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**GENETICS OF YIELD AND YIELD CONTRIBUTING
CHARACTERS AND THEIR RESPONSE TO SELECTION
IN SPRING WHEAT**

A Thesis
by

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Examination Roll No. 01

Reg. No. 14954 (1986-87)

Semester: July-December, 2002

হাজী মোহাম্মদ দানেশ বিজ্ঞান ও প্রযুক্তি বিশ্ববিদ্যালয়
ময়মনসিংহ।



MASTER OF SCIENCE (M.S.)
IN
GENETICS AND PLANT BREEDING

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বিশ্ববিদ্যালয়, ময়মনসিংহ।

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তারিখ

**DEPARTMENT OF GENETICS AND PLANT BREEDING
BANGLADESH AGRICULTURAL UNIVERSITY
MYMENSINGH**

November, 2002

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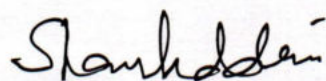
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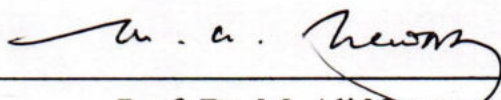
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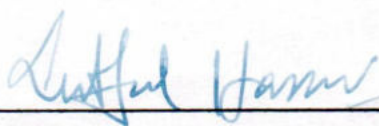
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DEDICATED
TO MY
BELOVED PARENTS

श्रीमद्भगवद्गीता प्रकाशित
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ABSTRACT

Present study was performed on combining ability, heterosis and gene actions for yield and yield contributing characters from a diallel cross population, and other was selection response of different yield contributing characters in two crosses of spring wheat.

The analysis of variance studied in the diallel cross populations, showed that, there were significant variations among the genotypes for the characters plant height, tillers per plant, spike length, spikelets per spike, grains per spike, 100-grain weight and grain yield per plant. Both general combining ability (GCA) and specific combining ability (SCA) variances were significant for all characters except grains per spike. This character had only significant GCA variance. This suggests that both additive and non additive gene actions were involved in the inheritance of them. The parent Rawal was best general combiner for grain yield and some yield contributing characters. The crosses Gourav x Anja , Kanchan x Rawal, Rawal x Moyoor, Moyoor x Kheri and Chyria x Kheri showed positive and significant SCA effects for grain yield and some yield contributing characters.

The crosses Gourav x Anja, Rawal x Moyoor and Chyria x Kheri exhibited significant and positive mid parent heterosis for grain yield per plant. Maximum heterosis of grain yield per plant was 155. 94% in the crosses Gourav x Anja. A positive relationship was observed between heterosis of the crosses with their corresponding SCA effects for yield and yield contributing characters.

Study of Wr-Vr graph showed that partial dominance was observed for plant height, tillers per plant, spike length and 100-grain weight. Over dominance was noticed for spikelets per spike and grains per spike. Tillers per plant, grains per spike and grain yield per plant expressed presence of epistasis.

Analysis of relationship between yield and yield contributing characters revealed that spike length, spikelets per spike and 100-grain weight were the most important yield contributing characters. They directly contributed to grain yield and had high correlation at genotypic level.

High heritability estimates in both broad and narrow sense were obtained for plant height, spike length, spikelets per spike and 100-grain weight. Medium heritability in broad sense but poor heritability in narrow sense were observed for tillers per plant and grains per spike. Grain yield per plant was highly heritable in broad sense and poorly heritable in narrow sense.

Study of response to selection showed that the characters tillers per plant, 100-grain weight and grain yield per plant in the cross Nk-5 x Opata and tillers per plant, spikelets per spike, grains per spike and grain yield per plant in the cross Rawal x SA-92 gave good response to selection. These characters had also positive realized heritability. The other characters in both crosses had negative response to selection and that might be due to the cause of genotype-environment interaction.

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CHAPTER 1 INTRODUCTION



INTRODUCTION

Wheat is one of the most important cereal crops in the world. Cultivated wheat belongs to the genus *Triticum*, family Gramineae. *Triticum* includes diploid ($2n = 2x = 14$), tetraploid ($2n = 4x = 28$) and hexaploid ($2n = 6x = 42$) species. The genomic constitution of diploid, tetraploid and hexaploid groups are AA, AABB and AABBDD (Sears, 1944) respectively. The *Triticum* includes two commercially cultivated species *Triticum aestivum* L. and *Triticum durum* L. *Triticum aestivum* is of two types winter and spring wheat. In Bangladesh only spring wheat are commercially grown.

As an important cereal crop, wheat is gaining popularity day by day in Bangladesh. Its ranks as second major cereal crop on the basis of acreage and production (BARI, 1982). In 2000-2001, wheat was grown on 2057 thousands acres of land and production was 1840 thousand tones. (BBS, 2001). In Bangladesh, there is a scope for increasing the production per unit area through breeding for yield improvement and management practices for growing wheat.

In terms of food value, wheat is more nutritious than rice. Wheat grain supplies carbohydrate, protein, minerals certain vitamins (BARI, 1990). Yield potentiality of the varieties cultivated in Bangladesh is much less than cultivars of the developed countries. The Wheat Research Centre (WRC) of Bangladesh Agricultural Research Institute (BARI) released 21 varieties of spring wheat for commercial cultivation in Bangladesh. Yield of these varieties nearly approached to 3 tons per hectare in farmers field. But in some of the developed countries yield is much higher even reach to about 8 to 10 tons per hectare. As food production in Bangladesh is not increasing keeping the pace with burgeoning population, the

country has been suffering from food shortage. Increasing food production through the cultivation of high yielding wheat varieties is therefore, necessary to meet food shortage in Bangladesh. This situation emphasizes further increase in yield potential for wheat.

Grain yield in wheat, as compared with other cereal crops, is a complex character and contributed by various yield-contributing characters. The goal of most breeding programme in spring wheat is to increase yielding capacity of the crops and it needs knowledge on inheritance of yield and yield contributing characters. The diallel cross technique is one of the quantitative genetic approaches which provides a systematic methods to study the inheritance of continuously varying characters needed for designing an appropriate plant breeding programme. Information generated from the combining ability analysis programming for a suitable breeding method helps breeders in pure line or hybrid variety development in the crop like wheat. With this method the resulting total genetic variation is partitioned into the effect of general and specific combining ability. Combining ability has been widely used to study genetic architecture of quantitative characters in many crop plants. Combining ability and heterosis help to identify the potential of parents or crosses for breeding to develop high yield potential cultivars. Parents with high general combining ability are used in conventional breeding programme, while the crosses with significant SCA effect and heterosis are used in hybrid variety development.

The selection process of identifying high yielding genotypes emphasizes on the analysis of heritability for yield contributing characters. A character with high heritability gives higher response to selection.

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Considering the above information the present study was, therefore, undertaken to analyze the combining ability and heterosis in a diallel cross and selection response in two crosses of spring wheat. The following objectives were aimed in the present study:

- i) To study general combining ability of the parents and specific combining ability of the crosses for yield and yield contributing characters.
- ii) To study heterosis for yield and yield contributing characters.
- iii) To study heritability for yield and yield contributing characters.
- iv) To study gene action for yield and yield contributing characters.
- v) To study relationship between yield and yield contributing characters.
- vi) To study selection responses of yield and different yield contributing characters in two crosses of spring wheat.

CHAPTER 2
REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1 Combining ability, heterosis and gene action for yield and yield contributing characters in spring wheat.

2.1.1 Inheritance of grain yield and its different contributing characters

Information on inheritance of grain yield and its different contributing characters is essential for evaluating a population for breeding purpose. As yield and yield contributing characters in wheat are quantitative in nature, their expression is controlled by genotypes and their interaction with environments. Many authors studied the inheritance of yield and yield contributing characters using different methods of analysis. This information is very pertinent to start any yield improvement programme in wheat

Plant height

Plant height is an important morphological yield contributing character in spring wheat. Both major genes (Rht_1 , Rht_2 and Rht_3) and minor gene were reported to control plant height in bread wheat. The character reported to be controlled by both additive and non-additive gene actions (Shamsuddin *et al.*, 1993; Rajara and Maheshwari, 1996). Karam-Chand *et al.*, 1996) observed only additive type of gene effect involved in plant height. Cammack (1984) and Malik *et al.* (1988) also observed additive type of gene action for the character. Rahman *et al.* (2000) reported both additive and non additive gene actions with comparatively higher estimates of additive gene action. Patil *et al.* (1995) and Dasgupta and Mondal (1988) reported predominance of additive gene effect.

Sheikh and Singh (2000) observed dominance effect for plant height. Rahman *et al.* (1986) reported both additive and non-additive genetic effects with predominance of the latter for the character. Predominance of non-additive gene

action was also reported by Dabholkar and Baghel (1980). Additive x additive gene interaction was reported by Nanda and Singh (1989). Amawate and Behl (1995) studied four crosses and noticed additive x additive and additive x dominance gene interactions in three crosses for this trait in spring wheat.

Tillers per plant

Sometimes tillers per plant indicates as spikes per plant and it is an important yield component in spring wheat. Ali and Khan (1998) reported that the character was controlled by both additive and non additive gene actions. Yadav *et al.* (1997) observed genes controlling spikes per plant were dominant and recessive in two crosses they made. They found both additive and non-additive gene effects.

Shamsuddin *et al.* (1993) reported additive and non-additive gene action and emphasized on importance of additive gene action for the character. Similarly, predominance of additive gene action for the character were also reported by many authors (Dasgupta and Mondal, 1988; Misra *et al.*, 1994; Patil *et al.*, 1995 and Zalewski 2000).

Rahman *et al.* (2000) reported non-additive gene action for this trait. Predominance of dominant component was reported by Sheikh and Singh (2000) in spring wheat. Singh *et al.* (1986a) and Srivastava *et al.* (1992a) reported presence of epistasis for the trait in bread wheat. They found additive x additive, additive x dominance and dominance x dominance epistasis. Partial dominance type of gene action for the character was observed by Lonc (1988) and Chowdhury *et al.* (1999).

Spike length

Spike length is an important sink character related to grain yield in wheat. Long spike contains higher number of spikelets than the short ones. Amawate and Behl

(1995) reported both additive and non-additive gene actions were involved in the inheritance of spike length; whereas Dasgupta and Mondal (1988) obtained only additive gene action for the trait. Rahman *et al.* (1986) reported both additive and non additive genetic effects for spike length. They observed pronounced non-additive genetic effect for the character. Singh *et al.* (1974) and Atale and Vitkare (1990) also observed predominance of non-additive component for this trait. Lonc (1988) reported partial dominance for this trait in his study with bread wheat.

Spikelets per spike

Spikelets per spike is the important sink character related to grain yield in spring wheat. Amawate and Behl (1995) reported both additive and non-additive gene actions for the character. Dasgupta and Mondal (1988) observed predominant gene action for this character. Among the different components of non-additive gene action, Lonc (1988) reported partial dominance, others reported epistasis for this character (Shamsuddin and Abi Antoun, 1986). Walia *et al.* (1994) reported that epistasis including additive x dominance component was significant for spikelets per spike.

Grains per spike

Grains per spike is one of the important sink character and primary yield component in spring wheat. Inheritance of grains per spike in bread wheat has been reported to be controlled by both additive and non additive gene actions. But the magnitude of additive effect was higher as reported by Singh *et al.* (1986a), Patil *et al.* (1995), and Dasgupta and Mondal, (1988). Both additive and dominance effects were reported by Walton (1971). Only additive type of gene effect for this character was reported by Ali and Khan (1998); Malik *et al.* (1988); Amawate and Behl (1995); Cammack (1984).

Singh *et al.* (1998) studied gene effects for grains per spike and observed the complexity of inheritance of this yield component. They reported additive and additive x additive gene effects for grains per spike. Nanda *et al.* (1990) also reported additive and additive x additive gene effects. Singh *et al.* (1998) also observed the presence of higher order genetic interactions or linkage or both in the genetic control of this character.

100-grain weight

Grain weight is one of the most important character. If 100-grain weight increases, the ultimate total yield increases. Ali and Khan (1998) reported both additive and non additive gene actions on grain weight. Malik *et al.* (1988) also reported additive and non-additive gene actions in the inheritance of 100-grain weight. But Patil *et al.* (1995); Dasgupta and Mondal (1988) and Singh *et al.* (1986) reported predominance of additive effect for this character.

