed.

Table 4.15 Estimates of specific combining ability (sca) effects for yield and yield contributing traits for pooled over 2 environments

Parental Combination	Characters												
	Days to 75% silking	Days to 75% pollen shedding	Leaf area/ plant	Plant height	Ear height	Ear length	Ear circumference	Kernel rows/ ear	Kernels/ row	100- seed weight	Grain yield	Biological yield	Harvest index
1	2	3	4	5	6	7	8	9	10	11	12	13	14
$P_1 X P_2$	-0.91	-1.24*	-54.69	-1.90	4.79	0.02	0.39	0.37	0.96	-0.14	4.15*	26.02*	-2.16*
$P_1 X P_3$	-0.52	-1.15*	-111.86	-0.85	-1.46	0.64	-0.13	-0.47	1.63	0.80	-0.66	-6.80	0.75*
$P_1 X P_4$	0.14	0.33	262.89	8.70*	6.91*	0.55	0.28	-0.30	-0.72	3.06*	-0.86	-32.12*	4.77*
$P_1 X P_5$	-0.11	-0.15	234.67	2.96	-1.04	-0.56	-0.10	0.38	-1.49	0.67	0.22	11.15*	-1.60*
$P_1 X P_6$	-0.78	-0.85	-21.68	4.03	-3.24	0.14	0.17	-0.19	0.75	0.33	5.00*	27.65*	-2.02*
$P_1 X P_7$	-0.07	-0.03	-244.78	-7.81*	-2.93	-0.45	-0.31	-0.84*	-0.76	0.16	-10.19*	-26.14*	0.04
$P_1 X P_8$	-0.80	-0.55	-286.34	8.74*	11.03*	0.11	-0.16	0.77*	0.25	-0.41	6.62*	-3.38	3.10*
$P_1 X P_9$	0.86	0.90	179.66	0.86	6.33*	1.22*	0.51*	-0.31	1.27	1.67*	5.08*	2.50	1.59*
$P_1 X P_{10}$	0.00	0.15	253.87	4.82	3.63	1.21*	-0.15	-0.14	1.72	0.19	8.33*	14.02*	1.00*
$P_1 X P_{11}$	0.34	0.26	-482.49*	1.40	-5.85	-0.50	0.43	0.16	-0.62	0.91	18.02*	28.02*	2.28*
$P_1 X P_{12}$	0.66	0.79	-32.69	1.01	-2.69	0.32	0.18	1.31*	-0.96	-1.40*	-1.70	-19.52*	2.43*
$P_2 X P_3$	-0.02	-0.67	-114.89	1.20	-8.75*	-0.12	0.66*	0.31	-0.46	-0.25	6.50*	20.31*	-0.64*
$P_2 X P_4$	0.39	0.31	-42.25	1.13	-4.47	-0.71	0.19	0.69*	-2.32*	1.90*	-4.00*	-12.60*	0.34
$P_2 X P_5$	1.64*	1.58*	-105.57	12.32*	9.02*	0.38	-0.07	-0.27	1.77*	-0.66	3.04	-1.30	1.52*
$P_2 X P_6$	-0.03	0.13	76.14	7.17	6.90*	0.96*	0.65*	0.77*	1.16	1.45*	2.16	0.16	0.69*
$P_2 X P_7$	-0.57	-0.05	302.22	0.75	-3.77	1.21*	0.40	0.59*	2.14*	0.78	12.88*	1.77	4.45*

Contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14
$P_2 X P_8$	-1.05	-0.31	90.85	2.79	6.01*	0.04	0.19	-0.39	0.56	1.86*	13.15*	33.14*	-0.07
$P_2 X P_9$	-0.64	-0.12	607.85*	6.62	3.64	1.04*	-0.11	-0.37	0.49	1.24	8.03*	12.29*	1.30*
$P_2 X P_{10}$	0.25	-0.37	-185.34	4.55	0.10	-1.82*	0.35	0.85*	-2.19*	-0.35	-0.79	1.35	-0.53
$P_2 X P_{11}$	0.84	0.99	-337.09	-2.63	2.74	0.57	-0.78*	-1.00*	1.38	-1.85*	-4.88*	-14.19*	0.43
$P_2 X P_{12}$	-1.59*	-1.23*	-336.69	0.92	-5.32	0.08	-0.26	-0.60*	0.59	0.69	-0.36	-10.25*	1.69*
$P_3 X P_4$	-0.21	-0.35	-72.99	5.44	1.90	0.52	-0.01	0.18	-0.10	-1.40*	-5.32*	-2.05	-1.88*
$P_3 X P_5$	0.79	0.42	50.19	13.48*	8.21*	0.50	0.07	-0.47	0.54	0.72	-1.04	16.86*	-2.99*
$P_3 X P_6$	-0.89	-0.53	131.76	10.22*	5.99*	-0.08	0.38	-0.65*	0.64	0.12	0.57	-17.07*	2.90*
$P_3 X P_7$	-0.68	-0.96	90.87	-0.70	4.01	-0.45	-0.17	0.52*	0.20	-0.88	4.23*	-12.28*	3.50*
$P_3 X P_8$	-0.66	-0.73	312.25	9.68*	11.85*	1.17*	0.30	-0.19	2.55*	1.17	9.12*	-4.28	4.15*
$P_3 X P_9$	0.75	0.72	187.86	12.16*	5.56	0.36	0.44	-1.12	-0.20	1.17	4.50*	-7.26	3.06*
$P_3 X P_{10}$	0.39	-0.03	305.51	2.84	3.70	-0.43	-0.31	0.51*	-0.75	0.95	13.27*	11.84*	3.09*
$P_3 X P_{11}$	-0.52	-0.67	56.88	9.32*	5.19	0.17	0.34	2.13*	0.23	1.45*	13.43*	4.61	4.16*
$P_3 X P_{12}$	-0.20	-0.39	59.18	1.42	-0.04	-0.29	-0.20	0.09	-0.40	0.34	2.26	-6.89	2.19*
$P_4 X P_5$	-0.30	-0.60	-78.10	-1.74	2.61	0.92*	0.43	1.08*	2.17*	-0.05	12.30*	6.59	3.37*
$P_4 X P_6$	1.27*	1.20*	299.69	2.71	0.54	0.55	-0.01	-0.24	1.47	-0.14	15.32*	28.58*	0.93*
$P_4 X P_7$	-0.77	-0.48	91.67	6.55	6.73*	-0.30	0.25	0.44	1.69	-0.76	7.13*	13.14*	0.35
$P_4 X P_8$	-1.00	-0.49	122.58	-0.88	-2.38	-0.08	0.22	0.82*	-0.64	-0.27	8.55*	17.65*	0.28
$P_4 X P_9$	-0.34	-0.30	293.10	7.50	0.68	0.61	0.42	0.55*	3.64*	-1.50*	16.37*	31.85*	1.03*
$P_4 X P_{10}$	-0.95	-0.80	-231.06	-2.17	-2.84	0.18	0.10	-0.33	-0.46	0.55	7.76*	2.49	2.26*

Contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14
$P_4 \times P_{11}$	-0.86	-0.94	-476.77*	-2.51	0.52	-1.30*	-0.35	-0.59*	-1.73	0.37	-3.49	-8.54	0.78*
$P_4 \times P_{12}$	-1.28*	-0.65	36.78	5.48	-0.30	0.29	-0.07	0.04	2.20*	0.13	9.79*	-4.32	4.46*
$P_5 \times P_6$	0.77	0.47	-53.65	6.57	5.47	0.18	0.12	-0.35	1.02	-0.79	-6.59*	-4.85	-2.10*
$P_5 \times P_7$	0.23	0.29	459.72*	0.26	0.69	0.29	0.04	-0.14	2.50*	1.21	5.68*	22.28*	-1.30*
$P_5 \times P_8$	-1.00	-1.23*	267.73	2.27	4.95	-0.79	0.19	0.25	-1.70	1.44*	-4.81*	-20.05*	1.29*
$P_5 \times P_9$	-0.84	-0.78	80.60	13.34*	3.69	0.30	-0.07	0.23	0.37	-0.26	5.19*	-5.37	3.16*
$P_5 \times P_{10}$	-2.95*	-2.03*	-35.10	1.70	-0.96	0.96*	0.27	0.25	2.22*	1.03	1.87	-1.27	1.05*
$P_5 \times P_{11}$	-0.86	-0.67	-216.34	4.14	2.31	-0.10	0.48*	0.82*	0.60	2.11*	8.65*	44.16*	-3.24*
$P_5 \times P_{12}$	-0.78	-1.14*	48.96	-5.59	-3.72	0.08	0.20	0.02	0.14	1.63*	20.97*	36.58*	2.04*
$P_6 \times P_7$	0.05	-0.15	-41.44	4.75	3.78	-0.57	0.56*	-0.51*	-1.98*	3.60*	13.67*	14.89*	2.57*
$P_6 \times P_8$	0.57	0.58	-315.05	-5.85	-3.21	-0.03	-0.42	-0.67*	1.32	-1.49*	3.06	-29.30*	6.76*
$P_6 \times P_9$	-0.27	0.52	-186.21	-6.03	-2.47	-0.12	-0.66*	0.41	1.68	-0.26	5.11*	-7.39	3.20*
$P_6 \times P_{10}$	-0.12	0.27	-189.30	-0.06	2.60	-0.43	0.25	-0.21	-2.33*	1.94*	4.59*	15.89*	-0.74*
$P_6 \times P_{11}$	-0.53	-0.37	-45.45	-9.52*	-2.88	-0.36	-0.38	-0.03	1.58	-2.73*	-6.13*	-23.25*	1.21*
$P_6 \times P_{12}$	-0.71	-0.33	49.47	-7.56	-8.63*	0.40	-0.38	0.20	0.37	-2.19*	-7.20*	-21.99*	0.77*
$P_7 \times P_8$	0.04	0.15	174.40	6.47	3.27	0.13	-0.14	-0.58*	-0.20	-0.47	7.94*	4.24	2.28*
$P_7 \times P_9$	-0.55	-0.40	4.30	2.82	-1.48	-0.36	0.09	0.20	-1.40	1.30	6.09*	0.86	2.22*
$P_7 \times P_{10}$	-0.16	-0.65	-39.57	6.22	-0.02	0.25	0.32	-0.05	-0.85	0.16	7.12*	-3.98	3.27*
$P_7 \times P_{11}$	0.43	0.45	297.12	5.14	2.24	0.12	0.39	0.53*	1.99*	-0.42	2.84	-0.64	1.14*
$P_7 \times P_{12}$	0.00	-0.01	-314.37	6.31	7.41*	0.32	0.14	0.49	2.97*	-0.83	8.77*	28.85*	-0.91*

Contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14
$P_8 \times P_9$	0.22	0.08	335.52	-0.16	0.65	0.35	-0.19	0.45	1.49	-0.15	6.24*	13.41*	0.40
$P_8 \times P_{10}$	1.11*	1.58*	-212.23	-4.24	1.68	-0.56	0.49*	0.44	0.90	-0.39	6.67*	21.04*	-0.64*
$P_8 \times P_{11}$	-1.30*	-1.56*	348.05	2.18	-4.16	-0.59	0.29	-0.10	-0.46	-0.24	-2.05	-6.17	0.18
$P_8 \times P_{12}$	0.77	0.72	438.26*	16.56*	10.17*	-0.07	0.39	-0.24	-1.26	2.13*	2.95	14.85*	-1.04*
$P_9 \times P_{10}$	0.02	-0.98	157.82	0.89	3.00	-0.08	-0.18	0.04	1.78*	-0.21	5.45*	2.07	1.94*
$P_9 \times P_{11}$	0.11	-0.37	-2.50	-6.53	-4.45	0.60	-0.03	-0.32	2.39*	1.18	3.83*	6.62	0.51
$P_9 \times P_{12}$	-0.57	-0.83	-49.47	-4.01	-5.58	-0.80	0.16	-0.17	-0.89	0.26	1.48	11.75*	-1.02*
$P_{10} \times P_{11}$	1.25*	1.38*	3.08	0.51	3.02	0.53	0.11	-0.59*	-0.23	0.84	-0.84	-6.92	0.79*
$P_{10} \times P_{12}$	0.82	0.92	253.44	1.51	1.96	1.16*	-0.03	-0.12	3.57*	0.25	4.79*	17.59*	-0.78*
$P_{11} \times P_{12}$	1.41*	1.52*	339.94	9.84*	5.76	-0.23	0.29	-0.47	-0.74	1.78*	13.79*	27.37*	0.87*
SE(sij)	0.54	0.54	183.52	3.90	2.99	0.45	0.24	0.26	0.89	0.71	1.79	4.57	0.33
SE(sij-sik)	0.79	0.79	268.42	5.71	4.37	0.65	0.35	0.38	1.30	1.04	2.62	6.69	0.48
SE(sij-skl)	0.76	0.76	257.89	5.48	4.20	0.63	0.33	0.36	1.25	1.00	2.51	6.43	0.46
CD(sij) at 5%	1.06	1.06	359.70	7.65	5.86	0.87	0.46	0.51	1.75	1.40	3.51	8.97	0.64

* Significant at $P \leq 0.05$

Shelling percentage

At Bajaura, positive sca effects were found for the cross combinations $P_1 \times P_8$, $P_2 \times P_4$, $P_3 \times P_4$, $P_3 \times P_{10}$, $P_5 \times P_{11}$, $P_5 \times P_{12}$, $P_6 \times P_7$, $P_6 \times P_9$ and $P_9 \times P_{11}$; and negative for $P_1 \times P_9$, $P_6 \times P_{12}$, $P_7 \times P_{11}$ and $P_8 \times P_{12}$. Pooled analysis for this trait could not be carried out due to nonsignificant variance at Palampur.

100-seed weight

Positive sca effects were observed for $P_2 \times P_4$, $P_5 \times P_{10}$, $P_5 \times P_{11}$, $P_5 \times P_{12}$, $P_6 \times P_7$ and $P_7 \times P_9$ cross combinations at Palampur; for $P_1 \times P_4$, $P_2 \times P_8$, $P_3 \times P_5$, $P_3 \times P_{11}$, $P_5 \times P_7$, $P_5 \times P_8$, $P_6 \times P_7$, $P_6 \times P_{10}$, $P_8 \times P_{12}$, $P_9 \times P_{12}$, $P_{10} \times P_{11}$ and $P_{11} \times P_{12}$ at Bajaura; and for $P_1 \times P_4$, $P_1 \times P_9$, $P_2 \times P_4$, $P_2 \times P_6$, $P_2 \times P_8$, $P_3 \times P_{11}$, $P_5 \times P_8$, $P_5 \times P_{11}$, $P_5 \times P_{12}$, $P_6 \times P_7$, $P_6 \times P_{10}$, $P_8 \times P_{12}$ and $P_{11} \times P_{12}$ on pooled basis. Negative sca effects were found for $P_2 \times P_5$, $P_6 \times P_{11}$, $P_6 \times P_{12}$ and $P_9 \times P_{12}$ at Palampur; for $P_2 \times P_{11}$, $P_5 \times P_9$, $P_6 \times P_8$, $P_6 \times P_{11}$ and $P_6 \times P_{12}$ at Bajaura; and for $P_1 \times P_{12}$, $P_2 \times P_{11}$, $P_3 \times P_4$, $P_4 \times P_9$, $P_6 \times P_8$, $P_6 \times P_{11}$ and $P_6 \times P_{12}$ in pooled analysis.

Grain yield

The number of cross combinations showing positive sca effects for this trait was relatively high. As many as 38 crosses at Palampur, 29 at Bajaura and 39 in pooled analysis revealed positive sca effects. Positive sca effects were exhibited by $P_1 \times P_{10}$, $P_1 \times P_{11}$, $P_2 \times P_7$, $P_2 \times P_8$, $P_2 \times P_9$, $P_3 \times P_8$, $P_3 \times P_{10}$, $P_3 \times P_{11}$, $P_4 \times P_5$, $P_4 \times P_6$, $P_4 \times P_8$, $P_4 \times P_9$, $P_5 \times P_{11}$, $P_5 \times P_{12}$, $P_6 \times P_7$, $P_7 \times P_8$, $P_7 \times P_{10}$, $P_7 \times P_{12}$ and $P_{11} \times P_{12}$ in all the environments i.e. at Palampur, Bajaura and in pooled analysis. A total of 3, 10 and 8 cross combinations were found negative sca effects at Palampur, Bajaura and in pooled analysis, respectively.

Biological yield

Most of the cross combinations showing positive sca effects for grain yield were also found to have positive sca effects for biological yield. Eighteen cross combinations at Palampur, 22 at Bajaura and 26 in pooled analysis revealed positive sca effects. The common crosses which exhibited positive sca effects in all conditions were $P_1 \times P_6$, $P_1 \times P_{11}$, $P_2 \times P_8$, $P_3 \times P_5$, $P_4 \times P_6$, $P_5 \times P_7$, $P_5 \times P_{11}$, $P_5 \times P_{12}$, $P_7 \times P_{12}$, $P_8 \times P_{10}$, $P_{10} \times P_{12}$ and $P_{11} \times P_{12}$. Negative sca effects were found in 6 crosses at Palampur, 14 crosses at Bajaura and 12 crosses in pooled analysis.

Harvest index

Cross combinations $P_1 \times P_4$, $P_1 \times P_8$, $P_1 \times P_{12}$, $P_2 \times P_5$, $P_2 \times P_7$, $P_2 \times P_{12}$, $P_3 \times P_6$, $P_3 \times P_7$, $P_3 \times P_8$, $P_3 \times P_9$, $P_3 \times P_{10}$, $P_3 \times P_{11}$, $P_3 \times P_{12}$, $P_4 \times P_7$, $P_4 \times P_{10}$, $P_4 \times P_{12}$, $P_5 \times P_8$, $P_5 \times P_9$, $P_5 \times P_{12}$, $P_6 \times P_7$, $P_6 \times P_8$, $P_6 \times P_9$, $P_7 \times P_8$, $P_7 \times P_9$, $P_7 \times P_{10}$ and $P_9 \times P_{10}$ were common and showed positive sca effects and $P_1 \times P_2$, $P_1 \times P_6$, $P_3 \times P_4$, $P_3 \times P_5$, $P_5 \times P_6$, $P_5 \times P_{11}$ and $P_8 \times P_{12}$ were common and showed negative sca effects at both the environments. Whereas, in case of pooled analysis 41 cross combinations exhibited positive sca effects.

The estimates of specific combining ability (sca) effects for different seed quality traits are presented in Table 4.16. The significant sca effects observed for different characters are given below:

100-seed weight

Analysis for sca effects showed that 9 cross combinations $P_2 \times P_3$, $P_2 \times P_4$, $P_3 \times P_{11}$, $P_5 \times P_{10}$, $P_5 \times P_{11}$, $P_5 \times P_{12}$, $P_6 \times P_7$, $P_7 \times P_9$ and $P_9 \times P_{12}$ had consistent positive sca effects and two $P_3 \times P_{12}$ and $P_6 \times P_9$ had negative sca effects for this trait.

Table 4.16 Estimates of specific combining ability (sca) effects for seed quality traits

Combination	Characters							
	100-seed weight	100-seed volume	Seed density	Accelerated aging test	Osmotic stress test	Germination percentage	Seed vigour index	Field emergence
1	2	3	4	5	6	7	8	9
$P_1 \times P_2$	1.63	1.00	0.02	5.79*	4.41	3.51*	-1.48	0.61
$P_1 \times P_3$	-0.63	-0.29	-0.02	5.65*	1.87	2.69	-5.21*	-0.18
$P_1 \times P_4$	0.58	-0.11	0.03*	0.29	1.73	-1.20	-0.81	0.40
$P_1 \times P_5$	-0.69	-0.97	0.02	2.25	0.09	0.01	-0.11	1.68
$P_1 \times P_6$	-0.33	-0.25	-0.01	-2.28	1.98	-3.70*	0.65	-6.82*
$P_1 \times P_7$	-0.73	-1.22	0.03*	-8.32*	3.12	-2.56	3.68*	-5.46*
$P_1 \times P_8$	1.72	1.57*	-0.02	3.54	-2.52	3.08	2.24	9.40*
$P_1 \times P_9$	0.92	0.96	-0.02	1.97	3.30	1.01	-1.47	1.68
$P_1 \times P_{10}$	-0.76	-1.07	0.02	-3.46	-0.06	-2.49	-1.85	1.11
$P_1 \times P_{11}$	1.11	0.03	0.04*	3.04	-4.20	0.80	2.25	1.90
$P_1 \times P_{12}$	-1.77	-0.72	-0.05*	-1.39	-6.24*	-2.74	1.18	-0.53
$P_2 \times P_3$	2.17*	2.68*	-0.05*	1.97	1.01	1.40	2.37	-0.68
$P_2 \times P_4$	2.05*	1.35*	0.02	-8.39*	-9.13*	-3.49*	1.25	-6.10*
$P_2 \times P_5$	-0.91	-0.50	-0.01	-5.93*	2.23	-1.27	-0.95	-0.82
$P_2 \times P_6$	1.64	1.21	0.01	-3.96	-9.88*	-2.99	-2.61	-21.32*
$P_2 \times P_7$	-1.04	-1.25	0.03*	3.50	4.26	0.15	1.72	6.04*
$P_2 \times P_8$	1.40	0.53	0.04*	-3.14	-0.38	-0.20	-0.63	2.90
$P_2 \times P_9$	-1.01	-1.07	0.01	6.29*	-1.56	3.73*	2.15	8.18*
$P_2 \times P_{10}$	0.23	-0.11	-0.01	5.86*	3.09	2.23	-0.51	2.61
$P_2 \times P_{11}$	-1.59	-1.50*	0.02	2.36	5.94*	2.51	0.78	3.40
$P_2 \times P_{12}$	0.54	0.75	-0.02	-1.57	0.91	-0.02	-0.05	4.97
$P_3 \times P_4$	-0.34	0.07	-0.03*	2.47	6.84*	1.69	3.62*	-1.89
$P_3 \times P_5$	0.62	0.21	0.02	4.43*	-3.31	3.90*	-0.10	2.40
$P_3 \times P_6$	0.86	0.43	0.01	0.90	-2.41	-0.81	-1.13	0.90

Contd...

1	2	3	4	5	6	7	8	9
$P_3 \times P_7$	-1.05	-1.04	0.01	2.36	1.73	0.33	0.58	3.25
$P_3 \times P_8$	0.77	1.25	-0.03*	2.28	1.09	-3.02	1.67	-1.89
$P_3 \times P_9$	1.75	1.14	0.01	1.15	-3.09	-1.10	0.28	3.40
$P_3 \times P_{10}$	1.38	1.10	0.00	1.72	1.55	-1.60	2.15	1.82
$P_3 \times P_{11}$	1.98*	0.71	0.05*	-14.78*	-14.59*	-5.31*	-1.72	-1.39
$P_3 \times P_{12}$	-2.21*	-2.04*	0.01	2.79	4.37	-1.35	-0.39	1.18
$P_4 \times P_5$	-0.75	-0.61	0.00	3.07	7.55*	3.01	-1.07	1.97
$P_4 \times P_6$	-1.76	-1.40*	-1.01*	0.54	-2.56	-0.70	-2.02	1.47
$P_4 \times P_7$	-0.94	-0.86	0.01	5.50*	-0.41	1.44	-0.11	3.82
$P_4 \times P_8$	1.29	0.43	0.03*	-2.64	-0.06	-1.92	1.04	-0.32
$P_4 \times P_9$	-0.99	-0.68	0.04*	0.29	5.76*	2.01	-1.02	3.97
$P_4 \times P_{10}$	0.54	-0.22	0.04*	-14.64*	-6.59*	-1.49	-2.49	0.40
$P_4 \times P_{11}$	0.09	-0.11	0.01	0.86	-10.74*	-4.20*	-2.07	1.18
$P_4 \times P_{12}$	0.83	1.64*	-0.06*	6.43*	-10.77*	3.28	-0.58	-0.25
$P_5 \times P_6$	-0.27	-0.25	0.00	-3.50	-0.70	2.51	2.97*	1.75
$P_5 \times P_7$	0.89	0.28	0.03*	0.97	-1.06	1.65	1.73	1.11
$P_5 \times P_8$	1.48	1.07	0.01	2.82	-1.70	-1.70	0.58	0.03
$P_5 \times P_9$	0.65	0.46	0.00	-3.25	3.12	-1.77	0.60	8.25*
$P_5 \times P_{10}$	2.50*	2.43*	-0.02	4.32*	4.76*	0.73	0.94	8.68*
$P_5 \times P_{11}$	1.93*	1.03	0.03*	-9.68*	-3.38	-1.99	2.32	-5.53*
$P_5 \times P_{12}$	2.25*	1.78*	0.00	2.40	-1.41	-1.52	0.67	-7.96*
$P_6 \times P_7$	2.73*	1.50*	0.04*	2.43	3.84	1.94	-1.60	6.61*
$P_6 \times P_8$	0.60	-0.22	0.04*	-0.21	2.19	-0.42	-1.04	-2.53
$P_6 \times P_9$	-2.07*	-2.32*	0.04*	0.22	4.01	-1.49	-1.23	0.75
$P_6 \times P_{10}$	0.66	0.64	0.00	2.79	4.66	3.01	0.25	5.18
$P_6 \times P_{11}$	-0.03	0.25	-0.01	3.29	10.01*	3.30*	-1.68	3.97
$P_6 \times P_{12}$	0.41	-0.50	0.05*	5.86*	1.48	3.76*	2.87*	7.54*

Contd...

