ENETIC ANALYSIS OF SOME QUANTITATIVE CHARACTERS SPRING X WINTER WHEAT CROSSES (*Triticum aestivum* L.)

THESIS

By

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Submitted to

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for the degree of

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Dedicated to

MY YOUNGER BROTHER

DR RANJIT SINGH

CERTIFICATE I

This is to certify that this thesis entitled, "Genetic analysis of some quantitative characters in spring x winter wheat crosses (*Triticum aestivum* L.)", submitted for the degree of Doctor of Philosophy, in the subject of Plant Breeding of the Himachal Pradesh Krishi Vishva Vidyalaya, Palampur, is a bonafide research work carried out by Shri Kehar Singh Thakur, under my supervision and that no part of this thesis has been submitted for any other degree.

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

(Dr. Tashi Dawa)
Major Advisor

Palampur
Dated the 30th January, 1988.

CERTIFICATE II

This is to certify that the thesis entitled, "Genetic analysis of some quantitative characters in spring x winter wheat crosses (*Triticum aestivum* L.)", submitted by Shri Kehar Singh Thakur to the Himachal Pradesh Krishi Vishva Vidyalaya, Palampur in partial fulfilment of the requirements for the degree of Doctor of Philosophy in the subject of Plant Breeding has been approved by the Student's Advisory Committee, after an oral examination on the same, in collaboration with an External Examiner.

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CONTENTS

Chapter		Page
1	INTRODUCTION	1
2	REVIEW OF LITERATURE	4
	2.1 Combining ability	4
	2.2 Heterosis	10
	2.3 Gene action	16
3	MATERIALS AND METHODS	21
	3.1 Material	21
	3.2 Recording of observations	21
	3.3 Analysis of variance for the experimental design	22
	3.4 Analysis of variance for combining ability	23
	3.4.1 Estimation of general and specific combining ability effects	25
	3.5 Estimation of heterosis	27
	3.6 Generation mean analysis	28
	3.6.1 Scaling tests for the detection of digenic interactions	28
	3.6.2 Estimation of gene effects	29
4	EXPERIMENTAL RESULTS	31
	4.1 Analysis of variance for the experimental design	31
	4.2 Analysis of variance for combining ability	33
	4.3 General combining ability effects	33
	4.4 Specific combining ability effects	39
	4.5 Heterosis	43
	4.6 Estimates of scaling tests and gene effects	49
5	DISCUSSION	63
	5.1 Combining ability	65
	5.1.1 Analysis of variance	65

5.1.2	Combining ability effects	66
5.2	Heterosis	72
5.3	Gene action	77
5.3.1	Combining ability analysis	78
5.3.2	Generation mean analysis	79
SUMMARY		89
REFERENCES		i - ix
APPENDIX		I

1 INTRODUCTION

Wheat production in our country has witnessed an appreciable augmentation since the advent of Mexican germplasm and its utilization in wheat improvement programme. As situation stands today, a plateau has almost been arrived at, and a big breakthrough in the yield potential is not expected in the near future (Agrawal, 1986). A probable reason is the replacement of highly variable land races by genetically uniform pure-line varieties, which has alarmingly shrunken the pool of potential genes in the spring wheats. The picture, however, becomes somewhat encouraging when we perceive that bread wheat is blessed with another gene pool - winter wheats, which are accessible sources of some desirable genes that can be used for the improvement of spring wheats.

The importance of winter wheat for the improvement of spring wheat has since been emphasized by Akerman and Mackey(1949), but concerted efforts have not been made in this direction. Recently, a great interest has been generated in the intercrossing of spring wheat with winter types with an expectation that this will help in surpassing the existing yield plateau of spring wheats by generating additional variability. This expectation seems to be based on fairly sound grounds, for it is well known that the two groups of bread wheat, representing different genetic constellations, have rarely been brought together, and have been improved upon as distinct groups by exploiting the variability within each group.

In Himachal Pradesh, wheat growing environments range from severe winter in the cold high altitude areas to mild winter in the foot hills, with transitional environments between the two extremes. Moreover, most of the area (about 85%) under this crop is dependent upon natural precipitation. Therefore, spring x winter wheat hybridization programme may reach its payoff in the Pradesh in developing improved spring varieties that are superior for a plant type which remains longer in vegetative phase, and will be especially useful where wheat could be sown immediately after the monsoon but would not head until early February. Moreover, tillering ability is invariably greater in the late-flowering varieties as compared to the early ones (Chinoy, 1963).

Another feasibility to achieve a quantum jump in the yield of wheat is the commercial production of hybrid varieties. Although, heterosis was observed in wheat as early as in 1919 by Freeman, its commercial exploitation has not become a reality, mainly due to self-pollinating nature of the crop plant. However, Engledow and Pal (1934) have suggested the use of advanced generations to exploit hybrid vigour for it is not commercially feasible to produce sufficient F_1 seed. Heterosis in spring x winter wheat hybrids is expected to be markedly high as has been reported by Grand and McKenzie (1970) and Tandon (1980).

One of the most important factors which determine the feasibility of hybrid production is the nature and magnitude of heterosis exhibited by the crosses of different inbred lines. The presence of heterosis indicates the ability of parents to combine well in hybrid combination. The combining ability of parents, which depends on the nature of genetic system

operating in them, also predicts the efficiency of selection. In order to exploit different types of gene action present in the population, information regarding relative magnitudes of genetic variances and combining ability of parents for yield and its components is essential. Such information will be a boon in the choice of parental lines having superior performance for their further use in the breeding programme. The technique of line x tester analysis lends itself to a detailed genetic analysis and identifies superior parents and cross combinations on the basis of combining ability, besides providing information pertaining to the nature of genetic variances.

The choice of an efficient breeding strategy to exploit the promising crosses rests on the genetic system operating for yield and its component traits in them. Recent developments in biometrical genetics, specifically using the first degree statistics, have made it possible to estimate the non-allelic interactions, besides additive and dominance gene effects (Mather and Jinks, 1982).

Keeping the above in view, a complete set of 22 crosses (involving 11 diverse lines of spring wheat and 2 winter types of Mongolian origin, used as testers) was studied over generations with the following objectives :

i) To estimate general and specific combining ability effects in the F_1, F_2 and F_3 generations,

ii) to estimate heterosis over the mid-parent and better parent in the F_1 and F_2 generations, and

iii) to elucidate the nature of gene effects in the crosses studied.

2 REVIEW OF LITERATURE

The literature pertaining to the present study has been reviewed, under different heads.

2.1 Combining ability

For the development of promising varieties identification of genetically superior parents is an important prerequisite. A wrong choice of parents may undo an efficiently planned and well-executed follow-up programme (Dhillon, 1975). The combining ability analysis is a rapid and successful method to understand the genetic worth of parents and helps in understanding the nature and magnitude of gene effects involved in the expression of various traits, which aids in formulating an efficient breeding programme. In the past quarter century, quantitative genetics and advanced biometrical models like diallel, partial diallel, line x tester, etc., have played a leading role in providing basic information regarding the genetic make up of different polygenic traits.

The analysis of diallel set of crosses produced by involving 'n' lines in all possible combinations provide an alternative, but the number of parents to be included imposes limitation in its use (Kempthorne and Curnow, 1961, Curnow, 1963, Kearsey, 1965, Dhillon, 1975, Dhillon and Singh, 1981). Diallel with a large number of parents not only creates problems in making crosses but is also unmanageable under field conditions. On the other hand, diallel involving a small number of parents gives biased estimates of genetic

parameters because of large sampling errors. Kempthorne and Curnow (1961), Curnow (1963) and Hinkelmann (1965) presented the concept of partial diallel in which only a random sample of crosses, is analysed. Pederson (1980) developed analytical procedures for augumented partial diallel. This design estimates general combining ability (gca) and specific combining ability (sca) effects in which one or more primary lines are crossed with all others but the lines of secondary interest may form a partial diallel cross. Gilbert (1967) suggested the method of analysing the combining ability of numerous crosses developed without any systematic mating design. In this model parental effects are not balanced because some of the crosses may not be attempted at all.

Kempthorne (1957) gave the use of line x tester crosses which is an extension of top cross method in which several testers are used. This design provides information about the combining ability of the parents so as to formulate an efficient breeding programme. In this system 'l' lines and 't' testers are taken. All of these 'l' lines are crossed to each of 't' testers, and l x t full sib progenies are evaluated in an appropriate experimental design. This provides information on gca estimates of lines, testers and sca estimates of the crosses. Kearsey (1965), Múrty et al.(1967) Dhillon (1973), Dhillon and Singh (1981) and Sohan Pal (1983) have compared the efficiency of different analyses in estimating combining ability effects, and advocated the superiority of line x tester analysis.

Paroda and Joshi (1970b) studied combining ability in 6 x 6 diallel for yield and its components in the F_2 generations and the results were compared with those recorded from F_1 data (Paroda & Joshi 1970a). The correlation between gca effects obtained from F_1 and F_2 data was highly significant for all the characters studied in two years, whereas correlation between sca effects was neither higher nor consistent indicating that F_2 generation can be used efficiently for assessing the gca. A marked decline in estimates of sca variances and effects was observed in the F_2 generation.

Gill et al. (1974) studied combining ability in wheat following line x tester analysis and observed high general combining ability effects for kernel yield, kernel/spike and spike per plant for variety Kalyansona.

Singh and Chaudhary (1977) studied combining ability for seven yield components in a cro involving seven lines and three testers. The best hybrid resulted from cross involving the varieties that showed the best gca. All the yield components studied, except tiller number were mostly governed by additive type of gene action.

Jain and Singh (1978), carried out line x tester analysis using 21 lines and 3 testers in wheat in the F_2 and F_3 generations, under moisture stress and non-stress conditions. They reported that the pooled analysis for combining ability had significant variance due to sca and sca x generation for grain yield and ear number under both the conditions. Additive x additive epistasis was important for grain yield and ear number, whereas dominance component of variance was important for

100-grain weight. Only additive variance played role under stress conditions, while both additive and additive x additive components influenced the trait under non-stress conditions.

Wegrzyn et al. (1979), from the line x tester analysis of F_2 population of winter wheat, indicated that the values for sca and gca and their inter-relationship had predominantly additive effects for stem length and grain weight/ear. However, in case of ear length and number of grains/ear, dominance had the main influence.

Ziauddin et al. (1979) from a line x tester analysis, reported the preponderance of non-additive gene action for all traits, except spike length and 1000-grain weight. Further, a line having good general combining ability effects did not necessarily produce better hybrids, but there was a close relationship between specific combining ability effects and heterotic response.

Saakyan (1979) studied the combining ability in 60 F_1 hybrids involving 15 winter bread wheats of different origin with four testers for plant height, number of productive tillers, grain weight/plant and 1000-grain weight. General combining ability variances contributed more than sca variances to the total variation, indicating that the characters studied were mostly controlled by additive genes. Selection of best genotypes with additive genes was most effective in the progeny of high yielding hybrids.

Tandon (1980), in diallel analysis involving winter and spring wheats, concluded that winter types offer potential

source of genetic variability and a choice of winter type parents based on combining ability estimates is very essential because a predominance of non-allelic gene action has been observed in winter x spring wheat crosses.

Chand and Randhawa (1981) in a diallel analysis of 8 parents (excluding reciprocals) reported variety WG 1025 as the best general combiner for yield, 1000-grain weight and tillers/plant. Seven high yielding crosses showed high sca effects.

Konovalov and Vlaxnkog (1981) from different studies on 9 x 9 and 10 x 10 diallel using two different sets of varieties, concluded that breeding value of hybrids does not depend upon the extent to which the parents contrast in yield components. Crosses in which the parents differed little were not inferior to those whose parents differ appreciably in these characters. Both gca and sca values were maintained from F_1 to F_2 generation in these studies.

Srivastava et al. (1981) studied the genetic architecture of grain yield, harvest index and related traits in the F_1 progenies of wheat, resulting from crossing 16 lines and 3 testers. They concluded that additive gene effects were most important for grain yield/plant, biological yield, harvest index, grains/spike, tillers/plant and flag-leaf area, whereas non-additive effects were most important for spike length, spikelets/spike, grain weight/spike and 1000-seed weight.

Voronkova (1982) from a study on seven parental diallel crosses suggested the high absolute values for the character in

varieties used for hybridization with high general combining ability can serve as a criterion for evaluating varieties.

Khangil (1982) studied inheritance of number of productive tillers, using 14 varieties as maternal parents with three testers. He reported that additive effects were predominant for this character.

Medveder (1982), in a line x tester analysis involving 17 lines and two testers, found that the short strawed varieties showed high gca for grain yield, 1000-grain weight, grain number/ear and grain weight/ear. In breeding for short straw, the early varieties were the most effective. Their hybrids had short straw and high sca value for height.

Singh et al. (1983), in a line x tester analysis involving eleven lines and four testers, reported the prevalence of non-additive gene action in the manifestation of grain yield and most of its components. The females, WH 157 and VP 270, and the male, HD 1987, were the best combiner on the basis of gca effects as well as per se performance.

Jatasra and Paroda (1983) studied 8 x 8 diallel, and concluded that grain yield/plant is controlled by non-additive gene effects, whereas yield components are controlled by additive effects. Agra local for grain yield and tillers/plant, Kalyan Sona for grains/ear and grain weight/ear, and Sonalika for 100-grain weight were the best general combiners, and the cross, VP 301 x Agra local was found to be the most promising one.

Pochaba et al. (1984) studied combining ability in F_1 and F_2 populations resulting from 6 lines and 3 testers, and

reported significant gca effects for yield and its components. The values of sca were significant though not always positive for all characters, thereby indicating the presence of non-allelic interactions.

Khangil and Biryukov (1984) in a combining ability study of winter wheats involving 14 lines and 3 testers, parents, reported the preponderance of additive effects for grain yield and its component traits.

Jag Shoran et al. (1984) studied a line x tester set involving 10 lines and 3 testers in the F_2 generation. They reported significant differences among the parents and crosses in all the generations, and also significant gca and sca effects.

Korobeinikov (1985) observed sca for duration of emergence to heading period and 100-grain weight in 105 F_1 hybrids resulting from a diallel set of crosses. He reported little association between the per se values for characters and sca assessments. It was considered inadvisable to use sca effects as a criterion for selecting useful hybrids.

Kraljevic (1986) in a 5 x 5 diallel cross (excluding reciprocals) in wheat, reported that while, both gca and sca variances were significant in the F_1, only the former was significant in the F_2 for productive tillers/plant.

2.2 Heterosis

Manifestation of hybrid vigour in crop plants has been observed for nearly two centuries by plant breeders (East and Hayes, 1912). The German botanist Koelreuter carried out

systematic studies on artificial hybridization in plants between 1760 and 1766 (Poehlman, 1959). The modern concept of hybrid vigour came with the work of Shull (1948) who produced the hybrid maize. The current use of hybrid vigour in plant development was stimulated by the marked success of hybrid corn (Burton and Sprague, 1961).

Heterosis in wheat was first reported in 1919 by Freeman, who studied date of first heading, height and leaf width in crosses involving durum and common wheats. However, for grain yield, heterosis was first observed by Engledow and Pal (1934), who also suggested the possibility of increasing wheat yield by growing F_5 and F_6 generations of a particular cross which exhibited hybrid vigour in the F_1, since the growing of F_1 generation in wheat on commercial scale is impracticable.

Boyce (1948) presented preliminary results on the manifestation of heterosis for spikes/plant, number of grains/spike and mean grain weight. Although the only component displaying significant heterosis was the number of spikes/plant, the F_1 yielded 32.7 per cent more grains per plant, showing that the total yield depends upon the product of yield components which individually may or may not display heterosis.

Sikka et al. (1959) in 12 intervarietal crosses of wheat, reported heterosis for number of spikes/plant, 100-grain weight and number of grains/spike in the F_1, F_2 and F_3 generations. The F_1 generation had increased number of spikelets/spike and spike length, but comparisons with parental means were not significant. The F_1 generation also had the tallest plants,

the highest grain yield, followed by F_2 and F_3, the yield differences being highly significant.

Akemine and Kumagai (1966), in a study involving 28 crosses in a eight parental diallel, observed 20 per cent heterobeltiosis for grain yield in F_1 generation. However, it was reduced in the F_2 generation, reached the parental level in the F_3 generation, emphasizing that higher yielding parents gave a lower degree of heterobeltiosis.

Fonseca and Patterson (1968) reported a considerable but non-significant heterosis over the better parent for earliness and significant heterosis for tillers/plant, kernel weight and grain yield in the F_1 and F_2 generations of some crosses.

Nettevich (1968) reported heterosis 48 F_1s, 7 F_2s and F_3s for yield, and concluded that a steep rise in yield of the F_1 was manifested in crosses involving high yielding varieties which differed in origin and agronomic characters.

Singh and Dawa (1968) in 3 intervarietal crosses, reported heterosis for plant height, grain yield, 100-seed weight, spike number, spikelets/spike, leaf length and leaf width in the F_1 generation, and inbreeding depression in the F_2 and F_3 generations.

Singh and Kandola (1968) reported manifestation of heterosis in the F_1 hybrids over better parent for grain yield components, viz., number of spikes/plant, number of spikelets/spike and 100-kernel weight. For plant height, leaf area and days to earing, negative heterosis was observed.

Nettevich (1969) studied 91 combinations of spring wheat and found their mean yield to have exceeded that of the better parent by 9.2 per cent. In maturity, the hybrids were intermediate or equal to the earlier parent. He concluded that the greatest heterosis could be obtained in hybrids between contrasting ecotypes, provided both were adapted to the locality.

Paroda and Joshi (1970a) reported that heterosis for grain yield in wheat was higher than that of yield components, and found 1000-grain weight to be the most reliable yield contributing character.

Singh and Singh (1970) found that 80 per cent and 60 per cent of the F_1 hybrids exceeded the better parent and standard variety, respectively, for grain yield, and reduction in yield appeared to be reflected through heterosis for spike number and 1000-kernel weight.

Mospan (1972) observed heterosis for yield in 50 of the 146 winter wheat hybrids studied. Productive tillers were 31-58 per cent higher in the F_1 than in the female parent but declined by 2 to 11 per cent in the F_2 generation. Heterosis for grain weight was observed in 56 hybrids, but it was maintained in the F_2 by only those hybrids which had the highest heterosis in F_1.

Pepov and Stankov (1972), in a study of hybrids derived from 125 combinations, reported that 79.2 per cent hybrids out yielded the better parent and 42.3 per cent excelled the better parent. Most of the hybrids had better tillering and higher 1000-grain weight than their respective parents.

Chawas and Abel-Halim (1973), in a genetic analysis of yield components in wheat, reported negative heterosis for tillers/plant, length of spike, grain yield/spike, kernels/spike 100-grain weight and grain yield/plant.

In a 10-parent diallel in durum wheat, Winder and Lebsock (1973) reported a range of heterosis from 19 to 84 per cent in the F_1s and 23-26 per cent in the F_2s for grain yield. As-many-as, 11 F_2 populations yielded significantly less than their respective F_1s.

Selim et al. (1974), in a study of heterosis in the F_1s obtained from a diallel cross, reported increased tillering by about 20 per cent in 4 combinations. In all combinations, except one, heterosis for grain yield/plot was found to vary between 22 and 63 per cent while heterosis for ear length was nearly 20 per cent in 3 combinations.