Singh *et al.* (1998) studied gene effects in a set of 19 crosses of spring wheat and reported additive gene action including dominance and dominance x dominance interaction in three crosses. Hundred grain weight was controlled by additive, dominance and all types of epistasis as reported by Shamsuddin and Rahman (1998). Rajara and Maheshwari (1996) reported the inheritance of 100-grain weight was totally under the control of non-additive gene action. They observed the predominance of non-additive gene action for the character.

Grain yield per plant

The inheritance of grain yield per plant in spring wheat was reported to be controlled by additive type of gene action (Ali and Khan, 1998). Non-additive gene action for grain yield per plant was reported by Yadav and Iqbal (1987) and Sharma *et al.* (1984).

additive and non-additive gene effects were reported by Aglodiya and Shukla (1994). Chowdhury *et al.* (1999) observed differences in expression of gene action with environments and reported grain yield per plant exhibited over dominance gene action under irrigated condition and partial dominance gene action under non-irrigated conditions.

Mehla *et al.* (2000) studied parental, F_1 , F_2 and back cross generations of spring wheat and they reported dominance, additive x additive and dominance x dominance epistasis effects were involved in the inheritance of grain yield per plant.

2.1.2 Combining ability for yield and yield contributing characters

General and specific combining ability for yield and yield contributing characters in bread wheat was studied by many authors in order to identify the best parents or crosses for breeding programme.

Plant height

Salgotra *et al.* (1997) noticed predominance of SCA variance over GCA variance and emphasized on importance of non-additive gene action for this characters. Similar results were obtained by Malik *et al.* (1988), Taleei and Beigi (1996). The higher estimates of SCA variance over GCA indicated the predominance of non-additive gene action. (Borghi and Perenzin, 1994., Mishra *et al.*, 1994 and Selim, 1974). Sharma and Singh (1978) studied combining ability for plant height and reported that both GCA and SCA variances were significant in spring wheat. Khan and Ali (1998) also reported significant GCA and SCA mean squares for the character. Significant GCA and SCA variances for plant height were reported by Rahman *et al.* (2000). Comparatively higher estimates of additive genetic variance over non-additive genetic variance was reported by them. Among the parents they

studied, Rawal, NK-5 and SA-92 had high and positive GCA effect for the character. Masood and Kronstad (2000) observed that significant variances were present for the GCA as well as SCA effects. They obtained high value for GCA to SCA ratio, which indicated importance of additive gene action for the character. Patil *et al.* (1995) also estimated higher GCA variance over SCA and emphasized on importance of additive gene action for plant height. On the other hand, Singh *et al.* (1982) observed only SCA variance to be significant for the character in spring wheat.

Tillers per plant

Srivastava *et al.* (1992b) crossed nine variety in a half diallel system and found mean squares for both GCA and SCA were highly significant for tillers per plant. This indicated both additive and non-additive gene effects for the trait. The variances due to GCA were higher than SCA, showing more importance for additive gene action for this character. Higher magnitude of GCA variances in bread wheat were reported by Patil *et al.* (1995). Higher estimated of GCA mean square for the character in bread wheat was also reported by Ivanovska *et al.* (2000) and Zalewski (2000). Deshpande and Nayeem (1999) estimated significant GCA effects in parents Hindi 61 and Ajastha for the character.

Many authors reported higher estimates of SCA mean squares for tillers per plant emphasizing on importance of non-additive gene action (Kumar *et al.*, 1983; Singh *et al.*, 1986a; Singh *et al.*, 1987; Singh and Paroda, 1987 and Prabhu and Sharma, 1987).

Significant SCA effect but non significant GCA effect for tillers per plant reported by Rahman *et al.* (2000). In their study the crosses Barkat X Opata, Rawal X Opata and NK-5 X SA-92 showed significant and positive SCA effect for this trait.

Significant SCA effect for the character was also reported by Masood and Kronstad (2000) and Sheikh and Singh (2000)

Spike length

Atale and Vitkare (1990) studied a set of 15 x 15 diallel cross of bread wheat and found highly significant variances for both GCA and SCA for spike length. However, the GCA/SCA variance ratio was less than unity for the character indicating the predominance of non-additive gene action in the inheritance of it.

Patil *et al.* (1995) also reported higher estimates of SCA mean square for this trait. Malik *et al.* (1988) and Khan and Ali (1998) reported significant GCA and SCA effects for spike length in spring wheat.

Singh *et al.* (1982) observed that GCA mean square was higher than SCA mean square indicating the predominance of additive gene action for the character in bread wheat.

Spikelets per Spike

Patil *et al.* (1995) studied combining ability for spikelets per spike in spring wheat and reported significant GCA and SCA mean squares but higher magnitude of SCA mean square than GCA mean square. This result suggested that non-additive gene action for spikelets per spike was predominant. Khan and Ali (1998) reported significant GCA effects for spikelets per spike suggesting importance of additive gene action for it.

Grains per spike

Taleei and Beigi (1996) reported that both GCA and SCA mean squares for grain yield per plant were highly significant. Similar results were observed by Malik *et al.* (1988), Patil *et al.* (1995) and Srivastava *et al.* (1992b). They obtained higher GCA mean square than SCA mean square suggesting preponderance of additive gene effects for this character.

Rahman *et al.* (2000) observed both GCA and SCA mean squares in spring wheat were significant for the character. They found Opata as a good general combiner. Three out of 21 crosses showed significant SCA effect for the character. Bhullar *et al.* (1981) also reported both significant GCA and SCA variances for grains per spike in durum wheat.

Malik *et al.* (1988) studied combining ability and reported that additive gene action was more important for grain per spike. Ali and Khan (1998) reported highly significant GCA mean squares for grains per spike. On the other hand, Sheikh and Singh (2000) found significant SCA variance for the character in bread wheat.

100-grain weight

Malik *et al.* (1988) studied combining ability in spring wheat and reported both GCA and SCA mean squares were significant for 100-grain weight. Significant variances for GCA and SCA for the character were also reported by Taleei and Beigi (1996) and Ali and Khan (1998).

Atale and Vitkare (1990) studied combining ability in bread wheat and found highly significant GCA variance but non-significant SCA variance for 100-grain weight, which indicated that the trait was mostly governed by additive genetic system. GCA and SCA effects for 100-grain weight were reported to be significant by Rahman *et al.* (2000). Out of nine parents Srivastava *et al.* (1992b) reported that variety Lock -1 was the best general combiner for the character.

Grain yield per plant

El-Hennawy (1996) studied combining ability for yield and yield contributing characters in spring wheat. He obtained significant estimates of both GCA and SCA mean squares for grain yield per plant. He estimated high ratio of GCA/SCA

mean squares for grain yield per plant, which indicated role of additive gene effect in the inheritance of this trait. Ibrahim (1994) reported variances due to GCA and SCA were significant for grain yield per plant and indicated the importance of additive and non additive gene actions in the inheritance of grain yield per plant.

Malik *et al.* (1988) and Taleei and Beigi (1996) studied combining ability in bread wheat and reported that both GCA and SCA mean squares were highly significant for grain yield per plant. They obtained higher GCA mean square than SCA mean square suggesting preponderance of additive gene effects for this character.

Atale and Vitkare (1990) reported that the ratio of GCA and SCA variance was less than unity, which indicated that preponderance of non-additive gene action for grain yield per plant. The similar fact was also reported by Jatotra and Paroda (1978).

Singh and Gupta (1969) and Bhullar *et al.* (1979) reported positive relation between mean performance and GCA effect of the parents in spring wheat. Paroda and Joshi (1970) reported that at least one parent in a cross with high GCA effect gave usually high SCA effect for yield and yield components.

2.1.3 Relationship between GCA, SCA and mean performance of the parents.

A positive relation between mean performance and GCA effect of the parents was reported by Singh and Gupta (1969), Paroda and Joshi (1970), Bhullar *et al.* (1979) and Rahman *et al.* (2000). They suggested that the parents with high mean performance estimated significant GCA effects.

Srivastava *et al.* (1992b) reported significant SCA effects of the crosses for grain yield by crossing the parents with low x low and low x average general combiners. Masood and Kronstad (2000) also observed high SCA effects for grain yield by

crossing the parents with low x low and low x average general combiners in bread wheat. Sharma et al. (1978) reported significant SCA effects of the crosses for grain yield by crossing the parents with high x high and high x low general combiners. Paroda and Joshi (1970) obtained high SCA effects of the crosses for yield and yield contributing characters involving at least one parent with high GCA effect.

2.1.4 Heterosis for yield and yield contributing characters

Heterosis for yield and yield contributing characters have been studied for identifying the crosses showing significant heterosis and also the parents those conferred heterosis. Information on heterosis of the crosses is needed in breeding for hybrid variety in spring wheat.

Plant height

Sadeque *et al.* (1991) reported negative heterosis for plant height over the tallest parent in spring wheat. Khan and Khan (1996) observed 5.23% heterosis over mid parent for the character. Singh *et al.* (1997) reported positive significant heterosis for plant height. Positive heterosis for plant height in spring wheat were also reported by many researchers (Shamsuddin *et al.* 1993; Wang *et al.* 1997 and Patil *et al.* 1998). But Deshpandae and Nayeem (1999) reported negative heterosis over better parent for plant height in the cross of Hindi 62 x Kalyansona. Shamsuddin and Rahman (1989) reported significant negative heterosis for plant height. On the other hand Yagdi and Karan (2000) observed positive heterosis for this trait in some crosses and negative heterosis in others.

Tillers per Plant

Hasan and Saad (1996) reported significant and positive heterosis for spikes per plant over mid and better parent. Significant positive heterosis for the character

was also reported by Wang *et al.* (1997). Khan and Khan (1996) reported 31.91% and 15.82% heterosis over mid parent and better parent respectively. Sadeque *et al.* (1991) studied heterosis for spikes per plant in spring wheat and reported maximum heterosis over better parent was 141.7%.

Knobel *et al.* (1997) reported maximum negative heterosis upto -38.0% over better parent for spikes per plant in bread wheat; whereas Shamsuddin (1985) observed 77.31% heterosis for the character in the cross Balaka X Lyallpur.

Spike length

Atale and Vitkare (1990) reported considerably high, mid parent and better parent heterosis for spike length in two crosses of spring wheat NI 5439 X UP 215 and C 306 X CPAN 1581. Highly significant and positive heterosis over better parent for the character was reported by Deshpande and Nayeem (1999). Hassan and Saad (1996) reported significant heterosis over the mid and better parent values for the trait. Shamsuddin and Rahman (1989) and Yagdi *et al.* (2000) reported both positive and negative heterosis for spike length in spring wheat.

Spikelets per spike

Information on heterosis for spikelets per spike is very limited. Ioan (1999) reported positive heterosis for spikelets per spike. Walia *et al.* (1994) reported significant heterosis over better parent for spikelets per spike in the F₁ generation. Hassan and Saad (1996) observed heterosis 10.9% to 8.9% for spikelets per spike over mid parent. Wang *et al.* (1997) observed negative heterosis for spikelets per spike in spring wheat.

Grains per spike

Khan *et al.* (1995) observed maximum 40.33% heterosis over better parent for grains per spike in spring wheat. Khan and Khan (1996) reported 11.37% heterosis

and 215.4% respectively for grain yield per plant reported by Sadeque *et al.* (1991). Deshpandae and Nayeem (1999) studied heterosis for grain yield in bread wheat and observed both positive and negative heterosis over mid and better parental values. Khan *et al.* (1995) reported 62.32% heterosis over better parent. EL-Hennawy (1996) reported mid parent and better parent heterosis ranging from -70.82% to 72.75% and from -79.24% to 61.34% respectively for grain yield per plant in bread wheat. Sharma and Menon (1996) reported high and significant positive heterosis (39.7% to 89.1%) for grain yield. Prasad *et al.* (1998) observed maximum 59.7% better parent heterosis for grain yield per plant. Afiah *et al.* (1999) reported significant positive heterosis ranging from 16.04-43.73% for this trait.

2.1.5 Relationship between heterosis of F₁ hybrids with their corresponding SCA effects.

Many researchers studied the relationship between combining ability effects and heterotic response of the crosses in spring wheat. Shamsuddin (1985) reported positive and significant correlation between heterosis and SCA effects of the crosses for grain yield in spring wheat.