1	2	3	4	5	6	7	8	9
$P_7 X P_8$	0.21	0.32	-1.01*	2.25	-0.66	0.73	-3.47*	-11.18*
$P_7 X P_9$	2.09*	1.71*	0.00	-8.82*	-2.84	-1.35	-1.73	-12.89*
$P_7 X P_{10}$	0.61	0.68	-0.01	3.25	-0.20	-1.85	1.64	-9.46*
$P_7 X P_{11}$	0.12	-0.22	0.02	0.75	0.66	-0.56	-1.06	3.32
$P_7 X P_{12}$	0.16	0.03	0.01	-5.68*	1.62	-0.10	0.39	2.90
$P_8 X P_9$	0.09	-0.50	0.03*	-2.96	-5.49*	-2.70	-1.14	5.97*
$P_8 X P_{10}$	-1.70	-1.04	-0.02	5.61*	-0.84	3.80*	1.36	0.40
$P_8 X P_{11}$	-0.80	0.07	-0.04*	2.11	4.01	1.08	-0.64	-1.82
$P_8 X P_{12}$	-0.57	-0.68	0.02	-2.32	4.98*	0.55	-1.68	-0.25
$P_9 X P_{10}$	-0.21	-0.15	-0.01	-3.46	-11.52*	-2.27	-0.71	3.68
$P_9 X P_{11}$	1.21	0.96	0.00	6.54*	6.84*	3.01	0.17	5.47*
$P_9 X P_{12}$	2.08*	1.71*	0.00	-2.89	-5.20*	0.48	-0.20	-2.96
$P_{10} X P_{11}$	1.45	1.43*	-0.01	3.11	-5.52*	1.51	2.00	-4.10
$P_{10} X P_{12}$	-0.42	-0.32	0.00	-4.32*	3.44	-0.02	-0.08	5.47*
$P_{11} X P_{12}$	0.02	0.28	-0.02	-0.82	-3.70	2.26	-1.34	-3.75
SE(sij)	0.93	0.63	0.01	2.08	2.37	1.66	1.43	2.67
SE(gij-sik)	1.35	0.93	0.02	3.04	3.47	2.43	2.09	3.91
SE (sij-skl)	1.30	0.89	0.02	2.92	3.33	2.33	2.01	3.75
CD(sij) at 5%	1.84	1.26	0.03	4.14	4.71	3.30	2.84	5.31

Significant at $P \leq 0.05$

100-seed volume

For seed volume, positive sca effects were obtained for $P_1 \times P_8$, $P_2 \times P_3$, $P_2 \times P_4$, $P_4 \times P_{12}$, $P_5 \times P_{10}$, $P_5 \times P_{12}$, $P_6 \times P_7$, $P_7 \times P_9$, $P_9 \times P_{12}$ and $P_{10} \times P_{11}$ cross combinations. However, negative sca effects were observed for $P_2 \times P_{11}$, $P_3 \times P_{12}$, $P_4 \times P_6$ and $P_6 \times P_9$.

Seed density

Positive sca effects were observed for the cross combinations $P_1 \times P_4$, $P_1 \times P_7$, $P_1 \times P_{11}$, $P_2 \times P_7$, $P_2 \times P_8$, $P_3 \times P_{11}$, $P_4 \times P_8$, $P_4 \times P_9$, $P_4 \times P_{10}$, $P_5 \times P_7$, $P_5 \times P_{11}$, $P_6 \times P_7$, $P_6 \times P_8$, $P_6 \times P_9$, $P_6 \times P_{12}$ and $P_8 \times P_9$ and negative in $P_1 \times P_{12}$, $P_2 \times P_3$, $P_3 \times P_4$, $P_3 \times P_8$, $P_4 \times P_6$, $P_4 \times P_{12}$, $P_7 \times P_8$ and $P_8 \times P_{11}$.

Accelerated aging test

Eleven crosses viz., $P_1 \times P_2$, $P_1 \times P_3$, $P_2 \times P_9$, $P_2 \times P_{10}$, $P_3 \times P_5$, $P_4 \times P_7$, $P_4 \times P_{12}$, $P_5 \times P_{10}$, $P_6 \times P_{12}$, $P_8 \times P_{10}$ and $P_9 \times P_{11}$ had positive, whereas, 9 crosses $P_1 \times P_7$, $P_2 \times P_4$, $P_2 \times P_5$, $P_3 \times P_{11}$, $P_4 \times P_{10}$, $P_5 \times P_{11}$, $P_7 \times P_9$, $P_7 \times P_{12}$ and $P_{10} \times P_{12}$ had negative sca effects for accelerated aging test.

Osmotic stress test

The estimates of sca effects for osmotic stress test were positive for $P_2 \times P_{11}$, $P_3 \times P_4$, $P_4 \times P_5$, $P_4 \times P_9$, $P_5 \times P_{10}$, $P_6 \times P_{11}$, $P_8 \times P_{12}$ and $P_9 \times P_{11}$ and negative for $P_1 \times P_{12}$, $P_2 \times P_4$, $P_2 \times P_6$, $P_3 \times P_{11}$, $P_4 \times P_{10}$, $P_4 \times P_{11}$, $P_4 \times P_{12}$, $P_8 \times P_9$, $P_9 \times P_{10}$, $P_9 \times P_{12}$ and $P_{10} \times P_{11}$ cross combinations.

Germination percentage

Positive sca effects were observed for $P_1 \times P_2$, $P_2 \times P_9$, $P_3 \times P_5$, $P_6 \times P_{11}$, $P_6 \times P_{12}$ and $P_8 \times P_{10}$ and negative for $P_1 \times P_6$, $P_2 \times P_4$, $P_3 \times P_{11}$ and $P_4 \times P_{11}$ for this trait.

Seed vigour index

The estimates of sca for seed vigour index were and positive for $P_1 \times P_7$, $P_3 \times P_4$, $P_5 \times P_6$ and $P_6 \times P_{12}$ and negative for $P_1 \times P_3$ and $P_7 \times P_8$ cross combinations.

Field emergence

Cross combinations $P_1 \times P_8$, $P_2 \times P_7$, $P_2 \times P_9$, $P_5 \times P_9$, $P_5 \times P_{10}$, $P_6 \times P_7$, $P_6 \times P_{12}$, $P_8 \times P_9$, $P_9 \times P_{11}$ and $P_{10} \times P_{12}$ had positive sca effects, whereas, negative sca effects were observed for $P_1 \times P_6$, $P_1 \times P_7$, $P_2 \times P_4$, $P_2 \times P_6$, $P_5 \times P_{11}$, $P_5 \times P_{12}$, $P_7 \times P_8$, $P_7 \times P_9$ and $P_7 \times P_{10}$.

4.2.2 Genetic component analysis

4.2.2.1 Estimates of components of genetic variance

Estimates of genetic components of variation and other estimates derived from them for different yield and yield contributing traits at both the locations and on pooled basis are presented in Table 4.17, 4.18 and 4.19 for Palampur, Bajaura and on pooled basis, respectively.

E: Environmental component of variance was found to be nonsignificant for grain yield, biological yield and harvest index at both the locations and on pooled basis and significnat for remaining traits.

D: Additive component of variance was found to be significant for leaf area/plant, plant height, ear height, ear length, kernel rows/ear, shelling percentage, biological yield and harvest index at Palampur and on pooled basis; 100-seed weight on pooled basis; and for days to pollen shedding, leaf area/plant, plant height, ear height, days to maturity, kernel rows/ear, biological yield and harvest index at Bajaura.

F: The F value was significantly positive for ear height, biological yield and harvest index at Palampur; for plant height, ear height and harvest index at Bajaura; and for harvest index, biological yield, leaf area/plant, plant height, ear height and ear length on pooled basis.

H_1 & H_2: The dominance components (H_1) and (H_2) were significant for all the characters i.e. days to silking, days to pollen shedding, days to maturity, leaf area/plant, plant height, ear height, ear length, ear circumference, kernel rows/ ear, kernels/row, shelling percentage, 100-seed weight, grain yield, biological yield and harvest index at both the locations and on pooled basis.

h^2: The net dominance effect was positive and significant for all the characters except days to pollen shedding, days to maturity and kernel rows/ear in Palampur; for ear length in Bajaura; and for biological yield on pooled basis.

$\sqrt{H_1/D}$: The mean degree of dominance ($\sqrt{H_1/D}$) was calculated only for those traits in which both D and H_1 components were significant. For the characters under present study viz., leaf area/plant, plant height, ear height, ear length, kernel rows/ear, shelling percentage, biological yield and harvest index at Palampur; for days to pollen shedding, days to maturity, leaf area/plant, plant height, ear height, kernel rows/ear, biological yield and harvest index at Bajaura; and for leaf area/plant, plant height, ear height, ear length, kernel rows/ear, shelling percentage, biological yield, 100-seed weight and harvest index on pooled basis, the values for degree of dominance was more than unity indicating over dominance.

h^2_{ns}: Estimates of heritability in narrow sense (h^2_{ns}) were grouped in three categories i.e. low (<15%), medium (15-30%) and high (>30%). Estimates of heritability were high for ear height at Palampur; plant height and ear height at Bajaura; and leaf area/plant, plant height and ear height on the pooled basis.

Table 4.17 Estimates of components of variation for different yield and yield contributing traits at Palampur (E_1)

Component	Days to 75% silking	Days to 75% pollen shedding	Leaf area/ plant	Plant height	Ear height	Days to 75 % maturity	Ear length	Ear circum-ference	Kernel rows/ ear	Kernels/ row	Shelling percen-tage	100- seed weight	Grain yield	Biological yield	Harvest index
E	0.93*	0.86*	100889.82*	42.92*	24.01*	1.74*	0.50*	0.12*	0.13*	1.89*	2.15*	1.21*	7.37	51.12	0.29
	±0.19	±0.17	±22001.33	±10.05	±5.90	±0.12	±0.08	±0.02	±0.04	±0.43	±0.36	±0.24	±6.06	±39.96	±0.78
D	-0.21	0.29	211382.22*	132.21*	140.67*	0.01	0.68*	0.06	0.82*	2.74	3.93*	0.95	14.02	467.73*	8.21*
	±0.67	±0.63	±79326.93	±36.23	±21.26	±0.44	±0.29	±0.07	±0.15	±1.56	±1.30	±0.86	±21.84	±144.08	±2.83
F	-0.65	0.41	323195.69	129.92	156.76*	-0.29	0.99	0.08	0.23	3.65	4.88	0.55	11.34	818.00*	15.37*
	±1.53	±1.42	±179789.76	±82.12	±48.18	±1.00	±0.67	±0.16	±0.35	±3.54	±2.94	±1.95	±49.50	±326.54	±6.40
H_1	5.28*	4.70*	674475.23*	408.65*	269.20*	2.87*	2.41*	0.83*	1.79*	18.43*	7.51*	10.03*	757.41*	2310.16*	48.95*
	±1.35	±1.25	±158696.23	±72.49	±42.53	±0.88	±0.59	±0.14	±0.30	±3.13	±2.59	±1.72	±43.69	±288.23	±5.65
H_2	5.07*	4.06*	479013.61*	338.24*	179.32*	2.79*	1.93*	0.68*	1.47*	16.32*	5.67*	8.44*	693.06*	1800.98*	39.16*
	±1.12	±1.04	±132007.99	±60.30	±35.38	±0.73	±0.49	±0.11	±0.25	±2.60	±2.16	±1.43	±36.34	±239.76	±4.70
h^2	3.03*	0.31	1747602.59*	1508.76*	572.88*	0.06	5.05*	1.72*	0.29	27.53*	14.88*	20.87*	4939.10*	5418.00*	218.40*
	±0.75	±0.70	±88261.72	±40.31	±23.65	±0.49	±0.33	±0.08	±0.17	±1.74	±1.44	±0.96	±24.30	±160.30	±3.14
$\sqrt{H_1/D}$	--	--	1.79	1.76	1.38	--	1.88	--	1.48	--	1.38	--	--	2.22	2.44
$H_2/4H_1$	0.24	0.22	0.18	0.21	0.17	0.24	0.20	0.21	0.20	0.22	0.19	0.21	0.23	0.19	0.20
h^2_{ns}	-2.61	3.56	21.88	22.69	40.29	0.06	16.63	4.54	28.28	10.74	25.94	6.23	1.78	21.61	19.12
K_D/K_R	-	0.001	2.50	1.78	2.35	--	2.26	1.44	1.21	1.69	2.63	1.20	1.12	2.30	2.24
h^2/H_2	0.60	0.08	3.65	4.46	3.20	0.02	2.62	2.53	0.20	1.69	2.32	2.47	7.13	3.01	5.58
r	0.35	0.11	-0.91*	-0.82*	-0.75*	0.12	-0.78*	-0.56	0.20	-0.76*	-0.80*	-0.62*	-0.93*	-0.66*	-0.87*
b	0.15	0.02	0.34	0.36	0.57*	0.65*	0.27	0.34	0.51*	0.47*	0.57*	0.48*	0.24	0.50*	0.16
	±0.12	±0.15	±0.16	±0.24	±0.21	±0.26	±0.16	±0.19	±0.11	±0.21	±0.22	±0.13	±0.15	±0.18	±0.14
1-b	0.85*	0.98*	0.66*	0.64*	0.43	0.36	0.73*	0.66*	0.49*	0.53*	0.43	0.52*	0.76*	0.50*	0.84*
t^2	11.94*	6.21*	4.23*	0.38	0.31	0.02	4.59*	2.05	9.10*	0.77	0.21	5.47*	5.27*	1.46	7.27*

* Significant at $P \leq 0.05$

Table 4.18 Estimates of components of variation for different yield and yield contributing traits at Bajaura (E_2)

Component	Characters														
	Days to 75% silking	Days to 75% pollen shedding	Leaf area/ plant	Plant height	Ear height	Days to 75 % maturity	Ear length	Ear circum-ference	Kernel rows/ ear	Kernels/ row	Shelling percen-tage	100- seed weight	Grain yield	Biological yield	Harvest index
E	0.41*	0.50*	54286.68*	27.29*	17.11*	0.51*	0.42*	0.13*	0.18*	1.76*	1.48*	1.13*	7.39	45.23	0.20
	±0.06	±0.09	±12784.31	±5.89	±3.91	±0.05	±0.09	±0.02	±0.04	±0.31	±0.38	±0.24	±6.95	±45.29	±0.74
D	-0.01	0.81*	161083.14*	153.55*	83.22*	0.76*	0.56	0.01	0.39*	0.14	2.02	1.13	18.48	549.22*	9.10*
	±0.23	±0.34	±46094.47	±21.25	±14.08	±0.16	±0.31	±0.07	±0.16	±1.11	±1.38	±0.87	±25.05	±163.30	±2.67*
F	-0.47	0.74	204630.95	223.27*	115.64*	0.44	0.47	-0.08	-0.02	0.30	0.91	0.30	19.67	654.98	16.32*
	±0.52	±0.77	±104470.38	±48.17	±31.92	±0.37	±0.70	±0.16	±0.36	±2.53	±3.13	±1.98	±56.77	±370.12	±6.04
H_1	1.38*	2.44*	443868.31*	356.32*	176.89*	1.00*	3.43*	0.72*	2.34*	19.19*	12.70*	10.17*	452.38*	2207.65*	43.91*
	±0.46	±0.68	±92213.57	±42.52	±28.18	±0.33	±0.62	±0.14	±0.32	±2.23	±2.76	±1.74	±50.11	±326.69	±5.33
H_2	1.36*	2.11*	291720.95*	250.90*	123.53*	0.56*	3.14*	0.71*	2.14*	18.05*	10.78*	9.82*	405.98*	1835.01*	34.81*
	±0.38	±0.57	±76705.84	*±35.37	±23.44	±0.27	±0.52	±0.12	±0.27	±1.85	±2.30	±1.45	±41.69	±271.75	±4.44
h^2	4.10*	6.81*	205135.80*	568.37	127.44*	0.76*	-0.13	1.00*	0.62*	34.31*	13.24*	13.30*	1546.49*	626.92*	148.50*
	±0.26	±0.38	±51286.21	±23.65	±15.67	±0.18	±0.35	±0.08	±0.18	±1.24	±1.54	±0.97	±27.87	±181.70	±2.97
$\sqrt{H_1/D}$	--	1.73	1.66	1.52	1.46	1.15	--	--	2.44	--	--	--	--	2.00	2.20
$H_2/4H_1$	0.25	0.22	0.16	0.18	0.17	0.14	0.23	0.24	0.23	0.24	0.21	0.24	0.22	0.21	0.20
h^2_{ns}	0.24	18.00	26.09	38.80	39.09	22.74	10.84	0.61	11.37	0.54	10.26	7.30	3.84	24.06	24.26
K_D/K_R	--	1.71	2.24	2.83	2.82	1.68	1.41	--	--	1.20	1.20	1.09	1.24	1.85	2.38
h^2/H_2	3.02	3.23	0.70	2.27	1.03	1.36	--	1.41	0.29	1.90	1.23	1.35	3.81	0.34	4.27
r	0.73*	0.95*	0.75*	-0.74*	-0.55	0.50	-0.41	-0.36	-0.56	-0.75*	-0.32	-0.58*	-0.77*	-0.57	-0.70*
b	0.09	0.06	0.09	0.62	0.52*	0.53*	0.02	0.17	0.42	0.14	0.29	0.30	0.20	0.32	0.26
	±0.15	±0.23	±0.23	±0.18	±0.19	±0.20	±0.17	±1.12	±0.22	±0.10	±0.23	±0.19	±0.14	±0.16	±0.24
1-b	0.91*	0.94	0.91*	0.38	0.48*	0.47*	1.02*	0.83*	0.58*	0.87*	0.71*	0.70*	0.80*	0.68*	0.74*
t^2	6.30*	1.18	0.98	0.69	0.92	0.69	4.29*	10.95*	0.63	18.45*	0.77	1.96	8.22*	4.42*	0.56

* Significant at $P \leq 0.05$

Table 4.19 Estimates of components of variation for different yield and yield contributing traits pooled over 2 environments

Component	Characters														
	Days to 75% silking	Days to 75% pollen shedding	Leaf area/ plant	Plant height	Ear height	Days to 75 % maturity	Ear length	Ear circum-ference	Kernel rows/ ear	Kernels/ row	Shelling percen-tage	100-seed weight	Grain yield	Biological yield	Harvest index
E	0.34*	0.34*	38796.09*	17.53*	10.38*	0.56*	0.23*	0.06*	0.08*	0.91*	0.91*	0.59*	3.69	24.10	0.12
	±0.09	±0.08	±7400.33	±5.65	±3.45	±0.05	±0.04	±0.01	±0.04	±0.26	±0.19	±0.15	±5.03	±35.45	±0.76
D	0.00	0.54	154779.96*	137.39*	99.27*	0.22	0.65*	0.02	0.59*	1.21	1.85*	1.28*	16.26	490.68*	8.56*
	±0.34	±0.30	±26682.26	±20.35	±12.46	±0.20	±0.16	±0.04	±0.14	±0.96	±0.69	±0.55	±18.12	±127.81	±2.74
F	-0.18	0.83	184802.54*	185.16*	114.38*	0.37	0.75*	-0.07	0.11	1.16	0.51	0.59	20.04	709.07*	15.76*
	±0.77	±0.68	±60473.75	±46.13	±28.23	±0.44	±0.35	±0.10	±0.33	±2.16	±1.57	±1.25	±41.07	±289.68	±6.21
H_1	2.59*	2.69*	300466.13*	270.11*	156.92*	1.45*	1.55*	0.43*	1.50*	11.10*	5.85*	7.14*	519.17*	1779.92*	44.79*
	±0.68	±0.60	±53378.77	±40.72	±24.92	±0.39	±0.31	±0.09	±0.29	±1.91	±1.38	±1.10	±36.25	±255.69	±5.48
H_2	2.36*	2.18*	181340.54*	198.57*	107.57*	1.14*	1.23*	0.40*	1.26*	9.93*	5.57*	6.44*	468.14*	1416.37*	35.56*
	±0.57	±0.50	±44401.96	±33.87	±20.73	±0.33	±0.26	±0.07	±0.24	±1.59	±1.15	±0.91	±30.16	±212.69	±4.56
h^2	3.65*	2.78*	174209.50*	987.90*	313.80*	0.58*	1.25*	1.35*	0.46*	31.11*	14.32*	17.06*	3004.59*	2444.18	181.81*
	±0.36	±0.33	±29687.55	±22.65	±13.86	±0.22	±0.17	±0.05	±0.16	±1.06	±0.77	±0.61	±20.16	±142.21	±3.05
$\sqrt{H_1/D}$	-	-	1.39	1.40	1.26	-	1.55	-	1.59	-	1.78	2.36	-	1.90	2.29
$H_2/4H_1$	0.23	0.20	0.15	0.18	0.17	0.20	1.20	1.23	0.21	0.22	0.24	0.23	0.23	0.20	0.20
h^2_{ns}	-	14.40	36.37	46.97	54.26	6.30	27.29	2.03	25.78	8.17	17.12	12.57	3.07	29.60	22.47
K_D/K_R	-	2.05	2.50	2.85	2.69	1.97	2.19	-	1.12	1.38	1.17	1.22	1.25	2.22	2.35
h^2/H_2	1.55	1.28	0.96	4.98	2.92	0.51	1.02	3.38	0.37	3.13	2.57	2.65	6.42	1.73	5.11
r	0.05	0.57	-0.44	-0.93*	-0.82*	0.60*	-0.51	-0.49	0.02	-0.78*	-0.70*	-0.81*	-0.87*	-0.76*	-0.79*
b	-0.04	0.10	0.24	0.63*	0.60*	0.12	0.16	0.14	0.39*	0.25	0.58*	0.47*	0.25	0.47	0.16
	±0.09	±0.21	±0.22	±0.17	±0.15	±0.37	±0.19	±0.12	±0.10	±0.21	±0.24	±0.21	±0.17	±0.21	±0.18
1-b	1.04*	0.90*	0.76*	0.37	0.40*	0.89*	0.84*	0.86*	0.61*	0.75*	0.42	0.54*	0.75*	0.53*	0.84*
t^2	27.36*	1.79	1.22	0.93	1.80	0.26	2.78	13.68*	13.29*	1.59	0.05	0.79	3.81*	0.62	3.01

* Significant at $P \leq 0.05$

Medium heritability was observed for ear length, kernel rows/ear, shelling percentage, biological yield and harvest index on pooled basis; for plant height, leaf area/plant, ear length, kernel rows/ear, shelling percentage, biological yield and harvest index at Palampur; and for days to pollen shedding, days to maturity, leaf area/plant, biological yield and harvest index at Bajaura. Low heritability was observed for days to pollen shedding, days to maturity, ear circumference, kernels/row, 100-seed weight and grain yield at Palampur and on pooled basis. Similarly for ear length, ear circumference, kernel rows/ear, kernels/row, shelling percentage, 100-seed weight and grain yield the heritability was low at Bajaura.