Mani and Rao (1975), studied crosses of 8 winter and 3 exotic spring varieties with 5 high yielding Indian spring varieties of different height. All the 55 hybrids and 16 parents were studied for grain yield/plant, number of effective tillers/plant, number of grains/ear 100-grain weight, plant height and number of days to flower. Heterosis to the extent of 193 per cent was observed for grain yield in one of the winter x spring wheat crosses when compared to the mid-parent. Only few crosses showed significant values of heterosis for number of tillers/plant, number of grains/ear, weight of grains/ear and 100-grain weight. Almost all the hybrids flowered a little late compared to their early parents. In general two

winter varieties showed good combining abilities with all the males involved.

Ketata et al. (1976), in a study of inheritance of 8 agronomic characters in winter wheat, found a significant heterosis for heading date and plant height, and attributed it to be due to non-additive gene action.

Parkasa Rao (1977) evaluated 21 F_1s and their F_2s, derived from a 7-parent diallel cross. Eight crosses showed heterosis for grain yield, and these crosses involved parents with high combining ability for 1000-grain weight, number of tillers and grains/spike.

Skatova (1979) in a study of winter x spring wheat hybrids found that the hybrids were superior to the parents in a number of yield components and exceeded the parents in grain yield by 61.8 to 77 per cent. Most useful hybrids for yield were those in which one of the parents was long strawed and the other short strawed.

Abugaliev (1982), while studying dynamics of yield components for wheat in hybrid populations, observed that degree of heterosis in the F_1 did not prove a reliable guide to breeding value, which depended on the extent to which heterosis was maintained in later generations. The most useful character by which to judge the breeding value was number of grains/ear and 1000-grain weight.

Quri et al. (1986) studied heterosis for grain yield/plant and for yield components in a 6 x 6 diallel of wheat. Heterosis for grain yield exceeded 50 per cent over the parental mean and

28 per cent over the better parent. Heterosis over the better parent ranged from 0.41 to 9.5 per cent for different characters. Seven of the 15 crosses exceeded the best parent in grain yield/plant.

2.3 Gene action

Most of the characters of economic importance, such as yield and its components, are governed by polygenic systems and are characterized by continuous variation, which do not have sharp effects and cannot be identified on individual plants. Therefore, superior crosses may not be identified until several generations have been grown and fixation of characters achieved. However, it is imperative for a breeder to apprise himself of the complexity of gene effects governing yield and other traits. The estimates of gene effects helpful in formulating an appropriate breeding strategy. The information pertaining to the nature of gene effects as obtained from the generation mean analysis is presented hereafter.

Bhatt (1972) in a study of F_1, back crosses and segregating generations in wheat crosses, reported additive type of gene action for days to flowering. Gamil and Saheal (1983) also reported additive gene effects in this trait. However, Ketata et al. (1976), in winter wheat crosses, observed non-additive gene effects or non-allelic interactions in different crosses. Importance of both additive and non-additive effects in the manifestation of this trait has been reported by Nanda et al. (1982).

For plant height, Johnson et al. (1966) in a study of F_1, backcrosses and segregating generations from a cross of two winter wheats, reported additive gene action for the [illegible]

Similar gene action for this character has been reported by Bhatt (1972) and Edward et al. (1976). Amaya et al. (1972) also observed the trait to be governed by additive genes in two crosses, whereas dominance effects were important in the third cross. In the fourth cross both additive and dominance effects were equally important. In a study involving parents, F_1, backcrosses and segregating generations of wheat, Ketata et al. (1976) reported the importance of non-additive effects, whereas Nanda et al. (1982) reported the importance of both additive and non-additive gene effects for this trait. Presence of non-allelic interactions for this trait has been reported by Singh and Dahiya (1984). However, Chapman and McNeal (1971) observed the absence of non-allelic interactions for this trait.

The number of effective tillers/plant has been reported to be governed by variable gene effects in different studies. Edward et al. (1976) reported the preponderance of additive gene effects for this trait. Nanda et al. (1981) in a study of intervarietal crosses of spring wheat reported the importance of additive gene effects, whereas in another study both additive and dominance effects were found to be equally important. Sawant and Jain (1985) evaluated parental, F_1, F_2 and F_3 generations of a wheat cross ad concluded that non-allelic interactions of additive x additive type were important for this character. Presence of non-allelic interactions for this trait has also been reported by Chapman and McNeal (1971), Ketata et al. (1976) and Singh and Dahiya (1984).

Johnson et al. (1966) in a study of F_1, back crosses and segregating generations from a cross of two winter wheats

indicated the presence of additive gene effects for spike length. Importance of additive gene effects in the manifestation of spike length has also been reported by Ceccarelli et al. (1973), Gill et al. (1974) and Nanda et al. (1982). Joshi (1987) studied 6 crosses involving 4 varieties of spring wheat, and reported complementary and duplicate type of non-allelic interactions in different crosses.

For grains/spike, Chapman and McNeal (1971) and Ketata et al. (1976) observed the trait to be governed by additive gene effects. Singh and Anand (1970b) detected significant additive, dominance and epistatic gene effects in one cross, whereas in another epistatic gene effects were found to be of lesser importance. Importance of additive gene effects coupled with additive x additive type of interactions has been reported by Ketata et. al. (1976). However, Singh and Dahiya (1984) advocated the importance of non-allelic interactions in the manifestation of grain number.

In a study of two spring wheat crosses, Bhatt (1972) reported additive gene effects governing the inheritance of kernel weight. Similar type of gene action for this trait has also been reported by Edward et al. (1976), Ketata et al.(1976) and Nanda et. al. (1981). On the other hand, Chapman and McNeal (1971) reported the importance of dominance gene effects for this trait. In a study of 6 wheat crosses, Sun et al.(1972) reported that both additive and dominance effects were equally important and consistent than non-allelic interactions. However, Lee and Kaltesikes (1971) reported higher level of

dominance and non-allelic interactions governing the inheritance of kernel weight.

For grain yield, different types of gene effects have been reported by different workers. Edward et al. (1976) reported additive gene effects for this character. Nanda et al. (1981) and Joshi (1987) have also reported the trait to be governed by additive gene effects. Importance of both additive and dominance gene effects in the manifestation of this trait, in spring x winter wheat crosses, has been reported by Nanda et al. (1982). Sawant and Jain (1985) attributed the variability in grain yield due to additive gene effects in one cross, whereas both additive and dominance gene effects were important in the other cross studied. However, Chapman and McNeal (1971), Ketata et al. (1976) and Singh and Dahiya (1984) have emphasized the importance of non-allelic interactions in the manifestation of grain yield. Ketata et al. (1976) reported duplicate type of non-allelic interactions for this trait.

3 MATERIALS AND METHODS

3.1 Material

Eleven genetically diverse lines of spring wheat, used as females (lines) and 3 of winter types as males (testers) listed below constituted the basic material for the present investigation :

Parents	Parentage
Females (lines)	
MP 195	C 306 x Hyb 65
Narmada 4	Hyb. 1-1 x BN 179
TMI 4	-
DL 20-9	Kal mutant/Frond x Son 64 - Kh Rend E 4870/S 310-547
Kharchia 65	Kharchia local x CG 953
K 7340	C 303 x E 4870
Pitic 62	Yt 54 - NIOB 126.1C
LSW 26	Sonalika x Kalyan Sona
Mukta	Hyb 633 x NP 842
NP 846	Rionegro x NP 760
NP 401	Gaza x Egypt 8626
Males (testers)	
Mong 1	Hair Conskia (R)
Mong 2	Region (M) - Samp II
Mong 3	Greukum - 40(M)

The 11 lines used as females were crossed with 3 testers (males) during the rabi 1982-83 at Palampur. However, only two

testers, Mong 2 and Mong 3 could be successfully crossed with the 11 lines after manipulating the sowing dates. A part of the F_1 seed was raised at the Regional Research Station, Kukumseri (Lahaul & Spiti) during summer 1983 to advance the generation. Random samples of the harvested F_2 bulks were raised during rabi 1983-84 at Palampur to generate F_3. Further, random samples of the F_3 bulks were drawn.

The experimental material, comprising 13 parents (11 females and 2 males) their 22 F_1s, F_2s and F_3s were raised in a randomised block design with three replications at Palampur under rainfed condition during rabi 1984-85. The parents and F_1s were raised each in a single row plot, 3 m long, with row-to-row distance of 25 cm. F_2s and F_3s were raised in the same way as the F_1s and parents, except that each plot comprised 3 rows.

3.2 Recording of Observations

Ten randomly selected plants in each replication were tagged in case of parents and F_1s, and 25 in case of the F_2s and F_3s for recording the observations on various characters. However, data on days to heading and days to maturity were recorded on plot basis. Data on different traits were recorded as under :

1. Days to flowering

Number of days from date of seeding to 75 per cent ear emergence.

2. Days to maturity

Number of days from date of seeding to 75 per cent maturity.

3. Plant height (cm)

The plant height of the main tillers from soil surface to the tip of the spike (excluding awns) at maturity.

4. Spikes/plant

Number of ear bearing tillers per plant.

5. Spike length (cm)

Length of the main spike excluding awns of effective tillers.

6. Grains/spike

Total number of grains counted from the main spike.

7. 100-grain weight (g)

Weight in grammes of a random sample of 100 grains taken from the produce of a plant was considered.

8. Grain yield/plant (g)

Weight of grain produced from the plant was recorded in grammes.

3.3 Analysis of variance for the experimental design

The data recorded on various characters were averaged and utilized for the analysis of variance. The analysis of variance for various characters was carried out as per the procedure suggested by Panse and Sukhatme (1978). The parents along with

the three generations were separately analysed. The analysis of variance for the comparison of enteries is given as under.

Source of variation	df
Replications	(r-1)
Parents	(p-1)
Lines (Females)	(l-1)
Testers (Males)	(t-1)
Line vs Testers	1
Hybrids	(lt-1)
Parents vs hybrids	1
Error	(p+lt)-1 (r-1)
Total	r(p+lt)-1

Where,

r = number of replications

p = number of parents

l = number of lines or females

t = number of tester or males

3.4 Analysis of variances for combining ability

Combining ability analysis was carried out separately for the F_1, F_2 and F_3 generations following the method of Kempthorne(195 The analysis of variance for combining ability is as under.

Source of variation	df	M S	Expectation of M S
Replications	(r-1)		
Testers or males	(t-1)	M_1	σ_e^2 +r(cov FS - 2 Cov HS) +rf Cov HS
Lines or females	(l-1)	M_2	σ_e^2 - r(Cov FS-2 Cov HS) +rm Cov HS
Lines x Testers	(l-1) (t-1)	M_3	σ_e^2 +r(Cov FS-2 Cov HS)
Error	(r-1) (tl-1)	M_4	σ_e
Total	rlt-1		

Where,

r = number of replications

t = number of tester

l = number of lines

From the expectations of the mean sum of squares the covariances of the full-sib (F S) and covariances of half-sib (H S) were estimated as follows :

$$\text{COV H S} = \frac{M_1 + M_2 - 2M_3}{r(t+l)}$$

$$\text{Cov F S} = \frac{M_1 + M_2 + M_3 - 3M_4}{3r} + \frac{6r \text{ Cov H S} - r(t+l)\text{Cov H S}}{3r}$$

Where,

M_1 = M S tester (male)

M_2 = M S line (female)

M_3 = M S line x tester

M_4 = M S error

σ_{gca}^2 = Cov H S $= (\frac{1+F}{4})\sigma_A^2$

Therefore,

$$\sigma^2_A = 4 \text{ Cov } H\ S, \text{ if } F = 0 \text{ (in the } F_1 \text{ generation)}$$

$$\sigma^2_A = \frac{8 \text{ Cov } H\ S}{3} \text{ if } F = \tfrac{1}{2} \text{ (in the } F_2 \text{ generation)}$$

$$\sigma^2_A = \frac{16 \text{ Cov } H\ S}{7} \text{ if } F = \tfrac{3}{4} \text{ (in the } F_3 \text{ generation)}$$

Likewise,

$$\sigma^2_{sca} = \left[\frac{1+F}{2}\right]^2 \sigma^2_D$$

$$\sigma^2_D = 4\ \sigma^2_{sca} \text{ if } F = 0 \text{ (in the } F_1 \text{ generation)}$$

$$\sigma^2_D = \frac{16}{9}\ \sigma^2_{sca} \text{ if } F = \tfrac{1}{2} \text{ (in the } F_2 \text{ generation)}$$

$$\sigma^2_D = \frac{64\ \sigma^2_{sca}}{49} \text{ if } F = \tfrac{3}{4} \text{ (in the } F_3 \text{ generation)}$$

3.4.1 Estimation of general and specific combining ability effects

The model of Kempthorne (1957) was used for estimating the gca and sca effects in combining ability analysis for the F_1, F_2 and F_3 generations of crosses. The model underlying the analysis is :

$$X_{ijk} = u + g_i + g_j + s_{ij} + l_{ijk}$$

Where,

U = general mean

g_i = gca effects of the ith male parent (tester)

$i = 1,2 - - - - t$

g_j = gca effect of the ith female parent

$j = 1,2 - - - - l$

S_{ij} = sca effect of ijth combinations

e_{ijk} = Error associated with the observation X_{ijk}

$K = 1,2 - - - - r$

The indivisual effects were estimated as follows :

(i) $U = \frac{x_{...}}{tlr}$

Where X ... = Total of all hybrid combinations (lines x testers)

(ii) $g_i = \frac{xi_{..}}{lr} - \frac{x_{...}}{tlr}$

Where xi.. = Total of all ith male parent (tester) over all females (lines) and replications.

(iii) $g_j = \frac{x_{.j.}}{tr} - \frac{x_{...}}{tlr}$

Where x.j. = Total of jth female parent over all male parents and replications

(iv) $S_{ij} = \frac{x_{ij.}}{r} - \frac{x_{i..}}{lr} - \frac{x_{.j}}{tr} + \frac{x_{...}}{ltr}$

Where x_{ij} = Total of ijth combinations in all the replications

Standard errors for combining ability estimates are given below :

SE $\pm$ (gca of lines) = $(Me/rt)^{\frac{1}{2}}$

SE $\pm$ (gca of tester) = $(Me/rl)^{\frac{1}{2}}$

SE $\pm$ (sca effects) = $(Me/r)^{\frac{1}{2}}$

SE $\pm$ $(g_i - g_j)$ line = $(2Me/rt)^{\frac{1}{2}}$

SE $\pm$ $(g_i - g_j)$ tester = $(2Me/rl)^{\frac{1}{2}}$

SE $\pm$ $(S_{ij} - S_{kl})$ = $(2Me/r)^{\frac{1}{2}}$

Where Me = Error mean square

3.5 Estimation of heterosis

Heterosis over mid-parent (H_1)

Heterosis over mid-parent was expressed as per cent increase or decrease in the mean value of F_1 hybrid over its mid-parent value.

$$H_1 = \frac{\bar{F}_1 - \overline{MP}}{\overline{MP}} \times 100$$

Where,

$\bar{F}_1$ = mean value of F_1 hybrid, and

$\overline{MP}$ = mean value of the two parents of that particular F_1 cross

Heterosis over better parent (H_2)

This was expressed as per cent increase or decrease in the mean value of F_1 hybrid over the better parent.

$$H_2 = \frac{\bar{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

Where,

$\overline{BP}$ = mean of the superior parent of that particular cross

Standard error of heterosis over mid-parental is :

$$SE \pm (H_1) = (3Me/2r)^{1/2}$$

Standard error of heterosis over the better parent is :

$$SE \pm (H_2) = (2Me/r)^{1/2}$$

Where,

Me = errors mean square of the analysis using parents and F_1s

r = number of replications

Significance of the F_1 means from the mid-parent and better parent was tested by 't' test.

$$t = \frac{\bar{F}_1 - \overline{MP}}{SE(H_1)} \quad \text{(for mid parent value)}$$

$$t = \frac{\bar{F}_1 - \overline{BP}}{SE(H_2)} \quad \text{(for better parent)}$$

The calculated 't' value was compared with tabulated value at error degree of freedom at $P \leq 0.05$

3.6 Generation mean analysis

3.6.1 Scaling tests for the detection of digenic interaction

The following scaling tests given by Mather (1949) and Hayman and Mather (1955) were used for detection of digenic interactions:

$$A = 2\,\bar{B}_1 - \bar{P}_1 - \bar{F}_1$$

$$B = 2\,\bar{B}_2 - \bar{P}_2 - \bar{F}_1$$

$$C = 4\,\bar{F}_2 - 2\,\bar{F}_1 - \bar{P}_1 - \bar{P}_2$$

$$D = 4\,\bar{F}_3 - 2\,\bar{F}_1 - \bar{P}_1 - \bar{P}_2$$

The standard errors of these tests were estimated as follows :

$$SE \pm (A) = \left[4\,V(\bar{B}_1) + V(\bar{P}_1) + V(\bar{F}_1)\right]^{\frac{1}{2}}$$

$$SE \pm (B) = \left[4\ V(\bar{B}_2) + V(\bar{F}_2) + V(\bar{F}_3)\right]^{\frac{1}{2}}$$

$$SE \pm (C) = \left[16\ V(\bar{F}_2) + 4\ V(\bar{F}_1) + V(\bar{P}_1) + V(\bar{P}_2)\right]^{\frac{1}{2}}$$

$$SE \pm (D) = \left[16\ V(\bar{F}_3) + 4\ V(\bar{F}_2) + V(\bar{P}_1) + V(\bar{P}_2)\right]^{\frac{1}{2}}.$$

Note : As the back cross generations were not available only C and D tests were applied.

Deviations of C and D from zero were tested for the individual cross. Significant deviation of C and D indicated the presence of l (dominance x dominance) and i (additive x additive) type of interactions, respectively.

Significance of C and D was tested using 't' test as follows :

$$t_{(c)} = C/SE(C)$$

$$t_{(d)} = D/SE(D)$$

The calculated values of 't' were compared with 1.96, which is the tabulated value at $P \angle 0.05$ level of significance.

When the scale is adequate i.e. additive - dominance model is fitting, C and D should be zero within the limits of their respective standard errors.