Budak and Yildirim (1996) studied 7 traits in a 6 x 6 diallel crosses of bread wheat and observed high heterosis for yield in the cross Orsa x AK702. They noticed that there was the positive relationship between heterosis and SCA effects. The crosses involving diverse parents had estimated high heterosis and specific combining ability. Hassan and Saad. (1996) found significant relationship between heterosis and SCA effects for all the traits. Shamsuddin and Rahman (1989) obtained positive but non-significant correlations of genetic divergence parent with heterosis and SCA effects of the crosses for grain yield.

Labuschangne and Deventer (1989) studied a diallel cross with 5 winter wheat cultivars and the parents of F_1 progeny and estimated heterosis and SCA effects. But they noticed negative relationship between heterosis and SCA effects of the crosses.

2.1.6 Relationship between yield and yield contributing characters.

2.1.6.1 Study of correlation coefficient

Yield performance of a genotype depend upon the expression of yield contributing characters which are influenced by different growth processes and the growth processes are influenced by the growing environment. Thus yield contributing characters form a complex chain of interrelationship between them. Relationship of various traits with yield was studied at genotypic and phenotypic levels. Genotypic correlation coefficients for most of the cases appeared to be higher than corresponding phenotypic correlation coefficients (Jatasra, 1978 and Das and Rahman, 1984)

Tammam *et al.* (2000) carried out an experiment with F_1 and F_2 generations of five bread wheat genotypes to estimate the relationship of grain yield and other characteristics. They reported that grain yield per plant had a positive correlation with number of spikes per plant, number of kernels per spike, 1000-grain weight and biological yield per plant in both generations.

Barma *et al.* (1990) studied the association of various characters with grain yield in spring wheat and reported that the correlation of grain yield per plant with ears per plant, ear length, grains per ear and 1000-grain weight were positive.

Budak and Yildirim (1995) found that grain yield was positively correlated with harvest index. Reyonod *et al.* (1994) also found that harvest index also exhibited a significant positive association with grain yield which indicates efficient translocation of photosynthates, whereas Fujita and Uzihara (1993) claimed that yield was not associated with harvest index. Yagbasanlar *et al.* (1995) found positive and significant correlations of days to maturity and harvest index.

Sharma *et al.* (1995) observed positive genotypic correlations between grain yield, effective tillers no, grains per spike. He suggested that selection of tiller number and grains per spike would be effective in yield improvement in bread wheat.

Narwal *et al.* (1999) studied genotypic and phenotypic correlation coefficients and observed significant and positive correlation of grain yield with tillers per plant, grains per spike and 1000-grain weight. Khan *et al.* (1999) found genotypic correlation were significant for grain yield in a positive direction with days to 50% heading and negative with 1000-grain weight.

Shoran (1995) reported grain yield per plant had significantly positive correlation with spikes per plant, grains per spike, biological yield per plant, harvest index and 1000-grain weight in bread wheat. He noticed significant but negative association of grain yield with days to 50% flowering and days to maturity. He also revealed that the associations of grain yield per plant with plant height and spikelets per spike were positive but non-significant.

Jadhav (1989) observed the grain yield was found to be positively and highly significantly correlated with yield contributing characters. Bielawska (1999) reported that plant height showed low correlation with 1000-grain weight. Grains per spike, spikelets per spike, plant height and harvest index were positively and

significantly associated with grain yield (Raut *et al.*, 1995 and Sharma *et al.*, 1995).

Yield improvement and associated characteristics of some Australian spring wheat cultivars were evaluated by Perry and Antuono (1989). They found grains per ear and grains per m² were strongly and positively correlated with grain yield, but there were weak negative correlations between 100-grain weight and yield.

Singh *et al.* (1998) explained significantly positive correlation between spikes per plant and grain yield per plant. They asserted that spikelets per spike was positively correlated with days to flowering, spike length and grains per spike, but spikelets per spike negatively correlated with 100-grain weight and spikes per plant. According to Shen *et al.* (1997) grains per spike and 1000-grain weight has highly negative correlation, suggesting existence of compensation effect between them in determining grain yield in spring wheat.

Razzaque *et al.* (1981) found significant and positive correlations of number of spikes per plant, spike length, number of grains per spike and 100-grain weight with grain yield per plant. Ehdaie and Waines (1989) reported grain yield showed a positive correlation with harvest index. On the contrary, Jensen (1988) asserted a negative correlation between harvest index and plant height.

Bhuyian *et al.* (1998) stated grain yield was significantly correlated with harvest index. They found non significant phenotypic correlation between grain yield and 100-grain weight but genotypic correlation between them was considerably high and positive. They noticed that phenotypic correlation of spikes per plant, spike length, grains per spike with yield were not significant and their genotypic correlations were low. Shamsuddin (1990) reported that harvest index was positively correlated with grain yield in spring wheat.

2.1.6.2 Study of path coefficient

Correlations among agronomic and morphological characters are helpful in determining the components of complex trait yield, but they did not provide an exact picture of the relative importance of direct and indirect influences of each of the component characters on yield. Therefore, the correlations between yield and its contributing characters are further analysed through path coefficient. In the study of correlation coefficient and path analysis in bread wheat Bhuyian et al. (1998) observed that harvest index had the highest direct effect on grain yield. Plant height and grains per spike had also substantial direct effect on grain yield but 100-grain weight had negative direct effect. They also reported indirect effect of 100-grain weight through harvest index resulted positive relationship with grain yield. Shamsuddin (1987) found harvest index and grains per spike had positive correlation with grain yield mainly through their direct effects.

Tamman *et al.* (2000) stated that grain yield was directly affected by number of spikes per plant, number of kernels per spike and 1000-kernel weight in both genotypic and phenotypic levels. They noticed that grain yield was also affected indirectly by biological yield via number of spikes per plant, number of kernels per spike, 1000-kernel weight and days to heading.

Bariga (1984) studied path analysis in bread wheat then he mentioned high and positive direct effects of grains per spike on grain yield. He also reported that plant height showed low effect on yield. Stova (1981) reported that grains per spike had substantial direct effect on grain yield.

In an experiment with 47 F₄ progenies of two wheat crosses (WL711 x HD2122 and HD2122 x Sonalika), Pawar et al. (1989) found number of effective tillers per

plant had strongest direct on yield in cross WL711 x HD2122, while 100-grain weight made maximum contribution towards yield in the cross HD2122 x Sonalika, Paroda and Joshi (1970) observed that 1000-grain weight and grains per spike had high positive direct effects on yield in spring wheat.

Chaturvedi and Gupta (1995) studied path analysis in 44 wheat strains and observed that harvest index, plant height, days to maturity had direct positive effects on grain yield. Khan *et al.* (1994) reported that 1000-grain weight had high direct effect on grain yield and showed positive association with yield. In another study of path analysis Khan *et al.* (1999) narrated the contribution of harvest index, grains per spike, plant height and spike length to grain yield.

Studying on correlation and path analysis in bread wheat Das (1972) and Jamini *et al.* (1974) reported that number of spikes per plant had the highest direct effect on grain yield followed by number of spikelets per spike and 100-grain weight. Sinha and Sharma (1979) observed positive direct effects of 100-grain weight, number of grains per spike and number of spikes per plant on grain yield of wheat.

Das and Mondal (1984) reported that number of grains per spike had a moderate direct effect on grain yield, suggesting that number of grains per spike was one of the major components of yield in bread wheat. Mondal *et al.* (1997) found plant height had negative direct effect on yield, but grain per ear, 100-grain weight and tillers per plant had positive direct effects on grain yield.

In the genotypic and phenotypic levels of path analysis in wheat grains per spike, 100-grain weight and spike per plant had high positive direct effect on yield per plant (Ibrahim, 1994 and Subhani and Khaliq, 1994).

While studying path coefficient in bread and durum wheat Shamsuddin (1990) noticed biological yield and harvest index were correlated with grain yield mainly through their direct effects. Shen *et al.* (1997) and Ram *et al.* (1975) analysed path coefficient and showed considerable direct effects of grains per spike, 1000-grain weight and number of spikes per plant appeared as most important yield contributing characters. An experiment was carried out by Razzaque *et al.* (1981) with 80 wheat cultivars to study path analysis and they indicated 1000-grain weight as the most important components of yield and grains per spike was the next in importance. They found days to maturity had moderate positive effect on grain yield.

From the above review of the path coefficient analysis studied by various scientists it appeared the importance of different characters for their contribution to grain yield in wheat. Most of the scientist suggested that hybridization programme should include genotypes with spikes per plant, grains per spike, grain weight, harvest index and high grain yield to obtain further improvement in wheat breeding programme.

2.1.7 Heritability for yield and yield contributing characters

The success of breeding programme largely depends upon the amount of genetic variability present in the base population and the extent to which the desirable are heritable. Heritability is the most important parameters for selection in breeding programme. The knowledge of heritability helps plant breeders in predicting the response to selection.

Plant height

Khan *et al.* (1994) observed high heritability for plant height in spring wheat. Rahman *et al.* (1986) studied both broad and narrow sense heritability and

observed high broad sense heritability and moderate narrow sense heritability for the character. Mandal and Sarkar (1996) estimated moderate heritability for plant height.

Fida *et al.* (1997) estimated poor to moderate heritability (2.33% to 56.33%) for plant height in spring wheat. Oliveira Camargo *et al.* (2000) observed high narrow sense heritability (86.1%) for this character.

Tillers per plant

Rahman *et al.* (1986) studied both broad and narrow sense heritability for spike per plant in spring wheat and observed high heritability in broad sense and low in narrow sense. The high difference between broad and narrow sense heritability indicated that the character was predominantly controlled by non-additive gene action.

Moderate to high heritability for this trait reported by Islam and Saha (1986). Pawar *et al.* (1989) also observed a relatively higher heritability for spikes per plant. On the other hand, Balchand and Lodhi (1994) observed low heritability for spikes per plant. Moderate to higher heritability were estimated by Mann and Sharma (1995). Camargo *et al.* (1998) estimated heritability and correlations between grain yield and yield components in biparental wheat crosses. He observed that narrow sense heritability of grains per spike was 0.717. This value indicated that the selection for this trait could be efficient for F_2 or F_3 generations. Kamboj *et al.* (2000) reported low heritability for spikes per plant. Afiah *et al.* (2000) observed moderately to low narrow sense heritability for this trait in spring wheat.

Spikelets per spike

Balchand and Lodhi (1994) reported high estimates of heritability for spikelets per spike in spring wheat. Similar results were reported by Singh and Yunus (1988) and Khan *et al.* (1994). But Shoran (1995) reported this character as a moderately heritable. Medium to high narrow sense heritability for spikelets per spike was reported by Camargo *et al.* (1998). Fida *et al.* (1997) reported broad sense heritability for this character in the range of 2.04-64.85%.

Grain per spike

As a primary yield component, heritability for grains per spike was extensively studied by many authors. Barma *et al.* (1990) and Shoran (1995) reported high heritability for number of grains per spike. Mann and Sharma (1995) estimated heritability that was moderate in high for the character. High heritability also reported by Chaturvedi and Gupta (1995), Sharma *et al.* (1995). Moderate heritability for number of grains per spike estimated by Mondal and Sarker (1996) and Uddin *et al.* (1997).

Low heritability for number of grains per spike was reported by Singh and Tewari (1990). Amin *et al.* (1992) reported poor broad sense heritability in spring wheat. Poor narrow sense heritability was reported by Gill *et al.* (1973) and Afiah *et al.* (2000), and they suggested that low heritability might be due to non-additive gene action.

100-grain weight

Heritability estimates were moderate to high magnitude for 1000-grain weight in spring wheat as reported by Mann and Sharma (1995). High broad sense heritability and poor narrow sense heritability were studied in spring wheat by

Rahman *et al.* (1986). Shamsuddin *et al.* (1993) reported high broad sense heritability and medium narrow sense heritability for the character. Vitkare and Atale (1996) reported narrow sense heritability were less than 0.5 for the trait indicating a low response to selection.