K_D/K_R: The ratio exhibiting the relative frequencies of dominant and recessive alleles in the parents was observed to be greater than one at both the locations and on pooled basis for all characters except, days to pollen shedding at Palampur.

r: The coefficient of correlation between the parental order of dominance (Wr + Vr) and parental measurement (Yr) was found to be positive and significant only for days to silking, pollen shedding and leaf area/plant at Bajaura; and for days to maturity in pooled analysis. However, significantly negative for leaf area/plant, plant height, ear length, ear height, kernels/row, 100-seed weight, grain yield, biological yield, harvest index and shelling percentage at Palampur; for plant height, kernels/row, 100-seed weight, grain yield and harvest index at Bajaura; and for plant height, ear height, kernels/row, 100-seed weight, grain yield, harvest index, shelling percentage and biological yield on pooled basis.

Considering the practical knowledge of the material under investigation, some of the assumptions like diploid segregation and homozygosity of the parents were safely assumed to be fulfilled. For rest of the assumptions Hayman (1954) proposed t^2-test to examine the independent distribution of genes among the parents and regression coefficient (b) as a test for non-allelic interactions.

t^2-test: In the present investigation the t^2- values were nonsignificant for plant height, ear height, days to maturity, ear circumference, kernels/row, shelling percentage and biological yield at Palampur; for days to pollen shedding, leaf area/plant, plant height, ear height, days to maturity, kernel rows/ear, shelling percentage, 100-seed weight and harvest index at Bajaura; and for days to pollen shedding, days to maturity, leaf area/plant, plant height, ear height, ear length, kernels/row, shelling percentage, 100-seed weight, biological yield and harvest index over pooled analysis.

b: Both the regression coefficient (b) and its deviation from unit (1-b) were significant for kernel rows/ear, kernels/row, 100-seed weight and biological yield at Palampur; for ear height and days to maturity at Bajaura; and for ear height, kernel rows/ear and 100-seed weight over the pooled analysis. Whereas, in addition to this deviation from unity (1-b) were also significant for days to silking, pollen shedding, leaf area/plant, plant height, ear length, ear circumference, grain yield and harvest index at Palampur; for days to silking, leaf areas/plant, ear length, ear circumference, kernel rows/ear, kernels/row, shelling percentage, 100-seed weight, grain yield, biological yield and harvest index at Bajaura; and for days to silking, pollen shedding, leaf area/plant, days to maturity, ear length, ear circumference, kernels/row, grain yield, biological yield and harvest index in pooled analaysis.

The estimates of genetic components of variation and various estimates derived from them for different seed quality traits are presented in Table 4.20 and are described below :

E: Environmental component of variance (E) was found to be significant for 100-seed weight, 100-seed volume, accelerated aging, test, germination percentage and seed vigour index.

D: The additive component of variance (D) was found to be significant for 100-seed weight, 100 seed volume, germination percentage and field emergence.

F: None of the characters exhibited significant F value for seed traits.

H_1 & H_2: The dominance components (H_1) and (H_2) were significant for 100-seed weight, 100-seed volume, accelerated aging test, osmotic stress test, germination percentage, seed vigour index and field emergence.

h^2: The net dominance effect (h^2) was positive and significant for 100-seed weight and 100-seed volume.

($\sqrt{H_1/D}$): The mean degree of dominance ($\sqrt{H_1/D}$) was calculated where both D and H_1 were significant. For the characters viz., 100-seed weight, 100-seed volume, germination percentage and field emergence, the values for degree of dominance was more than unity indicating over dominance.

h^2_{ns}: The heritability was found high (>30 %) for seed density; and medium (15-30%) for 100-seed volume and field emergence. Low heritability (< 15%) was observed for 100-seed weight, accelerated aging test, osmotic stress test, germination percentage and seed vigour index.

K_D/K_R: The component K_D/K_R that measures the relative frequencies for dominant and recessive alleles in the parents was observed to be greater than one and positive for all characters except seed density indicating excess of dominant alleles in the parents.

Table 4.20 Estimates of components of variation for different seed quality traits

Components	Characters							
	100-seed weight	100-seed volume	Seed density	Accelerated aging test	Osmotic stress test	Germination percentage	Seed vigour index	Field emergence
E	0.98*	0.46*	0.00	4.98*	6.46	3.17*	2.35*	8.21
	±0.11	±0.09		±2.01	±4.15	±0.41	±0.33	±4.32
D	1.00*	1.12*	0.00	4.31	11.63	3.17*	1.72	44.85*
	±0.41	±0.34		±7.26	±14.97	±1.48	±1.17	±15.59
F	0.40	0.93	0.00	1.07	22.94	1.57	3.29	49.20
	±0.94	±0.77		±16.44	±33.92	±3.35	±2.66	±35.33
H_1	6.65*	5.16*	0.00	82.84*	117.82*	15.18*	10.89*	127.53*
	±0.83	±0.68		±14.52	±29.94	±2.96	±2.35	±31.19
H_2	5.94*	4.11*	0.00	80.08*	91.38*	15.02*	8.15*	104.07*
	±0.69	±0.57		±12.07	±24.90	±2.46	±1.95	±25.94
h^2	16.53*	4.14*	0.00	-1.22	4.70	0.70	-0.33	29.92
	±0.46	±0.38		±8.07	±16.65	±1.64	±1.30	±17.34
$\sqrt{H_1/D}$	2.58	2.14	-	-	-	2.19	-	1.69
$H_2/4H_1$	0.22	0.20	0.17	0.24	0.19	0.25	0.19	0.20
h^2_{ns}	8.96	15.60	31.58	4.07	8.78	10.75	9.20	28.74
K_D/K_R	1.17	1.48	-	1.06	1.90	1.26	2.23	1.96
h^2/H_2	2.78	1.01	-	-	0.05	0.05	-	0.29
r	-0.59*	0.40	-0.81	0.38	0.54	-0.21	-0.32	-0.50
b	0.57*	0.36*	0.67	0.13	0.02	0.41	0.29	0.41
	±0.15	±0.14	±0.31	±0.14	±0.11	±0.43	±0.26	±0.20
1-b	0.43*	0.64*	0.33	0.87*	0.98*	0.59	0.72*	0.59*
t^2	2.40	5.32*	0.42	7.46*	14.89*	1.43	0.19	1.30

* Significant at $P \leq 0.05$

r: Coefficient of correlation between the parental order of dominance (Wr + Vr) and parental measurement (Yr) was found to be negative and significant for 100-seed weight and seed density. None of the characters exhibited positive and significant value.

t^2 - test: In the present investigation the values of t^2 were nonsignificant for 100-seed weight, seed density, germination percentage, seed vigour index and field emergence.

b: The regression coefficient (b) and its deviation from unity (1-b) were significant for 100-seed weight and 100-seed volume. Whereas, in addition to this (1-b) were also significant for accelerated aging test, osmotic stress test, seed vigour index and field emergence.

4.3 Heterosis on the best check

Out of three hybrids (EHB - 1520, KH-101 and PSCL-3436) used as check, hybrid PSCL-3436 excelled in grain yield and many other traits at both the locations and hence the heterosis had been estimated over this hybrid and the estimates so obtained have been presented in Table 4.21 and 4.22 for Palampur and Bajaura, respectively. The significant heterotic effects observed for different characters are given below:

Days to silking

Negative heterosis was exhibited by 34 crosses at Palampur and by 16 crosses at Bajaura. The crosses showing negative heterosis in both the environments were $P_2 \times P_{12}$, $P_3 \times P_{11}$, $P_4 \times P_{10}$, $P_4 \times P_{11}$, $P_4 \times P_{12}$, $P_5 \times P_8$, $P_5 \times P_{10}$ and $P_5 \times P_{12}$.

Days to pollen shedding

Out of sixty six, 38 crosses at Palampur and 20 crosses at Bajaura were depicting negative heterosis. The crosses showing heterosis in the desirable direction were P_1 x P_2, P_1 x P_3, P_2 x P_{12}, P_3 x P_{11}, P_4 x P_{10}, P_4 x P_{11}, P_4 x P_{12}, P_5 x P_8, P_5 x P_{10}, P_5 x P_{11} and P_5 x P_{12} in both the environments.

Leaf area/plant

Twelve crosses at Palampur and 17 crosses at Bajaura displayed positive heterosis. Positive heterosis in both the environments was observed for only 3 crosses viz., P_1 x P_{10}, P_2 x P_7 and P_2 x P_9.

Plant height

Negative heterosis was exhibited by 15 crosses at Palampur and by 5 crosses at Bajaura. Whereas, out of these none of the cross combination exhibited desirable heterosis in both the environments.

Ear height

Twenty eight crosses at Palampur and 21 crosses at Bajaura were depicting negative heterosis. The crosses showing desirable heterosis in both the environments were P_1 x P_5, P_2 x P_3, P_2 x P_4, P_2 x P_7, P_4 x P_6, P_4 x P_8, P_4 x P_9, P_5 x P_7, P_5 x P_8, P_6 x P_8, P_6 x P_{12}, P_7 x P_9, P_8 x P_{11} and P_9 x P_{11}.

Days to maturity

Heterosis over best check was found to be negative in 15 crosses at Palampur and almost all crosses i.e. 59 at Bajaura. The crosses showing negative heterosis in both the environments were P_1 X P_5, P_2 x P_3, P_2 x P_4, P_2 x P_7, P_4 x P_6, P_4 x P_8, P_4 x P_9, P_5 x P_8, P_6 x P_8, P_6 X P_{12}, P_7 x P_9, P_8 x P_{11} and P_9 x P_{11}.

Table 4.21 Percentage of heterosis over best check (BC) for yield and yield components at Palampur (E_1)

Hybrid	Characters														
	Days to 75% silking	Days to 75% pollen shedding	Leaf area/ plant	Plant height	Ear height	Days to 75% maturity	Ear length	Ear circum-ference	Kernel rows/ ear	Kernels/ row	Shelling percen-tage	100-seed weight	Grain yield	Biological yield	Harvest index
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$P_1 X P_2$	-5.65*	-6.61*	13.79*	1.34	2.54	-4.74*	5.86	13.03*	14.55*	13.58*	3.84	3.56	-12.84*	6.28	-18.01*
$P_1 X P_3$	-4.03*	-4.96*	7.96	-4.48	-0.97	-2.37	10.07	6.63	7.27	11.41*	-1.53	5.92	-13.73*	0.66	-13.17*
$P_1 X P_4$	-5.65*	-5.79*	8.76	2.72	0.37	-0.95	3.23	5.42	7.27	5.63	2.32	6.76	-11.36*	-6.56	-5.11*
$P_1 X P_5$	-2.42	-3.31	5.49	-2.59	-10.20*	-1.42	5.92	0.23	0.00	-1.96	4.99	8.64	-16.05*	7.60*	-21.95*
$P_1 X P_6$	-4.84*	-5.79*	8.72	1.21	-6.80	-1.90	7.20	4.37	2.98	13.40*	6.94*	-4.40	-12.05*	16.37*	-24.13*
$P_1 X P_7$	-4.03*	-4.96*	13.65*	-0.17	-1.99	-1.90	8.73	4.97	3.42	9.04	4.42	0.80	-7.17*	10.20*	-15.71*
$P_1 X P_8$	-5.65*	-4.96*	6.96	-3.57	-0.15	-4.74*	8.73	5.20	8.22*	7.60	5.56	3.72	-8.60*	6.05	-13.81*
$P_1 X P_9$	-2.42	-3.31	11.38	-2.05	-0.40	-1.90	7.20	7.30*	0.95	6.18	4.27	11.72*	-7.17*	5.26	-11.84*
$P_1 X P_{10}$	-3.23	-4.96*	13.00*	6.75*	8.66	-1.42	11.78	7.08*	3.64	1.85	0.73	14.17*	2.96	16.57*	-11.59*
$P_1 X P_{11}$	-3.23	-4.96*	-6.49	1.98	-4.63	-0.47	2.63	6.70	7.27	4.91	8.30*	3.00	8.89*	21.96*	-10.68*
$P_1 X P_{12}$	-1.61	-1.65	11.49	1.09	-3.75	0.00	15.63*	6.10	8.22*	18.63*	5.71*	-1.76	-7.17*	1.61	-8.63*
$P_2 X P_3$	-3.23	-5.79*	3.08	-4.62	-12.34*	-1.90	4.70	9.41*	11.85*	8.52	4.09	-0.56	3.45	19.18*	-13.22*
$P_2 X P_4$	-2.42	-3.31	6.03	-5.69	-14.83*	-0.95	3.79	6.33	6.62	4.71	5.79*	13.09*	-9.67*	1.04	-10.62*
$P_2 X P_5$	0.00	-0.83	5.63	-5.71	-5.89	-0.47	6.65	5.57	2.69	16.81*	3.14	-7.04	-7.70*	2.87	-10.28*
$P_2 X P_6$	-3.23	-3.31	7.97	-0.79	-0.92	-1.90	15.02*	4.97	0.00	13.20*	2.44	2.92	-11.85*	-1.29	-10.70*
$P_2 X P_7$	-2.42	-1.65	19.52*	-5.41	-15.23*	0.00	16.73*	10.84*	14.55*	12.48*	4.80	2.48	9.88*	12.86*	-2.66

Contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$P_2 \times P_8$	-8.06*	-5.79*	17.28*	-8.43*	-7.28	-1.90	7.20	9.26*	3.56	7.97	4.16	8.60	0.49	17.77*	-14.67*
$P_2 \times P_9$	-5.65*	-4.96*	26.54*	0.95	-3.64	-0.47	19.29*	0.30	-6.76	12.65*	4.05	9.72	1.38	14.19*	-11.25*
$P_2 \times P_{10}$	-4.03*	-4.96*	6.41	3.51	-2.17	-0.47	-2.87	12.05*	12.73*	-5.75	2.93	2.88	-0.05	8.88*	-8.23*
$P_2 \times P_{11}$	0.81	-1.65	7.04	-4.67	-4.13	-3.32*	10.07	0.98	-1.82	6.90	2.17	-5.28	-10.37*	2.45	-12.46*
$P_2 \times P_{12}$	-7.26*	-6.61*	4.05	-5.51	-13.72*	-2.37	4.76	0.75	-3.64	2.20	4.92	0.28	-6.67*	0.23	-6.88*
$P_3 \times P_4$	-5.65*	-5.79*	1.99	-6.21	-15.38*	-2.37	0.92	5.87	3.64	3.09	4.20	-2.64	-9.39*	5.98	-14.50*
$P_3 \times P_5$	-2.42	-3.31	-1.53	1.98	-1.37	-1.90	2.75	-0.90	-6.33	-1.82	5.98*	-0.12	-9.41*	10.13*	-17.75*
$P_3 \times P_6$	-7.26*	-5.79*	10.57	-1.44	-0.68	-0.95	8.55	9.56*	1.67	11.93*	5.02	2.16	-3.71	1.75	-5.34*
$P_3 \times P_7$	-4.84*	-5.79*	12.03	-1.09	-0.45	-2.37	6.29	5.65	12.58*	5.63	5.64	-4.00	3.71	8.37*	-4.33*
$P_3 \times P_8$	-7.26*	-6.61*	10.31	-6.49	0.15	0.00	7.94	9.41*	8.44*	8.72	5.18	8.92	3.21	7.01	-3.57*
$P_3 \times P_9$	-2.42	-2.48	7.46	1.04	-4.98	-3.79*	-2.14	5.95	-11.27*	-8.72	2.84	11.64*	-3.41	3.33	-6.57*
$P_3 \times P_{10}$	-2.42	-3.31	11.97	-0.70	-0.21	-1.42	6.11	8.06*	5.45	4.33	3.87	12.69*	8.34*	12.18*	-3.42*
$P_3 \times P_{11}$	-4.03*	-4.13*	2.18	-1.89	-4.47	-0.95	-2.69	9.19*	20.00*	-3.24	5.50	5.44	5.93*	8.88*	-2.74
$P_3 \times P_{12}$	-3.23	-3.31	4.11	-5.69	-4.09	-1.90	5.80	1.66	-3.42	9.13	7.29*	3.52	-0.96	7.20	-7.62*
$P_4 \times P_5$	-6.45*	-6.61*	0.88	-12.21*	-23.68*	0.47	14.29*	7.53*	7.27	11.96*	5.12	7.64	2.13	8.20*	-5.64*
$P_4 \times P_6$	-2.42	-2.48	12.18	-0.66	-11.16*	-1.42	12.33*	0.38	3.71	12.94*	8.98*	-3.28	-7.69*	20.99*	-10.98*
$P_4 \times P_7$	-6.45*	-5.79*	15.55*	-2.71	-7.92	-3.32*	5.80	5.65	8.95*	13.92*	4.84	-4.00	7.42*	16.87*	-8.09*
$P_4 \times P_8$	-9.68*	-7.44*	10.07	-4.51	-11.16*	-0.95	9.89	9.94*	11.85*	7.08	6.56*	8.72	-0.55	8.41*	-8.28*
$P_4 \times P_9$	-6.45*	-6.61*	16.03*	2.00	-11.67*	-0.95	18.80*	6.78	4.73	19.27*	4.80	3.12	4.61	12.07*	-6.65*
$P_4 \times P_{10}$	-5.65*	-5.79*	2.81	-7.12*	-8.89	-3.32*	7.81	7.98*	-1.96	2.54	5.06	13.01*	9.43*	14.03*	-4.03*---

Contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$P_4 \times P_{11}$	-6.45*	-7.44*	-0.03	-2.36	-8.41	-2.37	4.21	3.69	-0.80	3.09	3.93	7.96	-0.35	5.73	-5.74*
$P_4 \times P_{12}$	-7.26*	-4.96*	4.36	-0.95	-9.05	-2.84	11.05	0.23	-3.64	13.20*	6.15*	7.08	0.20	1.84	-1.60
$P_5 \times P_6$	-2.42	-3.31	-5.64	-7.46*	-15.09*	-0.95	7.20	1.43	-6.33	11.55*	3.70	-8.32	-21.48*	-3.77	-18.39*
$P_5 \times P_7$	-0.81	-0.83	23.47*	-7.09*	-15.38*	0.00	6.59	5.72	0.72	16.06*	5.86*	-1.32	4.26	21.75*	-14.42*
$P_5 \times P_8$	-7.26*	-7.44*	14.71*	-9.34*	-15.87*	-1.90	12.52*	8.51*	0.95	9.97	2.45	4.72	-4.35	7.25	-10.83*
$P_5 \times P_9$	-7.26*	-7.44*	13.48*	2.78	-13.99*	-2.84	17.46*	7.53*	-2.47	12.85*	5.06	13.49*	7.40*	16.60*	-7.87*
$P_5 \times P_{10}$	-9.68*	-7.44*	2.93	-2.99	-8.62	-0.47	13.13*	9.94*	0.95	7.97	8.24*	18.89*	-5.49	3.27	-8.47*
$P_5 \times P_{11}$	-6.45*	-5.79*	-0.04	-0.20	-12.74*	-2.37	13.13*	10.09*	5.45	12.85*	3.22	18.85*	0.99	24.97*	-19.19*
$P_5 \times P_{12}$	-4.84*	-4.96*	5.38	-9.42*	-19.13*	-3.32*	12.82*	10.24*	2.18	12.85*	8.19*	18.41*	7.12*	15.25*	-7.05*
$P_6 \times P_7$	-2.42	-3.31	9.22	-3.84	-7.65	-1.90	5.37	12.88*	0.95	3.64	6.82*	8.84	4.24	16.01*	-10.34*
$P_6 \times P_8$	-2.42	-0.83	0.51	-13.47*	-21.06*	-3.32*	11.05	-1.36	-5.45	15.37*	6.34*	-2.64	-6.91*	-3.16	-1.96
$P_6 \times P_9$	-3.23	-0.83	-0.15	-9.31*	-18.59*	0.00	4.52	-1.20	-8.95*	15.66*	6.32*	5.36	-3.39	5.71	-8.59*
$P_6 \times P_{10}$	-3.23	-2.48	5.47	-5.58	-10.02*	-1.42	9.10	4.22	-0.22	2.02	5.14	7.80	4.35	21.14*	13.89*
$P_6 \times P_{11}$	-5.65*	-5.79*	0.64	-11.41*	-17.82*	-0.95	3.60	-0.53	0.07	11.96*	6.23*	-9.92	-14.47*	-1.64	-13.05*
$P_6 \times P_{12}$	-5.65*	-4.13*	7.11	-6.05	-17.47*	-2.84	11.05	-2.11	-6.33	11.76*	6.17*	-11.36*	-12.50*	0.49	-12.94*
$P_7 \times P_8$	-4.03*	-3.31	10.73	-5.89	-14.93*	-4.27*	7.26	5.42	2.69	6.35	3.18	-2.16	1.63	12.90*	-9.99*
$P_7 \times P_9$	-4.84*	-3.31	14.12*	-1.29	-15.87*	-4.27*	2.69	5.42	3.64	0.75	8.99*	13.05*	4.54	15.20*	-9.25*
$P_7 \times P_{10}$	-2.42	-4.13*	7.40	-1.64	-6.02	-3.32*	6.84	7.83*	0.95	1.65	4.45	3.08	8.39*	12.86*	-3.95*
$P_7 \times P_{11}$	-2.42	-1.65	10.97	-1.83	-4.34	-4.27*	9.89	6.10	13.60*	11.76*	5.37	-5.56	-1.04	11.95*	-11.59*
$P_7 \times P_{12}$	-1.61	-1.65	2.84	-2.56	-6.10	-3.32*	11.05	2.18	5.45	16.98*	5.94*	-6.04	4.09	22.59*	-15.09*

Contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$P_8 \times P_9$	-4.03*	-4.13*	10.91	-7.86*	-19.90*	-1.42	6.29	0.98	-6.18	13.63*	3.83	5.44	0.88	16.50*	-13.43*
$P_8 \times P_{10}$	-2.42	0.83	5.53	-12.65*	-16.69*	-2.84	8.18	9.64*	0.95	9.97	2.85	5.16	5.38	21.63*	-13.38*
$P_8 \times P_{11}$	7.26*	-8.26*	11.24	-6.97*	-20.66*	1.90	7.88	5.87	4.80	10.28	4.73	5.00	-5.54	10.70*	-14.67*
$P_8 \times P_{12}$	-0.81	0.00	11.13	-5.53	-8.46	-3.32*	5.31	6.55	-0.44	1.73	2.62	11.16	-7.81*	9.54*	-15.85*
$P_9 \times P_{10}$	-3.23	-5.79*	10.29	-1.58	-6.05	-2.37	14.47*	4.07	-2.69	18.11*	3.40	13.21*	5.33	14.03*	-7.64*
$P_9 \times P_{11}$	-4.03*	-4.96*	9.71	-9.01*	-15.09*	-3.32*	10.56	5.20	-4.58	8.46	8.72*	9.96	-2.28	12.52*	-13.17*
$P_9 \times P_{12}$	-4.03*	-4.13*	1.05	-10.27*	-24.56*	-2.84	0.55	-0.45	-9.96*	0.03	4.38	-4.84	-6.67*	9.32*	-14.63*
$P_{10} \times P_{11}$	-0.81	-1.65	6.02	-5.92	-6.23	0.28	4.09	7.98*	0.65	-2.95	4.02	6.28	0.87	10.60*	-8.80*
$P_{10} \times P_{12}$	-2.42	-2.48	6.97	-2.74	-5.84	-2.37	15.45*	6.32	-4.58	19.15*	5.73*	10.32	3.56	16.95*	-11.46*
$P_{11} \times P_{12}$	0.00	0.00	8.25	1.31	-2.54	-2.37	4.95	-0.45	-9.09*	-1.94	1.88	5.80	5.63	17.68*	-10.26*
SE(BC)	1.06	1.04	402.66	7.61	5.78	1.63	0.97	0.47	0.53	1.94	2.18	1.43	3.75	10.09	0.70

* Significant at $P \leq 0.05$

Ear length

Out of sixty six, 14 crosses at Palampur and 16 at Bajaura had positive heterosis over the best check, with the common cross combinations at both the locations as $P_2 \times P_7$, $P_4 \times P_6$, $P_5 \times P_{10}$ and $P_{10} \times P_{12}$.