3.6.2 Estimation of gene effects

For detecting the effects of allelic and non-allelic interactions m, (d), (h), (i), and (l) were worked out as per Jinks and Jones (1958). The estimates of these parameters, when F_3 is available while B_1 and B_2 are absent, are given below.

$$m = \bar{F}_2$$

$$(d) = \tfrac{1}{2}\,\bar{p}_1 - \tfrac{1}{2}\,\bar{p}_2$$

$$(h) = \frac{1}{6}\,(4\,\bar{F}_1 + 12\,\bar{F}_2 - 16\,\bar{F}_3)$$

$$(i) = \bar{p}_1 - \bar{p}_2 + \tfrac{1}{2}\,(\bar{p}_1 - \bar{p}_2 + h) - \tfrac{1}{4}\,l$$

$$(l) = \frac{1}{3}\,(16\,\bar{F}_3 - 24\,\bar{F}_2 + 8\,\bar{F}_1)$$

Variances and standard errors of these parameters were calculated as under :

$$V\,m = V\,\bar{F}_2$$

$$V(d) = \tfrac{1}{2}\,(V\bar{p}_1 + V\bar{p}_2)$$

$$V(h) = \frac{1}{36}\,(16\,V\,\bar{F}_1 + 144\,V\,\bar{F}_2 + 256\,V\,\bar{F}_3)$$

$$V(i) = V\,\bar{p}_1 + V\,\bar{F}_2 + \tfrac{1}{4}\,(V\,\bar{p}_1 + V\,h) \pm \frac{1}{16}\,Vl$$

$$V(l) = \frac{1}{9}\,(256\,V\,\bar{F}_3 + 576\,V\,\bar{F}_2 + 64\,V\,\bar{F}_1)$$

$$SE \pm m = (V\,m)^{\frac{1}{2}}$$

$$SE \pm d = (V\,d)^{\frac{1}{2}}$$

$$SE \pm h + (V\,h)^{\frac{1}{2}}$$

$$SE \pm i = (V\,i)^{\frac{1}{2}}$$

$$SE \pm l = (V\,b)^{\frac{1}{2}}$$

The significance of these parameters was determined by calculating the 't' value

$$t\,m = m/SE\,m$$
$$t\,d = d/SE\,d$$
$$t\,h = h/SE\,h$$
$$t\,i = i/SE\,i$$
$$tl = l/SE\,l$$

The calculated values were compared with 1.96, the tabulated value at $P \leq 0.05$

4 EXPERIMENTAL RESULTS

The results obtained in the present investigation are presented under different heads :

4.1 Analysis of variance for the experimental design

The analysis of variance for the parents and hybrids for different traits in the F_1, F_2 and F_3 generations, presented in Table 1, showed significant differences among the parents in all the traits studied in all the generations, except for grain yield/plant in the F_2 generation. Mean squares due to females were significant for all the traits in the three generations, except for days to flowering, and grain yield/plant in the F_2 generation and spike length in the F_3 generation. Significant differences between the male parents were present only for number of spikes/plant and 100-grain weight in all the generations. Mean squares due to females versus males were significant for all the traits, except grain yield/plant in all the generations. Differences among the hybrids were significant for all the traits in the three generations, except for spikes/plant in the F_1 and F_2 generations, spike length in the F_2 and F_3 generations and grain yield/plant in F_2 and F_3 generations. Mean square due to parents versus hybrids were significant for all the characters in all the generations, except for days to maturity, 100-grain weight and grain yield/plant in the F_2 generation, and grains/spike and yield/plant in F_3 generation.

Table 1. Analysis of variance for the experimental design in the F_1, F_2 and F_3 generations

Source	df	Generation	Mean sum of squares							
			Days to flowering	Days to maturity	Plant height	Spikes/ plant	Spike length	Grains/ spike	100-grain weight	Grain yield/ plant
Replications	2	F_1	19.75	2.75	898.77	163.41	11.47	700.94	0.22	495.92
		F_2	34.75	10.70	38.16	8.69	1.33	184.47	0.01	32.38
		F_3	28.85	10.15	412.56	24.81	4.57	529.93	0.46	21.92
Parents	12	F_1	340.60*	40.78*	1227.68*	10.92*	10.56*	176.18*	0.90*	17.83*
		F_2	340.60*	40.78*	1227.68*	10.92*	10.56*	176.18*	0.90*	17.83
		F_3	340.60*	40.78*	1227.68*	10.92*	10.56*	176.18*	0.90*	17.83*
Females	10	F_1	19.30*	21.96*	337.13*	9.54*	2.72*	186.30*	0.50*	19.37*
		F_2	19.30	21.96*	337.13*	9.54*	2.72*	186.30*	0.50*	19.37
		F_3	19.30*	21.96*	337.13*	9.54*	2.72	186.30*	0.50*	19.37*
Males	1	F_1	16.67	0.16	83.63	14.42*	2.28	2.70	0.96*	3.38
		F_2	16.67	0.16	83.63	14.42*	2.28	2.70	0.96*	3.38
		F_3	16.67	0.16	83.63	14.42*	2.28	2.70	0.96*	3.38
Females vs Males	1	F_1	3877.60*	269.60*	11277.20*	21.21*	97.28*	251.14*	4.80*	16.87
		F_2	3877.60*	269.60*	11277.20*	21.21*	97.28*	251.14*	4.80*	16.87
		F_3	3877.60*	269.60*	11277.20*	21.21*	97.28*	251.14*	4.80*	16.87
Hybrids	21	F_1	35.12*	12.19*	283.33*	3.48	2.89*	149.70*	0.26*	18.37*
		F_2	32.18*	9.85*	135.07*	2.57	0.96	147.28*	0.24*	10.98
		F_3	39.41*	10.75*	449.35*	3.36*	4.50	196.27*	0.20*	7.52
Parents vs Hybrids	1	F_1	134.10*	250.50*	3367.52*	50.20*	52.90*	1023.52*	0.32*	292.02*
		F_2	1177.30*	8.20	1272.13*	33.67*	6.04*	348.88*	0.17	14.64
		F_3	91.30*	131.70*	780.22*	9.25*	11.99*	112.82	0.47*	0.29
Error	68	F_1	7.65	4.92	62.23	2.93	1.25	54.00	0.07	9.43
		F_2	10.90	3.48	58.05	2.93	0.89	39.68	0.09	9.89
		F_3	7.78	4.07	65.05	1.83	1.73	47.89	0.09	9.19

*Significant at $P < 0.05$

4.2 Analysis of variance for combining ability

The analysis of variance for combining ability (Table 2) showed significant differences among the female progenies for all the traits in all the generations, except for spikes/plant in the three generations, grains/spike in the F_3, 100-grain weight in the F_2 and F_3 and grain yield/plant in the F_1 and F_3 generations. Mean squares due to the male progenies were significant only for grains/spike in all the generations, 100-grain weight and grain yield/plant in the F_1 and F_2 generations, and days to flowering and spike length in the F_1 and F_3 generations. Means squares for female x male progenies interaction were significant only for days to flowering, days to maturity and grain yield/plant in the F_3 generation, plant height in the F_1 and F_3 generations, grains/spike in the F_2 and F_3 generations and spike length in the F_1 generation.

In the F_1 generation σ^2_A was predominant for all the traits, except days to maturity, plant height and spike length. In the F_2 generations also, σ^2_A was higher than σ^2_D for all the traits, except for days to heading, spikes/plant and spike length. However, in the F_3 generations, the values of σ^2_D were higher than those of σ^2_A for all the traits, except days to heading and spikes/plant.

4.3 General combining ability effects

Estimates of general combining ability (gca) effects of the parents, i.e. lines and testers, computed in the F_1, F_2 and F_3 generations for different traits are presented in Table 3 and described hereafter :

Table 2. Analysis of variance for combining ability in the F_1, F_2 and F_3 generations

Source	df	Generation	Mean sum of squares							
			Days to flowering	Days to maturity	Plant height	Spikes/ plant	Spike length	Grains/ spike	100-grain weight	Grain yield/ plant
Replications	2	F_1	39.60	4.60	681.20	139.99	20.64	367.68	0.03	336.89
		F_2	56.20	8.60	92.55	10.31	1.10	101.85	0.32	44.81
		F_3	41.75	8.40	150.28	4.48	8.62	275.28	0.16	26.56
Females	10	F_1	41.80*	16.34*	293.85*	4.96	3.63*	133.65*	0.27*	8.14
		F_2	42.17*	15.01*	243.77*	2.27	1.51*	81.17*	0.14	8.74*
		F_3	19.60*	10.99*	342.05*	4.29	6.28*	78.32	0.22	6.60
Males	1	F_1	154.50*	18.70	33.86	8.30	6.18*	841.73*	1.58*	153.54*
		F_2	51.00	0.20	82.49	4.48	2.11	1144.16*	2.29*	57.49*
		F_3	427.60*	9.50	251.73	9.70	97.00*	1242.80*	0.00	3.55
Females × Males	10	F_1	16.50	7.38	297.75*	1.51	1.83*	96.54	0.12	15.08
		F_2	20.30	5.65	31.62	2.68	0.30	113.65*	0.14	8.57
		F_3	20.41*	10.63*	576.42*	1.79	3.17	188.56*	0.21	8.84*
Error	42	F_1	5.58	5.42	63.43	3.30	0.83	56.49	0.08	11.64
		F_2	13.27	3.27	43.71	2.11	0.70	21.37	0.08	4.21
		F_3	9.12	4.21	70.13	1.37	1.85	42.86	0.11	3.47
σ^2_A		F_1	16.75	2.08	27.46	1.05	0.63	80.24	0.16	13.50
		F_2	3.59	2.67	17.98	0.10	0.21	68.24	0.15	3.36
		F_3	23.82	-0.05	-32.77	6.10	-0.003	55.33	0.01	-0.44
σ^2_D		F_1	14.56	2.60	312.40	-2.40	1.32	53.40	0.04	4.60
		F_2	4.16	1.40	-6.93	0.33	0.23	54.68	0.04	2.58
		F_3	4.91	2.80	220.42	0.18	0.57	63.44	0.04	2.34
σ^2_A/σ^2_D		F_1	11.50	0.80	0.09	-0.44	0.48	1.50	4.00	2.93
		F_2	0.86	1.91	-2.59	0.30	-0.91	1.24	3.75	1.30
		F_3	4.85	-0.02	-0.15	33.89	-0.01	0.87	0.25	-0.18

*Significant at $P \leq 0.05$

Table 3. Estimates of general combining ability (gca) effects of different characters in the F_1, F_2 and F_3 generations

Parents	Generation	Days to flowering	Days to maturity	Plant height	Spikes/ plant	Spike length	Grains/ spike	100-grain weight	Grain yield/ plant
Females									
MP 195	F_1	0.55	0.47	-0.51	0.23	-0.08	6.47*	0.29*	1.16
	F_2	1.46	1.26	-2.21	-0.08	-0.06	2.48	0.21	1.26
	F_3	-1.88	1.02	1.01	-0.43	-0.35	5.54*	0.23	0.74
Narmada 4	F_1	1.88	0.30	3.28	-0.55	-0.62	1.26	-0.14	-1.99
	F_2	3.79*	1.26	2.36	0.03	-0.53	-0.12	-0.21	-1.40
	F_3	3.46*	-0.49	6.87*	0.37	-0.35	1.86	-0.17	-0.30
TMI 4	F_1	0.88	0.30	-4.01	-0.17	0.62	5.42	-0.21	0.21
	F_2	0.12	-0.08	-3.59	-0.72	-0.61	2.90	-0.16	-0.82
	F_3	0.12	1.35	5.72	0.04	0.12	2.66	-0.14	0.17
DL 20-9	F_1	-0.12	1.14	-4.39	-0.52	1.02*	1.77	0.22*	0.72
	F_2	-0.21	1.09	-10.24*	-0.18	0.72*	5.93*	0.06	0.41
	F_3	0.96	0.35	-1.58	-0.68	1.02	-2.94	0.10	-0.96
Kharchia 65	F_1	3.21*	0.47	6.38	-0.82	-0.40	2.27	0.01	-1.16
	F_2	1.79	0.59	2.88	-0.60	-0.74*	-1.34	-0.14	-0.80
	F_3	2.12	0.35	-3.81	-0.64	-0.56	1.32	-0.19	-0.60
K 7340	F_1	1.38	0.80	-2.96	0.45	0.37	-5.43	-0.14	-0.93
	F_2	1.12	1.09	-3.27	0.25	0.41	4.71*	-0.06	0.43
	F_3	-0.71	1.35	-4.85	0.82	0.09	-3.89	-0.09	0.02
Pitic 62	F_1	-4.12*	-0.53	2.99	-0.30	-0.92*	2.91	-0.14	-0.24
	F_2	0.12	-1.08	-4.02	-0.72	-0.36	-3.34	0.03	-2.14*
	F_3	0.29	0.52	4.09	-0.44	0.14	1.76	-0.15	-0.65
LSW 26	F_1	-4.46*	-4.20*	0.54	-0.92	0.65	-8.06*	0.26*	-0.43
	F_2	-5.88*	-3.74*	-2.54	-0.22	0.26	-3.86*	0.18	-0.17
	F_3	-2.55*	-2.65*	-5.66	-1.43*	0.26	-0.06	0.03	-1.13
Mukta	F_1	1.55	0.14	-9.37*	1.32	-0.47	0.82	-0.18	-0.35
	F_2	-2.21	0.59	4.34	0.15	0.52	-1.27	0.20	0.76
	F_3	0.62	0.68	-2.36	1.37*	-0.75	2.64	-0.19	1.65*
NP 845	F_1	2.21	2.30*	15.53*	1.52*	1.02*	-1.44	-0.23*	0.97
	F_2	2.46	-1.74*	14.66*	1.24*	0.39	-5.86*	-0.14	0.48
	F_3	-0.38	-0.15	14.34*	1.07*	2.21*	-1.58	0.20	1.95*
NP 401	F_1	-2.95*	-1.20	-7.47*	-0.64	-1.16*	-5.99	0.26*	2.04
	F_2	-1.55	0.76	1.64	0.84	-0.01	-0.29	0.03	1.98*
	F_3	-2.05	-2.32*	-13.75*	-0.08	-1.83*	-7.19*	0.35*	-0.90
Males									
Mong 2	F_1	-1.53*	-0.53	-0.72	-0.36	-0.31	-3.57*	-0.16*	-1.53*
	F_2	-0.88	0.06	-1.12	-0.26	-0.18	-4.16*	-0.19*	-0.93*
	F_3	-2.55*	-0.38	1.95	0.38	-0.01	-4.34*	-0.00	-0.23
Mong 3	F_1	1.53*	0.53	0.72	0.36	0.31	3.57*	0.16*	1.53*
	F_2	0.88	-0.06	1.12	0.25	0.18	4.16*	0.19*	0.93*
	F_3	2.55*	0.38	-1.95	-0.38	0.01	4.34*	0.00	0.23
SE± (lines)	F_1	1.20	0.95	3.25	0.74	0.37	3.07	0.11	1.39
	F_2	1.49	0.74	2.70	0.59	0.34	1.89	0.11	0.84
	F_3	1.23	0.84	3.42	0.48	0.56	2.67	0.14	0.76
SE± (testers)	F_1	0.51	0.41	1.39	0.32	0.16	1.31	0.05	0.59
	F_2	0.63	0.31	1.15	0.25	0.15	0.80	0.05	0.36
	F_3	0.53	0.36	1.46	0.20	0.24	1.14	0.06	0.32

*Significant at $P \leq 0.05$

4.3.1 Days to flowering

Among the female parents, majority of the gca effects were non-significant in the F_1, F_2 and F_3 generations. Significant and negative values of gca effects were observed for LSW 26 in all the generations, and for Pitic 62 and NP 401 in the F_1 generation only. However, significant and positive gca effects were observed for Narmada 4 in the F_2 and F_3 generations, and for Kharchia 65 in the F_1 generation only. Both the testers (males) showed significant gca effects in the F_1 and F_3 generations. However, the values were negative for Mong 2.

4.3.2 Days to maturity

Significant and negative values of gca effects, among the female parents, were found for LSW 26 in all the generation, and NP 401 in F_3 generation only. General combining ability effects for the remaining lines and both the testers were found to be non-significant in all the generations, except for NP 846, which showed significantly positive and negative gca effects in the F_1 and F_2 generations, respectively.

4.3.3 Plant height

General combining ability effects were found to be non-significant for most of the female parents in all the generations. However, significant gca effects were observed for NP 846 in all the generations, NP 401 in the F_1 and F_3 generations, Mukta in the F_1 generation, Narmada 4 in the F_3 generation and DL 20-9 in the F_2 generations. Of these, gca effects for NP 846 in all the generations and Narmada 4 in the

F_3 generation were positive. The gca effects of both the testers were non-significant in the three generations.

4.3.4 Spikes/plant

For female parents, significantly positive gca effects were recorded for NP 846 in all the generations, and for Mukta in the F_3 generation. Significant and negative gca effect was observed for one parent only, i.e. LSW 26 in the F_3 generation. Both the testers failed to exhibit significant values of gca effects in any of the generations studied.

4.3.5 Spike length

Significant and positive gca effects, among the female parents, were observed for NP 846 in the F_1 and F_3 generations, and DL 20-9 in the F_1 and F_2 generations. However, for Kharchia 65 in the F_2 generation, Pitic 62 in the F_1 generation and NP 401 in the F_1 and F_3 generations, significant values of gca effects were negative. For this trait also, both the testers failed to exhibit significant values of gca effects in all the generations studied.

4.3.6 Grains/spike

For number of grains/spike, most of the gca effects were non-significant for female parents in the three generations. However, significantly positive gca effects were observed for DL 20-9 and K 7340 in the F_2 generation, MP 195 in the F_1 and F_3 generations. Besides, NP 846 in the F_2 generation, NP 401 in the F_3 generation and LSW 26 in the F_1 and F_2 generations

exhibited significant but the negative gca effects. Both the testers, i.e., Mong 2 and Mong 3 showed significantly negative and positive gca effects, respectively in the three generations.

4.3.7 100-grain weight

Among the female parents, significant and positive gca effects were observed for MP 195, DL 20-9 and LSW 26 in the F_1 generation, and for NP 401 in the F_1 and F_3 generations. However, the value of gca effect was observed to be significant and negative for NP 846 in the F_1 generation only. For rest of the female parents, the values of gca effects were found to be non-significant in all the generations. The two testers used, exhibited significant gca effects in the F_1 and F_2 generations only. However, the values were significantly positive for Mong 3.

4.3.8 Grain yield/plant

The values of gca effects, among the female parents were found to be non-significant in majority of the cases. Parents Pitic 62 exhibited significant value in the F_2 generation, whereas Mukta and NP 846 showed significant and positive gca effects in the F_3 generation only. Besides, NP 401 showed significantly negative gca effects in the F_2 generation. Significant values of gca effects for the two testers were observed only in the F_1 and F_2 generations, and were positive for Mong 3.

4.4 Specific combining ability effects

The estimates of specific combining ability effects obtained in respect of different characters in the F_1, F_2 and F_3 generations, are presented in the Table 4 and described below :

4.4.1 Days to flowering

Specific combining ability effects for days to flowering, for most of the hybrids, in different generations were non-significant. However, cross combination of Kharchia 65 with Mong 2 and Mong 3 showed significantly positive and negative sca effects, respectively in the F_3 generation only.

4.4.2 Days to maturity

Specific combining ability effects for days to maturity in the F_1 generation were non-significant for all the hybrids. In the F_2 generation also, the values of sca effects were non-significant, except for the crosses, NP 846 x Mong 2 and NP 846 x Mong 3. The value was negative in the former cross and positive in the latter. Only two crosses, DL 20-9 x Mong 2 and DL 20-9 x Mong 3 showed significant positive and negative sca effects, respectively in the F_3 generation.