Uddin *et al.* (1997) and Mehta *et al.* (1998) also noted high heritability for 100-grain weight. Moderate estimates of heritability was reported by Moghaddam *et al.* (1998). Kamboj *et al.* (2000) observed intermediate heritability for 100-grain weight indicating selection in later generation will be effective for this trait.

Grain yield per plant

High estimates of heritability in broad sense for grain yield in spring wheat was reported by Shamsuddin *et al.* (1995), Khan *et al.* (1994), Shoran (1995), Chaturvedi and Gupta (1995), Deswal. *et al.* (1996) and Rahman *et al.* (1986). They explained the estimates of high heritability in their study materials was probably due to additive genetic variance, which was exploited by direct selection.

Poor narrow sense heritability for grain yield per plant in spring wheat was reported by Ortiz *et al.* (2001). Paroda and Joshi (1970) and Tanno *et al.* (1985) reported that both broad sense and narrow sense heritability were very low for this character. Thomas *et al.* (1971) reported that grain yield was influenced by genetic and environmental effects of different yield contributing characters. So, poor heritability for grain yield might be expected.

2.2 Selection for yield and yield contributing characters.

Low heritability for grain yield in spring wheat are responsible for slow response to selection. So direct selection for grain yield discouraged and improvement is sought for through indirect selection of yield components.

Many selection criteria/indices for grain yield in spring wheat have been formulated based on relationship between yield and yield components. Different selection indices constructed by Das (1972) and got a maximum gain of 7.44% in grain yield selecting through an index, which included grains per spike, spike length, 250-grain weight and grain yield. An index including spikes per plant, grains per spike, grain weight and grain yield was 34% more efficient than direct selection for grain yield reported by Sethi *et al.* (1979). Sharma and Ahmad (1978b) suggested that the primary yield components influenced grain yield through plant height. Singh and Singh (2001) suggested that selection for improving grain yield in spring wheat should largely depend upon number of seeds per spike and spike length. Jedynski (2001) studied heritability and path coefficient analysis of yield components in spring wheat and suggested that number of grains per spike was the most important character in selection for high grain yield. From a selection index studies of Uddin *et al.* (1997) revealed that three variable indices including grain yield per plant, spikes per plant and 1000-grain weight gave the highest relative efficiency over trait selection for grain yield per plant.

From a study of variability and characters association in wheat, Dhonde *et al.* (2000) suggested the plant height, productive tillers, length of spike, grains per ear and 1000-grain weight should be given more emphasis during selection for yield improvement.

Besides indirect selection through various morpho-physiological yield components, direct selection for yield has been advocated. Dhansoban and Smith (1978) reported a good response in yield of spring wheat through direct selection. Briggs and Shebeski (1971) and Pawar *et al.* (1985) observed significant intergeneration correlations for grain yield.

Pawar *et al.* (1985) studying with spring wheat reported that additive and additive x additive types of gene actions increased response to selection in F_3 generation as compared with those in F_2 generation. Therefore, selection for grain yield may be started from F_3 or onward generations. Paroda (1968) indicated that selection programme based on 1000-grain weight and grain yield per plant would lead to a gain of 16 percent over straight selection.

জাতীয় মোটামুড় কার্ভার বিজ্ঞান ও প্রযুক্তি
বিদ্যালয়, কুমিল্লা

সংযোজন নং ...

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CHAPTER 3
MATERIALS AND METHODS

MATERIALS AND METHODS

The present study contained two experiments: One was study of combining ability, heterosis and gene action for yield and yield contributing characters from a diallel cross population and the other was selection response of different yield contributing characters in two crosses of spring wheat.

The experiments were conducted at the experimental Farm of the Department of Genetics and Plant Breeding, Bangladesh Agricultural University (BAU), Mymensingh, during the rabi season of 2000-2001 and 2001-2002.

3.1 Soil and agro –ecological zone

The land in which the experiments were carried out was a medium high land belonging to the old Brahmaputra Floodplain, Agro-Ecological zones (AEZ-9) having non calcareous dark gray floodplain soil (UNDP and FAO, 1998). The soil was sandy loam in texture with pH value of 6.5 (Uddin, 1975).

The nutrient status of the experimental soil as tested by Humboldt Soil Testing Laboratory, Department of Soil Science Bangladesh Agricultural University, Mymensingh is as follows-

Table 3.1 Nutrient status of the experimental soil

Sl. no.	Soil properties	Result.
i	Organic Carbon	0.79%
ii	Total nitrogen	0.06%
ii	Exchangeable potassium	70.90 ppm
iv	Sulphur	14 ppm
v	Phosphorus	13 ppm
vi	pH	6.5

3.2 Climate

The climate of the experimental location is characterized by high rainfall, humidity and temperature from March to October and relatively low rainfall, humidity and temperature from November to February. Meteorological data for the period of experiment for 2000-2001 and 2001-2002 are presented in Appendix I. and Appendix II.

3.3 Materials

3.3.1 Study of the combining ability, heterosis and gene action for yield and yield contributing characters

The study included eight genotypes of spring wheat used as parents and their twenty-eight F_1 s obtained from a diallel cross without reciprocals. In Table: 3.2 name and origin of parental genotypes are given.

Table 3.2 List of genotypes and their origin

Sl. no.	Genotype	Origin	Source
1.	Sonalika	India	Wheat Breeding Project, Department of Genetics and Plant Breeding, BAU, Mymensingh
2.	Gourav	Bangladesh	
3.	Kanchon	Bangladesh	
4.	Rawal	Pakistan	
5.	Moyoor	Pakistan	
6.	Chyria	Pakistan	
7.	Anja	Mexico	
8.	Kheri	Bangladesh	

3.3.2 Response to selection of yield and yield contributing characters was studied in the second experiment.

The study included F_2 and F_3 populations of the crosses NK-5 x Opata and Rawal x SA-92. The F_2 populations were obtained by selfing the F_1 population which were grown in rabi of 2000-2001.

3.4 Methods

3.4.1 Study of the combining ability, heterosis and gene action for yield and yield contributing characters

3.4.1.1 Crossing between parents

The parental materials were grown in crossing block during Rabi of 2000 to 2001. Plants of flowering stage just before anthesis stage were selected and crossed in diallel fashion excluding reciprocals. The matured F_1 seeds were carefully harvested, threshed and stored in a desicator. To protect the seeds from the attack of pests, insecticide savin dust was applied.

3.4.1.2 Land preparation and fertilization

Land was opened in early November (2000 and 2001) for both seasons with a tractor. Later on cross-ploughing and final preparation of land were done with power tiller followed by laddering. After ploughing and laddering all the stubbles and uprooted weeds were removed from the land. Fertilization was done with urea, TSP, MP and cowdung using the recommended dose.

Table 3.3 Rates of fertilizers and manures applied.

Name of the fertilizer/manure	Rate (kg/ha)
1. Urea	200
2. Triple super phosphate (TSP)	200
3. Murate of potash (MP)	80
4. Cowdung	6000

Total amounts of fertilizers and manures except urea were applied at the time of final land preparation. Half amount of urea was applied with other fertilizers at the

time of final preparation in the field and remaining half was applied in two top dressings, one at tillering stage and other at flowering stage in both season. Basudin was applied in the field before sowing to protect the seedling from attack of cutworm.

3.4.1.3 Sowing and intercultural operation

The eight parents and their 28 F_1 hybrids were sown in a randomized block design with three replications in November 19, 2001. Each genotype was grown in a single row plot of 1m long in each replication. The spacing between rows was 25 cm and between plants within the same row was 5 cm.. Weeding was done at the tillering and booting stage. The experimental plot was irrigated two times, one at just after first weeding and other at flowering stage.

3.4.2 Response to selection of yield and yield contributing characters was studied in the second experiment.

200 plants were randomly selected from each cross of the F_2 population. Top 10% plants were selected independently for each character from each of the populations in F_2 generation. The F_3 progenies of selected plants were grown in head to row in 2001-2002 in a randomized block design with three replications. The rows were 1 m in length with 25 cm between rows and 5 cm between plants in a row. There were 70 families in NK-5 x Opata and 65 families in Rawal x SA-92 in F_3 generation.

3.5 Harvesting

Different genotypes matured at different times. So harvesting was completed from 20 th to 31th March, 2002. Ten plants were randomly selected to collect the data and harvested by up rooting. Border effect was avoided by discarding border plants from sampling.

3.6 Data collection

Data on seven different characters were recorded from both experiments in the field laboratory after harvesting. The characters were-

Plant height: Height of the main tiller from the base to tip of spike excluding own was measured in cm.

Tillers per plant: Number of ear bearing tillers were counted from each of the sample plant.

Spike length: Length of main spike excluding own was measured in cm.

Spikelets per spike: Spikelets from the main spike of the sample plants were counted.

Grains per spike: Grains were obtained from main spike of the sample plants were counted.

100-grain weight: One hundred clean sun dried grains were randomly taken out from each plot and weighed in gram.

Grain yield per plant: Total grain weight of each sample plant was measured in gram.

3.7 Data analysis

3.7.1 Analysis of variance

The data recorded for each character in the first experiment was averaged to obtain mean plot data and analysis of variance was performed by computer using MSTAT-C software. The test of significance between the mean of genotypes was done by using MSTAT-C software.

3.7.2 Analysis of combining ability

The data were analysed for variance of combining ability for grain yield and its different contributing characters in the diallel population. Combining ability was analysed by Griffing's (1956a) method II and model I (fixed model):

The mathematical model for combining ability analysis assumed :

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

Where,

X_{ij} = Performance of cross between i th and j th parents

μ = Population mean

g_i = GCA effect of the i th parent

g_j = GCA effect of the j th parent

s_{ij} = SCA effect of the cross between i th and j th parents

e = Environmental influence peculiar to the cross

The sum of squares in the analysis of variance due to GCA and SCA effects were calculated using the following formula:

$$S_g = \frac{1}{P+2} \left\{ \sum (X_{i.} + X_{ii})^2 - \frac{4}{P} X_{..}^2 \right\}$$

$$S_s = \sum \sum X_{ij}^2 - \frac{1}{P+2} \sum (X_{i.} + X_{ii})^2 + \frac{2}{(P+1)(P+2)} X_{..}^2$$

Where, S_g = Sum of squares due to GCA

S_s = Sum of squares due to SCA

P = Number of parents

$X_{i.}$ = Array total of the i th parent

X_{ii} = Performance of the i th parent

$X_{..}$ = Grand total of diallel table

X_{ij} = Performance of the cross between i th and j th parents

GCA effects of the parents (g_i) and SCA effects of the crosses (s_{ij}) were calculated using-

$$g_i = \frac{1}{P+2} \left[\sum (X_{i.} + X_{ii}) \right] - \frac{2}{P} X_{..}$$

$$s_{ij} = X_{ij} - \frac{1}{P+2} [X_{i.} - X_{ii} + X_{.j} + X_{jj}] + \frac{2}{(P+1)(P+2)} X_{..}$$

Where,

$X_{.j}$ = Array total of the j th parent

X_{jj} = Performance of the j th parent

The effects were tested against zero by conventional t-test

$$t \text{ for } g_i = \frac{g_i}{S.E.(g_i)}$$

$$t \text{ for } s_{ij} = \frac{s_{ij}}{S.E.(s_{ij})}$$

The standard error for g_i { $S.E. (g_i)$ } and s_{ij} { $S.E. (s_{ij})$ } were obtained as

$$S.E. (g_i) = \left[\frac{P-1}{P(P+2)} \sigma_e^2 \right]^{\frac{1}{2}}$$

$$S.E. (s_{ij}) = \left[\frac{2(P-1)}{(P+1)(P-2)} \sigma_e^2 \right]^{\frac{1}{2}}$$

Where,

σ_e^2 = Error variance obtained from analysis of variance of combining ability.

3.7.3 Estimation of heterosis of F₁ hybrids over mid parent

The amount of heterosis was estimated by comparing the mean of F₁ hybrids over mid parental value using following formula (Rai, 1979).

$$\text{Percent of heterosis over mid parent (MP)} = \frac{\bar{F}_1 - \text{MP}}{\text{MP}} \times 100$$

Where,

$\bar{F}_1$ = Mean of the character of F₁ hybrids

MP = Mid parental value of the character i.e. average of two parents mean.