Ear circumference

Twenty three crosses at Palampur and 2 at Bajaura exhibited positive heterosis; and 4 crosses at Bajaura had negative heterosis. The crosses showing positive heterosis in both the environments were $P_7 \times P_{10}$ and $P_8 \times P_{10}$.

Kernel rows/ear

Positive heterosis was exhibited by 12 crosses at Palampur and 20 crosses at Bajaura; and heterosis in negative direction by 4 crosses at Palampur and 1 at Bajaura. The crosses showing heterosis in the desirable direction were $P_1 \times P_8$, $P_1 \times P_{12}$, $P_2 \times P_3$, $P_2 \times P_7$, $P_2 \times P_{10}$, $P_3 \times P_7$, $P_3 \times P_{11}$, $P_4 \times P_7$, $P_4 \times P_8$ and $P_7 \times P_{11}$ in both the environments.

Kernels/row

Twenty eight crosses at Palampur and 30 at Bajaura had positive heterosis over the best check. Positive heterosis in both the environments was observed for $P_1 \times P_6$, $P_2 \times P_6$, $P_2 \times P_7$, $P_4 \times P_5$, $P_4 \times P_6$, $P_4 \times P_7$, $P_4 \times P_9$, $P_5 \times P_6$, $P_5 \times P_7$, $P_6 \times P_8$, $P_6 \times P_9$, $P_6 \times P_{11}$, $P_6 \times P_{12}$, $P_7 \times P_{12}$, $P_8 \times P_9$ and $P_{10} \times P_{12}$.

Shelling percentage

Twenty one crosses at Palampur and 32 crosses at Bajaura were depicting positive heterosis. The crosses showing heterosis in desirable direction in both the environments were $P_1 \times P_{11}$, $P_2 \times P_4$, $P_3 \times P_5$, $P_3 \times P_{12}$,

$P_4 \times P_6$, $P_4 \times P_{12}$, $P_5 \times P_{10}$, $P_5 \times P_{12}$, $P_6 \times P_7$, $P_6 \times P_8$, $P_6 \times P_9$, $P_6 \times P_{11}$, $P_7 \times P_{12}$ and $P_9 \times P_{11}$.

100-seed weight

Positive heterosis was observed for $P_1 \times P_9$, $P_1 \times P_{10}$, $P_2 \times P_4$, $P_3 \times P_9$, $P_3 \times P_{10}$, $P_4 \times P_{10}$, $P_5 \times P_9$, $P_5 \times P_{10}$, $P_5 \times P_{11}$, $P_5 \times P_{12}$, $P_7 \times P_9$ and $P_9 \times P_{10}$ at Palampur, and for $P_1 \times P_4$, $P_3 \times P_{11}$, $P_5 \times P_8$, $P_6 \times P_7$, $P_6 \times P_{10}$, $P_8 \times P_{12}$, $P_9 \times P_{11}$, $P_9 \times P_{12}$, $P_{10} \times P_{11}$ and $P_{11} \times P_{12}$ at Bajaura over the best check.

Grain yield

Nine crosses at Palampur and 21 crosses at Bajaura were depicting heterosis in positive direction, whereas, heterosis was negative for 23 crosses at Palampur and for 6 crosses at Bajaura. Positive heterosis in both the environments was observed for $P_1 \times P_{11}$, $P_2 \times P_7$, $P_3 \times P_{10}$, $P_3 \times P_{11}$, $P_4 \times P_7$, $P_4 \times P_{10}$, $P_5 \times P_{12}$ and $P_7 \times P_{10}$.

Biological yield

Heterosis estimates for biological yield over the best check were positive in 41 crosses at Palampur and 21 crosses at Bajaura, whereas, it was in negative direction for 6 crosses at Bajaura. The crosses showing heterosis in the desirable direction were $P_1 \times P_6$, $P_1 \times P_{11}$, $P_2 \times P_8$, $P_4 \times P_6$, $P_4 \times P_7$, $P_4 \times P_8$, $P_4 \times P_9$, $P_5 \times P_7$, $P_5 \times P_{11}$, $P_5 \times P_{12}$, $P_6 \times P_7$, $P_7 \times P_8$, $P_7 \times P_{11}$, $P_7 \times P_{12}$, $P_8 \times P_{12}$, $P_9 \times P_{12}$ and $P_{11} \times P_{12}$ in both the environments.

Harvest index

Compared to the best check, heterosis was positive for 1 cross at Palampur and for 22 at Bajaura; and negative for 61 crosses at Palampur and for 20 cross combinations at Bajaura.

Table 4.22 Percentage of heterosis over best check (BC) for yield and yield components at Bajaura (E_2)

Hybrid	Characters														
	Days to 75% silking	Days to 75% pollen shedding	Leaf area/ plant	Plant height	Ear height	Days to 75% maturity	Ear length	Ear circum-ference	Kernel rows/ ear	Kernels/ row	Shelling percen-tage	100- seed weight	Grain yield	Biological yield	Harvest index
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$P_1 X P_2$	-1.69	-3.51*	10.39	-12.10*	-4.14	-1.85*	3.69	-1.82	6.45	12.40	1.63	-6.03	6.12	22.83*	-13.61*
$P_1 X P_3$	-1.69	-3.51*	-0.23	-5.00	-9.12	-3.24*	-0.34	-2.55	3.23	10.00	3.36	1.75	3.06	6.38	-3.10*
$P_1 X P_4$	0.00	0.00	26.61*	-1.40	-4.14	-1.39	18.12*	2.92	1.61	12.40	1.63	24.81*	5.10	-0.88	6.04*
$P_1 X P_5$	-2.54	-2.63	13.81	-5.24	-13.04*	-3.24*	-6.38	0.00	11.29*	12.80	1.63	-0.87	-2.55	5.10	-7.26*
$P_1 X P_6$	-2.54	-2.63	8.72	-3.32	-13.79*	-2.78*	5.70	-0.36	1.61	16.80*	1.36	5.20	3.57	14.58*	-9.58*
$P_1 X P_7$	0.85	0.88	2.90	-14.25*	-20.99*	-1.39	-0.67	-2.92	3.23	0.80	-0.18	0.58	-16.33*	-9.21*	-7.88*
$P_1 X P_8$	-2.54	-2.63	3.90	0.58	0.32	-1.39	4.03	-1.09	17.74*	15.20*	5.97*	0.75	7.14	3.61	3.42*
$P_1 X P_9$	1.69	1.75	25.61*	-0.87	-3.29	-1.85*	18.46*	2.55	-6.45	24.80*	-1.22	11.64	4.59	9.80*	-4.71*
$P_1 X P_{10}$	0.00	0.88	24.79*	-8.73*	-7.32	-2.31*	16.78*	0.00	3.23	27.60*	-0.36	1.08	4.59	6.81	-2.10
$P_1 X P_{11}$	0.00	0.00	9.59	-4.65	-18.56*	-1.39	-0.34	4.38	6.45	6.80	6.38*	11.60	12.76*	15.36*	-2.17
$P_1 X P_{12}$	0.00	0.00	1.30	-6.34	-9.44	-3.24*	-0.67	-2.19	13.87*	-9.20	-0.39	-7.15	-8.67*	-7.29	-1.50
$P_2 X P_3$	-2.54	-2.63	13.30	-4.65	-17.07*	-3.24*	-2.01	6.57	11.29*	-2.40	1.69	-3.87	0.00	0.83	-0.79
$P_2 X P_4$	-4.24*	-4.39*	17.15	-1.34	-16.01*	-2.78*	3.36	1.09	18.79*	1.20	7.30*	5.03	1.02	1.04	0.00
$P_2 X P_5$	-0.85	-0.88	-3.45	7.56	-3.61	-4.17*	8.05	-4.38	-1.61	13.20	1.05	0.75	-3.06	-6.22	3.37*
$P_2 X P_6$	-3.39*	-3.51*	20.46*	0.76	-6.15	-3.70*	10.74	6.57	20.97*	20.80*	4.90*	3.20	2.04	5.10	-2.91
$P_2 X P_7$	-4.24*	-4.39*	29.66*	0.41	-12.94*	-3.70*	15.44*	2.19	14.52*	19.60*	4.09	0.37	13.27*	5.53	7.33*

Contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$P_2 \times P_8$	-2.54	-2.63	11.38	-3.32	-8.06	-3.24*	7.38	0.36	4.84	17.60*	4.15	10.97	13.27*	15.36*	-1.84
$P_2 \times P_9$	-1.69	-1.75	26.82*	-0.35	-11.56	-2.31*	5.37	0.73	1.61	10.00	-0.11	6.57	4.08	1.90	2.13
$P_2 \times P_{10}$	-1.69	-2.63	14.53	-6.98	-7.95	-2.31*	-5.03	2.92	9.68*	7.20	3.15	4.70	-5.61	-1.31	-4.32*
$P_2 \times P_{11}$	-2.54	-2.63	-3.62	-2.79	-7.53	-3.70*	8.39	-7.30	-1.61	20.40*	5.78*	-6.23	-4.59	-4.51	-0.12
$P_2 \times P_{12}$	-3.39*	-3.51*	1.09	0.06	-9.23	-3.24*	10.74	-2.20	-3.23	26.40*	4.05	4.53	-2.04	-3.87	1.91
$P_3 \times P_4$	-2.54	-2.63	4.65	2.56	2.12	3.24*	1.34	-0.73	16.13*	10.40	9.78*	-3.66	3.57	8.09*	-4.16*
$P_3 \times P_5$	-0.85	-0.88	1.75	-3.03	-6.99	-4.63*	6.38	4.74	-7.26	18.40*	5.21*	7.44	-3.57	4.67	-7.69*
$P_3 \times P_6$	-1.69	-1.75	0.38	3.37	-4.45	-2.78*	-3.69	-1.09	-1.61	7.60	7.32*	-4.61	-6.12	-9.42*	3.68*
$P_3 \times P_7$	-1.69	-1.75	12.67	-8.78*	-10.82	-2.78*	-3.02	-0.36	17.74*	2.80	3.43	-4.20	9.18*	2.32	6.71*
$P_3 \times P_8$	-1.69	-1.75	20.32*	0.35	-0.95	-2.78*	14.09*	2.55	4.84	21.60*	4.74*	7.27	7.14	-0.67	7.83*
$P_3 \times P_9$	0.00	0.00	19.50	4.19	-1.91	-3.24*	12.08*	4.01	-3.23	23.20*	4.47*	6.48	8.67*	1.26	7.33*
$P_3 \times P_{10}$	-0.85	-1.75	15.74	-5.24	1.17	-2.78*	-4.03	-2.19	14.52*	-6.00	7.56*	7.73	17.86*	7.56	9.58*
$P_3 \times P_{11}$	-3.39*	-4.39*	11.95	5.64	2.01	-2.78*	9.40	1.82	26.85*	14.40	6.68*	12.47*	17.35*	7.88	8.79*
$P_3 \times P_{12}$	-2.54	-2.63	7.15	-0.93	-6.04	-3.24*	-3.02	-2.19	9.68*	-2.00	6.28*	0.62	1.53	-5.30	7.21*
$P_4 \times P_5$	-2.54	3.51*	-5.85	-0.06	-2.33	-4.17*	11.41	0.00	12.90*	25.60*	6.78*	-1.83	14.29	5.74	8.07*
$P_4 \times P_6$	-1.69	-1.75	12.76	-4.42	-14.10*	-4.17*	12.75*	0.36	-1.61	26.00*	4.62*	4.03	14.80*	15.25*	-0.31
$P_4 \times P_7$	-2.54	-2.63	10.92	3.78	-6.89	-3.70*	11.74	4.01	16.13*	16.40*	3.57	1.95	15.82*	21.98*	-12.20*
$P_4 \times P_8$	-2.54	-2.63	14.07	-12.57*	-28.21*	-3.70*	7.38	-0.73	12.90*	11.60	2.53	0.75	16.33*	24.11*	-6.28*
$P_4 \times P_9$	-1.69	-1.75	14.37	-0.52	-15.06*	-2.78*	4.70	1.09	1.61	28.40*	4.74*	-1.70	28.06*	32.34*	-3.25*
$P_4 \times P_{10}$	-4.24*	-4.39*	5.32	-0.64	-13.04*	-3.70*	14.43*	2.19	4.84	12.00	1.01	9.31	-10.71*	5.10	5.40*

Contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$P_4 \times P_{11}$	-4.24*	-4.39*	-11.86	-5.53	-14.10*	-3.70*	-5.70	-4.74	1.61	3.20	5.88*	6.03	-3.57	7.88	-4.92*
$P_4 \times P_{12}$	-4.24*	-4.39*	10.34	-0.47	-11.56	-3.70*	11.07	-0.73	4.84	26.40*	5.59*	0.37	20.92*	10.66*	9.27*
$P_5 \times P_6$	-1.69	-1.75	8.14	4.89	-3.92	-4.17*	6.71	-1.09	-1.61	20.40*	5.20*	0.00	-8.16*	0.12	-8.31*
$P_5 \times P_7$	-3.39*	-3.51*	0.92	-1.92	-15.59*	3.70*	12.08*	-1.46	6.45	16.00*	4.02	11.60	1.02	9.37*	-7.64*
$P_5 \times P_8$	-3.39*	-3.51*	-3.42	-6.69	-11.98*	-3.70*	-11.74*	-2.19	6.45	-4.80	3.66	15.09*	-21.94*	-21.60*	-0.45
$P_5 \times P_9$	-0.85	-0.88	-11.30	1.11	-10.92	-3.70*	-4.70	-9.12*	-4.84	7.20	4.55*	-6.11	-14.29*	-19.47*	6.42*
$P_5 \times P_{10}$	-5.08*	-5.26*	-0.15	-5.70	-14.53*	-3.70*	12.42*	0.36	1.61	22.00*	4.40*	3.24	2.04	-0.67	2.67
$P_5 \times P_{11}$	-2.54	-3.51*	-13.08	-4.77	-10.07	-3.24*	-6.04	-1.09	8.06	4.40	8.82*	5.24	3.57	16.10*	10.82*
$P_5 \times P_{12}$	-3.39*	-4.39*	-8.33	-6.34	-11.45	-3.70*	-0.34	-8.76*	-11.29*	6.40	9.14*	-2.87	18.88*	15.46*	2.94
$P_6 \times P_7$	-2.54	-2.63	14.75	4.71	-10.50	-3.70*	6.04	-1.09	3.23	4.80	8.46*	16.29*	18.88*	14.93*	3.46*
$P_6 \times P_8$	-3.39*	-4.39*	5.25	-5.00	-14.74*	-4.63*	5.03	-1.82	1.61	19.20*	7.23*	-6.19	-1.02	-12.31*	12.87*
$P_6 \times P_9$	-3.39*	-3.51*	15.91	0.17	-10.18	-3.70*	8.05	-9.49*	8.06	21.20*	13.48*	-2.29	1.02	-3.44	4.63*
$P_6 \times P_{10}$	-2.54	-2.63	2.48	1.34	2.86	-2.31*	2.35	5.47	-1.61	1.20	3.55	17.62*	-3.57	-1.09	-2.51
$P_6 \times P_{11}$	-2.54	-2.63	13.41	-0.23	-6.68	2.78*	5.03	-3.65	3.23	20.80*	5.66*	-9.77	-5.10	-5.79	0.72
$P_6 \times P_{12}$	-2.54	-2.63	5.51	-7.39	-15.80*	-4.63*	11.07	-5.47	4.03	17.20*	0.50	-8.35	-11.73*	-12.42*	0.79
$P_7 \times P_8$	-1.69	-1.75	33.44*	0.35	-10.50	-2.78*	13.76*	0.73	6.45	9.60	2.89	4.11	15.31*	13.22*	12.86*
$P_7 \times P_9$	-0.85	-2.63	17.57	0.93	-13.36*	-3.24*	10.07	0.00	3.23	7.20	2.42	4.99	10.20*	7.99	2.05
$P_7 \times P_{10}$	-1.69	-2.63	25.71*	4.48	-9.54	-2.78*	17.11*	8.03*	12.10*	3.60	0.08	10.02	13.78*	6.60	6.74*
$P_7 \times P_{11}$	-0.85	-2.63	32.24*	5.24	-14.42*	-3.24*	7.72	6.20	9.68*	14.40	-0.17	7.23	13.27*	13.22*	0.07
$P_7 \times P_{12}$	-2.54	-2.63	20.00	5.18	2.23	-4.63*	12.08*	2.92	8.06	20.80*	6.28*	-0.29	16.84*	21.02*	-3.44*

Contd...

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$P_8 \times P_9$	-1.69	-1.75	34.97*	-3.96	-9.86	-3.24*	12.75*	0.00	12.10*	16.80*	2.93	8.73	2.55	5.85	-3.08*
$P_8 \times P_{10}$	-1.69	-1.75	9.12	-3.26	1.27	-3.70*	2.01	8.39*	13.87*	10.40	2.13	11.22	4.08	6.60	-2.36
$P_8 \times P_{11}$	-4.24*	-4.39*	25.39*	-1.51	-13.79*	-2.78*	-2.35	4.74	3.23	1.20	6.10*	5.57	-3.57	-1.46	-2.15
$P_8 \times P_{12}$	-3.39*	-3.51*	30.04*	7.45	4.98	-3.24*	10.40	2.19	-3.23	12.40	0.80	14.34*	7.65	12.58*	-4.37*
$P_9 \times P_{10}$	-0.85	-2.63	24.20*	-0.99	-3.08	-3.24*	-0.67	0.00	-3.23	5.60	1.74	6.32	4.08	-0.67	4.78*
$P_9 \times P_{11}$	-0.85	-2.63	7.91	1.92	-15.27*	-3.24*	8.39	-3.28	-4.84	26.00*	10.08*	14.26*	6.63	7.66	-0.96
$P_9 \times P_{12}$	-2.54	-3.51*	20.74*	4.13	-2.44	-3.24*	3.69	1.46	-6.45	17.20*	4.59*	17.37*	5.61	10.44*	-4.37*
$P_{10} \times P_{11}$	0.00	0.00	13.20	5.18	2.55	-2.31*	18.12*	2.92	-4.84	14.00	1.41	19.49*	-0.51	-1.63	1.10
$P_{10} \times P_{12}$	0.85	0.88	25.75*	-0.23	3.29	-3.24*	17.11*	-1.09	-1.61	19.60*	2.61	5.86	5.61	6.81	-1.07
$P_{11} \times P_{12}$	-0.85	-0.88	21.18*	5.88	-0.32	-3.24*	5.70	5.84	0.00	16.40*	5.35*	16.21*	17.35*	17.06*	0.24
SE (BC)	0.81	0.88	323.59	6.62	5.50	0.93	0.86	0.49	0.59	1.90	1.58	1.49	3.74	9.45	0.62

* Significant at $P \leq 0.05$

Estimates of heterosis over best check for different seed quality traits have been presented in Table 4.23. The heterotic effects observed or different characters are given below :

100-seed weight

Ten cross combinations exhibited negative heterosis over best checks were $P_1 \times P_3$, $P_1 \times P_7$, $P_2 \times P_7$, $P_2 \times P_9$, $P_3 \times P_7$, $P_3 \times P_{12}$, $P_4 \times P_6$, $P_4 \times P_7$, $P_4 \times P_9$ and $P_6 \times P_9$.

100-seed volume

Heterosis in negative direction was exhibited by $P_1 \times P_3$, $P_1 \times P_4$, $P_1 \times P_5$, $P_1 \times P_7$, $P_1 \times P_{10}$, $P_2 \times P_5$, $P_2 \times P_7$, $P_2 \times P_9$, $P_2 \times P_{11}$, $P_3 \times P_4$, $P_3 \times P_{12}$, $P_4 \times P_5$, $P_4 \times P_6$, $P_4 \times P_7$, $P_4 \times P_9$ and $P_6 \times P_9$ and in positive direction was exhibited by $P_3 \times P_7$, $P_5 \times P_{10}$, $P_5 \times P_{12}$ and $P_9 \times P_{12}$ for 100-seed volume.

Seed density

Seed density was found to have positive heterosis for $P_1 \times P_4$, $P_1 \times P_{11}$, $P_2 \times P_4$, $P_2 \times P_8$, $P_3 \times P_{11}$, $P_4 \times P_8$, $P_4 \times P_9$ and $P_4 \times P_{10}$ cross combinations, and negative heterosis for $P_1 \times P_{12}$, $P_4 \times P_{12}$ and $P_8 \times P_{11}$.

Accelerated aging test

All cross combinations except $P_4 \times P_{10}$ for accelerated aging test had positive heterosis over the best check.

Osmotic stress test

Positive heterosis over the best check was observed for 60 crosses, except $P_2 \times P_4$, $P_2 \times P_6$, $P_3 \times P_{11}$, $P_4 \times P_{11}$, $P_4 \times P_{12}$ and $P_9 \times P_{10}$ for osmotic stress test.

Table 4.23 Estimates of heterosis over best check (BC) for seed quality traits

Hybrid	Trait							
	100-seed weight	100-seed volume	Seed density	Accelerated aging test	Osmotic stress test	Germination percetage	Seed vigour index	Field emergence
1	2	3	4	5	6	7	8	9
$P_1 \times P_2$	-2.10	-4.44	2.40	36.30*	29.03*	8.79*	-4.48	35.48*
$P_1 \times P_3$	-9.27*	-8.89*	-0.80	39.26*	30.65*	8.79*	-17.42*	37.10*
$P_1 \times P_4$	-5.60	-8.89*	3.20*	31.85*	29.03*	5.49	-3.82	38.71*
$P_1 \times P_5$	-7.17	-8.89*	1.60	33.33*	29.03*	4.40	3.27	35.48*
$P_1 \times P_6$	-7.17	-6.67	-0.80	28.89*	32.26*	2.20	3.23	22.58*
$P_1 \times P_7$	-11.16*	-13.33*	1.60	16.30*	35.48*	1.10	17.97*	19.35*
$P_1 \times P_8$	1.14	2.22	-1.60	36.30*	27.42*	8.79*	11.80	48.39*
$P_1 \times P_9$	-1.96	0.00	-1.60	31.85*	30.65*	6.59*	-2.13	29.03*
$P_1 \times P_{10}$	-6.63	-8.89*	1.60	21.48*	24.19*	2.20	-8.67	32.26*
$P_1 \times P_{11}$	1.39	-2.22	3.20*	34.81*	17.74*	6.59*	13.71	35.48*
$P_1 \times P_{12}$	-8.49	-4.44	-4.80*	24.44*	14.52*	1.10	6.39	29.03*
$P_2 \times P_3$	-0.11	2.22	-2.24	31.85*	25.81*	6.59*	9.63	43.55*
$P_2 \times P_4$	-1.14	-4.44	3.20*	17.04*	8.06	2.20	2.87	35.48*
$P_2 \times P_5$	-8.70	-8.89*	0.00	19.26*	29.03*	2.20	-0.66	38.71*
$P_2 \times P_6$	-0.96	-2.22	0.80	24.44*	9.68	2.20	-9.59	6.45
$P_2 \times P_7$	-13.09*	-15.56*	2.40	31.85*	33.87*	3.30	9.89	45.16*
$P_2 \times P_8$	-0.78	-4.44	3.20*	24.44*	27.42*	4.40	0.37	45.16*
$P_2 \times P_9$	-9.66*	-11.11*	0.80	36.30*	19.35*	8.79*	10.36	46.77*
$P_2 \times P_{10}$	-3.92	-6.67	0.00	33.33*	25.81*	6.59*	-4.56	41.94*
$P_2 \times P_{11}$	-9.22	-11.11*	1.60	31.85*	30.65*	7.69*	7.49	45.16*
$P_2 \times P_{12}$	-1.07	0.00	-1.60	22.22*	22.58*	3.30	1.03	45.16*
$P_3 \times P_4$	-8.81	-8.89*	0.00	36.30*	39.52*	8.79*	12.39	45.16*
$P_3 \times P_5$	-2.39	-4.44	1.60	37.78*	25.81*	8.79*	3.20	46.77*

Contd...