4.4.3 Plant height

A perusal of sca effects involving 22 hybrids in different generations revealed that, in the F_1 generation, Mukta x Mong 2 and NP 401 x Mong 3 showed significant and positive effects, whereas the values were negative in 2 crosses, Mukta x Mong 3 and NP 401 x Mong 2. In the F_2 generation, none of the crosses

Table 4. Estimates of specific combining ability (sca) effects for different traits in F_1, F_2 and F_3 generations

Crosses	Generation	Days to flowering	Days to maturity	Plant height	Spikes/ plant	Spike length	Grains/ spike	100-grain weight	Grain yield/ plant
1	2	3	4	5	6	7	8	9	10
WB 195 x Mong 2	F_1	1.70	0.86	1.12	0.47	0.04	2.19	-0.21	1.01
	F_2	1.88	-0.23	1.20	-0.05	0.33	1.86	-0.13	1.10
	F_3	1.21	0.71	1.28	-0.02	0.25	-1.23	-0.31	-0.95
x Mong 3	F_1	-1.70	-0.86	-1.12	-0.47	-0.04	-2.19	0.21	-1.01
	F_2	-1.88	0.23	-1.20	0.05	-0.33	-1.86	0.13	-1.10
	F_3	-1.21	-0.71	-1.28	0.02	-0.25	1.23	0.31	0.95
Narmada 4 x Mong 2	F_1	-0.30	-0.30	-3.13	-0.18	-0.09	3.97	-0.15	0.53
	F_2	2.21	0.12	-0.97	0.21	0.06	5.00	0.32*	2.00
	F_3	1.88	2.21	-5.54	0.15	0.31	8.52*	-0.12	-1.22
x Mong 3	F_1	0.30	0.30	3.12	0.18	0.09	-3.97	0.15	-0.53
	F_2	-2.21	-0.12	0.97	-0.21	-0.06	-5.00	-0.32*	-2.00
	F_3	-1.88	-2.21	5.54	-0.15	-0.31	-8.52*	0.12	1.22
TMI 4 x Mong 2	F_1	-0.30	-0.36	-0.58	-0.43	0.54	2.50	-0.01	0.53
	F_2	0.55	-0.56	4.65	0.73	-0.16	2.11	-0.03	1.42
	F_3	-2.12	-0.29	-2.37	0.52	-0.09	2.36	0.12	1.35
x Mong 3	F_1	0.30	-0.36	0.58	0.43	-0.54	-2.50	0.01	-0.53
	F_2	-0.55	0.56	-4.65	-0.73	0.16	-2.11	0.03	-1.42
	F_3	2.12	0.36	2.37	-0.52	0.09	-2.36	-0.12	-1.35
DL 20-9 x Mong 2	F_1	-0.64	-1.40	-4.30	0.32	0.17	-3.01	0.12	0.18
	F_2	-1.46	0.94	-3.20	-0.01	0.25	0.15	-0.18	-0.98
	F_3	0.38	2.38*	0.90	-0.30	0.35	1.22	0.12	0.28
x Mong 3	F_1	0.64	1.40	4.30	-0.32	-0.17	3.01	-0.12	-0.18
	F_2	1.46	-0.94	3.20	0.01	-0.25	-0.15	0.18	0.98
	F_3	-0.38	-2.38*	-0.90	0.30	-0.35	-1.22	-0.12	-0.28
Kharchia 65 x Mong 2	F_1	1.70	0.20	-0.60	0.42	-0.61	3.56	0.07	0.46
	F_2	0.21	0.77	-2.02	-0.09	0.23	3.81	0.22	0.43
	F_3	3.88*	0.05	11.63*	-0.03	-0.37	2.70	-0.20	-0.59
x Mong 3	F_1	-1.70	-0.20	0.60	-0.42	0.61	-3.56	-0.07	-0.46
	F_2	-0.21	-0.70	2.02	0.09	-0.23	-3.81	-0.22	-0.43
	F_3	-3.88*	-0.05	-11.63*	0.03	0.37	-2.72	0.20	0.59
K 7340 x Mong 2	F_1	-0.14	-0.80	-1.17	-0.21	-0.54	-1.65	0.29	1.29
	F_2	-0.46	0.27	-2.07	-0.17	0.06	-0.10	0.00	-0.63
	F_3	0.05	-0.62	-12.07*	-0.27	-0.59	-3.29	0.04	0.97
x Mong 3	F_1	0.14	0.80	1.17	0.21	0.54	1.65	-0.29	-1.29
	F_2	0.46	-0.27	2.07	0.17	-0.06	1.10	-0.00	0.63
	F_3	-0.05	0.62	12.07*	0.27	0.59	3.29	-0.04	-0.97
Nitic 62 x Mong 2	F_1	-3.30	1.20	5.45	0.84	-0.16	0.32	-0.11	0.74
	F_2	1.21	0.70	-0.72	-0.04	0.23	-3.65	-0.05	-1.07
	F_3	-1.29	-1.12	-5.63	0.57	-0.37	-3.54	0.04	0.66
x Mong 3	F_1	3.30	-1.20	-5.45	-0.84	0.16	-0.31	0.11	-0.74
	F_2	-1.21	-0.77	0.72	0.04	-0.23	3.65	0.05	1.07
	F_3	1.29	1.12	5.63	-0.57	0.37	3.54	-0.04	-0.66
LSD 26 x Mong 2	F_1	-0.64	-2.47	2.47	-0.11	0.17	-4.61	-0.05	-2.61
	F_2	-0.79	0.44	0.07	0.09	0.05	-9.21*	-0.16	-1.67
	F_3	-0.79	-0.96	9.78*	-0.45	0.01	-7.62*	-0.15	-1.65
x Mong 3	F_1	0.64	2.47	-2.47	0.11	-0.17	4.61	0.05	2.61
	F_2	0.79	-0.44	-0.07	-0.09	-0.05	9.21*	0.16	1.67
	F_3	0.79	0.96	-9.78*	0.45	-0.01	7.62*	0.15	1.65

Table 4 contd....

1	2	3	4	5	6	7	8	9	10
Mukta x Mong 2	F_1	3.03	0.86	15.92*	-0.41	1.29*	5.44	0.09	2.13
	F_2	-3.12	0.77	2.55	0.66	0.05	4.45	-0.03	0.73
	F_3	0.39	0.38	12.05*	-0.58	0.01	2.67	0.04	-0.20
x Mong 3	F_1	-3.03	-0.86	-15.92*	0.41	-1.29*	-5.44	-0.09	-2.13
	F_2	3.12	-0.77	-2.85	-0.66	-0.05	-4.55	0.03	-0.73
	F_3	-0.39	-0.38	-12.05*	0.58	-0.01	-2.67	-0.04	0.20
NP 846 x Mong 2	F_1	-0.64	-0.97	-2.08	-0.91	-0.36	-1.13	-0.03	-1.51
	F_2	-2.46	-2.24*	1.47	0.44	-0.29	0.53	-0.01	-0.38
	F_3	-1.29	-1.12	-2.22	-0.58	-1.60*	7.32*	0.05	2.10
x Mong 3	F_1	0.64	0.97	2.08	0.91	0.36	1.13	0.03	1.51
	F_2	2.46	2.24*	-1.47	-0.44	0.29	-0.53	0.01	0.38
	F_3	1.29	1.12	2.22	0.58	1.60*	-7.32*	-0.05	-2.10
NP 401 x Mong 2	F_1	-0.47	1.20	-13.08*	-0.91	-0.44	-7.58	-0.01	-2.74
	F_2	2.21	-1.06	-0.98	0.44	-0.32	-5.04	0.05	-0.95
	F_3	-2.29	-1.82	-19.07*	0.81	-1.31	-9.12*	6.37*	-1.25
x Mong 3	F_1	0.47	-1.20	13.08*	0.91	0.44	7.58	0.01	2.74
	F_2	-2.21	1.06	0.98	-0.44	0.32	5.04	-0.05	0.95
	F_3	2.29	1.82	19.07*	-0.81	1.31	9.12*	-6.37*	1.25
r (per se performance and combining ability effects of progenies)	F_1	0.25	0.62*	0.54*	0.59*	0.35	0.48*	-0.02	-0.002
	F_2	0.32	0.40	0.90*	0.42	0.55*	-0.24	0.38	-0.17
	F_3	-0.12	0.49*	0.20	0.42	0.52*	0.61*	-0.14	0.61*
SE± e_{ij}	F_1	1.69	1.34	4.60	1.05	0.53	4.34	0.16	1.97
	F_2	2.10	1.04	3.82	0.84	0.48	2.67	0.16	1.18
	F_3	1.74	1.18	4.84	0.68	0.79	2.78	0.19	1.07

*Significant at $P \leq 0.05$

showed significant sca effects. However, in F_3 generation, 5 crosses, viz., Kharchia 65 x Mong 2, K 7340 x Mong 3, LSW 26 x Mong 2, Mukta x Mong 2 and NP 401 x Mong 3 showed significant and positive sca effects. The cross combination of these females with the other tester exibited significant and negative sca effects.

4.4.4 Spikes/plant

The values for sca effects for spikes/plant were found to be non-significant for all the crosses in the three generations.

4.4.5 Spike length

Specific combining ability effects for all the crosses in the F_1 and F_2 generations were found to be non-significant, except for the cross combination of Mukta with Mong 2 and Mong 3 in the F_1 generation. In the former cross the sca effects was significantly positive while in the latter the value observed was significantly negative. Only two crosses, NP 846 x Mong 2 and NP 846 x Mong 3, exibited significantly negative and positive sca effects, respectively, for this trait in the F_3 generation.

4.4.6 Grains/spike

The sca effects were found to be non-significant in all the crosses in the F_1 generation. In F_2 generation, only two crosses, LSW 26 x Mong 3 and LSW 26 x Mong 2 showed significantly positive and negative sca effects, respectively. In the F_3 generation, eight crosses exibited significant sca effects. While the sca effects for Narmada 4 x Mong 2, LSW 26 x Mong 3, NP 846 x Mong 2 and NP 401 x Mong 3 were significantly positive,

they were, however negatively significant for Narmada 4 x Mong 3, LSW 26 x Mong 2, NP 846 x Mong 3 and NP 401 x Mong 2.

4.4.7 100-grain weight

None of the crosses showed significant sca effects in the F_1 generation. In the F_2 and F_3 generations also, sca effects were found to be non-significant in most of the cases. However, for Narmada 4 x Mong 2 and Narmada 4 x Mong 3 sca effects were found to be significantly positive and negative, respectively in the F_2 generation. Likewise, sca effects for cross combination of NP 401 with Mong 2 and Mong 3 were significantly positive and negative, respectively in the F_3 generation.

4.4.8 Grain yield/plant

None of the values of sca effects for different crosses were found to be significant in any of the generations studied. Correlation coefficients between per se performance and combining ability were found significant for days to maturity in F_1 and F_3 generations, for plant height in F_1 and F_2 generations, for spikes/plant in F_1, for spike length in all the three generations, for grains/spike and grain yield in F_3 generation only.

4.5 Heterosis

Estimates of heterosis over mid-parent and better parent in the F_1 and F_2 generations are presented in Table 5. The results obtained have been described below character-wise :

Table 5. Estimates of heterosis (%) over mid-parent (MP) and better parent (BP) in the F_1 and F_2 generations

Cross	Generation	Days to flowering		Days to maturity		Plant height		Spikes/plant		Spike length		Grains/spike		100-grain weight		Grain yield/plant	
		MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
1	2	3		4		5		6		7		8		9		10	
MP 195 x Mong 2	F_1	-4.06*	6.28*	0.27	1.84	-2.29	24.18*	16.33	-16.48	1.40	-13.98*	8.27	4.84	2.72	-15.38*	27.40	15.83
	F_2	-0.62	11.48*	-1.00	0.55	-8.59	16.20*	-34.69	-53.11*	-3.07	-12.77*	-7.58	-10.50	2.72	-15.39*	5.82	-14.42
x Mong 3	F_1	-5.48*	6.01*	0.00	1.47	-6.43	23.21*	47.83*	22.78	0.66	-17.43*	14.19	10.43	9.61*	1.28	48.17*	43.92
	F_2	-2.07	9.84*	-0.73	0.74	-11.91*	15.99*	-2.34	-18.89	-10.23	-26.36*	2.16	-1.21	7.47	-3.21	-1.91	-7.73
Narmada 4 x Mong 2	F_1	-3.85*	7.50*	0.37	2.81*	-5.27	15.78*	-2.15	-32.23*	-2.14	-18.72*	20.75	4.53	2.11	-11.03*	14.38	-16.88
	F_2	-3.35	15.26*	0.00	2.43*	-9.71	11.57	-26.46	-49.08*	-7.28	-22.99*	11.70	-3.30	12.24*	-2.21	-4.42	-29.90
x Mong 3	F_1	-2.33	10.56*	1.37	3.75*	-1.50	24.60*	52.28*	20.56	-0.54	-20.04*	18.95	3.10	6.51	2.21	52.09	16.89
	F_2	0.12	13.33*	0.09	2.25*	-8.02	16.35*	-0.35	-21.11	-10.03	-27.67*	7.73	-6.63	-4.22	-9.09	-23.08	-40.83
TMI 4 x Mong 2	F_1	-6.68*	1.59	1.47	4.75*	-1.42	38.89*	-16.56	-30.76*	9.17	-5.49	12.16	10.35	9.33	-3.81	14.64	3.17
	F_2	-2.80	5.82*	-0.37	2.85*	-0.67	39.95*	-41.72*	-51.65*	-13.54*	-25.12*	-1.42	-3.01	10.22	0.00	-22.16	-29.90
x Mong 3	F_1	-5.16*	4.50*	1.75*	4.94*	-2.48	42.64*	31.11	31.11	0.26	-16.12*	17.00	15.27	6.83	0.27	44.81	39.19
	F_2	-3.48*	6.35*	0.28	3.42*	-11.29*	29.76*	-42.22*	-42.22	-12.50*	-26.80*	7.92	6.12	10.04	9.60	-26.17	-29.03
OL 20-9 x Mong 2	F_1	-6.05*	4.40*	-0.36	0.73	-2.31	46.97*	1.26	-26.37	5.40	-5.21	21.37	-9.41	9.80*	-9.09*	37.02	4.66
	F_2	-3.50	7.14*	-0.90	0.18	-12.50*	31.56*	-36.52*	-53.85*	-3.03	-12.80*	33.01*	-0.72	-1.18	-18.18*	-21.70	-40.19
x Mong 3	F_1	-4.02*	8.00*	0.45	1.46	-4.20	62.97*	33.55	12.78	2.51	-11.11*	59.69*	19.30	10.79	-7.79	84.03*	47.92
	F_2	-1.34	10.99*	-1.90*	-0.91	-7.08	45.32*	-6.57	-21.11	-8.54	-20.70*	56.51*	16.93	6.09	3.90	34.03	7.77
Kharchia 65 x Mong 2	F_1	-1.61	9.67*	0.09	1.85	-3.43	12.44	-17.72	-28.57	6.96	-20.85*	9.15	5.82	7.32	-8.97	-4.65	-9.41
	F_2	0.12	11.60*	-0.64	1.11	-12.33	2.07	-53.16*	-59.34*	-13.93*	-26.78*	5.60	-8.48	7.32	-8.97	-35.20	-38.43
x Mong 3	F_1	-3.06*	9.39*	0.55	2.22*	-4.28	15.21*	0.26	-4.98	-3.05	-15.25*	9.38	6.20	1.49	-5.52	23.72	21.49
	F_2	-0.12	12.71*	-1.46*	0.18	-9.71*	8.68	-30.70	-34.33	-11.26*	-27.02*	-3.90	-6.70	-3.70	-10.34*	-20.04	-21.82
K 7340 x Mong 2	F_1	-6.65*	1.05	-0.36	1.29	-5.22	23.80*	-7.15	-21.61	-6.39	-14.93*	-16.46	-21.98	8.06	-9.84	5.54	0.00
	F_2	-3.26	4.71*	-0.73	0.92	-11.23*	15.95*	-41.87*	-50.92*	-7.95	-16.35*	2.90	-3.88	-3.23	-12.93*	-33.06	-36.94
x Mong 3	F_1	-5.38*	3.67*	1.18	2.77*	-5.01	28.61*	34.78*	31.95	1.99	-10.68	7.78	0.79	-7.35	-14.29*	18.14	16.39
	F_2	-2.51	6.81*	-1.00	0.55	-8.35	24.09*	-13.04	-14.89	-10.45*	-21.57*	22.80*	14.84	2.21	-5.44	2.83	1.31
Pitic 62 x Mong 2	F_1	-11.66*	-2.70	0.82	3.39*	-6.30	37.24*	-0.22	-18.22	-7.65	-21.33*	2.09	0.22	-4.69	-21.29*	-1.95	-4.70
	F_2	-1.35	8.65*	-0.82	1.69	-11.30*	14.52	-51.23*	-60.07*	-6.82	-21.62*	27.55*	-28.88*	3.78	-16.77*	-25.53	-65.47*
x Mong 3	F_1	-5.70*	5.14*	0.18	2.63*	-6.30	25.36*	9.61	7.79	-4.76	-21.57*	16.53	14.55	-1.43	-10.17*	19.15	8.29
	F_2	-3.03	8.11*	-1.65*	0.75	-10.96*	19.12*	-28.24	-29.44	-12.17*	-27.67*	6.93	5.12	2.14	-7.74	-80.72	-32.32
LSW 26 x Mong 2	F_1	-8.59*	2.51	-2.76*	0.19	-0.51	28.75*	-11.78	-35.53*	13.58	-7.82	-21.44	-34.05*	16.24*	2.26	-6.84	-2.99
	F_2	-5.85*	5.59*	-2.02*	0.95	-9.55	15.86*	-35.84	-53.11*	1.61	-17.54*	-30.50*	-41.67*	11.11*	-2.26	-35.30	-51.36*
x Mong 3	F_1	-6.52*	6.15*	0.64	3.60*	-6.26	24.41*	33.33	13.33	9.97	-13.51*	20.79	1.51	14.73*	11.28*	108.12*	64.53*
	F_2	-4.55*	8.38*	-2.48*	0.38	-10.74*	18.46*	-9.80	-23.33	1.39	-22.44*	37.93*	15.92	17.05*	13.53*	-37.51	8.78
Mukta x Mong 2	F_1	-2.10	8.79*	0.36	0.73	-1.23	17.44*	11.70	-14.28	4.99	-7.82	8.63	6.75	0.79	-15.89*	14.65	12.31
	F_2	-5.56*	4.95*	-1.26	-0.18	-5.42	12.42	-25.54	-42.86*	-3.91	-15.64*	-5.34	-6.97	7.14	-10.60*	-20.37	-22.34
x Mong 3	F_1	-5.49*	6.32*	-0.63	0.37	-31.53*	-15.81*	71.77*	55.56*	-15.17*	-28.10*	0.59	-1.01	-5.07	-13.25*	11.40	6.12
	F_2	-0.86	11.54*	-2.08*	-1.10	-11.11*	9.29	-19.02	-26.67	-6.43	-20.70*	-6.44	-7.93	7.25	-2.00	-10.75	-14.99
NP 846 x Mong 2	F_1	-5.26*	4.03*	0.27	1.84	-1.65	15.57*	16.70	-19.93	-1.53	-9.00	-8.74	-12.29	0.41	-14.09*	-9.52	-11.05
	F_2	-2.57	6.99*	-3.72*	-2.21*	-0.34	13.31*	-36.03*	-38.51*	-12.31*	-18.96*	-22.27*	-25.29*	2.88	-11.97*	-35.45	-36.54
x Mong 3	F_1	-3.27*	7.53*	2.00*	3.50*	-3.20	21.23*	31.51*	73.89*	-3.79	-7.63	12.50	8.29	-0.37	-6.34	52.83*	40.51
	F_2	-1.09	12.37*	-1.27	0.18	-4.14	12.60*	-28.15	-42.23*	-9.43	-19.39*	-5.84	-9.37	2.62	-3.52	-6.53	-14.16
NP 401 x Mong 2	F_1	-7.81*	2.76	0.92	3.98*	-23.54*	-4.48	-9.98	-28.94	-13.22*	-25.36*	-25.60*	-35.99	23.42*	13.22*	17.47	-9.41
	F_2	-0.87	10.50*	-0.37	2.65*	-8.03	14.90*	-52.20*	-52.27*	-9.37	-22.04*	-13.15	-25.29	18.92*	9.09	4.20	-26.12
x Mong 3	F_1	-6.00*	6.08*	0.28	3.23*	-0.86	28.34*	20.11	12.79	-5.64	-21.57*	30.49*	12.39	19.51*	17.60*	134.93*	90.88*
	F_2	-4.04*	8.29*	0.83	3.79*	-7.32	19.90*	33.73	25.56	-5.90	-21.79*	33.17*	14.70	13.82*	15.70*	51.77*	23.31
SE±	F_1	1.96	2.26	1.57	1.81	5.58	6.44	1.21	1.40	0.79	0.91	5.20	6.00	0.19	0.22	2.17	2.49
	F_2	2.33	2.70	1.32	1.52	5.39	6.22	1.21	1.40	0.67	0.77	4.45	5.14	0.21	0.25	2.22	2.57

*Significant at $P < 0.05$

4.5.4 Spikes/plant

On comparing F_1 hybrids with their mid-parents, cross combinations of MP 195, Narmada 4, K 7340, Mukta and NP 846 with Mong 3 exhibited significantly positive heterosis. Heterotic values for the remaining crosses were found to be non-significant. In the F_2 generation, significant heterosis was obtained for 8 crosses, however, none of the values was positive.