The test of significance for heterosis was done by using t-test.

$$t = \frac{\bar{F}_1 - \text{MP}}{\text{Sd}} \times 100$$

Where, $\text{Sd} = \sqrt{\frac{2\text{EMS}}{r}}$

Sd = Standard error of difference

EMS = Error mean square

r = Number of replication

3.7.4 Estimation of heritability for yield and yield contributing characters

Heritability in broad sense and narrow sense were estimated from the components of variance of combining ability (Bulmer, 1980).

Sources of variation	Expectation of means squares
GCA	(P-2) V _g + V _e
SCA	V _s + V _e
Error	V _e

Where,

V_g = Variance

V_s = Variance due to SCA

V_e = Environmental variance

P = Number of parents.

These variances were translated into different components of phenotypic variance as-

Additive genetic variance, $V_A = 2 V_g$

Total genetic variance, $V_G = 2V_g + V_s$

Phenotypic variance, $V_P = 2 V_g + V_s + V_e$

Now heritability in broad sense (h^2_b) and narrow sense (h^2_n) were estimated as follows-

$$h^2_b = \frac{V_G}{V_P} \times 100$$

$$h^2_n = \frac{V_A}{V_P} \times 100$$

Narrow sense heritability was also estimated from parents –offsprings regression

$$b = \frac{\text{Cov}(PO)}{V(P)}$$

Where,

b = Regression coefficient of offsprings on mid parents

$\text{Cov}(PO)$ = Mid parents –offsprings covariance

$V(P)$ = Mid parents variance

The regression coefficient was tested against zero by conventional t-test.

$$t = \frac{b}{S.E.(b)}$$

Where, S.E. (b) = Standard error of b

$$S.E. (b) = \left[\frac{SS(O) - b.SP(PO)}{N - 2.SS(P)} \right]^{\frac{1}{2}}$$

Where

SS (O) = Sum of squares due to offsprings

SS (P) = Sum of squares due to parents

SP (PO) = Sum of products due to parent-offsprings

N = Number of observations

3.7.5 Analysis of gene action for yield and yield contributing characters

3.7.5.1 V_r - V_r Analysis and graphical presentation

Hayman's (1954) approach for V_r - W_r analysis and graphical presentation was followed for the study of genetic control of the characters. Array variance (v_r) and parent offspring covariance (W_r) for each array were calculated by the following formula-

Variance of each array

$$V_r = \frac{1}{n-1} [\text{Sum of square of the crosses involving a particular parent- C.F.}]$$

Where,

$$C.F. = \frac{(\text{Sum of all the crosses involving a particular parent})^2}{\text{Number of crosses}}$$

$$\text{Parent mean} = \frac{\text{Sum of all the parents}}{\text{Number of parents}}$$

$$\text{Variance of parents} = V_0L_0 = \frac{1}{n-1} [\text{Sum of square of all the parents} - \text{C.F.}]$$

$$\text{Where, C.F.} = \frac{(\text{Sum of all the parents})^2}{\text{Number of parents}}$$

Covariance between parents and their offspring (W_r) were calculated. This is in fact the covariance of the arrays with non-recurring parents.

3.7.5.2 Estimation of regression coefficient of W_r on V_r

The regression coefficient of W_r on V_r was estimates as :

$$b = \frac{\text{Cob}(W_r, V_r)}{\text{Var}(V_r)}$$

$$\text{Where, Cov}(W_r, V_r) = \left[\sum V_r W_r - \frac{\sum V_r \sum W_r}{n} \right] / (n-1)$$

$$\text{Var}(V_r) = \left[\sum V_r^2 - \frac{(\sum V_r)^2}{n} \right] / (n-1)$$

Standard error of b was calculated by the following formula -

$$\text{S.E}(b) = \left[\frac{\text{Var}(W_r) - b \cdot \text{Cob}(W_r, V_r)}{n - 2\text{Var}(V_r)} \right]^{\frac{1}{2}}$$

Where,

$$\text{Var}(W_r) = \frac{\sum W_r^2 - \frac{(\sum W_r)^2}{n}}{(n-1)}$$

The significance of b from zero and unity were tested as follows-

$$H_0: b = 0$$

$$= (b-0)/S.E(b)$$

$$\text{and } H_0: b = 1$$

$$= (1-b)/S.E. (b)$$

These values were tested against tabulated value of 't' for (n-2) degrees of freedom

3.7.5.3 Construction of Wr-Vr graph

- i) The limiting parabola on the regression line was constructed by using the following formula-

$$W_{ri} = (V_{ri} \times V_0 L_0)^{1/2}$$

- ii) For drawing regression line the expected Wri values were calculated by the following formula-

$$W_{rei} = a + bV_{ri}$$

These values were plotted against Vr values and a straight line was drawn. The point of interception of this regression line on Wr ordinate i.e. 'a' was obtained by the following equation-

$$a = \bar{W}_r - b.\bar{V}_r$$

- iii) Drawing of Wr-Vr graph: Following steps are involved plotting the graph of Vr, Wr
- Vr values took the position of X-axis. An appropriate interval between observed Vr values were chosen and the X-axis was marked accordingly.
 - Likewise the Y-axis was marked with values of Wr spread at same intervals.

- c) For regression line, against the observed values of Vr corresponding expected values of Wr (Wrei) were plotted. By joining the points a linear regression line passing through the Wr and Vr was obtained. The regression line intercepted the Wr-axis and the difference between the intercept point and the origin was designated by 'a'
- d) For parabola, the expected values of Wr were plotted against the observed values of Vr and a free hand drawing joined the points. This has given a parabola.
- e) Lastly observed values of Wr were plotted against the corresponding observed values of Vr. There have been eight array points, which scattered around the regression line.

3.7.6 Estimation of relationship between yield and yield contributing characters

3.7.6.1 Estimation of genotypic and phenotypic correlation coefficients

Genotypic and phenotypic correlation coefficients were estimated using the formula suggested by Johnson *et al.* 1955; Miller *et al.* 1958; Singh and Chaudhury, 1985.

$$\text{Genotypic correlation co-efficient } (r_g) = \frac{\text{Cov}_{(g)1.2}}{\sqrt{\sigma^2_{(g)1} \cdot \sigma^2_{(g)2}}}$$

Where,

$\text{Cov}_{(g)1.2}$ = Genotypic covariance between the variables X_1 and X_2

$\sigma^2_{(g)1}$ = Genotypic variance of the variable X_1

$\sigma^2_{(g)2}$ = Genotypic variance of the variable X_2

$$\text{Phenotypic correlation coefficient } (r_{ph}) = \frac{\text{Cov}_{(ph)1.2}}{\sqrt{\sigma^2_{(ph)1} \cdot \sigma^2_{(ph)2}}}$$

Where,

$\text{Cov}_{(ph)1.2}$ = Phenotypic covariance between the variables X_1 and X_2

$\sigma^2_{(ph)1}$ = Phenotypic variance of the variable X_1

$\sigma^2_{(ph)2}$ = Phenotypic variance of the variable X_2

3.7.6.2 Estimation of path coefficients

The components of genotypic correlation coefficients of different yield contributing characters with grain yield were partitioned into components of direct and indirect effects by path coefficient analysis. Path coefficient analysis was done according to the procedure stated by Singh and Chaudhury (1985) and Dabholkar (1992) which was originally suggested by Dewy and Lu (1959). In the present study, grain yield per plant was considered as the dependent variable (effect) and the six yield contributing characters were considered as the independent variables. The following sets of simultaneous equations were used depending upon the cause and effect relationship

$$r_{ly} = P_{ly} + r_{12}P_{2y} + r_{13}P_{3y} + r_{14}P_{4y} + r_{15}P_{5y} + r_{16}P_{6y}$$

$$r_{2y} = r_{21}P_{1y} + P_{2y} + r_{23}P_{3y} + r_{24}P_{4y} + r_{25}P_{5y} + r_{26}P_{6y}$$

$$r_{3y} = r_{31}P_{1y} + r_{32}P_{2y} + P_{3y} + r_{34}P_{4y} + r_{35}P_{5y} + r_{36}P_{6y}$$

$$r_{4y} = r_{41}P_{1y} + r_{42}P_{2y} + r_{43}P_{3y} + P_{4y} + r_{45}P_{5y} + r_{46}P_{6y}$$

$$r_{5y} = r_{51}P_{1y} + r_{52}P_{2y} + r_{53}P_{3y} + r_{54}P_{4y} + P_{5y} + r_{56}P_{6y}$$

$$r_{6y} = r_{61}P_{1y} + r_{62}P_{2y} + r_{63}P_{3y} + r_{64}P_{4y} + r_{65}P_{5y} + P_{6y}$$

Where,

r_{iy} = Correlation coefficient between y and ith character ($i = 1, 2, 3, \dots, 6$)

y = Grain yield per plant

P_{iy} = Path coefficient due to ith character (i=1,2,3,.....6)

1 = Plant height

2 = Tillers per plant

3 = Spike length

4 = Spikelets per spike

5 = Grains per spike

6 = 100-Grain weight

The residual effect (R) was calculated using the following formula suggested by Singh and Choudhury, (1985).

$$P^2_{Ry} = 1 - \sum P_{iy} r_{iy}$$

Where,

$$P^2_{Ry} = R^2$$

p_{iy} = Direct effect of the characters on yield per plant

r_{iy} = Correlation coefficient of the characters with yield per plant

Therefore,

$$\text{Residual effect, } R = \sqrt{P^2_{RY}} = \sqrt{1 - \sum P_{iy} r_{iy}}$$

3.7.7 Estimation of selection response for yield and yield contributing characters

Response was measured in F₃ generation through selection in F₂ generation. The response and realized heritability were estimated as-

$$\text{Genetic advance \% mean} = \frac{\bar{F}_3 - \bar{F}_2}{\bar{F}_2} \times 100$$

Selection response, $R = \bar{F}_3 - \bar{F}_2$

Selection differential, $D = \bar{F}_{2(s)} - \bar{F}_2$

$$\text{Realized heritability} = \frac{R}{D}$$

Where,

$\bar{F}_2$ = mean of F_2 generation.

$\bar{F}_{2(s)}$ = mean of selected F_2 plants.

$\bar{F}_3$ = mean of F_3 (selected lines).

Coefficient of variation (CV%) were estimated in F_2 generation as follows-

$$CV\% = \frac{\sqrt{\sigma_{F_2}^2}}{\bar{X}_{F_2}} \times 100$$

Where,

$\sqrt{\sigma_{F_2}^2}$ = Phenotypic standard deviation of F_2 generation

$\bar{X}_{F_2}$ = Mean of F_2 generation

CHAPTER 4
RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The present study includes two experiments- (1) analysis of combining ability, heterosis and gene actions for yield and yield contributing characters and (2) selection response for yield and different yield contributing characters in spring wheat. The results of the experiments are presented and discussed here separately.

4.1 Analysis of combining ability, heterosis and gene actions for yield and yield contributing characters in spring wheat.

4.1.1 Variations among parents and their F_1 hybrids for yield and different yield contributing characters

Analysis of variance for yield and yield contributing characters in spring wheat are presented in Table: 4.1. The results revealed that there were significant variations for all the characters plant height, tillers per plant, spike length, spikelets per spike, grains per spike, 100-grain weight and grain yield per plant. This indicates the presence of genetic variability among the genotypes. The variances due to genotypes were partitioned into the variances due to parents (P), F_{1S} and parents vs. F_{1S} . The variances due to parents were significant for the characters plant height, tillers per plant, spike length, spikelets per spike and 100-grain weight. The variances due to F_{1S} were significant for plant height, spike length, spikelets per spike, 100-grain weight and grain yield per plant. Significant variances due to parents vs. F_{1S} were obtained for spikelets per spike, grains per spike and grain yield per plant. This indicates the presence of heterotic expression for these characters in F_1 generation.