1	2	3	4	5	6	7	8	9
P_3 X P_6	-2.85	-4.44	0.80	34.81*	27.42*	5.49	-3.34	45.16*
P_3 X P_7	-12.27*	13.33*	0.80	33.33*	35.48*	4.40	6.47	43.55*
P_3 X P_8	-2.21	0.00	-2.40	28.89*	35.48*	2.20	9.59	40.32*
P_3 X P_9	1.07	0.00	0.80	31.85*	22.58*	4.40	4.19	41.94*
P_3 X P_{10}	1.03	0.00	0.80	30.37*	29.03*	3.30	5.95	43.55*
P_3 X P_{11}	4.56	0.00	4.00*	9.63*	3.23	0.00	-0.99	40.32*
P_3 X P_{12}	-10.02*	-11.11*	0.80	31.85*	33.87*	2.75	0.55	41.94*
P_4 X P_5	-7.92	-8.89*	0.80	36.30*	41.94*	8.79*	-2.90	46.77*
P_4 X P_6	-12.84*	-13.33*	0.00	34.81*	25.81*	6.59*	-9.22	46.77*
P_4 X P_7	-12.52*	-13.33*	0.80	38.52*	30.65*	6.59*	1.32	45.16*
P_4 X P_8	-0.96*	-4.44	3.20*	28.89*	32.26*	4.40	4.70	43.55*
P_4 X P_9	-9.34*	-8.89*	3.20*	31.11*	35.48*	8.79*	-3.16	43.55*
P_4 X P_{10}	-2.60	-6.67	4.00*	6.67	14.52*	4.40	-13.67	41.94*
P_4 X P_{11}	-2.82	-4.44	1.60	33.33*	8.06	2.20	-4.85	45.16*
P_4 X P_{12}	-0.21	4.44	-4.80*	37.78*	8.06	8.79*	-2.72	40.32*
P_5 X P_6	-4.56	-4.44	0.00	27.41*	31.45*	7.69*	13.63	41.94*
P_5 X P_7	-2.99	-4.44	0.80	30.37*	32.26*	4.40	12.64	35.48*
P_5 X P_8	2.71	4.44	0.00	35.56*	32.26*	2.20	7.53	38.71*
P_5 X P_9	-0.50	0.00	-0.80	24.44*	33.87*	2.20	7.35	45.16*
P_5 X P_{10}	7.38	8.89*	-1.60	33.33*	35.48*	4.40	3.45	50.00*
P_5 X P_{11}	6.70	4.44	1.60	16.30*	22.58*	2.20	15.84	29.03*
P_5 X P_{12}	8.24	8.89*	0.80	30.37*	25.81*	1.10	6.36	22.58*
P_6 X P_7	2.25	0.00	1.60	34.81*	40.32*	6.59*	-2.43	45.16*
P_6 X P_8	-1.75	-4.44	2.40	33.33*	38.71*	5.49	-1.21	35.48*
P_6 X P_9	-11.52	-13.33*	1.60	31.85*	35.48*	4.40	-2.21	33.87*
P_6 X P_{10}	-0.46	0.00	-0.80	33.33*	35.48*	8.79*	-1.87	45.16*
P_6 X P_{11}	-1.57	0.00	-1.60	37.78*	44.35*	9.89*	-1.69	45.16*

Contd...

1	2	3	4	5	6	7	8	9
$P_6 \times P_{12}$	0.39	-2.22	2.40	37.78*	30.65*	8.79*	11.65	48.39*
$P_7 \times P_8$	-5.74	-4.44	-1.60	33.33*	35.48*	4.40	-13.97	16.13*
$P_7 \times P_9$	0.75	2.22	-1.60	14.81*	25.81*	2.20	-0.48	6.45
$P_7 \times P_{10}$	-3.25	-2.22	-0.80	30.37*	29.03*	1.10	6.80	16.13*
$P_7 \times P_{11}$	-3.64	-4.44	0.00	30.37*	30.65*	3.30	4.15	38.71*
$P_7 \times P_{12}$	-3.10	-2.22	-0.80	17.04*	32.26*	2.20	6.10	35.48*
$P_8 \times P_9$	-2.85	-4.44	0.80	25.93*	22.58*	2.20	0.81	41.94*
$P_8 \times P_{10}$	-7.88	-6.67	-1.60	36.30*	29.03*	8.79*	4.89	37.10*
$P_8 \times P_{11}$	-3.32	0.00	-3.20*	34.81*	37.10*	6.59*	4.81	35.48*
$P_8 \times P_{12}$	-2.14	-2.22	0.00	24.44*	38.71*	4.40	9.96	35.48*
$P_9 \times P_{10}$	2.85	-2.22	-0.80	20.74*	5.65	2.20	-2.98	35.48*
$P_9 \times P_{11}$	3.64	4.44	-0.80	39.26*	35.48*	8.79*	7.53	40.32*
$P_9 \times P_{12}$	7.06	8.89*	-1.60	21.48*	16.13*	4.40	2.79	24.19*
$P_{10} \times P_{11}$	5.74	6.67	-0.80	31.85*	14.52*	6.59*	9.15	29.03*
$P_{10} \times P_{12}$	-0.50	0.0	-0.80	17.04*	29.03*	3.30	-1.91	41.94*
$P_{11} \times P_{12}$	2.43	4.44	-2.40	25.93*	17.74*	6.59*	0.77	29.03*
SE (BC)	1.28	0.91	0.02	3.15	3.89	2.51	2.19	4.12

Significant at $P \leq 0.05$

Germination percentage

Twenty six crosses depicting positive heterosis were $P_1 \times P_2$, $P_1 \times P_3$, $P_1 \times P_8$, $P_1 \times P_9$, $P_1 \times P_{11}$, $P_2 \times P_3$, $P_2 \times P_9$, $P_2 \times P_{10}$, $P_2 \times P_{11}$, $P_3 \times P_4$, $P_3 \times P_5$, $P_4 \times P_5$, $P_4 \times P_6$, $P_4 \times P_7$, $P_4 \times P_9$, $P_4 \times P_{12}$, $P_5 \times P_8$, $P_6 \times P_7$, $P_6 \times P_{10}$, $P_6 \times P_{11}$, $P_6 \times P_{12}$, $P_8 \times P_{10}$, $P_8 \times P_{11}$, $P_9 \times P_{11}$, $P_{10} \times P_{11}$ and $P_{11} \times P_{12}$ for germination percentage.

Seed vigour index

Positive as well as negative heterosis over the best check for seed vigour index was found in $P_1 \times P_7$ and $P_1 \times P_3$, respectively.

Field emergence

All crosses except $P_2 \times P_6$ and $P_7 \times P_9$ for field emergence exhibited positive heterosis over the best check.

4.4 Correlation studies in seed quality traits

All possible correlations among the seed quality traits were computed at phenotypic (P) and genotypic (G) levels and presented in Table 4.24. The phenotypic correlation coefficients observed for different characters are given below:

100-seed weight had positive and significant correlation with 100-seed volume. Similarly, osmotic stress test was positive and significantly correlated with accelerated aging test.

Germination percentage also exhibited positive and significant correlation with accelerated aging and osmotic stress test. Field emergence was positive and significant correlated with accelerated aging, osmotic stress test and germination percentage.

Table 4.24 Phenotypic (P) and genotypic (G) correlation coefficients among field emergence and seed related traits

Character		100-seed volume	Seed density	Accelerated aging test	Osmotic stress test	Germination percentage	Seed vigour index	Field Emergence
100-seed weight	P	0.919*	0.131	-0.133	-0.185	-0.062	0.115	-0.056
	G	0.924	0.231	-0.217	-0.376	-0.065	0.250	-0.088
100-seed volume	P		-0.149	-0.095	-0.170	-0.054	0.157	-0.138
	G		-0.389	-0.118	-0.316	-0.055	0.340	-0.198
Seed density	P			-0.118	-0.039	-0.002	-0.124	0.188
	G			-0.236	-0.073	0.013	-0.236	0.253
Accelerated aging test	P				0.453*	0.488*	0.091	0.348*
	G				0.570	0.550	0.159	0.536
Osmotic stress test	P					0.286*	0.107	0.240*
	G					0.495	0.384	0.321
Germination percentage	P						0.040	0.316*
	G						0.360	0.660
Seed vigour index	P							0.047
	G							0.059

* Significant at $P \leq 0.05$

4.5 Performance of maize inbreds and hybrids to blight and brown spot diseases

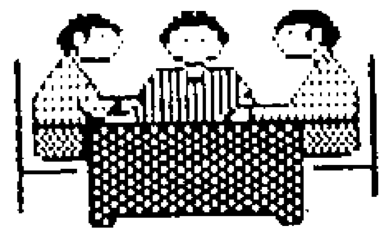
The parents and hybrids of maize in the present investigation were also evaluated under natural epiphytotic conditions during *kharif* 1998 at Palampur and Bajaura for reaction to leaf blight (*Helminthosporium maydis* and *H. turcicum*) and brown spot (*Physoderma zeae maydis*). The parents P_1, P_2, P_3 and P_6 had light leaf blight infection at Palampur and slight at Bajaura. The parents P_4, P_5, P_7, P_8, P_9, P_{10}, P_{11} and P_{12} showed light leaf blight infection at Bajaura whereas the disease reaction on these parents was moderate under Palampur conditions except P_{12}. The parents P_5 and P_8 had no brown spot infection at Bajaura whereas infection on these parents was slight at Palampur. The parents P_2, P_6, P_9 and P_{10} had slight brown spot infection at Bajaura but light at Palampur. The parents P_1, P_3, P_4, P_7, P_{11} and P_{12} also showed light infection at Bajaura.

Thirty six crosses viz., $P_1 \times P_3$, $P_1 \times P_5$, $P_1 \times P_9$, $P_1 \times P_{10}$, $P_1 \times P_{11}$, $P_2 \times P_3$, $P_2 \times P_4$, $P_2 \times P_6$, $P_2 \times P_7$, $P_2 \times P_8$, $P_2 \times P_9$, $P_2 \times P_{10}$, $P_3 \times P_4$, $P_3 \times P_5$, $P_3 \times P_7$, $P_3 \times P_8$, $P_3 \times P_9$, $P_3 \times P_{10}$, $P_3 \times P_{11}$, $P_3 \times P_{12}$, $P_4 \times P_5$, $P_4 \times P_7$, $P_4 \times P_{10}$, $P_5 \times P_6$, $P_5 \times P_9$, $P_5 \times P_{10}$, $P_5 \times P_{11}$, $P_6 \times P_7$, $P_6 \times P_8$, $P_6 \times P_{11}$, $P_7 \times P_8$, $P_7 \times P_{10}$, $P_8 \times P_{10}$, $P_8 \times P_{11}$, $P_9 \times P_{10}$ and $P_{10} \times P_{11}$ had light leaf blight infection at Palampur whereas it was slight at Bajaura.

The crosses $P_2 \times P_{10}$, $P_2 \times P_{11}$, $P_3 \times P_9$, $P_3 \times P_{10}$, $P_3 \times P_{11}$, $P_4 \times P_5$, $P_4 \times P_{10}$, $P_5 \times P_7$, $P_5 \times P_8$, $P_5 \times P_{12}$, $P_6 \times P_8$, $P_6 \times P_9$, $P_6 \times P_{10}$, $P_7 \times P_8$ and $P_{10} \times P_{11}$ showed slight brown spot infection at Palampur and no infection at Bajaura. The crosses $P_3 \times P_5$, $P_4 \times P_9$, $P_5 \times P_6$ and $P_5 \times P_{11}$ showed slight infection for brown spot at both the locations. Light infection was observed at Palampur F_1's $P_1 \times P_3$, $P_1 \times P_4$, $P_1 \times P_6$, $P_1 \times P_9$, $P_1 \times P_{11}$, $P_2 \times P_3$, $P_2 \times P_4$,

$P_2 \times P_5$, $P_2 \times P_6$, $P_2 \times P_8$, $P_2 \times P_9$, $P_3 \times P_4$, $P_3 \times P_6$, $P_3 \times P_{12}$, $P_4 \times P_6$, $P_4 \times P_{11}$, $P_5 \times P_9$, $P_5 \times P_{10}$, $P_6 \times P_7$, $P_6 \times P_{12}$, $P_7 \times P_9$, $P_7 \times P_{10}$, $P_8 \times P_9$, $P_8 \times P_{10}$, $P_9 \times P_{10}$, $P_9 \times P_{11}$, $P_9 \times P_{12}$ and $P_{10} \times P_{12}$ whereas, all these crosses showed slight infection at Bajaura. Other crosses had moderate and high infection for both the diseases at both the locations.

Among the checks, EHB-1520 showed moderate leaf blight infection at Palampur and light infection at Bajaura; KH-101 slight at Palampur and no infection at Bajaura; and PSCL-3436 light infection at Palampur and slight at Bajaura. However, all the three checks showed light brown spot infection at Palampur and slight infection at Bajaura.



DISCUSSION

DISCUSSION

Maize (*Zea mays* L.) is one of the most important cereals of the world, grown in a wide range of climatic conditions and covering an area of about 140.17 m ha with average yield of 43.16 q/ha (Anonymous, 1999[a]). In India, the area under maize is spread over 6.31 m ha with average yield of 17.21 q/ha. Uttar Pradesh covers the largest area (1.07 m ha) followed by Rajasthan (0.96 m ha), Madhya Pradesh (0.83 m ha), Bihar (0.69 m ha), Karnataka (0.56 m ha), Andhra Pradesh, Gujarat (0.40 m ha) and Himachal Pradesh (0.31 m ha). Although the average yield of maize in H.P. is 19.90 q/ha which is slightly above the National average, yet with respect to State-wise ranking it stands fifth after West Bengal (29.98 q/ha), Karnataka (29.84 q/ha) Andhra Pradesh (27.37 q/ha) and Punjab (20.95 q/ha) (Anonymous, 1999[b]). Maize grain and stalk is used for food, feed, oil, fodder and even fuel. Apart from domestic consumption, it also provides raw material for the production of several industrial products. Presently most of the area under maize in the state is covered with local cultivars and composite varieties. Increase in demand for food has encouraged its cultivation to expand in marginal areas forcing more and more maize to be grown under various stresses. Non availability of suitable high yielding hybrids/varieties and maize production under stress/rainfed conditions are the main reasons for its low production. Therefore, there is a potential to bring break - through in the yield level which can be brought about by the development of suitable high yielding hybrids for commercial cultivation.

Various breeding technologies have already been developed and successfully utilized in maize improvement programme (Russell, 1991). But according to Donald (1963) lack of sufficient knowledge of physiological and morphological characters related to yield and their exploitation have kept the current breeding approaches quite empirical. Till date no rapid, inexpensive, simple and precise assay is available to develop physiological/genetic parameters that can accelerate the rate of crop improvement, and thus selection and evaluation of the breeding materials have to be conducted following the current available methodologies.

Diallel approach (Jinks and Hayman, 1953 and Griffing, 1956[b]) was followed in the present study to understand the nature of gene action involved in the inbreds for different traits. The importance of such an analysis lies in the fact that it provides a systematic approach in formulating further breeding programmes in order to get maximum possible information within minimum time period. Johnson (1963) described diallel analysis experimentally as a systematic approach and analytically it provides an overall genetic evaluation that would be useful in identifying the crosses with best potential in early generations. While the diallel analysis of Jinks and Hayman (1953) is useful for evaluating the mode of inheritance, yet the analysis of Griffing (1956[b]) is particularly useful to the breeders as gca are calculated for each inbred parent and sca for hybrids. From this analysis the performance of each specific genotype can be evaluated. From the combining ability analysis we can also predict the relative magnitude of additive and non-additive genetic variances. The variance due to gca contains only additive variance and epistatic interactions of similar type while the sca contains dominance variance and all types of epistatic interactions including additive X additive types also (Griffing, 1956a and 1956b; Arunachalam, 1976).

Hence, higher gca variance indicates mainly the importance of additive portion while the higher sca variance is an indication of the predominant role of non-additive portion or dominance portion of genetic variance.

Heterosis will not only facilitate the easy creation of new and more productive F_1 hybrids but also help the initial component of all plant breeding work, that is the creation of useful genetic variability prior to the second part, that of evaluation of the different genotypes (through their phenotypes) and selection of the superior ones (Tsaftaris, 1995). Since the first attempt to explain heterosis as due to union of unlike gametes by Shull (1910) and due to 'heterozygosis' by East and Hayes (1912), till today several theories have been proposed based on different disciplines like genetics, physiology, biochemistry and molecular genetics. Extensive utilization of heterosis in maize has resulted in the development of superior hybrids throughout the world, but in our state, a large part of more divergent local germplasm remains to be exploited for the development of high yielding hybrids having local adaptability.

To gather the information on combining ability, gene action and heterosis in maize, the present study was undertaken at two locations viz., Palampur (high rainfall) and Bajaura (low rainfall) of the state and the results obtained have been discussed hereunder:

Analysis of variance for the experimental design

The analysis of variance for the experimental design revealed significant differences among the genotypes for all traits under study at both the locations, except for days to maturity at Palampur, and hence pooling of data was not done for this trait. Pooled analysis over the two environments revealed significant differences due to locations for all the traits viz., days to silking, pollen shedding, maturity, leaf area/plant, plant height, ear height, ear length, ear circumference, kernel rows/ear, kernels/row, shelling percentage, 100-seed weight, grain yield, biological yield and harvest index. This indicates that the performance of material under study was inconsistent in two environments for these traits. The differences due to treatments and g x e interactions were significant for all the traits except for days to maturity. This showed that sufficient genetic variability existed in the material for yield contributing traits under study. The presence of g x e interaction might have resulted in the differential performance of these traits at the two locations. The seed quality traits also showed the presence of sufficient genetic variability in the material. These results are in agreement with the findings of Jha and Sinha (1989); Vozda and Kubecova (1989); Odiemah (1991); Cosmin *et al.* (1991); Sharma and Bhalla (1993); Sedhom (1994b); Vasal *et al.* (1995); Chen-Ling *et al.* (1996) and Ismail (1996).

Combining ability analysis

The combining ability analysis facilitates the partitioning of genotypic variation of the crosses into variation due to general combining ability (main effects) and specific combining ability (interactions), which indicates about a measure of additive and non-additive gene action. In the present study significance of gca and sca variances revealed the presence of both additive and non-additive components of variation for different traits.

The gca differences recorded were significant at both the locations for all the economic and seed quality traits except for days to maturity at Palampur. Specific combining ability (sca) effects were also significant for all the traits studied except for days to maturity at both the locations. In the pooled analysis, the significant differences due to gca, sca and locations indicated the presence of sufficient genetic variability for combining ability in the material for all the traits studied at both the locations. Similar results have also been reported by Bhalla and Khehra (1977); Qadri *et al.* (1983); Jha and Sinha (1989), Debnath *et al.* (1988); Beck *et al.* (1990); Mahajan *et al.* (1991); Altinbas (1995); Spaner *et al.* (1996); Joshi *et al.* (1998) and Mathur *et al.* (1998).

Significant gca x location and sca x location interaction for plant height, ear height, kernel rows/ear, grain yield, biological yield and harvest index; alone gca x location interaction for days to silking, pollen shedding and maturity; and sca x location interaction for leaf area/plant, ear length, ear circumference, shelling percentage and 100-seed weight indicated that the general and specific combining abilities for these traits were location specific, which implies that with the change in the environment the combining abilities for these traits did not remain same. These results are in agreement with the findings of Jha and Sinha (1989); Mahajan *et al.* (1991); Sedhom (1994b); Ferrao *et al.* (1994); and Ismail (1996).

Non-additive gene action predominated for days to silking, pollen shedding, leaf area/plant, plant height, ear height, ear length, ear circumference, kernel rows/ear, shelling percentage and 100-seed weight at both the locations and in pooled analysis. Non-additive gene action also predominated for kernels/row at Palampur; biological yield at Bajaura; and kernels/row, biological yield and days to maturity in pooled analysis. Hybrid varieties are the demand of the present era to boost the agricultural production. The vigour of the hybrid varieties are determined by the degree of dominance. In the present study, for most of the yield components, non-additive gene action predominated, which further authenticates exploitation of non-additive gene action through the development of hybrids in maize. Non-additive gene action also predominated for seed quality characters, viz., 100-seed weight, 100-seed volume, osmotic stress test, seed vigour index and field emergence which is desirable from breeding point of view as these traits can also be improved along with economic traits following exploitation of non-additive gene action through hybrid development.

These results are in close agreement with the findings of Mathur and Bhatnagar (1995), who reported both additive and non-additive gene action for days to pollen shed, days to silking, plant height, ear height, kernel rows/ear, kernels/row, ear length, ear circumference, 100-seed weight, shelling percentage and biological yield. Confirmatory reports on preponderance of non-additive gene action for kernels/row (El-Hosary and Sedhom, 1990); ear length and ear circumference (Satyanarayanan *et al.* 1990) are also available.

General combining ability effects

The gca effects are of direct utility to decide the next phase of the breeding programme i.e. to locate the parents which can be commercially exploited for development of suitable hybrids.

In the present study, the parents were classified as good, average and poor combiners based on the gca effects. Parents with the desirable gca effects significantly differing from zero were considered as good combiners, while those with nonsignificant estimates were called as average combiners. Poor combiners had significant but undesirable gca effects.

It is revealed from the results that the parents P_4 and P_7 were good general combiners for grain yield at both the locations. In addition, P_{10} was good general combiner at Palampur and P_{11} at Bajaura conditions. Whereas on pool basis, the parents P_4, P_7, P_{10} and P_{11} were good general combiners. These parents were also simultaneously better combiners for few other yield components. The *per se* performance of all these parents was also high in the respective locations. It would be interesting to find the behaviour of these good general combiners in various cross combinations exhibiting significant sca effects in both the locations. In view of this, these parents appeared to be worthy of exploiting in practical plant breeding for utilizing the fixable component of variation.

For seed quality traits the parent P_4 was good general combiner for field emergence, germination percentage, seed density and accelerated aging test, whereas P level was so for 100-seed weight and germination, and can be exploited in breeding superior genotypes having good seed quality.

Earlier many workers had also reported different parents as good average and poor general combiner for different yield, yield contributing and seed quality traits viz., Khristova (1975), Bhalla and Khehra (1977), Singh *et al.* (1979), Qadri *et al.*, (1983), Debnath *et al.* (1983a, b), Nawar and El-Hosary (1984), Prasad *et al.* (1988), Singh *et al.* (1989), Beck *et al.* (1990), Sharma and Bhalla (1993), Jha (1993), Villanueva *et al.* (1994), Sedhom (1994 a, b) Nagda *et al.* (1995), Spaner *et al.* (1996) and Mathur *et al.* (1998).

Specific combining ability effects

The sca effects are associated with dominance and epistatic components of variation i.e. mainly non-fixable components of variation. Nonsignificant sca mean squares indicate that the performance of single cross progeny can be predicted adequately on the basis of gca. Significant sca is the indication of relative importance of interactions in determining the performance of single cross.

A comparison of the combining ability effects of the parents and their corresponding crosses indicated that in most of the cases gca effects of the parents were not reflected in the sca effects of the crosses for most of the traits studied. Thus, in most cases, crossing the two good general combiners did not necessarily result in a good specific combination and the same was true for poor combiners. In some cases, however, good hybrid combinations involved one good combiner while in very few cases both good combiners could produce superior combinations. In some cases, when two poor combiners were crossed, best combinations were observed to be produced. This indicated wide diversity in nicking to produce hybrid vigour. In general, there was no generalized order of nicking among the parents to produce desirable combinations. Any sort of combination among the parents could give hybrid vigour over the parents which might be due to favourable dominant genes, overdominance or epistatic action of genes (Matzinger and Kempthorne 1956). Based on the present results it could be concluded that the production of hybrids based on the parental performance was not practically true.

At Palampur, the hybrid combination P_1 x P_{11} was the superior most in terms of grain yield and could be utilized for exploiting its high sca effects for grain yield, biological yield and harvest index. It was interesting to note that the parents of this hybrid were poor (P) and average (A) general combiners. The other best combination in respect to yield was P_5 x P_{12} where P_5 was poor combiner and P_{12} average combiner. The high sca of this hybrid appears to have resulted from the contribution of traits like 100-seed weight, biological yield, harvest index, ear circumference and kernel rows/ear. Combination P_4 x P_6, (GxP) is also one of the promising hybrid for grain yield at Palampur.