Five crosses, viz., Narmada 4 x Mong 2, TMI 4 x Mong 2, LSW 26 x Mong 2, Mukta x Mong 3 and NP 846 x Mong 3 showed significant heterosis over the better parent in the F_1 generation. However, positive values were recorded only for the last 2 crosses. In the F_2 generation, as-many-as 12 crosses showed significant heterosis, but none of the values was positive.

4.5.5 Spike length

In the F_1 generation, two crosses Mukta x Mong 3 and NP 401 x Mong 2 showed significantly negative heterosis over the mid-parent. The heterotic values for the remaining crosses were found to be non-significant. In the F_2 generation, TMI 4 x Mong 2 TMI 4 x Mong 3, Kharchia 65 x Mong 2, Kharchia 65 x Mong 3, K 7340 x Mong 3, Pitic 62 x Mong 3 and NP 846 x Mong 2, showed significant heterosis, but all the values were negative.

When compared to the respective better parent, none of the hybrids exhibited significant and positive heterosis in the F_1 and F_2 generations. However, 15 crosses in the F_1 and 22 crosses in the F_2 showed significantly negative heterosis over the better parent.

4.5.6 Grains/spike

Heterosis over the mid-parent in the F_1 generation was observed only for 3 crosses, however, positive values were obtained for 2 crosses, DL 20-9 x Mong 3 and NP 401 x Mong 3. In the F_2 generation, the cross combinations of DL 20-9 with Mong 2 and Mong 3, K 7340 with Mong 3 and Pitic 62 with Mong 2, showed significant and positive heterosis over the better parent. However, heterotic values were negative in the cross combinations of LSW 26 and NP 846 with Mong 2.

Only two crosses, LSW 26 x Mong 2 and NP 401 x Mong 2, showed significant heterosis over the better parent in the F_1 generation. Heterotic values in both these crosses were negative. In the F_2 generation also, none of the crosses showed significantly positive heterosis over the better parent. However, three crosses, Pitic 62 x Mong 2, LSW 26 x Mong 2 and NP 846 x Mong 2, delineated significant and negative heterosis over the respective better parent.

4.5.7 100-grain weight

Six crosses, viz., MP 195 x Mong 3, DL 20-9 x Mong 2, LSW 26 x Mong 2, LSW 26 x Mong 3, NP 401 x Mong 2 and NP 401 x Mong 3, showed significant and positive heterosis over the respective mid-parent in the F_1 generation. Heterotic values for the remaining crosses were non-significant. In the F_2 generation, the cross combinations of LSW 26 and NP 401 with Mong 2 and Mong 3, and Narmada 4 with Mong 2 excelled the mid-parent significantly. For the remaining crosses, heterosis was found to be non-significant.

When compared with the better parent, 12 crosses showed significant heterotic values in the F_1 generation. Of these only 3 crosses, viz., LSW 26 x Mong 3, NP 401 x Mong 2 and NP 401 x Mong 3, exhibited significantly positive values. In the F_2 generation, 9 crosses exhibited heterosis over the better parent but positive heterosis was observed only for 2 crosses, i.e., LSW 26 x Mong 3 and NP 40 x Mong 3.

4.5.8 Grain yield/plant

In the F_1 generation, heterotic values over the mid-parent were found to be significant and positive for 5 crosses, viz., MP 195 x Mong 3, DL 20-9 x Mong 3, LSW 26 x Mong 3, NP 846 x Mong 3 and NP 401 x Mong 3. Per cent heterosis for remaining cross combination was non-significant. In the F_2 generation only one cross, i.e., NP 401 x Mong 3, exhibited significant positive heterosis, and for the remaining 21 crosses, heterotic values were non-significant.

Only two crosses, LSW 26 x Mong 3 and NP 401 x Mong 3, exhibited significant and positive heterosis over the better parent in the F_1 generation. Heterotic values for the remaining crosses were non-significant. In the F_2 generation, significant heterotic values of the two crosses, LSW 26 x Mong 2 and Pitic 62 x Mong 2, were negative. In the remaining crosses heterosis over the better parent was non-significant.

4.6 Estimates of scaling tests and gene effects

Digenic intractions using 5-parameter model, were calculated only for those crosses where scaling tests showed significant values of C and/or D. The results obtained have been described hereunder.

4.6.1 Days to flowering

Scaling test C was significant only for two crosses, Kharchia 65 and NP 846 with Mong 2, whereas test D was significant for 12 cross combinations. Both the tests were significant for MP 195 x Mong 3 and DL 20-9 x Mong 2 only (Table 6).

Parameters m and (d) were significant for all the crosses. Nine crosses combinations showed significant value of parameter (h). Cross combinations of Narmada 4 and DL 20-9 with Mong 2, and TMI 4 and Kharchia 65 with Mong 3 were significant for both (i) and (l) parameters. Four combinations, viz., Kharchia 65 and NP 846 with Mong 2 and Narmada 4 and NP 846 with Mong 3 exibited significant values of (i). Significant value of (l) alone was obtained for the cross combinations of MP 195, K 7340, Mukta and NP 401 with Mong 2 and MP 195 and K 7340 with Mong 3.

4.6.2 Days to maturity

Nine cross combinations, viz., DL 20-9, LSW 26, Mukta, NP 846 and NP 401 with Mong 2, and Kharchia 65, LSW 26, Mukta and NP 846 with Mong 3 showed significant values of C test, whereas two crosses, Mukta x Mong 3 and LSW 26 x Mong 3 exibited significant value of C and D tests (Table 7).

All the cross combinations showed significant values for m and (d). Significant value of (h) was observed for 3 crosses, viz., K 7340 x Mong 2, Mukta x Mong 3 and NP 846 x Mong 2.

Table 6. Estimates of scaling tests and gene effects for days to flowering

Crosses	Scaling tests		Gene effects				
	C	D	m	(d)	(h)	(i)	(l)
MP 195 x Mong 2	14.33	-40.90*	136.00*	-13.17*	24.23*	3.40	-73.79*
x Mong 3	28.35*	-20.23*	138.67*	-14.17*	13.13*	-10.02	-64.93*
Narmada 4 x Mong 2	2.99	-44.99*	133.33*	-11.17*	24.10*	-22.43*	-63.97*
x Mong 3	-2.98	-20.32*	130.00*	-13.51*	4.90	-25.53*	-22.12
TMI 4 x Mong 2	5.68	-10.34	134.67*	-13.83*	5.34	-	-
x Mong 3	0.32	-41.00*	133.33*	-10.50*	8.23	-31.16*	-55.09*
DL 20-9 x Mong 2	24.34*	-39.66*	134.00*	-12.50*	14.67*	-37.17*	-85.33*
x Mong 3	-8.32	-28.98*	126.00*	-14.50*	6.43	-11.07	-27.54
Kharchia 65 x Mong 2	-24.34*	-16.32	127.33*	-13.50*	3.99	-20.18*	10.69
x Mong 3	0.35	-40.35*	132.67*	-12.17*	19.79*	-24.51*	-54.27*
K 7340 x Mong 2	16.32	-48.98*	133.33*	-13.83*	24.87*	7.71	-87.07*
x Mong 3	3.67	-29.67*	134.00*	-14.84*	12.89*	-9.28	-44.45*
Pitic 62 x Mong 2	6.99	-12.99	136.00*	-15.84*	6.66	-	-
x Mong 3	-5.01	-12.35	134.00*	-12.84*	0.23	-	-
LSW 26 x Mong 2	3.70	-15.64	134.67*	-15.18*	5.55	-	-
x Mong 3	7.66	-27.02*	136.00*	-15.50*	15.12*	-11.68	-36.24
Mukta x Mong 2	1.00	-109.68*	136.00*	-12.17*	65.79*	7.49	-147.57*
x Mong 3	-1.02	-10.98	133.33*	-14.17*	-0.73	-	-
NP 846 x Mong 2	-23.02*	-4.34	125.33*	-16.17*	-9.77	-33.29*	24.91
x Mong 3	10.32	-18.28*	135.33*	-15.17*	6.45	-35.50*	-38.21
NP 401 x Mong 2	14.99	-26.33*	139.33*	-13.84*	1.55	2.38	-55.09*
x Mong 3	-5.66	-8.36	130.67*	-15.50*	-3.54	-	-
SE±	9.37	8.47	2.10	1.20	6.36	6.57	19.72

*Significant at $P \leq 0.05$

Table 7. Estimates of scaling tests and gene effects for days to maturity

Crosses	Scaling tests		Gene effects				
	C	D	m	(d)	(h)	(i)	(l)
MP 195 x Mong 2	-8.33	4.33	182.00*	-2.84*	-3.78	-	-
x Mong 3	-1.35	-6.67	182.33*	-4.34*	-4.01	-	-
Narmada 4 x Mong 2	-8.02	10.66	180.33*	-5.67*	-5.79	-	-
x Mong 3	-5.34	4.66	183.00*	-2.00*	-4.67	-	-
TMI 4 x Mong 2	-5.02	-0.98	182.33*	-3.17*	-0.01	-	-
x Mong 3	-4.02	0.00	182.33*	-3.00*	-1.34	-	-
DL 20-9 x Mong 2	-9.00*	1.00	180.67*	-4.50*	-0.66	-11.16*	54.13*
x Mong 3	-4.65	-3.33	172.67*	-5.34*	-3.56	-	-
Kharchia 65 x Mong 2	-8.02	-0.68	182.33*	-2.00*	-1.55	-	-
x Mong 3	-28.33*	2.33	177.00*	-2.84*	-5.78	-11.45*	65.07*
K 7340 x Mong 2	-5.99	-10.69	180.67*	-5.34*	7.84*	-	-
x Mong 3	-5.19	1.25	182.37*	-2.67*	-1.69	-	-
Pitic 62 x Mong 2	-5.67	-7.01	182.00*	-4.17*	6.23	-	-
x Mong 3	-4.34	10.06	181.33*	-5.50*	-7.13	-	-
LSW 26 x Mong 2	-15.66*	-7.00	181.00*	-1.83*	2.89	-4.95	-17.87
x Mong 3	-12.64*	65.32*	180.67*	-3.00*	-4.65	-11.65*	28.16
Mukta x Mong 2	-11.66*	9.66	181.67*	-2.83*	-6.21	-14.05*	-53.92*
x Mong 3	-12.66*	16.68*	179.00*	-4.33*	-12.90*	-21.89*	30.53*
NP 846 x Mong 2	-20.31*	9.65	176.67*	-5.16*	-8.65*	-18.65*	-13.49
x Mong 3	-12.98*	2.98	180.67*	-1.83*	-5.32	-7.81*	31.09*
NP 401 x Mong 2	-16.67*	6.01	181.33*	-2.67*	-3.12	-12.12*	0.67
x Mong 3	5.01	1.65	182.67*	-5.17*	0.24	-	-
SE±	4.97	5.07	1.02	0.82	3.63	3.63	10.47

*Significant at $P \leq 0.05$

Both (i) and (l) parameters were significant for 5 crosses, viz., DL 20-9 x Mong 2, Kharchia 65 x Mong 3, Mukta x Mong 2, Mukta x Mong 3 and NP 846 x Mong 3. Parameter (i) alone was significant for 3 crosses (LSW 26 x Mong 3, NP 846 x Mong 3 and NP 401 x Mong 2), whereas none of the crosses exhibited significant value of (l) alone.

4.6.3 Plant height

None of the 22 crosses showed significant values of both C and D tests (Table 8). Test C alone, was significant for 5 crosses, viz., Narmada 4 x Mong 3, TMI 4 x Mong 2, DL 20-9 x Mong 2, DL 20-9 x Mong 3 and Pitic 62 x Mong 3, whereas cross combinations of TMI 4, LSW 26 and NP 846 with Mong 3, and K 7340 and NP 846 with Mong 2, exhibited significant values of test D.

Parameters m and (d) were significant for all the cross combinations, and (h) was significant for 5 crosses, viz., TMI 4 x Mong 3, K 7340 x Mong 2, LSW 26 x Mong 3, NP 846 x Mong 2 and NP 846 x Mong 3. Both, (i) and (l) parameters were significant for the cross combinations of DL 20-9 and K 7340 with Mong 2, and Narmada 4, Pitic 62, LSW 26 and NP 846 with Mong 3. Significant value of parameter (i) alone was observed for 2 crosses, i.e., TMI 4 x Mong 2 and DL 20-9 x Mong 3, whereas none of the crosses showed significant value for (l) parameter alone.

4.6.4 Spikes/plant

For this character scaling test C alone was significant for the cross combinations of Narmada 4, DL 20-9, Kharchia 65,

Table 8. Estimates of scaling tests and gene effects for plant height

Crosses	Scaling tests		Gene effects				
	C	D	m	(d)	(h)	(i)	(l)
MP 195 x Mong 2	-30.88	1.38	94.97*	-22.15*	-8.45	-	-
x Mong 3	-25.88	-12.84	97.37*	-19.38*	-1.37	-	-
Narmada 4 x Mong 2	-3.86	13.90	97.03*	-28.35*	-10.62	-	-
x Mong 3	-43.04*	32.18	82.53*	-31.65*	-30.81	-71.93*	100.29*
TMI 4 x Mong 2	-46.92*	6.64	96.83*	-15.58*	-16.03	-53.41*	71.41
x Mong 3	-35.34	-63.12*	90.60*	-23.93*	30.86*	-11.67	-37.04
DL 20-9 x Mong 2	-59.44*	40.64	91.23*	-23.18*	-30.52	-83.38*	133.44*
x Mong 3	-40.50*	-12.70	93.50*	-22.66*	-14.67	-60.53*	70.93
Kharchia 65 x Mong 2	-20.91	5.41	102.87*	-17.26*	-8.43	-	-
x Mong 3	-5.32	-10.76	112.10*	-13.55*	8.19	-	-
K 7340 x Mong 2	15.73	-144.71*	96.63*	-20.97*	74.36*	56.17*	-213.92*
x Mong 3	-36.17	-29.11	94.80*	-25.89*	5.83	-	-
Pitic 62 x Mong 2	-32.11	0.05	101.53*	-23.12*	-7.04	-	-
x Mong 3	-40.79*	23.93	89.96*	-32.09*	-25.27	-86.92*	86.29*
LSW 26 x Mong 2	-36.05	-14.15	91.16*	-35.39*	7.54	-	-
x Mong 3	-34.57	-122.05*	103.10*	-19.32*	70.72*	-130.73*	-491.64*
Mukta x Mong 2	-24.73	-2.47	97.00*	-27.67*	-7.78	-	-
x Mong 3	-33.31	-34.85	94.90*	-26.92*	8.30	-	-
NP 846 x Mong 2	-32.60	-92.88*	95.60*	-26.40*	49.79*	3.68	-80.37
x Mong 3	20.94	-108.60*	100.00*	-21.00*	40.42*	33.89*	-172.72*
NP 401 x Mong 2	-26.69	-14.71	111.40*	-17.29*	9.07	-	-
x Mong 3	-30.14	-23.66	100.83*	-24.70*	9.88	-	-
SE±	18.99	21.81	3.82	3.25	15.31	14.64	41.84

*Significant at $P \leq 0.05$

K 7340 and Mukta with Mong 2, and Narmada 4, TMI 4, Kharchia 65, Pitic 62, LSW 26, Mukta and NP 846 with Mong 3. Both scaling tests (C and D) were significant for the cross combinations of MP 195 and NP 401 with Mong 2, whereas D alone was not significant in any of the crosses (Table 9).

Parameters m and (d) were significant for all the crosses, except Mukta x Mong 2, Kharchia 65 x Mong 3, LSW 26 x Mong 3, NP 846 x Mong 3 and NP 401 x Mong 3, for which parameter (d) was found to be non-significant. Parameter (h) was non-significant for all the cross combinations. Both parameters (i) and (l) were significant for 3 crosses, i.e., MP 195 x Mong, TMI 4 x Mong 3 and DL-9 x Mong 2. Besides, (i) alone was significant for Narmada 4 x Mong 3, and (l) alone was significant for the cross combinations of Narmada 4 with Mong 2, and Pitic 62 and NP 846 with Mong 3.

4.6.5 Spike length

Scaling test C alone was significant for the cross combinations of Narmada 4, TMI 4, Pitic 62, LSW 26, Mukta and NP 401 with Mong 2, and Kharchia 65, K 7340, Pitic 62 and LSW 26 with Mong 3. Only one cross, K 7340 x Mong exhibited significant value of test D alone (Table 10). Both the scaling tests C and D were significant for one cross only, i.e., Kharchia 65 x Mong 3.