4.1.2 Combining ability for yield and yield contributing characters.

Analysis of variance of combining ability for yield and yield contributing characters in spring wheat are presented in Table 4.2. It showed that the variances

Table 4.1 Analysis of variance (mean squares) for yield and yield contributing characters

Source of variation	df	Plant height (cm)	Tillers per plant (no)	Spike length (cm)	Spikelets per spike (no)	Grains per spike (no)	100-grains weight (g)	Grain yield per plant (g)
Replication	2	54.42	1.73	1.54	8.74	584.86	0.18	21.72
Genotypes	35	211.24**	2.46**	1.57**	5.87**	99.17*	1.05**	6.29*
Parents	7	473.32**	4.44**	3.34**	7.93**	113.01	2.05**	2.83
F ₁ s	27	150.38**	1.93	1.16**	4.89**	83.01	0.81**	6.85*
Parents vs F ₁ s	1	19.63	2.66	0.04	17.83**	438.17**	0.26	14.96*
Error	70	24.90	1.23	0.28	1.40	59.12	0.18	3.60

***and ** indicate significant at 5% and 1% level of probability, respectively.**

due to GCA and SCA were significant for all the characters except SCA for grains per spike. Grains per spike had only significant GCA mean square.

GCA variance contains additive (additive and additive x additive epistasis), whereas SCA variance comprises non-additive (dominance and additive x dominance, dominance x dominance epistasis) genetic variation (Griffing, 1956b) and Baker, 1978). The significant estimates of GCA and SCA variances indicates the importance of both additive and non-additive gene effects for plant height, tillers per plant, spike length, spikelets per spike, grains per spike, 100-grain weight and grain yield per plant in their inheritance. Only additive gene action was noticed for grains per spike.

The ratio between GCA and SCA mean squares were estimated (Table: 4.2). The ratio estimated more than unity indicates the preponderance of additive gene action and less than unity indicates the preponderance of non-additive gene action for the character. The characters plant height, tillers per plant, spike length, spikelets per spike, grains per spike and 100-grain weight indicated predominance of additive gene action. Non-additive gene action was observed only for grain yield per plant.

Grain yield and its contributing characters were reported to be controlled by both additive and non-additive gene actions in bread wheat. Srivastava *et al.* (1992b) reported both additive and non-additive gene actions with higher estimates of GCA variance than SCA variance, showing a more importance of additive gene action for spikes per plant, grains per spike, 100-grain weight and grain yield per plant. Singh *et al.* (1988) reported only additive effect for grains per spike in spring wheat. Malik *et al.* (1988) studied combining ability and reported that additive gene action was more important for plant height, spike length and grains per spike. Atale and Vitkare (1990) studied combining ability in a 5 x 5 diallel cross and

Table 4.2 Analysis of variance (mean squares) for combining ability for yield and yield contributing characters

Source of variation	df	Plant height (cm)	Tillers per plant (no)	Spike length (cm)	Spikelets per spike (no)	Grains per spike (no)	100-grains weight (g)	Grain yield per plant (g)
GCA	7	297.49**	1.04*	1.61**	5.69**	52.17*	1.26**	3.78**
SCA	28	13.69*	0.77*	0.26**	1.02**	28.30	0.11*	5.95**
Error	70	8.30	0.40	0.10	0.50	19.70	0.10	1.20
GCA: SCA		21.70	1.30	6.40	5.60	1.80	11.50	0.60

***and** indicate significant at 5% and 1% level of probability, respectively.**

reported additive genetic system for spike length and grain yield per plant. They suggested that it might be due to the fact that the parental materials included in their study were highly selected for yield. Masood and Kronstad (2000) reported both significant GCA and SCA variances for plant height, spikes per plant, spike length and significant SCA variance for only grain yield per plant. They observed GCA/SCA variance ratio was more than unity for plant height, spike length and was less than unity for spikes per plant and grain yield per plant in bread wheat suggesting pronounced non-additive gene action for latter two traits. Predominance of non-additive gene action for grain yield per plant in spring wheat was reported by Ahmed *et al.* (1979).

The results of the present experiment suggests that the yield contributing characters were predominantly controlled by additive gene action and grain yield was controlled by non-additive gene action. The predominance of non-additive gene action for grain yield per plant was reported by Jatotra and Paroda (1978).

In the present study preponderance of additive gene actions for different yield contributing characters specially for tillers per plant, plant height, spike length spikelets per spike grains per spike and 100-grain weight indicated that they would give good response to selection. However, presence of non-additive gene action for grain yield per plant could be exploited by recurrent selection or development of hybrid varieties in spring wheat if that is feasible.

4.1.2.1 GCA effects of the parents for yield and yield contributing characters.

Estimates of GCA effect of the parents for yield and yield contributing characters in spring wheat are shown in Table: 4.3. The parent Rawal was the best general combiner for grain yield and for some yield contributing characters. This parent had significant positive estimates of GCA effect for spike length, spikelets per

spike, 100-grain weight in addition to grain yield. The parents in the present experiment were semi-dwarf in plant weight except Kheri, which was tall. Positive GCA effects of the parents are desirable for breeding short rather than semi-dwarf varieties in spring wheat. In this respect, Kheri which had positive GCA effect could be considered promising for breeding short variety in spring wheat.

The variety Mayoor was good general combiner for spike length, spikelets per spike and 100-grain weight. The variety Anja was good for tillers per plant but it had significant negative GCA effects for spike length and 100-grain weight. The variety Sonalika was also good general combiner for spike length but significant and negative GCA effects for plant height, spikelets per spike, 100-grain weight and grain yield per plant. These parents could be chosen for yield components improvement in spring wheat.

4.1.2.2 Relationship between GCA effects of the parents with their mean performance

There was a close relationship between the mean performance and GCA effects of the parents (Table: 4.3). All the parents except Kheri were semi-dwarf that was why they showed negative GCA effects for plant height. Kheri which was tall showed significant and positive estimate of GCA for this character. Rawal had the largest spike and showed higher estimates of GCA effect for the character. Number of spikelets per spike was higher in parents Rawal, Mayoor and Kheri, and they showed high GCA effects for the character. Rawal and Mayoor were better for 100-grain weight and showed significant positive GCA effect for this trait. For grain yield Rawal had medium yield and had estimated significant and positive GCA effect.

Table 4.3 Estimates of GCA effects of the parents for yield and yield contributing characters.

Parents	Plant height (cm)	Tillers per plant (no)	Spike length (cm)	Spikelets per spike (no)	Grains per spike (no)	100-grains weight (g)	Grain yield per plant (g)
1.Sonalika	-3.27* (82.29)	-1.19 (4.23)	3.92** (9.88)	-6.38** (14.38)	1.49 (29.14)	-6.13** (3.27)	-3.03* (3.28)
2.Gowrav	-5.73** (74.94)	-1.64 (3.24)	-2.66* (8.60)	-4.03** (15.07)	-1.29 (26.18)	3.44* (4.47)	-1.26 (3.40)
3.Kanchan	-2.81* (84.06)	-1.46 (4.56)	1.61 (9.43)	0.51 (17.26)	-1.19 (24.05)	1.14 (4.55)	1.12 (4.65)
4.Rawal	-1.30 (81.22)	-0.55 (3.89)	6.82** (10.22)	2.99* (17.78)	-2.06 (18.84)	5.88** (5.17)	2.70* (3.03)
5.Moyoor	-1.97 (83.77)	2.07 (5.77)	2.99* (9.26)	4.88** (17.76)	-1.39 (15.39)	4.04** (5.12)	1.15 (3.74)
6.Chyria	-0.81 (83.36)	-1.13 (3.80)	-4.58** (8.17)	-0.65 (15.81)	1.42 (33.75)	1.72 (4.50)	0.65 (4.23)
7.Anja	-1.11 (76.72)	2.51* (6.31)	-5.50** (6.93)	0.03 (15.50)	0.24 (20.93)	-2.47* (3.49)	-0.55 (2.00)
8.Kheri	15.23** (115.14)	1.39 (6.39)	-2.59* (9.39)	2.66* (19.10)	2.76* (29.63)	-7.67** (3.04)	0.64 (5.05)
S.E.	0.85	0.19	0.09	0.20	1.31	0.07	0.32

*and** indicate significant at 5% and 1% level of probability, respectively.
Average value of the characters are shown in parenthesis

The positive relationship between mean performance and GCA effects of the parents for yield and yield contributing characters were reported by Singh and Gupta (1969), Paroda and Joshi (1970), Bhullar *et al.* (1979) and Rahman *et al.* (2000). This information and the results of the present experiment suggest that parents with high mean performance expressed significant GCA effects and they might be selected in crossing for wheat improvement programme. The overall study of GCA effects of the parents suggests that Rawal was the best general combiner for grain yield and some yield contributing characters. Therefore, this variety could be used as parent for yield improvement programme in spring wheat.

4.1.2.3 SCA effects of the crosses for yield and yield contributing characters in spring wheat.

The estimates of SCA effects of the crosses for yield and yield contributing characters in spring wheat are presented in the Table:4.4. Out of 28 crosses, 5 showed significant SCA effects for plant height. They were Gourav x Anja, Gourav x Kheri, Kanchan x Kheri, Rawal x Chyria and Rawal x Anja. The crosses Gourav x Anja and Mayoor x Chyria showed significant positive SCA effects for tillers per plant. The crosses Rawal x Anja and Mayoor x Chyria, both had significant positive SCA effects for spike length and spikelets per spike and the former cross also showed positive significant SCA effects for 100-grain weight. The crosses Gourav x Anja, Kanchan X Rawal, Rawal x Moyoor, Moyoor x Kheri and Chyria x Kheri estimated significant and positive SCA effects for grain yield per plant. These five crosses also showed significant and positive SCA effects for some yield contributing characters such as plant height, tillers per plant, grains per spike etc. Such positive relationship between SCA effects of grain yield and yield contributing characters has been reported by Buller *et al.* (1981), Singh *et al.* (1982), Shamsuddin *et al.* (1991) and Barma *et al.* (1998).

Table 4.4 Estimates of SCA effects of the crosses for yield and yield contributing characters.

Cross	Plant height (cm)	Tillers per plant (no)	Spike length (cm)	Spikelets per spike (no)	Grains per spike (no)	100 Grain weight (g)	Yield per plant (g)
Sonalika X Gourav	0.64	0.90	0.10	0.54	0.59	0.19	1.41
Sonalika X Kanchon	0.24	1.69	-0.83	0.02	0.09	-0.71	-0.26
Sonalika X Rawal	0.07	-0.52	-0.79	-0.41	2.01	-0.46	-0.86
Sonalika X Moyoor	-1.76	-1.27	-1.98	-2.12*	0.01	-1.90	-0.63
Sonalika X Chyria	0.39	-0.84	1.95	0.02	1.05	-0.62	0.06
Sonalika X Anja	-0.70	-1.55	0.50	-0.87	-0.51	0.07	-0.63
Sonalika X Kheri	-1.93	0.88	-0.80	-1.39	-1.57	0.77	-0.64
Gourav X Kanchon	-0.09	0.48	0.10	-2.16*	-0.81	0.95	-1.41
Gourav X Rawal	1.14	0.32	0.73	0.70	-0.25	-0.72	-1.30
Gourav X Moyoor	-0.39	0.39	-0.80	-0.60	0.71	-0.55	0.12
Gourav X Chyria	-1.09	-0.57	-1.20	-1.22	-1.89	-0.51	-1.26
Gourav X Anja	2.66*	2.29**	1.77	1.12	2.01	1.06	3.91**
Gourav X Kheri	-3.15**	-2.03	-1.74	-1.64	-0.96	1.08	-0.63
Kanchon X Rawal	-0.51	0.75	-2.38*	-1.17	0.87	-2.76*	10.82**
Kanchon X Moyoor	-0.01	-2.2*	-0.23	0.48	-0.58	-0.05	-2.86**
Kanchon X Chyria	-0.49	-0.66	-0.27	0.44	-0.86	-0.12	-1.10
Kanchon X Anja	-0.13	-1.91	1.04	-1.42	1.08	0.00	-1.06
Kanchon X Kheri	-2.94**	-0.57	1.03	-0.75	0.77	-0.08	-2.62*
Rawal X Moyoor	-0.35	1.47	-0.52	-1.66	2.67*	-2.39*	2.79**
Rawal X Chyria	-2.51*	-1.02	-0.14	-1.53	-1.94	-1.16	-2.09*
Rawal X Anja	2.29*	1.18	5.54**	3.98**	-1.53	5.33**	0.13
Rawal X Kheri	0.84	-0.64	-2.84**	-3.04**	-0.40	0.02	-1.95
Moyoor X Chyria	1.70	3.91**	2.43*	3.05**	-0.35	-0.22	1.29
Moyoor X Anja	0.63	-1.49	1.90	1.45	0.61	-0.36	0.70
Moyoor X Kheri	0.41	-2.81**	1.14	-0.46	2.34*	1.11	2.24*
Chyria X Anja	-0.26	-1.08	-0.47	-1.72	0.93	0.56	0.68
Chyria X Kheri	1.94	1.27	-2.65*	0.04	2.21*	0.68	4.19**
Anja X Kheri	0.60	-1.63	-1.68	-1.29	1.10	-3.86**	-0.72
SE ($\pm$)	2.27	0.50	0.24	0.54	0.50	0.19	0.86

*and ** indicates significant at 5% and 1% level if probability respectively

The crosses Kanchan x Moyoor, Kanchan X Kheri and Rawal x Chyria had significant negative SCA effects for grain yield per plant, which resulted by the significant and negative SCA effects for different yield contributing characters. High specific combination for grain yield was observed in poor x high general combiners as in the cross Kanchan x Rawal and low x low general combiners in the cross Gourav x Anja. The crosses Rawal X Anja and Mayoor x Chyria were found high specific combination for different yield contributing character but not for yield per plant.