At Bajaura, the hybrid combination $P_5 \times P_{12}$ (PxA) was the superior most in terms of grain yield and also reflected good performance for shelling percentage, biological yield and harvest index. Other best hybrid combination was $P_4 \times P_9$ (GXA). Besides grain yield, the hybrid $P_4 \times P_9$ was also desirable for kernels/row and biological yield. Other hybrids like $P_4 \times P_8$ was desirable for plant height, ear height, grain yield and biological yield and $P_5 \times P_{10}$ for silking, pollen shedding, ear length, kernels/row and grain yield.

Across the two locations, the cross combinations $P_5 \times P_{12}$ (PXA) P_1, $\times P_{11}$ (PxG) and $P_4 \times P_9$ (GxA) were found to be promising for yield. The cross $P_5 \times P_{12}$ also behaved consistently better for biological yield, harvest index, pollen shedding and 100-seed weight, whereas $P_4 \times P_9$ was so for kernel rows/ ear, kernels/row, 100-seed weight, biological yield and harvest index. The cross $P_8 \times P_{11}$ gave consistently better performance across the two locations for silking, pollen shedding and plant height; $P_8 \times P_{12}$ for leaf area/plant and 100-seed weight; $P_2 \times P_3$ for ear height and ear circumference; $P_6 \times P_{12}$ for plant height and ear height; $P_1 \times P_9$ for ear length and grain yield; $P_1 \times P_{11}$ for ear height and grain yield; and $P_6 \times P_{11}$ for plant height.

The resultant high *per se* performance of crosses involving poor x poor parents indicated that a high magnitude of non-additive component was responsible for conferring the highest rank to these cross - combinations. A high degree of non-allelic interaction of the complementary type might be involved in the new genetic combination. These results are supported by the findings of Debnath (1981) and Mehta (1987).

In case of the seed quality traits, the hybrid combination $P_1 \times P_8$ (PxA) was found to be the superior most in terms of field emergence and 100-seed weight. $P_5 \times P_{10}$ (AxA) is the next best hybrid combination with respect to field emergence. Beside this, it appears significant for osmotic stress test, accelerated aging test, 100-seed weight and 100-seed volume. The cross P_5 x P_9 gave consistent performance for field emergence; P_2 x P_9 for field emergence, germination percentage and accelerated aging test; and P_6 x P_{12} for field emergence, seed vigour, germination percentage, accelerated aging test and 100-seed density.

A number of studies conducted earlier have also reported contradictory and conformatory reports about the relative importance of parents for general and specific combining ability effects. Dhillon and Singh (1976) and Mason and Zuber (1976) concluded that gca was more important than sca for days to silking, plant height, ear placement height, ear length, ear girth, grains/ ear and leaf area/plant; Beck *et al.* (1990) reported importance of gca for grain yield, plant height, ear height and days to silking while sca for ear height; Qadri *et al.* (1983) reported importance of sca for ear length, ear girth, ear placement height and grains/ear; and Barla *et al.* (1990) for seed vigour. Perez *et al.* (1991) concluded that the involvement of one high yielding parent with high gca resulted into highest sca effects. Dronavalli and Kang (1992) reported that sca was more important than gca for all seed quality traits except shoot length. For shoot length both gca and sca were equally important. Sedhom (1994 a,b) reported importance of sca for grain yield/plant, ear length, kernel rows/ear, plant height, ear height and silking date. Altinbas (1995) concluded that negative and high gca effects for days to silking and ear height resulted into best crosses. Kalita *et al.* (1995) reported that parents with high gca estimates did not always give rise to offspring with high sca. Dass *et al.* (1997) revealed good general combiners for grain yield and 100-seed weight and suggesting that the involvement of one good general combiner appears to be essential to get the better specific combination. Mathur *et al.* (1998) found significant sca for ear length, shelling per cent and grain yield.

Genetic component analysis

Hayman's (1954) diallel analysis is carried out if the assumptions underlying the analysis are fulfilled to show the validity of additive - dominance model. To employ the validity of such assumptions the t^2- values were computed. The nonsignificant t^2-values for majority of the traits at both the locations indicated the validity of most of the assumptions underlying diallel analysis.

The non-allelic interactions as indicated by the significant values of (1-b) were present for grain yield, biological yield, harvest index, 100-seed weight, days to silking, leaf area/plant, ear length, ear circumference, kernel rows/ear and kernels/row at Palampur, Bajaura and in pooled analysis. These interactions also prevailed for days to pollen shedding and plant height at Palampur for ear height, days to maturity and shelling percentage at Bajaura; and for days to pollen shedding, ear height and days to maturity in pooled analysis. Characters viz., kernel rows/ear, kernels/row, 100-seed weight and biological yield at Palampur; ear height and days to maturity at Bajaura; and ear height, kernel rows/ear and 100-seed weight in pooled analysis exhibiting significant regression coefficient values (b) coupled with significant values of (1-b), indicated the presence of probably complementary type of interactions.

In the present study, both additive (D) and dominance (H_1) components were important for leaf area/plant, plant height, ear height, kernel rows/ear, biological yield and harvest index at Palampur, Bajaura and over pooled analysis; for ear length and shelling percentage at Palampur; days to pollen shedding and days to maturity at Bajaura; and ear length, shelling percentage and 100-seed weight in pooled analysis. Since the magnitude of dominance variance was more than additive variance, this showed the predominance of dominance effects. Dominance component (H_1) was observed to be significant for all the traits under study in all environments.

A number of workers have earlier reported regarding the type of gene action governing the inheritance of various characters. Both additive and non-additive gene action were reported by Bhalla and Khehra (1977) for ear circumference; Bonaparte (1977) for days to 50 per cent silking; Krolikowskii (1977) for ear placement height and grain yield/plant; Bhalla and Khehra (1980) for days to 50 per cent silking and ear length; Martin (1981) and Yang (1982) for grain yield/plant; Saha (1981) for ear length and ear diameter; Ahuja *et al.* (1983) and Sanjay Swarup (1990) for ear diameter; Qadri *et al.* (1983) for ear length; Hemalatha (1986) for plant height and days to 50 per cent tasselling; Pal *et al.* (1986) and Vedeneev and Zhuzhukin (1986) for 100-seed weight; Ramesha (1988) for days to silking and tasselling; Debnath *et al.* (1988) for kernel rows/ear and kernels/row; and Jha and Sinha (1989) for grain yield, germination percentage and leaf yellowing. However, additive gene action was found to be more important by Rood and Major (1980) for days to 50 per cent tasselling; Verma and Singh (1980) and Cosmin *et al.* (1991) for grain yield/plant; Murthy *et al.* (1981) and Mathur and Bhatnagar (1995) for days to 50 per cent tasselling and silking; Sanghi *et al.* (1982) for number of kernel rows/ear and grain yield/plant; Qadri *et al.* (1983) for ear placement height, ear diameter, kernel rows/ear; Singh *et al.* (1983) for plant height; Hemalatha (1986) and Zambezi *et al.* (1986) for ear placement height; Nawar (1986) for plant height, ear placement height, ear length, ear diameter, kernel rows/ear and grain yield/

plant; Hallauer and Miranda (1988) for plant height, ear length, ear diameter and grain yield/plant; Leon *et al.* (1989) for 100-seed weight; Sanjay Swarup (1990) for ear length and grain yield/plant; and Turgut *et al.* (1995) for grain yield, ear diameter, ear length, number of grain rows and 100-grain weight. Importance of non-additive gene action has been reported by various workers e.g. Bhalla and Khehra (1980), Murthy *et al.* (1981), Genov (1987), Liao *et al.* (1987) and Wu (1987) for grain yield/plant; Ahuja (1980) for kernels/row; Genowa (1984), Pinto *et al.* (1985) and Stuber *et al.* (1987) for ear length and 100-seed weight; and Guo *et al.* (1986) for days to 50 per cent tasselling and grain yield/plant.

The relative distribution of dominant and recessive genes in the parents was noted from the significant values of F and the ratio K_D/K_R. When the value of K_D/K_R is greater than unity it shows the preponderance of dominant genes. In the present study, dominant genes predominated for leaf area/plant, plant height, ear height, ear length, kernels/row, shelling percentage, 100-seed weight, grain yield, biological yield and harvest index at Palampur, Bajaura and over pooled analysis, whereas recessive genes predominated for days to pollen shedding at Palampur. Earlier studies reported by Sokolov *et al.* (1971) for grain yield, ear length and kernels/row; by Barriga and Vencovsky (1973) for leaf area/plant and plant height; and by Krivoshoya and Zozulaya (1974) for 1000-grain weight, days to maturity and ear length also indicated the preponderance of dominant genes for these characters.

The positive and negative genes in the parents were distributed unequally for all the traits as was evident from the ratio $H_2/4H_1$, which was less than 0.25, except for days to silking at Bajaura where equal distribution of genes with positive and negative effects were noticed.

For the characters exhibiting significant additive (D) and dominance (H_1) component of variance, the average degree of dominance, $(H_1/D)^{½}$ was calculated, which reveals overdominance for leaf area/plant, plant height, ear height, kernel rows/per, biological yield and harvest index at both the locations; for ear length and shelling percentage at Palampur; for days to pollen shedding and days to maturity at Bajaura; and for ear length, shelling percentage and 100-seed weight over pooled analysis.

Earlier workers have also reported the varying levels of dominance for different characters studied. Khristova (1975) observed overdominance for grains/cob and Nesticky (1976) for plant height. Krolikowskii (1977) observed partial dominance for ear height but overdominance for ear length and grain yield. Vedeneev and Zhuzhukin (1986) observed partial to overdominance for 1000-grain weight and Debnath and Sarkar (1987a) reported complete dominance to overdominance for grain yield; whereas Debnath and Sarkar (1987b) reported partial to complete dominance for ear height.

The correlation coefficient between the parental order of dominance and parental measurement indicates about the dominance of positive and negative genes. If the correlation coefficient is significant and positive, it indicates that negative genes are dominant and *vice-versa*. In the present study, the correlation coefficient was negative and significant indicating the dominance of positive genes for plant height, kernels/row, 100-seed weight, grain yield and harvest index at both the locations and in pooled analysis; for leaf area/plant, ear height, ear length, shelling percentage and biological yield at Palampur; and for ear height, shelling percentage and biological yield over pooled analysis. Genes with negative effects dominated for days to silking, pollen shedding and leaf area/plant at Bajaura; and for days to maturity in pooled analysis. For the remaining traits in different locations, values of correlation coefficients was nonsignificant, thus revealing that dominant genes in the parental strains with positive and negative effects are equally distributed.

Direction of dominance can be ascertained from the values of h^2. If it is significantly positive, it indicates the positive direction of dominance and vice-versa. Positive direction of dominance for almost all the traits was recorded in the present study. Positive direction of dominance was also reported for grain yield by Wessels (1967) and for 1000-grain weight by Vedeneev and Zhuzhukin (1986).

Besides getting information on gene action, the other advantage of Hayman approach over combining ability is that, one can get information on heritability estimates (narrow sense). In the present investigation high heritability (> 30 %) was observed for ear height at Palampur; for plant height and ear height at Bajaura; and leaf area/plant, plant height and ear height in pooled analysis. Medium heritability (15-30 %) was observed for leaf area/plant, plant height, ear length, kernel rows/ear, shelling percentage, biological yield and harvest index at Palampur; for days to pollen shedding, leaf area/plant, days to maturity, biological yield and harvest index at Bajaura; and for ear length, kernel rows/ear, shelling percentage, biological yield and harvest index on pooled basis. For remaining traits including grain yield low heritability (< 15 %) was observed.

It may be concluded in the light of above discussion that the characters like plant height and ear height have high heritability. Consequently, any selection method adopted could lead to desirable improvement in the above mentioned traits. Earlier workers also reported the wide range of heritability for different characters studied. High heritability has been reported by Mulamba and Mock (1978) for days to silking, pollen shed period, plant height, cob placement height and grain yield. Regazzi *et al.* (1980) reported high heritability for plant height, cob placement height, 500-grain weight and grain yield; and Cosmin *et al.* (1984) for leaf area/plant. However, Dhillon and Singh (1976) reported heritability to be low for grain yield/plant and high for plant height, cob placement height, grains/cob and days to silking and low for cob length and cob girth which is in agreement with the findings of the present study. McIntosh and Miller (1980) reported low heritability for germination under high osmotic pressure; Ismail (1996) for days to tasselling and silking, protandrous interval and grain yield/plant. Chen-Ling *et al.* (1996) reported narrow sense heritability for ear length, ear thickness and kernel rows/ear.

For seed quality traits, the t^2-values were nonsignificant for most of the traits except 100-seed volume, accelerated aging test and osmotic stress test, which indicated the validity of most of the assumptions underlying diallel analysis. Non-allelic interactions as indicated by the significant values of (1-b) were present for 100-seed weight, 100-seed volume, accelerated aging test, osmotic stress test, seed vigour index and field emergence. Significant regression coefficient values (b) coupled with significant values of (1-b), indicated the presence of probably complementary type of interaction for 100-seed weight and 100-seed volume.

Significance of both additive (D) and dominance (H_1) components for 100-seed weight, 100-seed volume, germination percentage and field emergence indicated the importance of both type of gene actions, however, since the magnitude of dominance variance was more than additive variance, this showed the preponderance of dominance effects. Dominance component (H_1) was observed to be significant for all the traits except for seed density. Dominant genes predominated for 100-seed weight, 100-seed volume, accelerated aging test, osmotic stress test, germination percentage, seed vigour index and field emergence.

The positive and negative genes in the parents were distributed unequally for all the seed quality traits as was evident from the ratio $H_2/4H_1$, which was less than 0.25, except for germination percentage where equal distribution of genes with positive and negative effects were noticed.

The investigation reveals overdominance for 100-seed weight, 100-seed volume, germination percentage and field emergence. Negative and significant correlation coefficient for 100-seed weight indicated the dominance of positive genes. Due to nonsignificant value of correlation coefficients in the remaining traits, it can be concluded that dominant genes in the parental strains are equally positive and negative. Positive direction of dominance for 100-seed weight and 100-seed volume was also recorded. Low heritability was observed for 100-seed weight, accelerated aging test, osmotic stress test, germination percentage and seed vigour index; medium for 100-seed volume, and field emergence; and high for seed density. This indicated that the simple selection for these traits will not be useful for their improvement.

Heterosis

The objective of heterosis breeding is to identify the best cross combinations which perform significantly better than the better parent/best check. It may, however, be borne in mind that while selecting the best cross combinations on the basis of heterotic response, the *per se* performance of the crosses should also be given due consideration.

The economic heterosis was worked over the hybrid PSCL-3436 as it excelled the other two checks EHB-1520 and KH-101 for many of the traits at both the locations. Nine crosses at Palampur and 21 at Bajaura out yielded the best check PSCL-3436. Though the mean yield at Palampur was observed higher in different cross combinations and best check than at Bajaura, the range of heterosis at Bajaura was observed three times more than at Palampur which indicate that the cross combinations had better performing ability than best check under water stress conditions which were experienced at Bajaura during the cropping season. The cross $P_2 \times P_7$ at Palampur and $P_4 \times P_9$ at Bajaura exhibited the highest magnitude of heterosis over the best check to the tune of 9.88 and 28.06 per cent, respectively. The other promising crosses which exhibited heterosis for grain yield at Palampur were $P_4 \times P_{10}$, $P_1 \times P_{11}$, $P_7 \times P_{10}$, $P_3 \times P_{10}$ and $P_4 \times P_7$; and at Bajaura $P_4 \times P_{12}$, $P_5 \times P_{12}$, $P_6 \times P_7$, $P_3 \times P_{10}$, $P_3 \times P_{11}$ and $P_{11} \times P_{12}$. However, the crosses $P_3 \times P_{10}$, $P_5 \times P_{12}$, $P_3 \times P_{11}$, $P_4 \times P_7$ and $P_{11} \times P_{12}$ gave heterosis for grain yield and other contributing traits over the best check at both the locations.

The top most combinations exhibiting significant heterosis over the best check also showed high *per se* performance. At Palampur in addition to yield, the cross combinations $P_2 \times P_7$ and $P_4 \times P_{10}$ showed significant heterosis for as many as eight yield contributing traits followed by $P_7 \times P_{10}$ for five and $P_1 \times P_{11}$ and $P_3 \times P_{10}$ for four such traits. High heterosis in the cross $P_2 \times P_7$ might have resulted due to the simultaneous heterosis for leaf area/plant, ear height, ear length, ear circumference, kernel rows/ear, kernels/row and biological yield while, in $P_4 \times P_{10}$ cross simultaneous heterosis was also observed for days to silking, days to pollen shedding, plant height, days to maturity, ear circumference, 100-seed weight and biological yield.

At Bajaura in addition to yield the cross combinations $P_4 \times P_9$, $P_5 \times P_{12}$ and $P_6 \times P_7$ exhibited significant heterosis for as many as five yield contributing traits; $P_4 \times P_{12}$ for six; and for $P_3 \times P_{10}$ for four traits. The cross $P_4 \times P_9$ showed simultaneous heterosis for ear height, days to maturity, kernels/ row, shelling percentage and biological yield and cross $P_4 \times P_{12}$ for days to silking, days to pollen shedding, days to maturity, shelling percentage, biological yield and harvest index.

From the pooled analysis of sca and heterosis it is revealed that the five crosses viz., $P_3 \times P_{10}$, $P_5 \times P_{12}$, $P_3 \times P_{11}$, $P_4 \times P_7$ and $P_{11} \times P_{12}$ exhibited high sca, high heterosis over the best check and *pre se* performance. Keeping these factors in view, these crosses can be exploited commercially.

Most of the cross combinations showed high rate of field emergence (except $P_2 \times P_6$ and $P_7 \times P_9$) than the best check. $P_5 \times P_{10}$ revealed the highest heterosis percentage over the best check for field emergence. Cross $P_6 \times P_{11}$ expressed the highest magnitude of heterosis for osmotic stress test and germination percentage; $P_1 \times P_7$ for seed vigour index; $P_3 \times P_7$ for seed volume; $P_3 \times P_{11}$ and $P_4 \times P_{10}$ for seed density; and $P_1 \times P_3$ and $P_9 \times P_{11}$ for accelerated aging test.

There are numerous reports on heterosis for different characters in the literature. Earlier workers have reported high heterosis in respect of different characters, Hassabala *et al.* (1980) for early tasselling; Verma *et al.* (1980) for ear length, 100-grain weight and grain yield; Paterniani (1980) for ear placement height and plant height; Todorov (1981) for plant height; Simeonov (1983) for plant height and biological yield; Gupta *et al.* (1986) for ear length and kernel rows/ear; Debnath (1987) for grains/row, ear length and 1000-grain weight; Ganguli *et al.* (1989) ear height and grain yield; Tomov *et al.* (1990) for ear length, grain yield/unit area and kernel rows/ear; Alvarez *et al.* (1993) positive for plant height, ear height, kernels/row and grain weight; Altinbas (1995) and Sinha and Mishra (1997) for grain yield; and Chen-Ling *et al.* (1996) for grain yield/plant, 100-grain weight, ear length, ear thickness and kernel rows/ear.

Low heterosis was reported by Miranda Filho and Vencovsky (1984) for plant height and for yield, plant height, ear height and days to silking by Beck *et al.* (1990); Alvarez *et al.* (1993) reported negative heterosis for days to silking and tasselling; and it was reported negative for days to silking by Altinbas (1995) .

Correlation studies

From breeder's point of view the knowledge of interrelationships amongst different traits serve two main purposes. Firstly, these are highly useful in selecting for those characters, which are highly influenced by the environmental effects and can not be selected upon visually. Secondly, interrelationships between characters make available to the breeders sources of information as to the nature, extent and direction of selection pressure among characters.

The estimates of phenotypic and genotypic correlation coefficient amongst seed quality traits reveal that genotypic correlation coefficients were in general, higher than the corresponding phenotypic ones, indicating the inherent association among various seed quality traits studied.

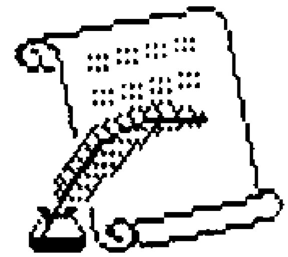
From the correlation studies it was found that the accelerated aging test, osmotic stress test and germination percentage are the best predictors of field emergence as reflected by positive correlation of field emergence with these traits, whereas, there was no association in 100-seed weight, 100-seed volume, seed density and seed vigour index with field emergence. These results are in close conformity with the findings of Milosevic *et al.* (1994) who reported a very high positive correlation of field emergence with accelerated aging test. However, to the present contrary, Lovato and Balboni (1997) reported germination test not to be a good indicator of field emergence.

Performance of maize inbreds and hybrids to blight and brown spot diseases

Nineteen crosses viz., P_1 x P_3, P_1 x P_9, P_1 x P_{11}, P_2 x P_3, P_2 x P_4, P_2 x P_6, P_2 x P_8, P_2 x P_9, P_3 x P_4, P_3 x P_5, P_3 x P_{12}, P_5 x P_6, P_5 x P_9, P_5 x P_{10}, P_5 x P_{11}, P_6 x P_7, P_7 x P_{10}, P_8 x P_{10} and P_9 x P_{10} showed light to slight infection of leaf blight and brown spot diseases at Palampur as well as at Bajaura indicating that these crosses possess resistance to both the disease. However, none of the crosses was completely free from leaf blight infection at both the locations. The crosses viz., P_2 x P_{10}, P_2 x P_{11}, P_3 x P_9, P_3 x P_{10}, P_3 x P_{11}, P_4 x P_5, P_4 x P_{10}, P_5 x P_7, P_5 x P_8, P_5 x P_{12}, P_6 x P_8, P_6 x P_9, P_6 x P_{10}, P_7 x P_8 and P_1 x P_{11} showed no brown spot infection at Bajaura. The results show that severity of both the diseases was slightly more under Palampur conditions that of Bajaura. The reason for low disease severity at Bajaura may be the drought conditions prevalent during crop growing season at Bajaura.

Among the crosses, showing slight to light infection to both the diseases at Palampur and Bajaura, the crosses P_1 x P_{11}, P_2 x P_8, P_2 x P_9, P_5 x P_{11}, P_6 x P_7 and P_7 x P_{10} exhibited high sca effects and crosses P_1 x P_{11}, and P_7 x P_{10} high heterosis for grain yield in both the environments. These hybrids, thus appear to be suitable for cultivation in maize growing areas of H.P. where blight and brown spot are the prominent diseases. The results of experiments conducted at Bajaura indicate that the cross combinations such as P_5 x P_{12}, P_3

x $P_{[illegible]}$, P_3 x $P_{[illegible]}$, P_4 x P_5, P_7 x P_8 and P_3 x P_9, which had high sca effects (21.60 to 6.57) and crosses P_5 x P_{12}, P_3 x P_{10}, P_3 x P_{11}, P_7 x P_8, P_4 x P_{10} and P_3 x P_9 had high heterosis (18.88 to 8.67) for grain yield, can be utilized under drought prone areas of H.P. because of high sca effects, heterosis for grain yield and high degree of resistance to brown spot.



SUMMARY

Chapter-VI

SUMMARY

The present study was undertaken with the objectives to estimate the general and specific combining ability, gene action and information on heterosis for different yield contributing and seed quality traits in maize. Correlation coefficients of different seed quality traits with field emergence were also studied.

Twelve parental inbred lines along with their 66 crosses developed through diallel mating system (excluding reciprocals) with three hybrid checks were evaluated in a simple lattice design with two replications at two locations viz., Palampur and Bajaura, during *kharif* 1998. The data were recorded on yield and yield contributing traits viz., days to silking, days to pollen shedding, leaf area/plant, plant height, ear height, days to maturity, ear length, ear circumference, kernel rows/ear, kernels/row, shelling percentage, 100-seed weight, grain yield, biological yield and harvest index. Reaction to leaf blight and brown spot were observed under field conditions. The data on seed quality traits viz., 100-seed weight, 100-seed volume, seed density, accelerated aging test, osmotic stress test, germination percentage, seed vigour index and field emergence, were also computed. The analysis was carried out following the Griffing's (1956b) and Hayman's (1954) approaches.