Significant values for m and (d) parameter were observed for all the crosses studied, whereas (h) parameter was significant only for 2 crosses, i.e., Kharchia 65 x Mong 3 and K 7340 x Mong 2. Both the parameters (i) and (l) were

Table 9. Estimates of scaling tests and gene effects for tillers/plant

Crosses	Scaling tests		Gene effects				
	C	D	m	(d)	(h)	(i)	(l)
MP 195 x Mong 2	-11.01*	9.19*	4.27*	-2.57*	-1.59	-7.73*	16.27*
x Mong 3	-6.42	4.86	4.63*	-2.70*	-3.75	-	-
Narmada 4 x Mong 2	-10.10*	2.90	4.40*	-1.55*	-4.87	-6.72	17.33*
x Mong 3	-9.83*	1.45	4.20*	-2.49*	-2.52	-7.66*	15.04
TMI 4 x Mong 2	2.0	0.68	4.70*	-2.20*	-2.85	-	-
x Mong 3	-9.75*	4.49	4.47*	-2.42*	-4.17	-9.45*	18.99*
DL 20-9 x Mong 2	-14.63*	2.92	3.63*	-1.65*	-4.51	-7.78*	24.21*
x Mong 3	-7.96	4.76	4.27*	-2.45*	1.07	-	-
Kharchia 65 x Mong 2	-8.77*	3.35	5.20*	-2.15*	-2.88	-7.63	16.16
x Mong 3	-10.49*	1.01	6.07*	0.39	-4.01	-1.65	15.33
K 7340 x Mong 2	-11.59*	1.95	3.93*	-1.92*	-1.35	-4.46	12.85
x Mong 3	-8.33	-2.93	4.87*	-2.58*	1.40	-	-
Pitic 62 x Mong 2	-8.14	0.34	4.73*	-2.80*	-0.27	-	-
x Mong 3	-16.96*	-2.44	3.47*	-1.56*	-0.88	-4.30	19.36*
LSW 26 x Mong 2	-7.85	-5.09	4.73*	-2.49*	2.24	-	-
x Mong 3	-10.94*	-5.52	4.40*	1.20	0.33	-0.55	7.23
Mukta x Mong 2	-10.59*	-0.15	5.33*	1.42	-1.08	-7.50	13.92
x Mong 3	-10.92*	-5.88	4.23*	1.65*	1.12	-1.20	6.72
NP 846 x Mong 2	-8.50	-4.90	4.60*	2.45*	2.00	-	-
x Mong 3	-15.03*	6.55	4.40*	-1.12	-4.53	-7.10	28.77*
NP 401 x Mong 2	-17.03*	-7.85*	5.70*	0.39	3.34	3.17	12.24
x Mong 3	3.11	-4.23	7.53*	-1.92*	2.77	-	-
SE±	4.23	3.53	0.84	0.74	2.56	3.84	8.13

*Significant at $P \leq 0.05$

Table 10. Estimates of scaling tests and gene effects for spike length

Crosses	Scaling tests		Gene effects				
	C	D	m	(d)	(h)	(i)	(l)
MP 195 x Mong 2	-1.79	-0.73	11.57*	-2.14*	0.35	-	-
x Mong 3	-2.91	1.49	10.83*	-2.39*	-1.73	-	-
Narmada 4 x Mong 2	-8.85*	1.37	10.53*	-1.89*	-1.27	-6.16*	13.63*
x Mong 3	-2.88	2.44	12.27*	-1.42*	-1.43	-	-
TMI 4 x Mong 2	-5.00*	-1.86	10.30*	-2.10*	-0.43	-3.88	4.52
x Mong 3	-2.43	-4.43	11.77*	-1.29*	1.73	-	-
DL 20-9 x Mong 2	-1.33	-0.49	11.17*	-2.14*	-0.77	-	-
x Mong 3	3.10	-0.86	12.97*	-2.65*	2.64	-	-
Kharchia 65 x Mong 2	-3.16	-3.64	11.87*	-1.72*	2.52	-	-
x Mong 3	-6.00*	13.08*	11.40*	-1.07*	-9.92*	-11.96*	25.44*
K 7340 x Mong 2	-3.52	-11.92*	10.92*	-1.97*	6.76*	-0.60	-11.20
x Mong 3	-5.28*	-3.24	11.27*	-2.75*	1.36	-4.22	2.72
Pitic 62 x Mong 2	-4.78*	-2.62	11.07*	-3.00*	0.88	-5.05	2.88
x Mong 3	-6.46*	-0.40	11.20*	-2.50*	-0.78	-5.81	8.05
LSW 26 x Mong 2	-9.21*	0.69	11.13*	-2.04*	-1.66	-3.57	13.20*
x Mong 3	-6.43*	-1.23	11.17*	-2.72*	0.13	-5.64	6.93
Mukta x Mong 2	-6.14*	-1.32	12.00*	-1.90*	0.13	-3.95	6.43
x Mong 3	-4.92	1.46	11.07*	-2.70*	-2.39	-	-
NP 846 x Mong 2	2.39	-2.81	13.23*	-3.27*	3.47	-	-
x Mong 3	-1.41	-3.51	12.13*	-2.34*	1.14	-	-
NP 401 x Mong 2	-6.17*	-2.69	12.33*	-1.69*	1.28	-2.61	4.64
x Mong 3	-1.55	-4.69	11.97*	-2.59*	2.15	-	-
SE±	2.32	3.39	0.48	0.38	2.34	2.95	5.87

*Significant at $P \leq 0.05$

significant for the cross combinations of Narmada 4 with Mong 2 and Kharchia 65 with Mong 3. Besides, (l) alone was significant for LSW 26 x Mong 2.

4.6.6 Grains/spike

A perusal of Table 11 showed that both C and D tests were significant for one cross only, i.e., NP 846 x Mong 2. Besides, test C alone was significant for the cross combinations of DL 20-9, LSW 26 and Mukta with Mong 2, and Narmada 4, DL 20-9, NP 401 and Kharchia 65 with Mong 3. Test D alone was significant for 2 crosses, TMI 4 x Mong 3 and K 7340 x Mong 2.

Parameter m was significant for all the crosses, whereas (d) was significant for the cross combinations of K 7340, LSW 26 and NP 846 with Mong 2, and Narmada 4, DL 20-9 and NP 401 with Mong 3. Parameter (h) was found to be significant for 5 crosses, viz., K 7340 x Mong 2, LSW 26 x Mong 2, NP 846 x Mong 2, Narmada 4 x Mong 3 and TMI 4 x Mong 3. Both (i) and (l) parameters were significant for 2 crosses, i.e., TMI 4 x Mong 3 and K 7340 x Mong 2. Parameter (i) alone was significant for NP 846 x Mong 2, whereas parameter (l) alone was significant for the cross combinations of Narmada 4 and Kharchia 65 with Mong 2 and Mong 3, respectively.

4.6.7 100-grain weight

Scaling test C was significant for 3 cross combinations, viz., NP 846 with Mong 2, and MP 195 and Kharchia 65 with Mong 3, whereas test D was significant for four combinations, viz., Narmada 4, K 7340 with Mong 2, and Narmada 4 and Mukta with Mong 3. Tests C and D were both significant only for one cross i.e. NP 846 x Mong 3 (Table 12).

Table 11. Estimates of scaling tests and gene effects for grains/spike

Crosses	Scaling tests		Gene effects				
	C	D	m	(d)	(h)	(i)	(l)
MP 195 x Mong 2	-20.47	-14.59	44.33*	1.57	9.95	-	-
x Mong 3	2.17	24.21	44.87*	-6.09	-7.45	-	-
Narmada 4 x Mong 2	-13.70	-8.90	45.00*	-0.75	9.20	-	-
x Mong 3	30.91*	-15.51	46.06*	-11.77*	22.89*	-8.04	-61.89*
TMI 4 x Mong 2	-6.19	-5.99	42.47*	-1.44	1.06	-	-
x Mong 3	19.33	-51.87*	44.60*	-3.07	30.67*	23.34*	-61.60*
DL 20-9 x Mong 2	-52.10*	-11.50	33.00*	-0.85	-0.07	-2.64	54.13
x Mong 3	-30.82*	-10.04	27.07*	-7.45*	6.80	-6.51	27.11
Kharchia 65 x Mong 2	-17.58	-3.54	43.17*	-0.80	3.36	-	-
x Mong 3	-31.92*	17.18	34.67*	-1.80	-18.67	-20.28	68.07*
K 7340 x Mong 2	-0.55	-61.69*	34.67*	-6.49*	30.89*	28.13*	-81.65*
x Mong 3	-9.48	20.76	48.93*	-1.63	-8.69	-	-
Pitic 62 x Mong 2	-2.80	-5.80	43.20*	-6.17	11.00	-	-
x Mong 3	-1.43	-1.09	49.10*	-0.69	8.23	-	-
LSW 26 x Mong 2	36.86*	-6.54	54.10*	-11.70*	31.13*	-12.90	-56.87
x Mong 3	-15.42	5.70	43.17*	-1.35	-2.16	-	-
Mukta x Mong 2	32.72*	-7.72	53.13	-3.00	3.76	-0.50	-53.92
x Mong 3	-2.45	20.45	48.63*	-0.79	-6.53	-	-
NP 846 x Mong 2	42.81*	33.09*	53.63*	-7.39*	-23.40*	-29.82*	-13.49
x Mong 3	-12.27	11.05	42.60*	-0.74	-9.15	-	-
NP 401 x Mong 2	-21.55	-21.05	41.93*	-1.74	16.01	-	-
x Mong 3	28.52*	9.36	53.07*	-6.42*	10.67	-12.06	-25.96
SE±	11.57	13.78	2.67	3.07	9.58	10.44	28.46

*Significant at $P \leq 0.05$

Table 12. Estimates of scaling tests and gene effects for 100-grain weight

Crosses	Scaling tests		Gene effects				
	C	D	m	(d)	(h)	(i)	(l)
MP 195 x Mong 2	0.23	0.11	4.40*	0.92*	0.08	-	-
x Mong 3	1.76*	-0.08	4.43*	0.58*	0.43	2.74*	-7.36*
Narmada 4 x Mong 2	0.82	2.18*	4.13*	0.38*	-0.93	-1.39*	5.20*
x Mong 3	-1.04	1.78*	4.20*	0.88*	-0.94	-1.48*	11.28*
TMI 4 x Mong 2	0.60	-0.72	4.90*	0.73*	0.88	-	-
x Mong 3	-0.13	0.79	4.27*	0.77*	-0.21	-	-
DL 20-9 x Mong 2	0.52	0.18	4.30*	0.90*	-0.23	-	-
x Mong 3	0.06	0.46	4.33*	0.73*	0.13	-	-
Kharchia 65 x Mong 2	1.14	0.20	4.50*	0.83*	0.35	-	-
x Mong 3	2.56*	1.30	4.70*	0.68*	-0.42	1.76*	-5.04*
K 7340 x Mong 2	1.06	4.46*	4.40*	0.33*	-1.94*	-4.43*	13.68*
x Mong 3	0.49	0.57	5.03*	0.52*	0.15	-	-
Pitic 62 x Mong 2	-0.28	0.56	4.17*	0.18	-0.31	-	-
x Mong 3	1.12	-0.64	5.57*	-0.02	0.89	-	-
LSW 26 x Mong 2	1.12	-1.51	4.97*	0.48*	1.28*	-	-
x Mong 3	-0.82	0.22	4.33*	0.33*	-0.21	-	-
Mukta x Mong 2	1.05	-1.01	4.63*	0.37*	0.51	-	-
x Mong 3	0.50	-1.78*	4.76*	0.50*	1.20	3.79*	-9.12*
NP 846 x Mong 2	1.66*	-0.14	4.03*	0.13	1.00	1.83*	-7.20*
x Mong 3	1.78*	-2.14*	4.93*	0.43*	1.49*	5.20*	-15.68*
NP 401 x Mong 2	0.52	0.36	5.57*	0.28*	-0.17	-	-
x Mong 3	0.68	0.68	4.67*	-0.07	-0.37	-	-
SE±	0.75	0.86	0.16	0.11	0.61	0.58	1.69

*Significant at P $\leq$ 0.05

Parameter m and (d) were significant for all the combinations, except for 4 crosses, i.e., Pitic 62 x Mong 2, Pitic 62 x Mong 3, NP 846 x Mong 2 and NP 401 x Mong 3 in which parameter (d) was non-significant. Parameter (h) was significant only for 3 crosses, viz., K 7340 x Mong 2, LSW 26 x Mong 2 and NP 846 x Mong 3. Both the parameters (i) and (l) were significant for the cross combinations of Narmada 4, K 7340 and NP 846 with Mong 2, and MP 195, Narmada 4, Kharchia 65, Mukta and NP 846 with Mong 3 only. Parameter (i) and (l) were not significant in any of the 22 crosses studied.

4.6.8 Yield/plant

Scaling test C was significant for 7 cross combinations, viz., TMI 4, DL 20-9 and Kharchia 65 NP 401 with Mong 2, and Narmada 4, TMI 4, Pitic 62 and Mukta with Mong 3, whereas test D was significant for one cross only, i.e., NP 846 x Mong 2 (Table 13). Both C and D tests were significant for cross, Kharchia 65 x Mong 3 only.

Parameter m was significat for all the crosses, whereas (d) was significant for the cross combinations of Pitic 62 and NP 846 with Mong 2, and MP 195 and DL 20-9 with Mong 3. Parameter (h) was significant for the cross combinations of Kharchia 65 and NP 401 with Mong 3. Both (i) and (l) parameters were significant for one cross only, i.e., Kharchia 65 x Mong 3. Parameter (l) alone was also found to be significant for DL 20-9 x Mong 2, whereas (i) alone was not significant in any of the crosses.

Table 13. Estimates of scaling tests and gene effects for grain yield/plant

Crosses	Scaling tests		Gene effects				
	C	D	m	(d)	(h)	(i)	(l)
MP 195 x Mong 2	-8.09	-4.81	9.73*	-1.04	2.29	-	-
x Mong 3	-3.85	6.02	7.17*	-3.04*	-1.09	-	-
Narmada 4 x Mong 2	-12.07	4.63	9.96*	-1.14	1.32	-	-
x Mong 3	-13.97*	1.31	6.80*	-2.69	0.01	-4.23	3.00
TMI 4 x Mong 2	-14.20*	-0.60	7.00*	-0.57	1.35	0.37	11.84
x Mong 3	-15.60*	-4.6	7.17*	-0.60	0.84	-0.82	14.56
DL 20-9 x Mong 2	-29.76*	3.3	4.17*	0.35	-4.34	-4.94	44.08*
x Mong 3	-10.52	-4.48	5.63*	-2.82*	0.49	-	-
Kharchia 65 x Mong 2	-12.21	0.79	8.87*	-0.24	-0.74	-	-
x Mong 3	-14.20*	13.52*	7.47*	0.20	-12.21*	-10.71*	36.45*
K 7340 x Mong 2	-4.54	-7.94	8.40*	-2.60	6.06	-	-
x Mong 3	-9.97	5.63	9.40*	-1.04	-0.80	-	-
Pitic 62 x Mong 2	-2.91	-2.03	8.83*	-3.04*	4.81	-	-
x Mong 3	-18.43*	1.55	7.00*	-1.14	1.74	-4.03	23.44
LSW 26 x Mong 2	-2.25	-5.25	10.63*	-2.69	7.31	-	-
x Mong 3	-12.76	0.70	8.00*	-0.59	-2.24	-	-
Mukta x Mong 2	-2.50	0.16	10.30*	-0.60	1.29	-	-
x Mong 3	-15.40*	-6.68	8.17*	-0.35	2.99	2.14	11.63
NP 846 x Mong 2	-5.14	-13.3*	10.73*	-2.82*	4.75	-7.78	9.33
x Mong 3	-6.83	4.97	9.27*	-2.24	-2.45	-	-
NP 401 x Mong 2	-14.30*	-5.56	10.10*	-0.20	7.03	2.07	11.65
x Mong 3	-5.02	-2.10	12.17*	-2.60	8.53*	-	-
SE±	6.75	5.63	1.18	1.39	3.93	4.52	12.22

*Significant at $P \angle 0.05$

5 DISCUSSION

Wheat is the most important crop of Himachal Pradesh and is being cultivated under diverse agroclimatic conditions. Most of the area (85%) under wheat is rainfed because of the scarcity of irrigation facilities. The crop sown during October remains under snow during winter in the high-altitude areas (above 1700 m amsl), and the spring wheats suffer considerably from cold injury. These two factors adversely affect the grain yield of spring wheats grown in different areas of the State. However, winter wheats are reported to have a great tolerance to drought as well as cold conditions (Rajaram and Skovmand, 1977). Besides, winter types have better root development and more photosythetic efficiency (Pinthus, 1967, Beste and Hodges, 1979, Bhatt, 1973) which can be transferred into spring wheats. Recently, a great interest has been generated in the intercrossing of spring wheats with winter wheats, and it is expected that this might help in surpassing the existing yield plateau by generating additional variability which has not been exploited much so far. This expectation seems to be based on a fairly sound ground as it is well known that the two wheat groups have rarely been brought together, and have been improved upon as distinct groups by exploiting variability within each group.

The material for the present investigation comprised 11 diverse lines of spring wheat, and three winter types of Mongolian origin. Spring types were crossed with the winter types during <u>rabi</u> 1982-83.

In general, spring types cannot be very easily crossed with winter types due to non-synchronization of flowering. However, under the Palampur conditions, mild winter types can be made to cross successfully with spring wheats by manipulating the sowing dates. In the present study one of the testers (Mong 1), being extreme winter type, could not be successfully crossed with all the lines of spring wheat even after manipulating the sowing dates. So, a complete set of 22 crosses (involving 11 lines and 2 testers) was studied in the F_1, F_2 and F_3 generations to estimate the general and specific combining ability effects, extent of heterosis over the mid-parent and better parent (in the F_1 and F_2 generations) and gene effects for yield and its associated traits. This type of study is important for the appraisal of breeding materials, and elimination of progenies of low potential. This is because all breeding programmes have size limitations, and elimination of poor materials enhances the probability of finding superior segregates in the remaining materials (Allard, 1960).

One of the criteria that has been used for selection among hybrids is the performance of early-generation bulk populations. Earlier workers like Harrington (1932) concluded that yield tests of a composite F_2 gave an indication of the yield potentialities of wheat crosses. Immer (1941) reached similar conclusion from his studies of bulk populations in barley, finding that some hybrids were consistently higher in yield in the F_2, F_3 and F_4 generations than the other hybrids. In the F_3 generation, family differences make their appearance. Each family should, therefore, be represented by enough plants

in F_3 generation to give an indication of the general feature of the family. Not less than 10 and preferably 30 or more individuals should be studied in each family (Allard, 1960). Accordingly, 25 plants in each F_2 and F_3 population were studied in the present investigation.

The results obtained in the present investigation have been discussed in the light of the available literature.

5.1 Combining ability

The knowledge of general combining ability (gca) and specific combining ability (sca) is of prime importance for formulating an efficient breeding programme because it provides guidelines for the assessment of relative breeding potential of the parental material, which cannot be judged by the phenotypic performance of the parents. It is, therefore, desirable to select the parents for hybridization on the basis of their combining ability. Of the different biometrical methods of estimating combining ability, the application of line x tester analysis is advantageous as it is an easy method of screening a large number of parents in the minimum possible time.

5.1.1 Analysis of variance

Existence of sufficient genetic variability among the females, males and hybrids for most of the characters in different generations was evident from the analysis of variance for the experimental design (Table 1).

The analysis of variance for combining ability exibited the presence of significant differences among the

female progenies for most of the traits studied. However, in the case of the male progenies and female x male progenies' interaction, significant differences were observed for only a few characters in different generations (Table 2). In this context, it is pertinent to mention that the experimental material (13 parents, 22 F_1s, 22 F_2s and 22 F_3s) was raised as a single experiment to eliminate the effect of years. For this, a part of the F_1s was carried through F_2 bulks in summer at Kukumseri, and again a random sample of each of these F_2 bulks was used to generate the F_3 bulks in winter at Palampur. However, by advancing generations under very diverse environments as in the present study, the genetic make-up of the populations is likely to shift in different directions. Moreover, the number of plants on which the data were recorded in the F_2 and F_3 generations might not have truly represented the segregating populations, which could have led to the non-significant differences in some cases. At the same time, the appearance of transgressive segregants in the F_3 generation could not be ruled out because the lines were extremely diverse from the testers. In addition, the lesser degrees of freedon (only one) could be responsible for the non-significant differences among the male progenies.

5.1.2 Combining ability effects

In the F_1 generation, amongst the lines, LSW 26 and Pitic 62 were good general combiners for days to heading while Kharchia 65 was the poorest combiner. The foremost parent

was also good general combiner for days to maturity, while NP 846 was the poorest one. For plant height, Mukta and NP 401 were the good general combiners, whereas NP 846 was the poorest combiner. However, NP 846 was a good general combiner for spikes/plant. For spike length, DL 20-9 was a good general combiner, but Pitic 62 was a poor one. MP 195 was good general combiner for grains/spike, whereas LSW 26 was a poor combiner. For 100-grain weight, four parents, viz., MP 195, DL 20-9, LSW 26 and NP 401, were good general combiners. On the other hand, NP 846 was a poor general combiner for this trait. None of the lines exibited significant value of gca effects for grain yield in the F_1 generation. Obviously, all the parents were average general combiners for this trait.

In the F_1 generation, of the two testers, Mong 2 was good general combiner for days to heading, whereas Mong 3 was a good general combiner for grain yield and its two components, grains/spike and 100-grain weight.