In spring wheat, SCA effects of the crosses has been studied by many authors. Sharma *et al.* (1978) reported significant SCA effects of the crosses for grain yield by crossing the parents with high x high and high x low general combiners. Paroda and Joshi (1970) obtained high SCA effect of the crosses for yield and yield contributing characters involving at least one parent with high GCA effect. Khan and Ali (1998) noticed that the better specific crosses for yield and yield contributing characters involved high x high and high x low general combiners. On the other hand, Massod and Kronstad (2000) observed high positive SCA effects for grain yield by crossing the parents with low x low and low x average general combiners in bread wheat.

In the present experimental materials both additive and non-additive gene actions were noticed.. The non-additive gene action was expressed through significant estimates of SCA effects of the crosses. Therefore, the crosses with high SCA effect for grain yield and yield-contributing characters may be used for hybrid development in spring wheat if suitable male sterility source is available.

4.1.3 Heterosis of the crosses for yield and yield contributing characters.

Heterosis for yield and yield contributing characters over mid parents in F_1 generation of different crosses are presented in the Table: 4.5. It appears that the

Table 4.5 Estimates of heterosis of F₁ hybrids over mid parent for yield and yield contributing characters

Cross	Plant height (cm)	Tillers per plant (no)	Spike length (cm)	Spikelets per spike (no)	Grains per spike (no)	100 Grain weight (g)	Yield per plant (g)
Sonalika X Gourav	-0.55	17.72	-1.63	-4.83	11.5	2.24	32.03
Sonalika X Kanchon	-4.12	9.14	-4.17	-7.37	12.54	-7.48	-5.69
Sonalika X Rawal	-1.37	-4.92	-3.18	-7.17	45.18	-4.9	18.5
Sonalika X Moyoor	-6.74	-19.82	-4.94	-10.53	28.88	-14.27	-2.5
Sonalika X Chyria	-1.25	-9.76	3.66	-4.5	14.57	-5.27	2.87
Sonalika X Anja	-0.55	-24.94	6.17	-5.83	15.9	3.84	17
Sonalika X Kheri	-8.64*	-6.57	-7.89	-14.42*	-2.61	3.64	1.94
Gourav X Kanchon	-3.25	6.07	-1.49	-13.68*	-10.78	2.59	-17.7
Gourav X Rawal	3.7	18.63	0.94	-2.66	3.3	-3.46	22.09
Gourav X Moyoor	-1.12	5.57	-1.57	-4.57	32.1	-5.19	29.96
Gourav X Chyria	-3.53	4.17	-4.47	-7.9	-26.37	-2.25	-13.84
Gourav X Anja	11.56*	28.85	11.21	2.18	44.98	10.3	155.94*
Gourav X Kheri	-10.23*	-29.31	-10.43	-14.18*	-3	7.13	-9.37
Kanchon X Rawal	-3.51	5.88	-6.98	-9.21	27.26	-15.69	31.58
Kanchon X Moyoor	-2.5	-32.44	-0.41	-1.94	17.2	-7.29	-32.22
Kanchon X Chyria	-4.21	-12.43	-2.04	-3.38	-10.74	-5.03	-5.35
Kanchon X Anja	0.43	-31.6	8.17	-7.37	38	-0.07	1.86
Kanchon X Kheri	-11.37**	-23.9	-3.16	-11.65*	23.96	-4.26	-20.04
Rawal X Moyoor	-0.21	14.11	-0.33	-7.05	94.75*	-15.08*	143.55**
Rawal X Chyria	-6.56	-5.14	-0.85	-7.89	-20.56	-8.23	6.11
Rawal X Anja	10.82*	6.8	21.27**	11.69	22.03	24.72**	95.9
Rawal X Kheri	-0.02	-16.09	-11.83*	-15.78**	15.7	-2.65	-1.85
Moyoor X Chyria	1.25	38.59	7.76	9.12	11.25	-6.52	57.34
Moyoor X Anja	5.55	-23.76	13.39*	5.82	60.43	-3.32	71.42
Moyoor X kheri	-1.33	-38.89*	-0.72	-7.22	69.47*	-0.26	61.31
Chyria X Anja	2.65	-16.26	5.05	-5.67	24.11	4.45	52.21
Chyria X Kheri	1.84	1.31	-12.68	-6.9	31.74	1.32	85.58*
Anja X Kheri	1.94	-30.73*	-4.23	-9.43	43.54	-19.16	-0.02

* and ** indicates significant at 5% and 1% level of probability respectively

crosses Gourav x Anja, Rawal x Moyoor, Chyria x Kheri had significant and positive heterosis for grain yield per plant. There were some crosses having significant and positive for yield and yield contributing characters. The crosses Rawal x Anja and Moyoor x Anja expressed significant and positive heterosis for spike length. For 100-grain weight the cross Rawal x Anja had significant and positive heterosis. For plant height the crosses Gourav x Anja and Rawal x Anja expressed significant and positive heterosis. The cross Rawal x Anja had estimated 95.9% heterosis for yield. This cross also expressed significant and positive heterosis for some yield contributing characters like 100-grain weight, spike length and plant height. Similarly, the cross Gourav x Anja showing significant and positive heterosis for yield contributing character like tillers per plant.

It appears that highly heterotic crosses frequently involved the parents Rawal and Anja. The GCA effect of the parent Rawal for grain yield and most of the yield contributing characters indicated it was a good general combiner (Table: 4.3). On the other hand, Anja was a poor combiner for yield and some yield contributing characters. Therefore, it can be concluded that the crosses involving at least one parent with good general combiner would give high heterotic performance when it is crossed with others.

Shamsuddin and Rahman (1989) reported both positive and negative heterosis for spike length. Positive heterosis for grains per spike were observed by Khan et al (1995), Khan and Khan (1996) and Deshpande and Nayeem (1999). Krishna and Ahmad (1992) reported significant positive heterosis for 100-grain weight. Similar findings were reported by Yagdi *et al* (2000). Nehvi *et al* (2000) found highest significant heterosis over both parents for grain yield per plant in bread wheat. This information suggests that heterosis breeding in wheat may be a good choice. In the present study the crosses Gourav x Anja, Rawal x Moyoor, Chyria x Kheri

expressed significant heterosis for grain yield and some of the yield contributing characters and they might be selected for development of hybrid variety.

4.1.4 Relationship between heterosis and SCA effects for yield and yield contributing characters.

The relationship between heterosis for yield and yield contributing characters of the crosses with their corresponding SCA effects are presented in the Table: 4.6. The table shows that the heterosis of the crosses were positively and significantly correlated with their SCA effects for all the characters. This suggests that heterosis in the present crosses were the function of the non-additive gene action. The crosses Gourav x Anja, Rawal x Anja and Chyria x Kheri had positive and significant heterosis for grain yield. These crosses had also significant and positive estimates of SCA effects for grain yield. In addition these three crosses expressed significant and positive estimates of both heterosis and SCA effects for some of the yield contributing characters. This implies that these crosses could be chosen for breeding hybrid variety in wheat if suitable male sterility source is available.

Table: 4.6 Estimates correlation coefficient between SCA and mid parent heterosis.

Characters	Correlation coefficient Between SCA and mid parent heterosis
Plant height (cm).	0.887**
Tillers per plant (no)	0.924**
Spike length (cm)	0.897**
Spikelets per spike (no)	0.921**
Grains per spike (no).	0.839**
100-grain weight (gm)	0.948**
Grain yield per plant (gm)	0.567**

** indicate significant at 1% level of probability

Chand and Randhawa (1981) observed a positive trend between SCA effects and heterotic responses of the crosses for grain yield and some yield contributing characters. Noric *et al.* (1977) also observed a close relationship between SCA effects and heterosis of the crosses for grain yield in bread wheat. This suggested non-additive gene action in the crosses conferred heterosis in them.

4.1.5 Genetic analysis for yields and yield contributing characters in spring wheat.

Genetic studies for yield and yield contributing characters were performed through analysis of regression of parents-offspring covariance (W_r) on array variance (V_r) in the diallel cross population. Regression of W_r on V_r for yield and yield contributing characters are shown in the figures from 4.1 to 4.7. and the genetical control of different characters are discussed separately.

Plant height

Regression coefficient of W_r on V_r for plant height was significant which indicates simple additive dominance genetic model was adequate for the character ($b = 0.89^{**} \pm 0.12$). There was an indication of partial dominance, because the regression line cut the W_r axis above the origin (Fig:4.1). The distribution of the parents along the regression line showed that the parent Gourav (b) took the position very close to the origin. This indicates that Gourav (b) contained most of the dominant alleles. Where as the parent Kheri (h) took the top position from the origin suggesting that recessive alleles were concentrated in this parent. The other parents took their position intermediate between this two parents, and indicating that they contained both dominant and recessive alleles. The correlation coefficient has been estimated between parental mean (Y_r) and ($V_r + W_r$), it was positive and high but non-significant ($r = 0.68$). This indicates that recessive alleles in the parents were responsible for increasing plant height.