Analysis of variance revealed ample genetic variability for all yield and yield components (except for days to maturity at Palampur) and seed quality traits. The pooled analysis revealed the wide variability among the locations, g x e interaction and the treatments for all yield and yield contributing traits.

The combining ability analysis revealed significant gca and sca variances for all yield and yield contributing traits (except days to maturity) at both the locations and for seed quality traits. Whereas, pooled analysis revealed significant variances for gca, sca, locations and the interactions of gca and sca with the location for almost *all* the yield and yield contributing traits.

Estimates of general combining ability effects revealed the parents P_4 and P_7 to be good general combiners for yield and other important traits at both the locations, whereas on pooled basis P_4, P_7, P_{10} and P_{11} were found to be good general combiners. The parent P_4 was the best combiner for field emergence and other seed quality traits. The estimates of sca effects revealed that 38 cross combinations at Palampur, 29 at Bajaura and 39 on pooled basis were best combiners for grain yield and its contributory traits. The top ranking five combinations across the two locations for yield and yield contributing traits $P_5 \times P_{12}$, $P_1 \times P_{11}$, $P_4 \times P_9$, $P_4 \times P_6$ and $P_{11} \times P_{12}$. The crosses $P_1 \times P_8$, $P_5 \times P_{10}$, $P_5 \times P_9$ and $P_2 \times P_9$ showed high sca for field emergence, 100-seed weight and 100-seed volume.

Combining ability approach indicated the preponderance of non-additive genetic variance ($\sigma^2 s$) for all the seed and yield traits at both the locations and in the pooled analysis.

Hayman's genetic component analysis indicated significant dominance and additive components with the preponderance of dominance component for leaf area/plant, plant height, ear height, kernel rows/ear, biological yield and harvest index at both the locations and on pooled basis, for ear length and shelling percentage at Palampur and on pooled basis; for days to pollen shed and maturity at Bajaura; and for 100-seed weight on pooled basis. For the remaining traits like grain yield, kernel rows/ear and ear circumference only dominance component was significant.

The ratio of $H_2/4H_1$ indicated asymmetrical distribution of dominant and recessive genes among the parents for all the traits, except for days to siliking at Bajaura. The K_D/K_R ratio showed high preponderance of dominant genes for all traits, except for days to pollen shedding at Palampur whereas r value indicated the genes with positive effects to be dominant among parents for majority of the traits.

Nonsignificant values of t^2, b and 1-b for majority of the traits indicated that the assumption underlying the analysis are fulfilled, however, significant b and 1-b for ear height, kernel rows/ear and 100-seed weight in pooled analysis indicated the presence of epistasis. Low and medium heritability was found for majority of the traits, except for leaf area/plant, plant height and ear height in pooled analysis which showed high heritability.

In seed quality traits overdominance was found for 100-seed weight, 100-seed volume, germination percentage and field emergence. The ratio of $H_2/4H_1$ was less than 0.25 for all the traits except germination percentage indicating the asymmetrical distribution of dominant and recessive genes. The K_D/K_R ratio showed the excess of dominant alleles among parents. The significant value of b and 1-b indicated the presence of epistasis for 100-seed weight and 100-seed volume. High heritability was found for seed density and low for other traits.

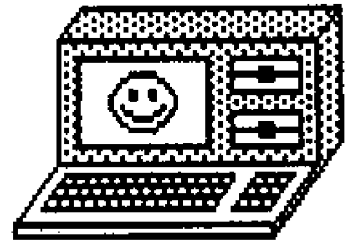
Desirable and high heterosis was observed over the best check PSCL-3436 for grain yield in 9 crosses at Palampur and 21 at Bajaura. The cross P_2 X P_7 (9.88%) at Palampur and P_4 x P_9 (28.06 %) at Bajaura had the highest magnitude of heterosis for yield over the best check. The cross P_2 x P_7 also showed significant heterosis for leaf area/plant, ear height, ear length, ear circumference, kernel rows/ear, kernels/rows and biological yield; and the cross P_4 x P_9 for ear height, days to maturity, kernels/rows, shelling percentage at biological yield. The top ranking crosses viz., P_3 x P_{10}, P_5 x P_{12}, P_3 x P_{11}, P_4 x P_7 and P_{11} x P_{12} showed the desirable heterosis over the best check, high sca and *per se* performance across the two environments. The hybrids P_3 x P_{10} and P_3 x P_{11} showed light and slight infection for leaf blight; and slight and no infection for brown spot diseases at Palampur and Bajaura, respectively.

For seed quality parameters the crosses P_5 x P_{10}, P_1 x P_8 and P_6 x P_{12} showed high heterosis for field emergence and other quality parameters. Field emergence was correlated with germination percentage, osmotic stress test and accelerated aging test.

Conclusions

- Wide range of genetic variability was observed in the material.
- Based on general combining ability effects P_4 , P_7, P_{10} and P_{11} were found to be good general combiners over the locations for yield and yield contributing traits.
- P_4 was the good combiner for seed quality parameters viz., field emergence, seed density, accelerated aging test, germination percentage.
- A few top ranking cross combinations viz., P_5 x P_{12}, P_1 x P_{11}, P_4 x P_9, P_4 x P_6 and P_{11} x P_{12} across the locatioins exhibited high sca effects for grain yield and its contributing traits. For seed quality traits, crosses P_1 x P_8, P_5 x P_{10}, P_5 x P_9 and P_2 x P_9 showed high sca for field emergence, 100-seed weight and 100- seed volume.

- Both additive and dominance components were important with the predominance of dominance component and showing medium to low heritability for leaf area/plant, plant height, ear height, ear length, kernel rows/ear, shelling percentage, biological yield, harvest index, 100-seed weight, 100-seed volume, germination percentage and field emergence. However, only dominance component was important for the remaining traits and the heritability for these traits was also low.
- The crosses P_3 x P_{10}, P_5 x P_{12}, P_3 x P_{11}, P_4 x P_7 and P_{11} x P_{12} across the two environments showed high heterosis, high sca and *per se* performance, thus can be exploited commercially.
- For seed quality parameters the crosses P_5 x P_{10}, P_1 x P_8 and P_6 x P_{12} showed high heterosis for field emergence and other quality parameters. Field emergence was correlated with germination percentage, osmotic stress test and accelerated aging test.
- The hybrids P_3 x P_{10} and P_3 x P_{11} with desirable heterosis, high sca and *per se* performance showed light and slight infection for leaf blight; and slight and no infection for brown spot diseases at Palampur and Bajaura, respectively.



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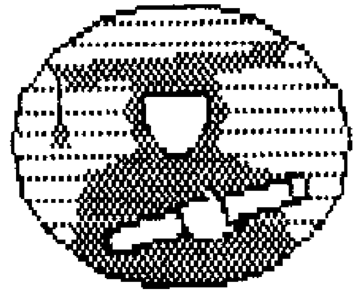

APPENDICES

APPENDIX -I a

Mean weekly weather data of Palampur for the year 1998

Standard weeks	Temperature (°C) Max.	Temperature (°C) Min.	R.H. (%)	BSS (Hrs)	Rain fall (mm)	Evaporation (mm)
11-17 June	26.5	18.1	66	5.4	111.4	4.4
18-24	31.4	19.5	57	11.0	13.6	6.0
25-1 July	28.9	20.7	70	4.6	69.8	3.3
2-8	26.8	20.3	82	4.6	123.1	1.7
9-15	27.8	21.0	82	3.5	75.4	1.8
16-22	26.9	20.2	83	5.1	40.7	2.0
23-29	28.2	19.4	76	5.7	51.5	2.7
30-5 Aug.	26.4	20.5	84	2.3	115.5	2.4
6-12	27.6	21.1	83	3.3	216.4	1.8
13-19	26.1	20.2	84	1.9	119.0	2.0
20-26	25.4	19.7	86	2.9	236.4	1.8
27-2 Sept.	26.9	19.1	73	6.5	63.2	2.6
3-9	27.7	18.8	74	7.2	30.2	3.0
10-16	26.0	18.3	72	5.1	72.2	3.0
17-23	24.7	17.7	80	2.1	137.5	2.4
24-30	26.4	17.9	78	7.3	51.0	2.0
1-7 Oct.	26.3	16.1	67	8.3	10.6	2.2
8-14	27.4	16.1	58	10.7	0.0	2.3
15-21	22.0	14.5	75	5.2	86.5	2.1

APPENDIX- I b

Mean weekly weather data of Bajaura for the year 1998

Standard weeks	Temperature (°C) Max.	Min.	R.H. (%)	BSS (Hrs)	Rain fall (mm)	Evaporation (mm)
11-17 June	25.8	14.9	76.5	5.3	126.2	2.7
18-24	32.2	19.3	66.5	9.5	5.5	4.9
25-1 July	33.0	21.4	72.5	7.1	7.6	4.7
2-8	30.6	22.2	74.5	6.4	23.3	4.2
9-15	32.8	22.6	73.0	8.7	5.4	5.5
16-22	32.1	21.3	74.5	7.7	17.5	5.3
23-29	33.5	21.8	67.5	8.6	0.0	5.5
30-5 Aug.	32.4	21.8	72.5	7.0	2.9	5.3
6-12	33.6	22.7	71.5	6.0	8.0	5.7
13-19	29.9	21.6	79.5	3.6	23.6	3.6
20-26	31.3	21.4	79.0	6.4	12.3	4.3
27-2 Sept.	30.4	19.5	71.5	6.5	25.6	4.2
3-9	31.5	19.8	70.0	7.1	28.1	4.5
10-16	27.2	17.9	79.5	4.9	59.3	3.4
17-23	26.7	17.9	81.5	3.6	123.3	2.9
24-30	28.5	17.6	71.5	6.2	40.0	2.9
1-7 Oct.	29.5	13.8	67.0	8.7	3.4	3.1
8-14	31.0	11.2	57.5	9.6	0.0	3.1
15-21	23.4	12.8	77.5	4.6	165.9	1.7

APPENDIX -II a

Mean values of yield and yield components at Palampur

Inbred/ hybrids	Days to silking	Days to Pollen shedding	Leaf area/ plant (cm^2)	Plant height (cm)	Ear height (cm)	Days to maturity	Ear length (cm)	Ear circum-ference (cm)	Kernel rows/ ear	Kernels/ row	Shelling percentage	100- seed weight (g)	Grain yield (g)	Biological yield (g)	Harvest index (%)
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
P_1	61.00	59.00	6609.56	201.69	101.82	102.50	14.56	13.05	14.41	37.79	72.96	22.82	86.57	265.03	32.66
P_2	61.50	59.00	6369.75	202.47	96.82	102.50	16.19	13.26	14.43	35.93	77.32	21.97	90.56	237.04	38.25
P_3	60.50	60.00	5579.04	178.65	91.35	102.50	15.05	13.54	14.38	32.00	80.32	22.27	89.07	272.44	32.71
P_4	59.50	57.00	6364.62	202.88	99.88	105.50	17.44	13.09	13.62	35.88	78.52	25.05	86.69	277.50	33.33
P_5	61.50	59.50	4947.53	175.88	71.57	106.00	15.53	12.41	11.84	32.58	80.77	21.19	81.07	204.46	39.69
P_6	59.50	57.00	5997.12	205.51	92.35	104.00	16.00	13.69	14.50	35.94	80.54	23.46	87.50	275.32	31.79
P_7	61.50	59.50	6583.66	196.19	88.79	105.50	17.58	13.28	15.00	31.15	80.81	22.27	87.99	284.34	30.95
P_8	60.50	58.50	5498.07	173.60	67.72	102.00	17.33	13.32	13.98	35.49	79.79	25.06	78.90	248.46	31.76
P_9	60.00	58.00	5386.96	205.88	98.32	104.00	15.67	12.82	12.27	31.72	74.85	24.26	77.71	244.07	31.86
P_{10}	60.00	57.50	6627.20	209.69	101.38	103.50	17.43	13.85	13.88	34.88	79.35	24.72	92.50	253.13	36.58
P_{11}	59.00	57.00	6357.58	210.50	95.19	103.50	17.25	13.91	13.75	35.00	79.27	25.89	89.28	245.94	36.33
P_{12}	60.50	58.50	6205.79	200.82	114.22	104.00	17.50	13.24	12.69	36.46	79.43	23.92	84.69	234.38	36.13
$P_1 \times P_2$	58.50	56.50	7144.87	229.57	119.79	100.50	17.34	15.01	15.75	39.32	80.05	25.88	110.32	284.00	38.84
$P_1 \times P_3$	59.50	57.50	6778.79	216.38	115.69	103.00	18.03	14.16	14.75	38.57	75.91	26.47	109.19	265.44	41.13
$P_1 \times P_4$	58.50	57.00	6828.92	232.69	117.25	104.50	16.91	14.00	14.75	36.57	78.88	26.68	112.19	249.69	44.95
$P_1 \times P_5$	60.50	58.50	6623.23	220.67	104.91	104.00	17.35	13.31	13.75	33.94	80.94	27.15	106.25	287.51	36.97
$P_1 \times P_6$	59.00	57.00	6826.42	229.26	108.88	103.50	17.56	13.86	14.16	39.26	82.44	23.89	111.32	310.94	35.94
$P_1 \times P_7$	59.50	57.50	7135.83	226.15	114.50	103.50	17.81	13.94	14.22	37.75	80.50	25.19	117.50	294.46	39.93

Contd--------

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
$P_1 X P_8$	58.50	57.50	6715.55	218.44	116.65	100.50	17.81	13.97	14.88	37.25	81.38	25.92	115.69	283.38	40.83
$P_1 X P_9$	60.50	58.50	6993.31	221.88	116.35	103.50	17.56	14.25	13.88	36.76	80.38	27.92	117.50	281.27	41.76
$P_1 X P_{10}$	60.00	57.50	7095.29	241.82	126.94	104.00	18.31	14.22	14.25	35.26	77.65	28.53	130.32	311.50	41.88
$P_1 X P_{11}$	60.00	57.50	5871.33	231.01	111.41	105.00	16.81	14.17	14.75	36.32	83.49	25.74	137.82	325.88	42.31
$P_1 X P_{12}$	61.00	59.50	6999.95	229.01	112.44	105.50	18.94	14.09	14.88	41.07	81.49	24.55	117.50	271.50	43.28
$P_2 X P_3$	60.00	57.00	6472.25	216.07	102.40	103.50	17.15	14.53	15.38	37.57	80.24	24.85	130.94	318.46	41.41
$P_2 X P_4$	60.50	58.50	6657.09	213.65	99.50	104.50	17.00	14.12	14.66	36.25	81.55	28.26	114.33	270.00	42.34
$P_2 X P_5$	62.00	60.00	6632.01	213.60	109.94	105.00	17.47	14.02	14.12	40.44	79.51	23.23	116.83	274.88	42.50
$P_2 X P_6$	60.00	58.50	6779.05	224.75	115.75	103.50	18.84	13.94	13.75	39.19	78.97	25.72	111.57	263.76	42.30
$P_2 X P_7$	60.50	59.50	7504.33	214.28	99.03	105.50	19.12	14.72	15.75	38.94	80.79	25.61	139.07	301.57	46.11
$P_2 X P_8$	57.00	57.00	7363.96	207.44	108.32	103.50	17.56	14.51	14.24	37.38	80.30	27.14	127.19	314.69	40.42
$P_2 X P_9$	58.50	57.50	7945.07	228.69	112.57	105.00	19.54	13.32	12.82	39.00	80.21	27.42	128.32	305.14	42.04
$P_2 X P_{10}$	59.50	57.50	6680.99	234.47	114.28	105.00	15.91	14.88	15.50	32.63	79.35	25.71	126.51	290.94	43.47
$P_2 X P_{11}$	61.50	59.50	6721.04	215.94	112.00	102.00	18.03	13.41	13.50	37.01	78.76	23.67	113.44	273.75	41.47
$P_2 X P_{12}$	57.50	56.50	6532.90	214.04	100.79	103.00	17.16	13.38	13.25	35.38	80.88	25.06	118.13	267.82	44.11
$P_3 X P_4$	58.50	57.00	6403.94	212.47	98.85	103.00	16.53	14.06	14.25	35.69	80.33	24.33	114.69	283.19	40.50
$P_3 X P_5$	60.50	58.50	6182.98	231.01	115.22	103.50	16.83	13.16	12.88	33.99	81.70	24.96	114.66	294.29	38.96
$P_3 X P_6$	57.50	57.00	6942.50	223.26	116.03	104.50	17.78	14.55	13.98	38.75	80.96	25.53	121.88	271.88	44.84
$P_3 X P_7$	59.00	57.00	7034.13	224.07	116.29	103.00	17.41	14.03	15.48	36.57	81.44	23.99	131.26	289.57	45.32
$P_3 X P_8$	57.50	56.50	6926.12	211.82	117.00	105.50	17.68	14.53	14.91	37.64	81.08	27.22	130.63	285.94	45.68
$P_3 X P_9$	60.50	59.00	6747.02	228.88	111.00	101.50	16.03	14.07	12.20	31.60	79.28	27.90	122.25	276.12	44.26
$P_3 X P_{10}$	60.50	58.50	7030.58	224.94	116.57	104.00	17.38	14.35	14.50	36.12	80.07	28.16	137.12	299.76	45.75
$P_3 X P_{11}$	59.50	58.00	6415.39	222.25	111.60	104.50	15.94	14.50	16.50	33.50	81.33	26.35	134.07	290.94	46.07
$P_3 X P_{12}$	60.00	58.50	6536.74	213.63	112.04	103.50	17.33	13.50	13.28	37.78	82.71	25.87	125.36	286.46	43.76

Contd——

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
$P_4 X P_5$	58.00	56.50	6334.01	198.88	89.16	106.00	18.72	14.28	14.75	38.76	81.04	26.90	129.26	289.13	44.70
$P_4 X P_6$	60.50	59.00	7043.56	225.04	103.78	104.00	18.40	13.33	14.26	39.10	84.01	24.17	136.30	323.30	42.17
$P_4 X P_7$	58.00	57.00	7255.17	220.38	107.57	102.00	17.33	14.03	14.98	39.44	80.82	23.99	135.96	312.28	43.54
$P_4 X P_8$	56.00	56.00	6910.74	216.32	103.78	104.50	18.00	14.60	15.38	37.07	82.15	27.17	125.88	289.69	43.45
$P_4 X P_9$	58.00	56.50	7285.52	231.07	103.19	104.50	19.46	14.18	14.40	41.29	80.79	25.77	132.41	299.46	44.22
$P_4 X P_{10}$	58.50	57.00	6455.34	210.44	106.44	102.00	17.66	14.34	13.48	35.50	80.99	28.24	138.51	304.69	45.46
$P_4 X P_{11}$	58.00	56.00	6276.55	221.19	107.00	103.00	17.07	13.77	13.64	35.69	80.12	26.98	126.13	282.51	44.65
$P_4 X P_{12}$	57.50	57.50	6552.50	224.38	106.25	102.50	18.19	13.31	13.25	39.19	81.83	26.76	126.82	272.13	46.61
$P_5 X P_6$	60.50	58.50	5924.92	209.63	99.19	104.50	17.56	13.47	12.88	38.62	79.94	22.91	99.38	257.13	38.66
$P_5 X P_7$	61.50	60.00	7752.34	210.47	98.85	105.50	17.46	14.04	13.85	40.18	81.61	24.66	113.96	325.34	40.54
$P_5 X P_8$	57.50	56.00	7202.61	205.38	98.28	103.50	18.43	14.41	13.88	38.07	78.98	26.17	121.07	286.57	42.24
$P_5 X P_9$	57.50	56.00	7125.20	232.82	100.47	102.50	19.24	14.28	13.41	39.07	80.99	28.36	135.94	311.57	43.64
$P_5 X P_{10}$	56.00	56.00	6462.54	219.75	106.75	105.00	18.53	14.60	13.88	37.38	83.44	29.71	119.62	275.94	43.36
$P_5 X P_{11}$	58.00	57.00	6276.00	226.07	101.94	103.00	18.53	14.62	14.50	39.07	79.57	29.70	127.82	333.94	38.28
$P_5 X P_{12}$	59.00	57.50	6616.32	205.19	94.47	102.00	18.48	14.64	14.05	39.07	83.40	29.59	135.58	307.96	44.03
$P_6 X P_7$	60.50	58.50	6857.80	217.82	107.88	103.50	17.26	14.99	13.88	35.88	82.35	27.20	131.94	310.00	42.47
$P_6 X P_8$	60.50	60.00	6310.79	196.01	92.22	102.00	18.19	13.10	13.00	39.94	81.98	24.33	117.82	258.76	46.44
$P_6 X P_9$	60.00	60.00	6269.28	205.44	95.10	105.50	17.12	13.12	12.52	40.04	81.96	26.33	122.29	282.46	43.30
$P_6 X P_{10}$	60.00	59.00	6621.93	213.88	105.12	104.00	17.87	13.84	13.72	35.32	81.05	26.94	132.07	323.71	40.79
$P_6 X P_{11}$	58.50	57.00	6318.72	200.69	96.00	104.50	16.97	13.21	13.76	38.76	81.89	22.51	108.25	262.82	41.19
$P_6 X P_{12}$	58.50	58.00	6724.90	212.82	96.41	102.50	18.19	13.00	12.88	38.69	81.85	22.15	110.75	268.52	41.24
$P_7 X P_8$	59.50	58.50	6952.18	213.19	99.38	101.00	17.57	14.00	14.12	36.82	79.54	24.45	128.63	301.69	42.64
$P_7 X P_9$	59.00	58.50	7165.46	223.60	98.28	101.00	16.82	14.00	14.25	34.88	84.02	28.25	132.32	307.82	42.99

Contd——

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
$P_7 X P_{10}$	60.50	58.00	6743.45	222.82	109.79	102.00	17.50	14.32	13.88	35.19	80.52	25.76	137.19	301.57	45.50
$P_7 X P_{11}$	60.50	59.50	6967.46	222.38	111.75	101.00	18.00	14.09	15.62	38.69	81.23	23.60	125.26	299.13	41.88
$P_7 X P_{12}$	61.00	59.50	6100.12	220.72	109.69	102.00	18.19	13.57	14.50	40.50	81.67	23.48	131.75	327.57	40.22
$P_8 X P_9$	59.50	58.00	6963.74	208.72	93.57	104.00	17.41	13.41	12.90	39.34	80.04	26.35	127.69	311.29	41.01
$P_8 X P_{10}$	61.50	61.00	6626.12	197.88	97.32	102.50	17.72	14.56	13.88	38.07	79.29	26.28	133.38	325.01	41.03
$P_8 X P_{11}$	57.50	55.50	6984.35	210.75	92.69	103.50	17.67	14.06	14.41	38.18	80.74	26.24	119.56	295.80	40.42
$P_8 X P_{12}$	61.50	60.50	6977.58	214.00	106.94	102.00	17.25	14.15	13.69	35.22	79.11	27.78	116.69	292.69	39.86
$P_9 X P_{10}$	60.00	57.00	6925.04	222.94	109.75	103.00	18.75	13.82	13.38	40.89	79.71	28.29	133.32	304.69	43.75
$P_9 X P_{11}$	59.50	57.50	6888.29	206.12	99.19	102.00	18.11	13.97	13.12	37.55	83.81	27.48	123.69	300.67	41.13
$P_9 X P_{12}$	59.50	58.00	6344.41	203.26	88.13	102.50	16.47	13.22	12.38	34.63	80.47	23.78	118.13	292.12	40.44
$P_{10} X P_{11}$	61.50	59.50	6656.72	213.12	109.54	102.50	17.05	14.34	13.84	33.60	80.19	26.56	127.67	295.54	43.20
$P_{10} X P_{12}$	60.50	59.00	6716.44	220.32	110.00	103.00	18.91	14.12	13.12	41.25	81.51	27.57	131.07	312.50	41.94
$P_{11} X P_{12}$	62.00	60.50	6796.85	229.50	113.85	103.00	17.19	13.22	12.50	33.95	78.54	26.44	133.69	314.44	42.51
EHB-1520	64.00	61.50	6384.90	209.47	98.60	105.00	16.54	14.82	15.10	37.75	80.86	24.42	123.29	273.45	47.39
KH-101	61.00	59.00	6925.12	189.19	93.97	105.50	16.56	15.03	15.25	38.00	75.96	27.18	124.69	297.32	43.62
PSCL-3436	62.00	60.50	6278.74	226.53	116.82	105.50	16.38	13.28	13.75	34.62	77.09	24.99	126.57	267.21	47.37