A perusal of the sca effects in the F_1 generation (Table 4) indicated that none of the 22 hybrids exibited significant sca effects for grain yield. Most of the sca effects for other traits studied were also non-significant. However, for spike length and plant height Mukta x Mong 2 and Mukta x Mong 3 exibiting significantly positive and negative sca effects, respectively. All these crosses involved average x average general combiners. Besides, NP 401 x Mong 2 and NP 401 x Mong 3 delineated significantly negative and positive sca effects, respectively, for plant height. Cross, Mukta x Mong 2 for spike length, and Mukta x Mong 3 and

NP 401 x Mong 2 for reduced plant height can be exploited for the improvement of these traits.

In the F_2 generation, amongst the lines, LSW 26 was a good general combiner for days to flowering and days to maturity. Narmada 4 was the only poor general combiner for days to heading. Rest of the parents were average combiners for these two traits. Only two parents, DL 20-9 and NP 846, exibited significant gca effects for plant height. Whereas the former was a good general combiner, the latter one was a poor combiner for this trait. NP 846 was a good general combiner for spikes/plant. For spike length, DL 20-9 was a good general combiner while Kharchia 65 was a poor one. Of the four parents showing significant gca effects, DL 20-9 and K 7340 were good general combiners, whereas LSW 26 and NP 846 were poor general combiners for grains/spike. None of the lines exibited significant gca effects for grain weight. For grain yield, only NP 401 showed significant and positive gca effect, whereas Pitic 62 was a poor combiner. Interestingly, these two parents were average general combiners for rest of the traits studied.

Of the 2 testers, Mong 3 was a good general combiner for grain yield coupled with grain number and 100-grain weight as in the F_1 generation.

None of the 22 hybrids exibited significant sca effects for grain yield in the F_2 generation as in the F_1 generation. For 100-grain weight, the cross combination of Narmada 4 with Mong 2 was the best, whereas Narmada 4 with Mong 3 was the poorest. These two crosses involved average x poor and

average x good general combiners, respectively. For grain number, crosses LSW 26 x Mong 2 and LSW 26 x Mong 3, were poor and good specific combinations, respectively. Cross combinations NP 846 x Mong 2 and NP 846 x Mong 3 were good and poor, respectively, for days to maturity and involved good x average general combiners.

In the F_3 generation, Narmada 4 was a poor general combiner, whereas LSW 26 was a good general combiner for days to heading. The latter was, however, a good general combiner for days to maturity. For reduced plant height, NP 401 was a good general combiner. However, Narmada 4 and NP 846 were poor general combiners for this trait. Two parents, Mukta and NP 846, were good general combiners for tiller number, whereas LSW 26 was a poor one. NP 846 was a good general combiner for spike length. For grains/spike, MP 195 was a good general combiner, whereas NP 401 was a poor one. The latter, however, was a good general combiner for 100-grain weight while rest of the lines were average general combiners. Parents, Mukta and NP 846, were good combiners for grain yield. Interestingly, NP 846 was also a good combiner for spike length and spikes/plant, whereas Mukta was a good combiner for spikes/plant only.

None of the two testers exibited significant gca effects for grain yield in the F_3 generation. However, for grains/spike, Mong 2, was a poor general combiner, whereas Mong 3 was a good general combiner. Mong 2 and Mong 3 were good and poor general combiners, respectively, for days to heading. For rest of the traits, the two testers were average general combiners.

None of the cross combinations delineated significant value of sca for grain yield. For 100-grain weight and plant height, cross combination of NP 401 with Mong 2 was the best specific combiner and the contrary was true for the cross, NP 401 x Mong 3. These crosses involved the combination of good x average general combiners. NP 846 x Mong 2 was the best specific combination for grains/spike while it was the poorest one for spike length. These crosses involved the combination of average x poor and good x average general combiners, respectively. NP 846 x Mong 3 was the best specific combination for spike length and involved good x average general combiners. This combination, however, was poor for grains/spike, whereas LSW 26 x Mong 3 and Narmada 4 x Mong 2 were good specific combinations. Kharchia 65 x Mong 3 and K 7340 x Mong 2 were the superior cross combinations for plant height and involved the average combining parents. For days to heading, the specific combination of Kharchia 65 x Mong 3 was the best one and involved average x poor general combiners.

A perusal of the results obtained from the general combining ability effects evinces that the values of gca effects were not consistently significant over generations in many cases. For example, for days to flowering, Narmada 4 delineated non-significant value of gca effect in the F_1 generation but significant in the F_2 and F_3 generations. Likewise, significant values of gca effects in case of Mukta and NP 846 were observed in the F_3 generation only for grain yield. However, in the case of significant gca effects, there was consistency with regards to the nature of combining ability effects. For

instance, LSW 26 was a good general combiner for days to flowering and days to maturity in all the three generations. Likewise, NP 846 was a good general combiner for spikes/plant, whereas it was a poor combiner for plant height in all the generations. Such a consistency of gca effects over generations is in conformity with the findings of Paroda and Joshi (1970) and Konovalor and Vlaxuko (1981). Parents, NP 846, NP 401 and Mukta, which were good general combiners for grain yield, were also so for one or more of the yield components.

For sca effects also, there was no consistency with regards to significant values over generations. However, a good or poor specific cross combination in one generation was also so in the other generation for the same trait. Ostensibly, there was a consistency regarding the superiority/inferiority of a cross combination exibiting significant sca effects over generations. This is in accordance with the findings of Knovalor and Vlaxuko (1981) who reported that sca effects were maintained from F_1 to F_2 generation. However, Paroda and Joshi (1981) reported a decline in the sca effects in the F_2 generation compared to the F_1 generation.

Most of the superior cross combinations involved either average x average or good x average general combiners. In no case, the two poor general combining parents resulted in a good specific cross combination. Singh and Choudhury (1977) reported the best hybrid resulting from varieties showing the best gca. On the other hand, Ziauddin et al. (1979) emphasized that lines

having good gca, may not necessarily produce superior hybrids. Interestingly, most of the cross combinations exibiting desirable sca effects, involved the tester Mong 3, which has also been observed to be a better combiner than Mong 2.

The per se performance of the lines did not show significant correlation with combining ability effects for grain yield, 100-grain weight and grains/spike and days to heading in the F_1 generations. In the F_2 generation also, sca effects of crosses for the above traits along with days to maturity and spikes/plant showed no correlation with per se performance. However, in the F_3 generation combining ability effects of progenies showed significant correlation with grain yield/plant and grains/spike. Besides, such correlation were also observed for days to maturity and spike length in the F_3 generation. This shows that per se performance to select the desirable parents may be misleading in F_1 and F_2 generations. For those traits in which significant correlations were observed between per se performance and combining ability effects. So, selection of good combining parents on the basis of per se performance for grain yield and grains/spike will be helpful in the F_3 generation only. Korobeinikov (1985) has also observed little association between per se performance and sca effects in the F_1 generation.

5.2 Heterosis

Exploitation of heterosis in crop plants is regarded as a major breakthrough in the field of plant breeding. It is

now being commercially exploited in an array of cross-pollinated crops, and has also become a major subject of study in self-pollinated crops. Recently, a considerable attention has been paid to increase the yield potential by the possible use of heterosis from intervarietal hybrids of wheat. Heterosis has been generally measured as the increased growth or yield of the F_1 hybrids either in relation to mid-parental value and/or superiority over the better parent. In the present investigation, comparisons of the performance of F_1 and F_2 hybrids were made both with the mid-parent and the better parent.

Grain yield, by itself, is a complex character and is the sum total of the contribution made by the individual components. Grafius (1959) has even doubted the individuality of grain yield. Hence, to breed for higher yield, the breeder has to simplify the complex situation and handle a number of related traits. The question as to the extent to which these components can efficiently be used in selecting for increased yield, however, is not fully understood. In the present study, though heterosis was manifested in almost all the characters studied, yet in none of the cases it reached the level obtained for grain yield.

In the F_1, heterosis over the mid-parent for grain yield ranged from -9.52 per cent to 134 per cent for crosses NP 846 x Mong 2 and NP 401 x Mong 3, respectively. Other cross combinations showing significantly positive heterosis over the mid-parent were MP 195 x Mong 3 (48.17%), DL 20-9 x Mong 3 (84.03%), LSW 26 x Mong 3 (108.12%) and NP 846 x Mong 3 (52.85%).

However, when compared with the respective better parent, per cent heterosis ranged from -11.05 to 90.88 for crosses NP 846 x Mong 2 and NP 401 x Mong 3, respectively. One more cross, LSW 26 x Mong 3, exibited significantly positive heterosis over the better parent (64.33%).

On the basis of manifestation of heterosis over mid-parent and better parent, two crosses, NP 401 x Mong 3 and LSW 26 x Mong 3, were adjudged to be the best. Three other crosses, MP 195 x Mong 3, DL.20-9 x Mong 3 and NP 846 x Mong 3, also exibited considerable heterosis over the mid-parent.

From the comparisons of the sca effects of the crosses and the per cent heterosis, it can be perceived that the cross combinations exibiting high heterotic value also had comparatively high specific combining ability effects though the values were non-significant. This indicates that manifestation of heterosis is mainly governed by non-additive type of gene effects.

From the persual of Table 5, it is evident that crosses exibiting heterosis for grain yield also exibited significant heterosis for one or more of the yield contributing characters. For example, MP 195 x Mong 3 showed desirable and significant heterosis for days to heading, spikes/plant and 100-grain weight, and the cross DL 20-9 x Mong 3, was also found to be superior over the mid-parent for days to heading and grains/spike. Likewise, LSW 26 x Mong 3 showed significant and desirable heterosis for days to heading, days to maturity and 100-grain weight, and NP 846 x Mong 3 was also superior over the

mid-parent for days to heading and spike length. Similarly, different workers have reported the importance of one or the other yield component in the determination of yield. Poehlman and Borthakur (1969) reported the number of spikelets/spike, grains/spike and grain weight as components of heterosis for yield in wheat. Singh and Singh (1970) reported heterosis in yield to be reflected through heterosis in spike number and 100-grain weight. Popov et al. (1972) showed grains/spike, ear length, number of spikelets in the main ear as the important yield contributing characters, and reported that increase in yield in the F_1 depended upon increase in the expression of one or more of them.

The manifestation of heterosis as observed in the present study, is in harmony with the previous studies, wherein heterosis for grain yield and its associated traits has been reported in different combinations of parents (Briggle, 1963, Johnson and Schmidt, 1968, Singh and Dawa, 1968, Bitzer, 1969, Paroda and Joshi, 1970a, Bhatt, 1971, Amaya et al. 1972, Wan et al., 1973, Gautam, 1974, Qureshi, 1978, Abugaliev, 1982, Quick et al., 1986).

Interestingly, none of the crosses was significantly inferior to the mid-parent and better parent for grain yield, though some of them were so for the other traits studied.

It was interesting to note that the cross of low x low yielding parents NP 401 and Mong 3 showed maximum heterosis over the mid-parent and better parent but their mean yields were lower than high x high (Pitic 62 x Mong 2) and

high x low (Pitic 62 x Mong 3) yielding parents. A probable reason for this behaviour appears to be that the poor yielding parents possessed different constellations of genes, which showed additive action when brought together in hybrid combination, but even the total number of favourable genes were less than those present in the highest yielding parent studied.

Since the commercial cultivation of F_1 generation is un-economical, the relative magnitude of heterosis in the F_2 and later generations may lead in finding out the promising populations for cultivation. The results obtained with regards to the heterosis in the F_2 shows the rare occurrence of significant heterosis for grain yield and other traits studied. In most of the cases, the hybrids in the F_2 generation were significantly poorer than their respective mid-parents and better parents. Singh and Dawa (1968) also observed a high degree of inbreeding depression in the F_2 and F_3 generations for most of the characters studied and indicated that these generations could not be used for commercial cultivation. However, in the present study, the cross combination NP 401 x Mong 3 exibited the presence of heterosis in the F_2 generation for grain yield, grains/spike and 100-grain weight. This is probably due to additive gene action and complementary epistasis which are fixable and usable components of heteresis.

It was striking to note that all the crosses exibiting significant superiority over the mid-parent and better parent for grain yield involved Mong 3 as one of the parents. The probable reason can be a high degree of genetic diversity of

Mong 3 from the lines used as female. Mong 3 has also been found to be a good general combiner in the F_1 and F_2 generations for grains/spike, 100-grain weight and grain yield. The heterosis for different traits was expressed mainly in those crosses where either dominance or intraction (i) or (l) effects or both were significant. However, in certain crosses where these effects were predominent, no heterosis was observed or vice-versa. Hayman (1956) suggested the factors associated with heterosis to be dominance, non-allelic interaction (l), and higher degree of epistasis, and pointed out that for the expression of heterosis, one of these factors must be operative.

5.3 Gene action

Another important aspect of the investigation was the analysis of gene effects controlling yield and other plant characters. Importance of such analysis in the purposeful management of genetic variability is obvious. The rational choice of the most suitable breeding method would depend, to a large extent, on the nature of gene action involved in the control of characters of interest (Cockerham, 1961). In wheat, several studies have been carried out to examine the nature of gene action for these characters. Most of these results have been obtained through combining ability analysis, graphic analysis, variance components and generation mean analysis.

In the present study, information regarding the genetic architecture of yield and its associated traits has been obtained following the combining ability and generation mean analysis.

5.3.1 Combining ability analysis

Combining ability analysis to elucidate the type of gene action governing grain yield and other quantitative traits has been used in wheat by several workers.

Wegrzyn et al. (1970), Jain and Singh (1978) and Srivastava et al. (1982) reported the preponderance of additive genetic variance for grain yield. However, Ziauddin et al. (1979) Tandon (1980), Singh et al. (1983) and Jatasra and Paroda (1983) have advocated the importance of non-additive genetic variance for the manifestation of grain yield. Preponderance of additive genetic variance for 100-grain weight has been reported by a number of workers (Wegrzyn et al., 1979, Sa'akyan 1979, Jatasara and Parada 1983). On the contrary, Ziauddin et al. (1979), Jain and Singh (1978), Tandon (1980), Srivastava et al. (1982), Singh et al. (1983) have reported the relative importance of non-additive variance for test weight. Likewise, for grains/spike, Wegrzyn et al. (1979), Tandon (1980), Singh et al. (1983) reported the preponderance of additive variance, whereas additive variance was found to be important by various workers (Singh and Chand, 1977, Sa'akyan, 1979) Jain and Singh, 1978, Srivastava et al. 1982, Jatasam and Paroda, 1983).

A persual of the relative magnitude and non-additive variances showed the preponderance of additive genetic variance in the F_1 and F_2 generations for grain yield, 100-grain weight and grain/spike. However, non-additive genetic variance was more important for these traits in the F_3 generations. For

days to flowering, additive variance was more important in the F_1 and F_3 generations, whereas non-additive genetic variance was more important in the F_2 generation. For spikes/plant, additive genetic variance increased progressively as the generation was advanced from F_1 to F_3. So, in general the relative importance of additive and non-additive genetic variances varied over generations. Jordan and Lanbescher(1968) also reported that the genetic variances intracts significantly with generations and locations. Similar results have also been reported by Jain and Singh (1978). It can, therefore, be concluded that the estimates of genetic variance be obtained not only over different generations but also under different environments to have reliable estimates.

5.3.2 Generation mean analysis

Generation mean analysis has been used by several workers to know the type of gene action governing the manifestation of different quantitative traits. Partitioning of means following Jinks and Jones (1958) methodology, was used to understand the nature of gene action involved in the expression of different characters. The parameters estimated were based on the following assumptions :

(i) Absence of multiple allelism,

(ii) absence of linkages,

(iii) absence of lethal genes,

(iv) constant variability for all genotypes, and

(v) environmental effects additive with the genotype values.

No serious bias would be expected in the estimates of the parameters from assumptions (1), (3) and (4). Since the parental lines were pure lines, barring mutations, multiple alleles should not be there. Lethal genes will also not be expected in a self-pollinated crop like wheat. As regards linkage, it is likely to be present but since early generations of the crosses, F_1, F_2 and F_3, were included in this study, linkage equilibrium is also not expected. Linkage may cause more bias particularly when epistatic gene action is present (Kempthorne, 1957). However, apparent linkage bias might be due to trigenic or higher order of non-allelic interactions. However, the assumption that environmental effects are additive with genotype values is not realistic in the present study and the bias due to genotype x environment will be rather high as the material was studied under a single environment only.

Scaling tests, C and D, as proposed by Mather (1949) and Hayman and Mather (1955) were computed to know the validity of additive - dominance model. Non-significant values of C and D inferred the validity of additive - dominance model. In such crosses, (i) and (l) parameters which represent additive x additive and dominance x dominance interactions, respectively, were not calculated. On the other hand, significant values of C and/or D reflect the presence of non-allelic interactions. Significant value of D gives indication about additive x additive (i) type of interaction while that of C represents dominance x dominance (l) type of interactions.

Five parameters, m, (d), (h), (i) and (l), were computed only in those crosses, where C and/or D were significant,

otherwise only 3 parameters, i.e. m, (d) and (h) were estimated. The results obtained with regard to the gene effects for different characters and crosses have briefly been discussed hereafter.

For days to heading, six crosses showed the absence of non-allelic interactions, and presence of additive type of gene action. Of the remaining 16 crosses, having significant values of additive parameter, dominance parameter was also significant in one cross i.e. LSW 26 x Mong 3. Additive gene effects for days to flowering have been reported by earlier workers (Bhatt, 1972, Gamil and Saheal, 1983, Joshi, 1987). However, Ketata et al. (1976) and Nanda et al. (1982) reported the importance of both additive and dominance gene effects for this trait. Presence of additive gene effects coupled with non-allelic interactions was observed in 4 crosses, whereas the remaining crosses showed the presence of additive, dominance and epistatic gene effects. Non-allelic interaction for this trait has also been reported by Nanda et al. (1981) and Joshi (1987). As many as 7 crosses exibited the presence of duplicate type of interaction as evident from the opposite sign of (h) and (1) parameters. Joshi (1987) has also reported duplicate type of interactions for this trait.

Absence of non-allelic interactions for days to maturity was observed in 13 crosses. All these crosses, except, K 7340 x Mong 2, delineated the preponderance of additive gene effects. Joshi (1987), Gamil and Saheal (1983) have reported the preponderance of additive gene effects for this trait. Additive gene effects coupled with additive x additive type of interactions were observed for 2 crosses, whereas additive effects and both

additive x additive and dominance x dominance interactions were observed for 4 crosses. For the remaining crosses, all types of digenic effects, i.e., additive, dominance and non-allelic interactions, were present. Joshi (1987) has also reported the presence of non-allelic interactions for developmental traits in wheat crosses.

For plant height, additive gene effects governed manifestation of the trait in 12 crosses. Presence of additive gene effects for this trait is in conformity with the findings of earlier workers (Johnson et al., 1966, Bhatt, 1972, Edward et al. 1976). Two crosses, viz., TMI 4 x Mong 3 and NP 846 x Mong 2 exibited the importance of both additive and dominance gene effects. Amaya et al. (1972) Nanda et al. (1982) have reported plant height to be under the control of both additive and dominance gene effects. Additive gene effects coupled with additive x additive and/or dominance x dominance interactions were observed for 5 crosses. For the remaining crosses, additive and dominance effects, coupled with non-allelic interactions governed the manifestation of plant height. Non-allelic interactions in 3 crosses were of duplicate type as evident from the oppositive sign of (h) and (l), whereas complementary type of interactions were important in one cross only. Chapman and McNeal (1971) and Singh and Dahiya (1984) have also reported the presence of non-allelic interactions for this trait.