Mean values of yield and yield components at Bajaura

Inbred/ hybrids	Days to silking	Days to Pollen shedding	Leaf area/ plant (cm^2)	Plant height (cm)	Ear height (cm)	Days to maturity	Ear length (cm)	Ear circum-ference (cm)	Kernel rows/ ear	Kernels/ row	Shelling percentage	100- seed weight (g)	Grain yield (g)	Biological yield (g)	Harvest index (%)
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
P_1	59.50	57.50	4361.75	164.60	89.50	106.50	15.10	13.45	13.00	25.60	73.71	20.97	81.00	247.25	32.76
P_2	58.00	55.00	4666.33	145.30	86.70	105.50	15.30	12.85	12.90	25.60	69.78	21.26	80.00	211.50	37.83
P_3	59.00	59.00	3276.24	131.60	74.30	104.00	14.85	13.00	13.60	24.30	73.59	22.60	85.50	253.00	33.79
P_4	59.50	57.50	3506.32	148.20	71.10	105.50	16.85	12.90	11.80	25.70	73.44	24.65	82.00	240.00	34.17
P_5	59.00	58.00	3354.87	141.40	68.40	103.50	14.80	12.85	11.80	24.10	72.40	21.40	74.50	179.50	41.50
P_6	58.00	55.50	4358.69	174.60	89.30	106.50	16.95	12.75	13.10	26.90	75.90	24.16	87.00	255.00	34.12
P_7	59.50	57.50	3833.45	163.10	74.20	105.50	16.90	13.25	13.60	26.10	72.10	22.42	84.00	257.50	32.64
P_8	58.50	56.50	3812.88	147.30	64.00	103.00	16.75	13.60	13.20	27.40	73.10	24.10	77.00	242.00	31.83
P_9	59.50	58.00	3678.44	159.50	75.10	105.50	14.40	13.75	12.20	23.10	72.57	24.59	73.00	227.50	32.08
P_{10}	59.50	57.50	3820.14	163.60	90.10	106.00	15.85	13.75	12.00	23.80	71.72	25.65	80.00	206.00	38.83
P_{11}	58.00	56.00	4207.19	174.10	93.40	105.00	16.80	12.90	12.80	23.70	74.35	22.67	90.50	249.00	36.37
P_{12}	59.00	57.00	3275.39	164.00	86.40	104.50	15.00	13.00	11.35	23.95	76.87	23.06	79.00	213.00	37.07
$P_1 X P_2$	58.00	55.00	3548.01	151.10	90.40	106.00	15.45	13.45	13.20	28.10	73.49	22.61	104.00	287.50	36.17
$P_1 X P_3$	58.00	55.00	3206.45	163.30	85.70	104.50	14.85	13.35	12.80	27.50	74.74	24.48	101.00	249.00	40.57
$P_1 X P_4$	59.00	57.50	4069.05	169.50	90.40	106.50	17.60	14.10	12.60	28.10	73.49	30.03	103.00	232.00	44.40
$P_1 X P_5$	57.50	55.50	3657.81	162.90	82.00	104.50	13.95	13.70	13.80	28.20	73.49	23.85	95.50	246.00	38.83
$P_1 X P_6$	57.50	55.50	3494.21	166.20	81.30	105.00	15.75	13.65	12.60	29.20	73.29	25.31	101.50	268.00	37.86
$P_1 X P_7$	59.50	57.50	3307.16	147.40	74.50	106.50	14.80	13.30	12.80	25.20	72.18	24.20	82.00	212.50	38.57

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
$P_1 X P_8$	57.50	55.50	3339.20	170.90	94.60	106.50	15.50	13.55	14.60	28.80	76.63	24.24	105.00	242.50	43.30
$P_1 X P_9$	60.00	58.00	4036.90	170.40	91.20	106.00	17.65	14.05	11.60	31.20	71.43	26.86	102.50	257.00	39.90
$P_1 X P_{10}$	59.00	57.50	4010.63	156.90	87.40	105.50	17.40	13.70	12.80	31.90	72.05	24.32	102.50	250.00	40.99
$P_1 X P_{11}$	59.00	57.00	3522.23	163.90	76.80	106.50	14.85	14.30	13.20	26.70	76.92	26.85	110.50	270.00	40.96
$P_1 X P_{12}$	59.00	57.00	3255.61	161.00	85.40	104.50	14.80	13.40	14.12	22.70	72.03	22.34	89.50	217.00	41.24
$P_2 X P_3$	57.50	55.50	3641.33	163.90	78.20	104.50	14.60	14.60	13.80	24.40	73.53	23.13	98.00	236.00	41.54
$P_2 X P_4$	56.50	54.50	3765.00	169.60	79.20	105.00	15.40	13.85	14.73	25.30	77.59	25.27	99.00	236.50	41.87
$P_2 X P_5$	58.50	56.50	3102.93	184.90	90.90	103.50	16.10	13.10	12.20	28.30	73.07	24.24	95.00	219.50	43.28
$P_2 X P_6$	57.00	55.00	3871.62	173.20	88.50	104.00	16.50	14.60	15.00	30.20	75.85	24.83	100.00	246.00	40.65
$P_2 X P_7$	56.50	54.50	4167.05	172.60	82.10	104.00	17.20	14.00	14.20	29.90	75.27	24.15	111.00	247.00	44.94
$P_2 X P_8$	57.50	55.50	3579.56	166.20	86.70	104.50	16.00	13.75	13.00	29.40	75.31	26.70	111.00	270.00	41.10
$P_2 X P_9$	58.00	56.00	4075.92	171.30	83.40	105.50	15.70	13.80	12.60	27.50	72.23	25.64	102.00	238.50	42.76
$P_2 X P_{10}$	58.00	55.50	3680.91	159.90	86.80	105.50	14.15	14.10	13.60	26.80	74.59	25.19	92.50	231.00	40.06
$P_2 X P_{11}$	57.50	55.50	3097.72	167.10	87.20	104.00	16.15	12.70	12.20	30.10	76.49	22.56	93.50	223.50	41.82
$P_2 X P_{12}$	57.00	55.00	3249.06	172.00	85.60	104.50	16.50	13.30	12.00	31.60	75.24	25.15	96.00	225.00	42.67
$P_3 X P_4$	57.50	55.50	3363.35	176.30	96.30	104.50	15.10	13.60	14.40	27.60	79.38	23.18	101.50	253.00	40.13
$P_3 X P_5$	58.50	56.50	3270.19	166.70	87.70	103.00	15.85	14.35	13.30	29.60	76.08	25.85	94.50	245.00	38.65
$P_3 X P_6$	58.00	56.00	3226.10	177.70	90.10	105.00	14.35	13.55	12.20	26.90	77.60	22.95	92.00	212.00	43.41
$P_3 X P_7$	58.00	56.00	3621.25	156.80	84.10	105.00	14.45	13.65	14.60	25.70	74.79	23.05	107.00	239.50	44.18
$P_3 X P_8$	58.00	56.00	3866.90	172.50	93.40	105.00	17.00	14.05	13.00	30.40	75.74	25.81	105.00	232.50	45.15
$P_3 X P_9$	59.00	57.00	3840.70	179.10	92.50	104.50	16.70	14.25	12.00	30.80	75.54	25.62	106.50	237.00	44.94
$P_3 X P_{10}$	58.50	56.00	3719.71	162.90	95.40	105.00	14.30	13.40	14.20	23.50	77.78	25.92	115.50	251.75	45.88
$P_3 X P_{11}$	57.00	54.50	3598.01	181.60	96.20	105.00	16.30	13.95	15.75	28.60	77.14	27.06	115.00	252.50	45.55
$P_3 X P_{12}$	57.50	55.50	3443.64	170.30	88.60	104.50	14.45	13.40	13.60	24.50	76.85	24.21	99.50	221.65	44.89

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
$P_4 \times P_5$	57.50	55.00	3025.81	171.80	92.10	103.50	16.60	13.70	14.00	31.40	77.21	23.62	112.00	247.50	45.25
$P_4 \times P_6$	58.00	56.00	3624.15	164.30	81.00	103.50	16.80	13.75	12.20	31.50	75.65	25.03	112.50	269.75	41.74
$P_4 \times P_7$	57.50	55.50	3565.06	178.40	87.80	104.00	16.65	14.25	14.40	29.10	74.89	24.53	113.50	285.50	39.76
$P_4 \times P_8$	57.50	55.50	3666.19	150.30	67.70	104.00	16.00	13.60	14.00	27.90	74.14	24.24	114.00	290.50	39.24
$P_4 \times P_9$	58.00	56.00	3675.91	171.00	80.10	105.00	15.60	13.85	12.60	32.10	75.74	23.65	125.50	309.75	40.51
$P_4 \times P_{10}$	56.50	54.50	3385.04	170.80	82.00	104.00	17.05	14.00	13.00	28.00	73.04	26.30	108.50	246.00	44.13
$P_4 \times P_{11}$	56.50	54.50	2832.77	162.40	81.00	104.00	14.05	13.05	12.60	25.80	76.56	25.51	94.50	252.50	39.81
$P_4 \times P_{12}$	56.50	54.50	3546.32	171.10	83.40	104.00	16.55	13.60	13.00	31.60	76.35	24.15	118.50	259.00	45.75
$P_5 \times P_6$	58.00	56.00	3475.61	180.30	90.60	103.50	15.90	13.55	12.20	30.10	76.07	24.06	90.00	234.34	38.39
$P_5 \times P_7$	57.00	55.00	3243.49	168.60	79.60	104.00	16.70	13.50	13.20	29.00	75.22	26.85	99.00	256.00	38.67
$P_5 \times P_8$	57.00	55.00	3104.12	160.40	83.00	104.00	13.15	13.40	13.20	23.80	74.96	27.69	76.50	183.50	41.68
$P_5 \times P_9$	58.50	56.50	2850.73	173.80	84.00	104.00	14.20	12.45	11.80	26.80	75.69	22.59	84.00	188.50	44.56
$P_5 \times P_{10}$	56.00	54.00	3209.27	162.10	80.60	104.00	16.75	13.75	12.60	30.50	75.49	24.84	100.00	232.50	42.99
$P_5 \times P_{11}$	57.50	55.00	2793.69	163.70	84.80	104.50	14.00	13.55	13.40	26.10	78.69	25.32	101.50	271.75	37.34
$P_5 \times P_{12}$	57.00	54.50	2946.37	161.00	83.50	104.00	14.85	12.50	11.00	26.60	78.92	27.37	116.50	270.25	43.10
$P_6 \times P_7$	57.50	55.50	3688.02	180.00	84.40	104.00	15.80	13.55	12.80	26.20	78.43	27.98	116.50	269.00	43.32
$P_6 \times P_8$	57.00	54.50	3382.66	163.30	80.40	103.00	15.65	13.45	12.60	29.80	77.54	22.57	97.00	205.25	47.26
$P_6 \times P_9$	57.00	55.00	3725.34	172.20	84.70	104.00	16.10	12.40	13.40	30.30	82.06	23.51	99.00	226.00	43.81
$P_6 \times P_{10}$	57.50	55.50	3293.78	174.20	97.00	105.50	15.25	14.45	12.20	25.30	74.88	28.30	94.50	231.50	40.82
$P_6 \times P_{11}$	57.50	55.50	3645.06	171.50	88.00	105.00	15.65	13.20	12.80	30.20	76.40	21.71	93.00	220.50	42.17
$P_6 \times P_{12}$	57.50	55.50	3391.10	159.20	79.40	103.00	16.55	12.95	12.90	29.30	72.67	22.05	86.50	205.00	42.20
$P_7 \times P_8$	58.00	56.00	4288.74	172.50	84.40	105.00	16.95	13.80	13.20	27.40	74.40	25.05	113.00	265.00	42.65
$P_7 \times P_9$	58.50	55.50	3778.73	173.50	81.70	104.50	16.40	13.70	12.80	26.80	74.06	25.26	108.00	252.75	42.73

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
$P_7 X P_{10}$	58.00	55.50	4040.28	179.60	85.30	105.00	17.45	14.80	13.90	25.90	72.37	26.47	111.50	249.50	44.69
$P_7 X P_{11}$	58.50	55.50	4250.01	180.90	80.70	104.50	16.05	14.55	13.60	28.60	72.19	25.80	111.00	265.00	41.90
$P_7 X P_{12}$	57.50	55.50	3856.75	180.80	96.40	103.00	16.70	14.10	13.40	30.20	76.85	23.99	114.50	283.25	40.43
$P_8 X P_9$	58.00	56.00	4337.76	165.10	85.00	104.50	16.80	13.70	13.90	29.20	74.43	26.16	100.50	247.75	40.58
$P_8 X P_{10}$	58.00	56.00	3507.17	166.30	95.50	104.00	15.20	14.85	14.12	27.60	73.85	26.76	102.00	249.50	40.88
$P_8 X P_{11}$	56.50	54.50	4029.85	169.30	81.30	105.00	14.55	14.35	12.80	25.30	76.72	25.40	94.50	230.65	40.97
$P_8 X P_{12}$	57.00	55.00	4179.44	184.70	99.00	104.50	16.45	14.00	12.00	28.10	72.89	27.51	105.50	263.50	40.04
$P_9 X P_{10}$	58.50	55.50	3991.82	170.20	91.40	104.50	14.80	13.70	12.00	26.40	73.57	25.58	102.00	232.50	43.87
$P_9 X P_{11}$	58.50	55.50	3468.29	175.20	79.90	104.50	16.15	13.25	11.80	31.50	79.60	27.49	104.50	252.00	41.47
$P_9 X P_{12}$	57.50	55.00	3880.62	179.00	92.00	104.50	15.45	13.90	11.60	29.30	75.63	28.24	103.50	258.50	40.04
$P_{10} X P_{11}$	59.00	57.00	3638.31	180.80	96.70	105.50	17.60	14.10	11.80	28.50	73.33	28.75	97.50	230.25	42.33
$P_{10} X P_{12}$	59.50	57.50	4041.69	171.50	97.40	104.50	17.45	13.55	12.20	29.90	74.20	25.47	103.50	250.00	41.42
$P_{11} X P_{12}$	58.50	56.50	3894.64	182.00	94.00	104.50	15.75	14.50	12.40	29.10	76.18	27.96	115.00	274.00	41.97
EHB-1520	60.00	58.00	4381.28	159.80	77.70	107.00	17.15	14.55	13.20	28.20	75.24	24.65	96.50	228.00	46.71
KH-101	59.00	57.00	4346.06	144.80	70.50	107.50	14.85	15.55	14.30	26.60	73.74	28.84	95.00	240.00	43.75
PSCL-3436	59.00	57.00	3213.95	171.90	94.30	108.00	14.90	13.70	12.40	25.00	72.31	24.06	98.00	234.05	41.87

APPENDIX -III

Mean values of seed quality traits

Inbred/ hybrid	100-seed weight (g)	100-seed volume (ml)	Seed density (g/ml)	Accelerated aging test	Osmotic stress test	Germination percentage	Seed Vigour index	Field emer-gence
	1	2	3	4	5	6	7	8
P_1	25.51	21.50	1.23	84.00	76.00	97.00	28.17	77.00
P_2	23.04	18.50	1.25	83.50	73.00	92.00	26.22	88.00
P_3	23.42	18.50	1.26	86.00	83.00	98.00	26.60	88.00
P_4	25.44	20.50	1.24	93.00	88.00	99.00	28.38	90.00
P_5	23.55	19.50	1.21	89.00	79.00	92.00	24.94	80.00
P_6	25.44	22.00	1.15	88.00	76.00	95.00	29.47	88.00
P_7	23.70	20.50	1.15	87.00	79.00	93.00	28.24	86.00
P_8	24.97	20.50	1.22	88.00	85.00	96.00	27.83	86.00
P_9	24.84	21.00	1.18	89.00	81.00	96.00	30.65	65.00
P_{10}	25.68	20.50	1.25	83.00	80.00	94.00	24.35	75.00
P_{11}	25.84	21.50	1.20	90.00	84.00	95.00	30.18	84.00
P_{12}	28.15	22.50	1.25	84.00	82.00	91.00	25.76	79.00
$P_1 \times P_2$	27.45	21.50	1.28	92.00	80.00	99.00	25.99	84.00
$P_1 \times P_3$	25.44	20.50	1.24	94.00	81.00	99.00	22.47	85.00
$P_1 \times P_4$	26.47	20.50	1.29	89.00	80.00	96.00	26.17	86.00
$P_1 \times P_5$	26.03	20.50	1.27	90.00	80.00	95.00	28.10	84.00
$P_1 \times P_6$	26.03	21.00	1.24	87.00	82.00	93.00	28.09	76.00
$P_1 \times P_7$	24.91	19.50	1.27	78.50	84.00	92.00	32.10	74.00
$P_1 \times P_8$	28.36	23.00	1.23	92.00	79.00	99.00	30.42	92.00
$P_1 \times P_9$	27.49	22.50	1.23	89.00	81.00	97.00	26.63	80.00
$P_1 \times P_{10}$	26.18	20.50	1.27	82.00	77.00	93.00	24.85	82.00
$P_1 \times P_{11}$	28.43	22.00	1.29	91.00	73.00	97.00	30.94	84.00
$P_1 \times P_{12}$	25.66	21.50	1.19	84.00	71.00	92.00	28.95	80.00
$P_2 \times P_3$	28.01	23.0	1.22	89.00	78.00	97.00	29.83	89.00
$P_2 \times P_4$	27.72	21.50	1.29	79.00	67.00	93.00	27.99	84.00
$P_2 \times P_5$	25.60	20.50	1.25	80.50	80.00	93.00	27.03	86.00
$P_2 \times P_6$	27.77	22.00	1.26	84.00	68.00	93.00	24.60	66.00
$P_2 \times P_7$	24.37	19.00	1.28	89.00	83.00	94.00	29.90	90.00
$P_2 \times P_8$	27.82	21.50	1.29	84.00	79.00	95.00	27.31	90.00

Contd....

	1	2	3	4	5	6	7	8
$P_2 \times P_9$	25.33	20.00	1.26	92.00	74.00	99.00	30.03	91.00
$P_2 \times P_{10}$	26.94	21.00	1.25	90.00	78.00	97.00	25.97	88.00
$P_2 \times P_{11}$	25.51	20.00	1.27	89.00	81.00	98.00	29.24	90.00
$P_2 \times P_{12}$	27.74	22.50	1.23	82.50	76.00	94.00	27.49	90.00
$P_3 \times P_4$	25.57	20.50	1.25	92.00	86.50	99.00	30.58	90.00
$P_3 \times P_5$	27.37	21.50	1.27	93.00	78.00	99.00	28.08	91.00
$P_3 \times P_6$	27.24	21.50	1.26	91.00	79.00	96.00	26.30	90.00
$P_3 \times P_7$	24.60	19.50	1.26	90.00	84.00	95.00	28.97	89.00
$P_3 \times P_8$	27.42	22.50	1.22	87.00	84.00	93.00	29.82	87.00
$P_3 \times P_9$	28.34	22.50	1.26	89.00	76.00	95.00	28.35	88.00
$P_3 \times P_{10}$	28.33	22.50	1.26	88.00	80.00	94.00	28.83	89.00
$P_3 \times P_{11}$	29.32	22.50	1.30	74.00	64.00	91.00	26.94	87.00
$P_3 \times P_{12}$	25.23	20.00	1.26	89.00	83.00	93.50	27.36	88.00
$P_4 \times P_5$	25.82	20.50	1.26	92.00	88.00	99.00	26.42	91.00
$P_4 \times P_6$	24.44	19.50	1.25	91.00	78.00	97.00	24.70	91.00
$P_4 \times P_7$	24.53	19.50	1.26	93.50	81.00	97.00	27.57	90.00
$P_4 \times P_8$	27.77	21.50	1.29	87.00	82.00	95.00	28.49	89.00
$P_4 \times P_9$	25.42	20.50	1.29	88.50	84.00	99.00	26.35	89.00
$P_4 \times P_{10}$	27.31	21.00	1.30	72.00	71.00	95.00	23.49	88.00
$P_4 \times P_{11}$	27.25	21.50	1.27	90.00	67.00	93.00	25.89	90.00
$P_4 \times P_{12}$	28.10	23.50	1.19	93.00	67.00	99.00	26.47	87.00
$P_5 \times P_6$	26.76	21.50	1.25	86.00	81.50	98.00	30.92	88.00
$P_5 \times P_7$	27.20	21.50	1.26	88.00	82.00	95.00	30.65	84.00
$P_5 \times P_8$	28.80	23.00	1.25	91.50	82.00	93.00	29.26	86.00
$P_5 \times P_9$	27.90	22.50	1.24	84.00	83.00	93.00	29.21	90.00
$P_5 \times P_{10}$	30.11	24.50	1.23	90.00	84.00	95.00	28.15	93.00
$P_5 \times P_{11}$	29.92	23.50	1.27	78.50	76.00	93.00	31.52	80.00
$P_5 \times P_{12}$	30.35	24.50	1.24	88.00	78.00	92.00	28.94	76.00
$P_6 \times P_7$	28.67	22.50	1.27	91.00	87.00	97.00	26.55	90.00
$P_6 \times P_8$	27.55	21.50	1.28	90.00	86.00	96.00	26.88	84.00
$P_6 \times P_9$	24.81	19.50	1.27	89.00	84.00	95.00	26.61	83.00
$P_6 \times P_{10}$	27.91	22.50	1.24	90.00	84.00	99.00	26.70	90.00
$P_6 \times P_{11}$	27.60	22.50	1.23	93.00	89.50	100.00	26.75	90.00
$P_6 \times P_{12}$	28.15	22.00	1.28	93.00	81.00	99.00	30.38	92.00

Contd....

	1	2	3	4	5	6	7	8
P_7 X P_8	26.43	21.50	1.23	90.00	84.00	95.00	25.41	72.00
P_7 X P_9	28.25	23.00	1.23	77.50	78.00	93.00	27.08	66.00
P_7 X P_{10}	27.13	22.00	1.24	88.00	80.00	92.00	29.06	72.00
P_7 X P_{11}	27.02	21.50	1.25	88.00	81.00	94.00	28.34	86.00
P_7 X P_{12}	27.17	22.00	1.24	79.00	82.00	93.00	28.87	84.00
P_8 X P_9	27.24	21.50	1.26	85.00	76.00	93.00	27.43	88.00
P_8 X P_{10}	25.83	21.00	1.23	92.00	80.00	99.00	28.54	85.00
P_8 X P_{11}	27.11	22.50	1.21	91.00	85.00	97.00	28.52	84.00
P_8 X P_{12}	27.44	22.00	1.25	84.00	86.00	95.00	29.92	84.00
P_9 X P_{10}	27.24	22.00	1.24	81.50	65.50	93.00	26.40	84.00
P_9 X P_{11}	29.06	23.50	1.24	94.00	84.00	99.00	29.26	87.00
P_9 X P_{12}	30.02	24.50	1.23	82.00	72.00	95.00	27.97	77.00
P_{10} X P_{11}	29.65	24.00	1.24	89.00	71.00	97.00	29.70	80.00
P_{10} X P_{12}	27.90	22.50	1.24	79.00	80.00	94.00	26.69	88.00
P_{11} X P_{12}	28.72	23.50	1.22	85.00	73.00	97.00	27.42	80.00
EHB-1520	26.58	22.00	1.21	87.00	79.00	93.00	27.76	82.00
KH-101	27.52	21.50	1.28	80.00	77.00	91.00	28.86	86.00
PSCL-3436	28.03	22.50	1.25	67.50	62.00	91.00	27.21	62.00