For spikes/plant, non-significant values of C and D tests evinced the absence of non-allelic interactions and probable adequacy of additive - dominance model for 5 crosses, and additive effects were important for these 5 crosses. Edward et al. (1976),

Kharchia 65 x Mong 3 delineated the presence of additive, dominance as well as non-allelic interactions. For the remaining crosses additive effects were mostly important. Though the presence of non-allelic interactions was apparent from the scaling tests, yet the interaction parameters (i) and (l) were non-significant. So, there could be the presence of digenic interactions of (j) type or still higher order of interactions and/or linkage, besides additive gene effects. Joshi (1987) has also reported the presence of non-allelic interactions for this trait.

For grains/spike, scaling tests C and D showed the absence of non-allelic interactions in the 12 crosses. At the same time, both additive and dominance gene effects were found to be non-significant for all these crosses. This inadequacy of digenic interaction model may be false, for A and B scaling tests could not be computed, which could have detected the (j) type of interactions, if present additive and dominance type of gene effects coupled with non-allelic interactions were important for 6 crosses, viz., Narmada x Mong 3, DL 20-9 x Mong 3, K 7340 x Mong 2, LSW 26 x Mong 2, NP 846 x Mong 2, and NP 401 x Mong 3. Dominance gene effect coupled with dominance x dominance interactions governed this trait in one cross, TMI 4 x Mong 3, whereas only dominance x dominance type of interaction was present in Kharchia 65 x Mong 3. Chapman and McNeal (1971) and Ketata et al. (1976) reported additive gene effect for this trait. Singh and Anand (1970) reported additive, dominance and epistasis in different crosses for this trait. Ketata et al. (1976) reported additive x additive and dominance x dominance gene interactions,

and Mani and Rao (1975) reported non-additive gene action for this trait. For DL 20-9 x Mong 2, Mukta x Mong 2 (j) type or higher order of non-allelic interactions might be present, which were not computed.

Absence of non-allelic interactions for 100-grain weight was evident from the non-significant values of scaling tests C and D in 14 crosses. All these crosses, except 3, exibited the presence of additive gene effects. Bhatt (1972), Ketata et al. (1976) and Nanda et al. (1982) have also reported additive gene effects for this trait. In the above exceptional 3 crosses, NP 401 x Mong 3, Pitic 62 x Mong 2 and Pitic 62 x Mong 3, the adequacy of additive - dominance model may be ambiguous because of the absence of A and B scaling tests, which in turn, refers to the presence of (j) type of interactions. Additive gene effects coupled with the non-allelic interactions governed the expression of trait in 6 crosses. In the remaining 2 crosses, K 7340 x Mong 2 and NP 846 x Mong 3, additive and dominance gene effects as well as additive x additive and dominance x dominance type of interactions were important. These interactions were of duplicate type. Chapman and McNeal (1971) and Sandhu and Anand (1972) reported dominance gene effects for this trait, whereas Sun et al. (1972) and Lee and Kaltsikes (1972) have reported non-allelic interactions.

For grain yield, one cross, NP 401 x Mong 3, showed significant value of dominance component. Dominance gene action for grain yield has also been reported by Amaya et al. (1972). Non-significant values of C and D tests revealed the absence of non-allelic interactions in 13 crosses. At the same time, both

additive and dominance parameters were non-significant in 9 of these crosses. As discussed earlier, this might be due to the non-applicability of A and B tests which could have detected the presence of additive x dominance type of interactions at digenic level, or higher order of interactions and/or linkage. The remaining 3 crosses, MP 195 x Mong 3, DL 20-9 x Mong 3, and Pitic 62 x Mong 2, exibited the importance of additive gene effects. This is in conformity with the findings of earlier workers (Sawant and Jain, 1985, Joshi, 1987). One more cross, NP 846 x Mong 2, showed significant additive effects only. Since scaling tests exibited the presence of non-allelic interaction in the cross the additive x dominance type of digenic interactions or higher order of interactions may also be present. Presence of additive x dominance or higher order of interactions and/or linkage has also been speculated in 6 crosses, viz., Narmada x Mong 3, TMI 4 x Mong 2, TMI 4 x Mong 3, Pitic 62 x Mong 3, Mukta x Mong 3 and NP 401 x Mong 2. One cross, i.e., Kharchia 65 x Mong 3 exhibited the presence of dominance coupled with additive x additive and dominance x dominance type of interactions. Opposite signs of (h) and (l) delineated the presence of duplicate type of gene interactions. Ketata (1976) has also reported dominance x dominance type of interactions for grain yield, whereas additive x additive interactions have been reported by Sawant and Jain (1985). Joshi (1987) reported the presence of both duplicate and complementary type of gene interactions for grain yield.

From the above discussion on the nature of gene effects, it can be concluded that for a particular cross it varied from

trait to trait. Even for the same trait, different crosses showed different gene effects. Sawant and Jain (1985) concluded that stability of genetic parameters was highly dependent on a particular set of genotypes grown in a particular environment. This necessitates the exploitation of a particular cross as per the nature of gene action.

Regarding the efficiency of combining ability approach and the generation mean analysis to extract information pertaining to the nature of gene action, it is to mention that the combining ability method gives crude estimates of the nature of the genetic variances present in a particular set of genotypes for a trait. On the other hand, generation mean analysis imparts information regarding the nature of gene effects, which is applicable to a particular cross only, and is thereby more authentic and applicable in plant breeding.

Considering the overall results and foregoing discussion, 5 crosses, viz., NP 401 x Mong 3, LSW 26 x Mong 3, MP 195 x Mong 3, DL 20-9 x Mong 3 and NP 846 x Mong 3, were found to be the potential ones on the basis of sca effects and heterosis. Interestingly, all these crosses involved at least one good general combiner in their parentage. Two of these crosses, NP 195 x Mong 3 and DL 20-9 x Mong 3, exibited the preponderance of additive gene effects for yield and some of its contributing characters. Ostensibly, it should be possible to develop high-yielding lines through simple selection procedures in these crosses. Of the remaining 3 crosses, for which non-additive gene effects were predominant, NP 401 x Mong 3 showed the importance

of dominance gene action for grain yield. For the remaining traits either additive gene effects or non-allelic interactions coupled with additive gene effects were important. Likewise, NP 846 x Mong 3 and LSU 26 x Mong 3 exibited non-additive gene effects for grain yield and other traits. Such type of gene action can be useful in the development of hybrid varieties. The conventional breeding approach could take advantage of additive x additive type of non-allelic interactions coupled with additive variation for the improvement of these traits, if selection is delayed until later generations when dominance effects would have diminished. Under such situations, the population improvement methods may be successfully employed for generation of additional variability.

6 SUMMARY

The present study was undertaken to estimate the general and specific combining ability effects in the F_1, F_2 and F_3 generations, extent of heterosis over the mid-parent and better parent in the F_1 and F_2 generations and nature of gene action for yield and its associated characters in wheat (*Triticum aestivum* L. em Thell.). The material for the investigation comprised 11 diverse lines of spring wheat, *viz.*, MP 195, Narmada 4, TMI 4, DL 20-9, Kharchia 65, K 7340, Pitic 62, NP 846, LSW 26, Mukta and NP 401. These lines, used as females, were crossed with 3 winter-type testers (Mong 1, Mong 2 and Mong 3) of Mongolian origin used as males, in a line x tester fashion during *rabi* 1982-83 at Palampur. However, Mong 1 could not be successfully crossed with all the lines. Therefore, a complete set of 22 crosses involving 11 lines and 2 testers was studied. A part of the F_1 seed was raised at the Regional Research Station, Kukumseri during summer 1983 to advance the generation. Random samples of the F_2 seed bulks of different crosses were advanced to generate F_3 bulks during *rabi* 1983-84.

The experimental material, comprising 13 parents (11 lines and 2 testers) 22 F_1s, 22 F_2s and 22 F_3s, was raised in a randomised block design with three replications at Palampur under rainfed conditions during *rabi* 1984-85.

Ten random plants were used in case of the parents and F_1s, and 25 in case of the F_2s and F_3s, for recording observations on plant height (cm), spikes/plant, spike length (cm),

grains/spike, 100-grain weight (g) and grain yield/plant (g). However, data on days to flowering and days to maturity were recorded on plot basis.

Combining ability analysis was carried out separately for the F_1, F_2 and F_3 generations following Kempthorne (1957). Nature of gene effects in different crosses were estimated as per the 5-parameter model of Jinks and Jones (1958), making use of scaling tests of Mather (1949) and Hayman and Mather (1955).

Analysis of variance for the experimental design revealed the presence of sufficient genetic variability among the lines (females), testers (males) and hybrids for most of the traits in different generations. Likewise, there were significant differences among the female and male progenies for different traits in different generations studied.

The estimates of the general combining ability (gca) effects of different lines showed that Mukta, NP 401 and NP 846 were the best general combiners for yield and some of its contributing traits, whereas Pitic 62 was the poorest combiner. Of the two testers, Mong 3 was the better general combiner.

However, the value of gca effects for individual parents were not consistently significant in the different generations studied, although, in case of significant gca effects in different generations for a particular parent, the nature of combining ability effects remained the same.

Relative magnitudes of the additive and non-additive genetic variances obtained from the combining ability analysis revealed the preponderance of additive genetic variances for grain

yield, 100-grain weight and grain/spike in the F_1 and F_2 generations, for spike/plant in F_3 generation and for days to heading in the F_1 and F_3 generations.

Most of the superior cross combinations, on the basis of specific combining ability (sca) effects, involved either average or a good general combiner as one of the parents. Five crosses, viz., NP 401 x Mong 3, LSW 26 x Mong 3, MP 195 x Mong 3, DL 20-9 x Mong 3 and Mukta x Mong 3 were adjudged to be the superior combinations. All these parents involved Mong 3 as the male parent which was also a better general combiner than Mong 2. Significant correlation between combining ability and per se performance for grain yield/plant and grains/spike in the F_3 generation showed the effectiveness of per se performance for the selection of good combiners in this generation.

On the basis of heterosis over the mid-parent and better parent, NP 401 x Mong 3 and LSW 26 x Mong 3 were adjudged to be the most promising. The former cross also showed the presence of significant heterosis even in the F_2 generation over the mid-parent. The other promising crosses screened on the basis of heterotic response were, MP 195 x Mong 3, DL 20-9 x Mong 3 and NP 846 x Mong 3. The crosses showing high heterosis also showed high sca effects for grain yield and other important traits, though the values of sca effects for grain yield were non-significant.

The nature of gene action in the aforementioned promising crosses showed the preponderance of additive gene effects for grain yield and most of the traits for two crosses, viz., MP 195 x Mong 3 and DL 20-9 x Mong 3. Dominance gene effects were mostly important in NP 401 x Mong 3, whereas non-allelic interactions mainly governed the manifestation of grain yield and its components in the remaining two crosses, LSW 26 x Mong 3 and NP 846 x Mong 3. Appropriate breeding strategies to exploit these potential crosses have been discussed.

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*Original not seen

[illegible] of parents and hybrids for different traits in the F_1, F_2 and F_3 generations

Parents/hybrids	Generation	Days to flowering	Days to maturity	Plant height (cm)	Spikes/ plant	Spike length (cm)	Grains/ spike	100-grain weight (g)	Grain yield/ plant (g)
1	2	3	4	5	6	7	8	9	10
Females									
MP 195	-	122.00	181.00	81.73	3.97	9.80	49.53	5.20	9.30
Narmada 4	-	120.00	178.00	87.27	3.50	9.30	33.93	4.53	5.30
TMI 4	-	126.00	175.33	69.33	6.00	10.30	44.90	4.13	9.10
DL 20-9	-	121.31	182.67	62.73	4.13	11.23	22.87	5.13	6.00
Kharchia 65	-	120.67	180.33	94.87	6.70	9.87	43.57	4.83	10.23
K 7340	-	127.33	180.67	78.17	6.27	11.50	40.27	4.90	10.17
Pitic 62	-	123.33	177.67	79.67	5.80	9.90	44.70	5.17	12.07
LSW 26	-	119.33	176.00	80.70	4.20	8.77	31.50	4.43	5.73
Mukta	-	121.33	182.67	91.50	4.87	10.63	44.80	5.03	10.90
NP 846	-	124.00	161.00	98.93	9.87	11.93	42.80	4.73	11.77
NP 401	-	120.67	176.00	84.10	5.27	10.13	33.43	4.03	6.17
Males									
Mong 2	-	148.33	186.67	126.03	9.10	14.07	46.40	3.37	11.37
Mong 3	-	151.67	186.33	133.50	6.00	15.30	46.27	4.17	9.87
Hybrids									
MP 195 x Mong 2	F_1	129.67	184.33	101.50	7.67	12.10	51.93	4.40	13.17
	F_2	136.00	182.00	94.97	4.27	11.52	44.33	4.40	9.73
	F_3	125.33	184.00	99.77	5.70	11.57	42.50	4.37	8.83
x Mong 3	F_1	129.33	183.67	100.7	7.37	12.63	54.70	5.13	14.20
	F_2	124.00	182.37	94.80	4.87	11.27	48.93	5.03	9.40
	F_3	128.00	183.33	93.93	4.97	11.10	53.63	5.00	10.90
Narmada 4 x Mong 2	F_1	129.00	183.00	101.03	6.17	11.43	48.50	4.03	9.53
	F_2	138.67	182.33	97.37	4.63	10.83	44.87	4.43	7.97
	F_3	131.33	184.00	98.80	6.67	11.63	48.57	4.17	9.67
x Mong 3	F_1	132.67	184.67	108.73	7.23	12.23	47.70	4.63	11.53
	F_2	136.00	182.00	101.53	4.73	11.07	43.20	4.17	8.83
	F_3	132.67	180.33	105.97	5.60	11.03	40.20	4.40	7.70
TMI 4 x Mong 2	F_1	128.00	183.67	96.30	6.30	13.30	51.20	4.10	11.72
	F_2	133.33	180.33	97.03	4.40	10.53	45.00	4.13	7.96
	F_3	124.00	183.33	100.83	6.70	11.70	43.10	4.47	10.27
x Mong 3	F_1	131.67	184.00	98.90	7.87	12.83	53.33	4.43	13.73
	F_2	134.00	181.33	89.96	3.47	11.20	49.10	4.57	7.00
	F_3	133.33	184.67	101.67	4.50	11.90	47.07	4.20	8.03
DL 20-9 x Mong 2	F_1	126.67	184.00	92.20	6.70	13.33	42.03	4.67	11.90
	F_2	130.00	183.00	82.53	4.20	12.27	46.06	4.20	6.80
	F_3	127.33	185.00	96.50	5.77	13.07	36.47	4.67	8.07
x Mong 3	F_1	131.00	185.33	102.23	6.77	13.60	55.20	4.73	14.60
	F_2	134.67	181.00	91.16	4.73	12.13	54.10	4.93	10.63
	F_3	131.67	181.00	91.10	4.40	12.37	42.70	4.43	7.97
Kharchia 65 x Mong 2	F_1	132.00	183.67	106.69	6.50	11.13	49.10	4.40	10.30
	F_2	134.67	182.33	96.83	3.70	10.30	42.47	4.40	7.07
	F_3	132.00	182.67	105.30	5.47	10.67	42.23	4.07	7.57
x Mong 3	F_1	132.00	184.33	109.30	6.37	12.97	49.13	4.57	12.33
	F_2	136.00	180.67	103.10	4.40	11.17	43.17	4.33	8.00
	F_3	129.33	183.33	78.3	4.77	11.57	45.47	4.47	9.20

Appendix I contd....

1	2	3	4	5	6	7	8	9	10
K 7340 x Mong 2	F_1	128.67	183.00	96.77	7.13	11.97	36.20	4.47	11.37
	F_2	133.33	182.33	90.63	4.47	11.77	44.60	4.27	7.17
	F_3	125.33	183.00	8.53	6.70	11.17	31.00	4.40	7.80
x Mong 3	F_1	132.00	185.67	100.53	8.27	13.67	46.63	4.20	11.83
	F_2	136.00	181.67	97.00	5.33	12.00	53.13	4.63	10.30
	F_3	130.33	185.00	100.80	6.47	12.37	46.27	4.33	10.20
Pitic 62 x Mong 2	F_1	120.00	183.67	109.33	7.43	11.07	46.50	4.07	11.50
	F_2	134.00	180.67	91.23	3.63	11.17	33.00	4.30	4.17
	F_3	125.00	181.67	107.20	6.27	11.43	36.40	4.33	8.77
x Mong 3	F_1	129.67	182.33	99.87	6.47	12.00	43.00	4.60	13.07
	F_2	133.33	179.00	99.90	4.23	11.07	48.63	4.76	8.17
	F_3	132.67	184.67	92.03	4.37	12.20	52.17	4.27	7.90
LSW 26 x Mong 2	F_1	122.33	176.33	103.90	5.87	12.97	30.60	4.53	7.97
	F_2	126.00	177.67	93.50	4.27	12.97	27.07	4.33	5.63
	F_3	122.67	178.67	101.60	4.27	11.93	30.50	4.33	5.97
x Mong 3	F_1	126.67	182.33	100.40	6.80	13.23	46.97	4.93	16.23
	F_2	125.33	176.67	95.60	4.60	13.23	53.63	5.03	10.73
	F_3	129.33	181.33	79.13	4.40	11.93	54.43	4.63	9.73
Mukta x Mong 2	F_1	132.00	184.00	107.43	7.80	12.97	49.53	4.23	12.77
	F_2	127.33	182.33	102.87	5.20	11.87	43.17	4.50	8.87
	F_3	127.00	193.33	107.17	6.93	11.20	43.50	4.30	10.20
x Mong 3	F_1	129.00	183.33	77.03	9.33	12.00	45.80	4.37	11.57
	F_2	135.33	180.67	10.00	4.40	12.13	42.60	4.93	9.27
	F_3	131.33	183.33	79.10	7.33	11.67	46.83	4.23	11.07
NP 846 x Mong 2	F_1	129.00	184.33	114.33	7.90	12.80	40.70	4.07	10.47
	F_2	132.67	177.00	112.10	6.07	11.40	34.67	4.17	7.47
	F_3	124.33	181.00	109.60	8.03	15.47	43.93	4.70	12.80
x Mong 3	F_1	133.33	197.33	119.93	10.43	14.13	50.10	4.43	16.53
	F_2	139.33	181.33	111.40	5.70	12.33	41.93	4.57	10.10
	F_3	132.00	184.00	110.13	5.63	12.30	37.97	4.60	9.07
NP 401 x Mong 2	F_1	124.00	183.00	80.33	6.47	11.50	29.70	4.57	10.30
	F_2	133.33	180.67	96.63	3.43	10.97	34.67	4.40	8.40
	F_3	121.67	178.33	64.67	5.07	8.53	21.87	5.17	6.60
x Mong 3	F_1	128.00	191.67	107.93	6.77	12.00	52.00	4.90	18.83
	F_2	130.67	182.67	100.83	7.53	11.97	53.07	4.67	12.17
	F_3	131.33	192.33	98.90	6.30	11.67	48.80	4.43	9.57
SE± (Parents and F_1s)		1.59	1.28	4.55	0.99	0.65	4.24	0.15	1.77
CD at ∠ 0.05		4.49	3.60	12.82	2.78	1.82	11.94	0.43	4.99
SE± (Parents and F_2s)		1.91	1.08	4.40	0.99	0.55	3.54	0.17	1.92
CD at ∠ 0.05		5.36	3.03	12.38	2.78	1.53	10.23	0.49	5.12
SE± (Parents and F_3s)		1.61	1.16	4.66	0.78	0.76	4.00	0.17	1.75
CD at ∠ 0.05		4.53	3.28	13.11	2.20	2.14	11.24	0.49	4.93