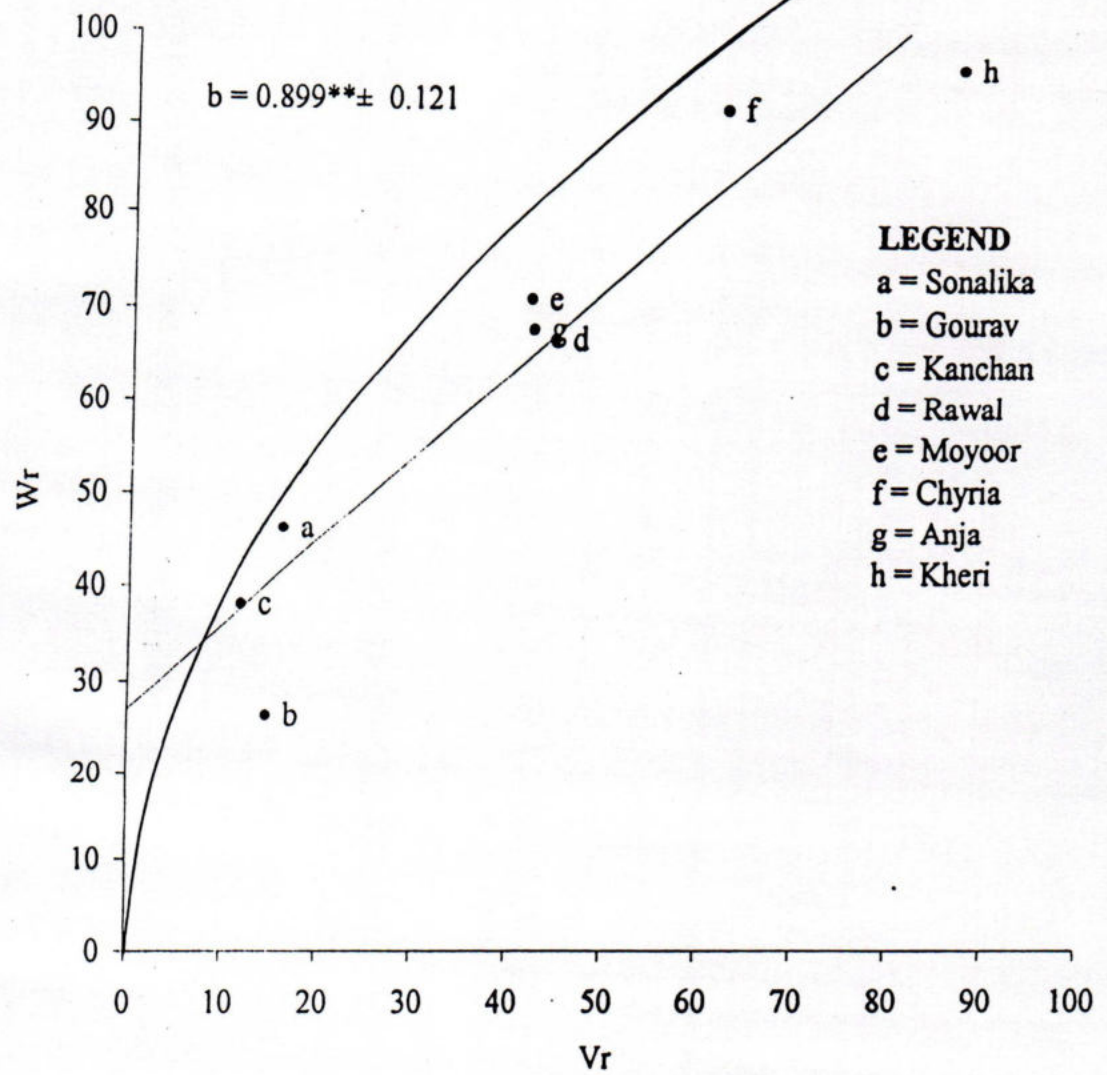


Fig.4.1 W_r - V_r graph for plant height

Both additive and non additive gene actions for plant height in bread wheat reported by many investigator (Shamsuddin *et al.* 1993; Aglodiya and Shukla, 1994 and Rajara and Mahashwari, 1996). Amawate and Behl (1995) reported additive dominance gene effect for the plant.

Tillers per plant

For tillers per plant the regression slope ($b = 0.17 \pm 0.45$) was not significantly different from zero (Fig:4.2) This indicates additive dominance model was inadequate for the character. That means there was presence of epistasis for controlling the character.

Distribution of the parents along the regression line showed that the parent Sonalika (a) took the position very close to the origin, indicating that the parent contained most of the dominant alleles for the character. Whereas the parent Chyria (f) took the distant position from the origin suggesting that it contained the largest number of recessive alleles. Rest of the parents took intermediate position between this two parents.

The correlation between Y_r and $(V_r + W_r)$ was negative and insignificant ($r = -0.16$) indicating that direction of dominance was ambiguous.

Lonc (1988) reported partial dominance for this character. Verma and Yunus (1986) observed additive dominance gene action for spikes per plant but Shamsuddin and Abi-Antoun (1986) reported over dominance for this character.

Spike length

W_r/V_r graph for spike length gave a regression coefficient ($b = 0.77^* \pm 0.22$) which was significant different from zero (Fig: 4.3) at $p < 0.05$. This indicates that

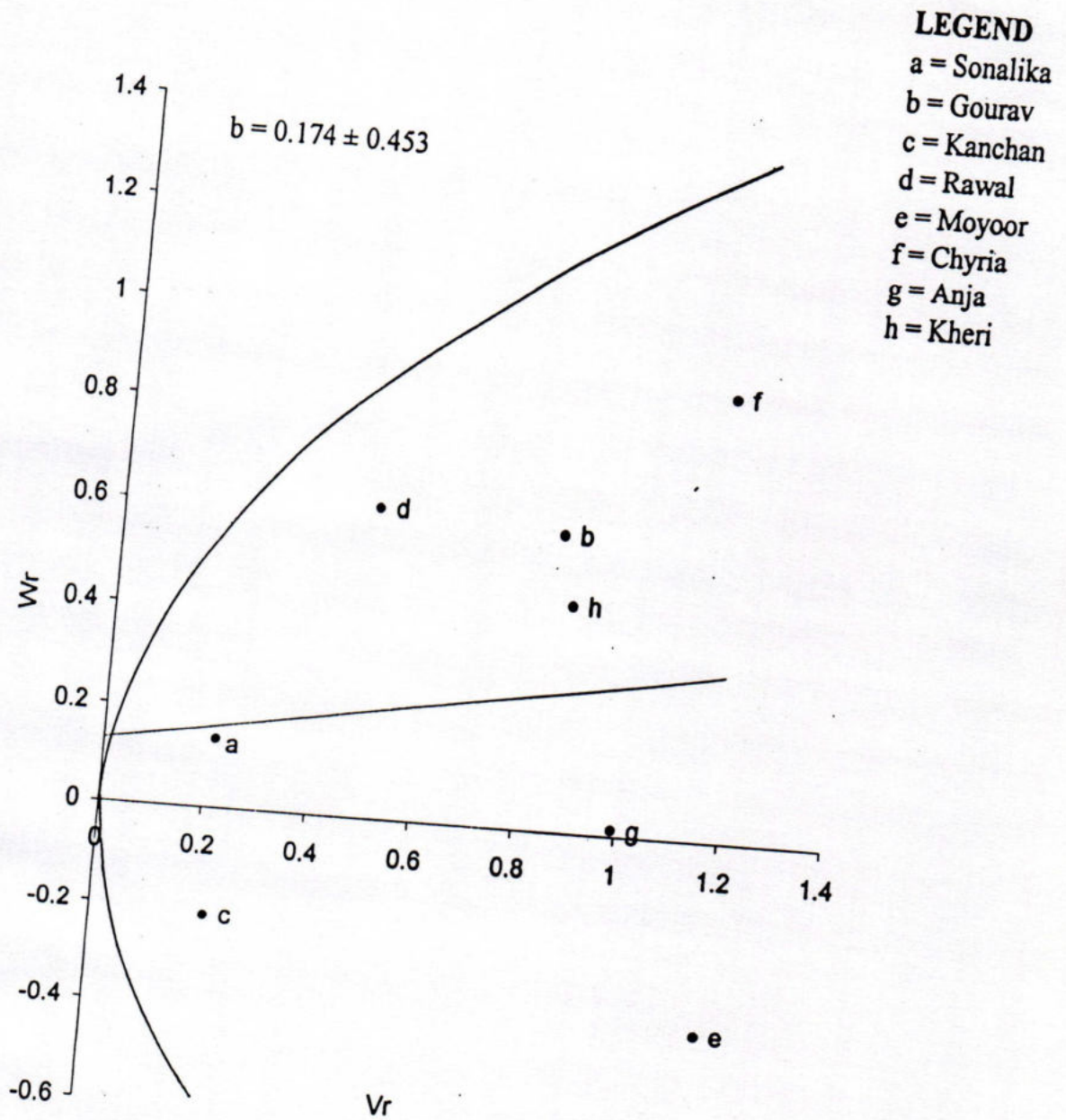


Fig.4.2 W_r - V_r graph for tillers per plant

LEGEND
a = Sonalika
b = Gourav
c = Kanchan
d = Rawal
e = Moyoor
f = Chyria
g = Anja
h = Kheri

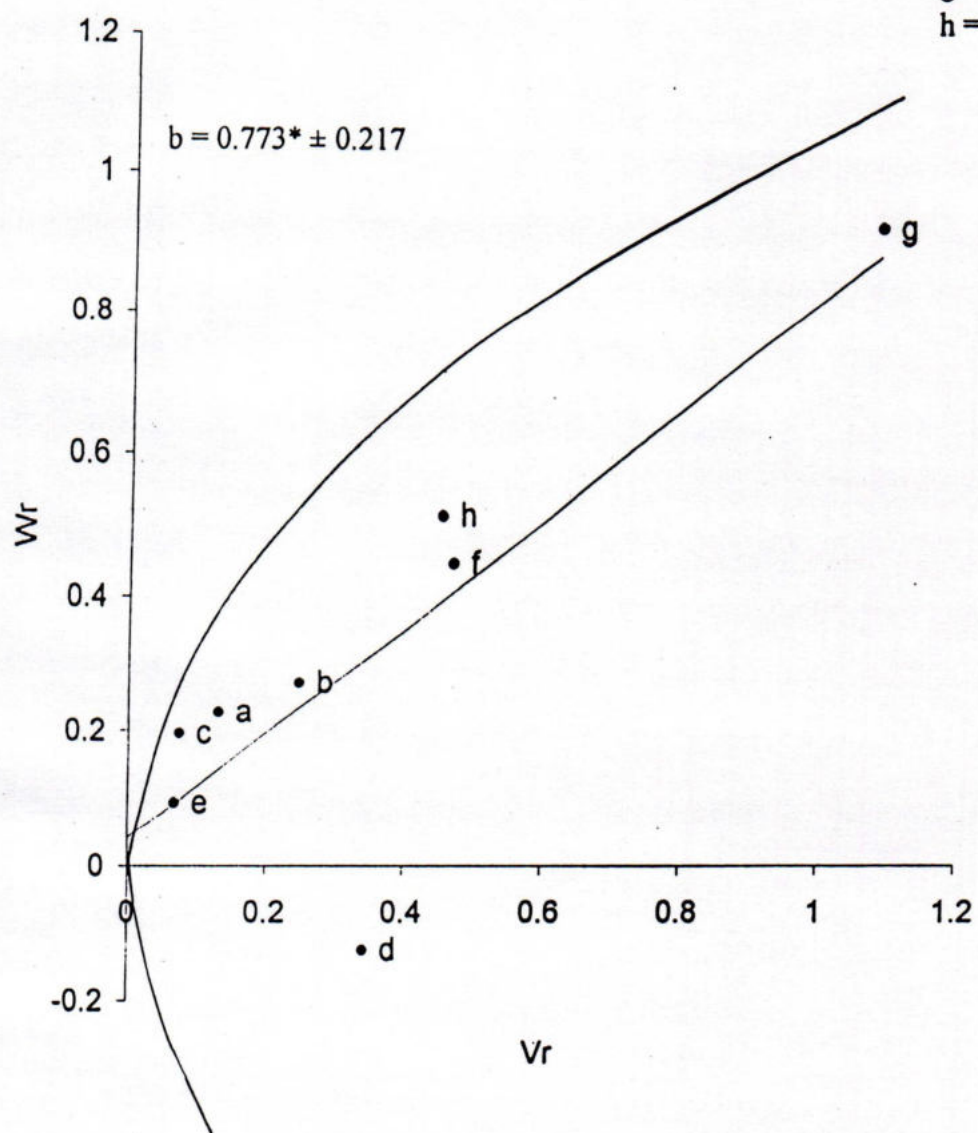


Fig.4.3 W_r - V_r graph for spike length

simple additive dominance genetic model to be adequate without complicity of non allelic interaction for spike length.

There was an indication of partial dominance, because the regression line cut the W_r axis above the origin (Fig:4.3) and took the position very close to the limiting parabola. The distribution of the parents along the regression line showed that the parent Moyoor (e) took the position close to the origin, indicating that the parent contained most of the dominant alleles for this character. Where as the parent Anja (g) took the distance position from the origin, suggesting that it contained the most of the recessive alleles. Rest of the parents took intermediate position between this two parents.

The correlation coefficient between Y_r and $(V_r + W_r)$ was negatively significant($r = -0.86^{**}$). This indicates that dominant alleles in the parents were responsible for increasing spike length.

Loric (1988) reported partial dominance for spike length. Chowdhury *et al.* (1999) observed this character was controlled by partial dominance. But Walia *et al.* (1994) reported additive and dominance gene action for spike length.

Spikelets per spike

W_r/V_r graph for spikelets per spike gave a regression slope ($b = 0.72^* \pm 0.24$), which was significantly different from zero (Fig. 4.4). This indicates that simple additive dominance genetic model to be adequate without complicity of non-allelic interaction for spikelets per spike. There was an indication of complete dominance, because regression line cut the W_r axis almost through the origin and took position away from the limiting parabola. Distribution of the parents along the regression line showed that parent Sonalika (a) contained the larger proportion of

LEGEND
a = Sonalika
b = Gourav
c = Kanchan
d = Rawal
e = Moyoor
f = Chyria
g = Anja
h = Kheri

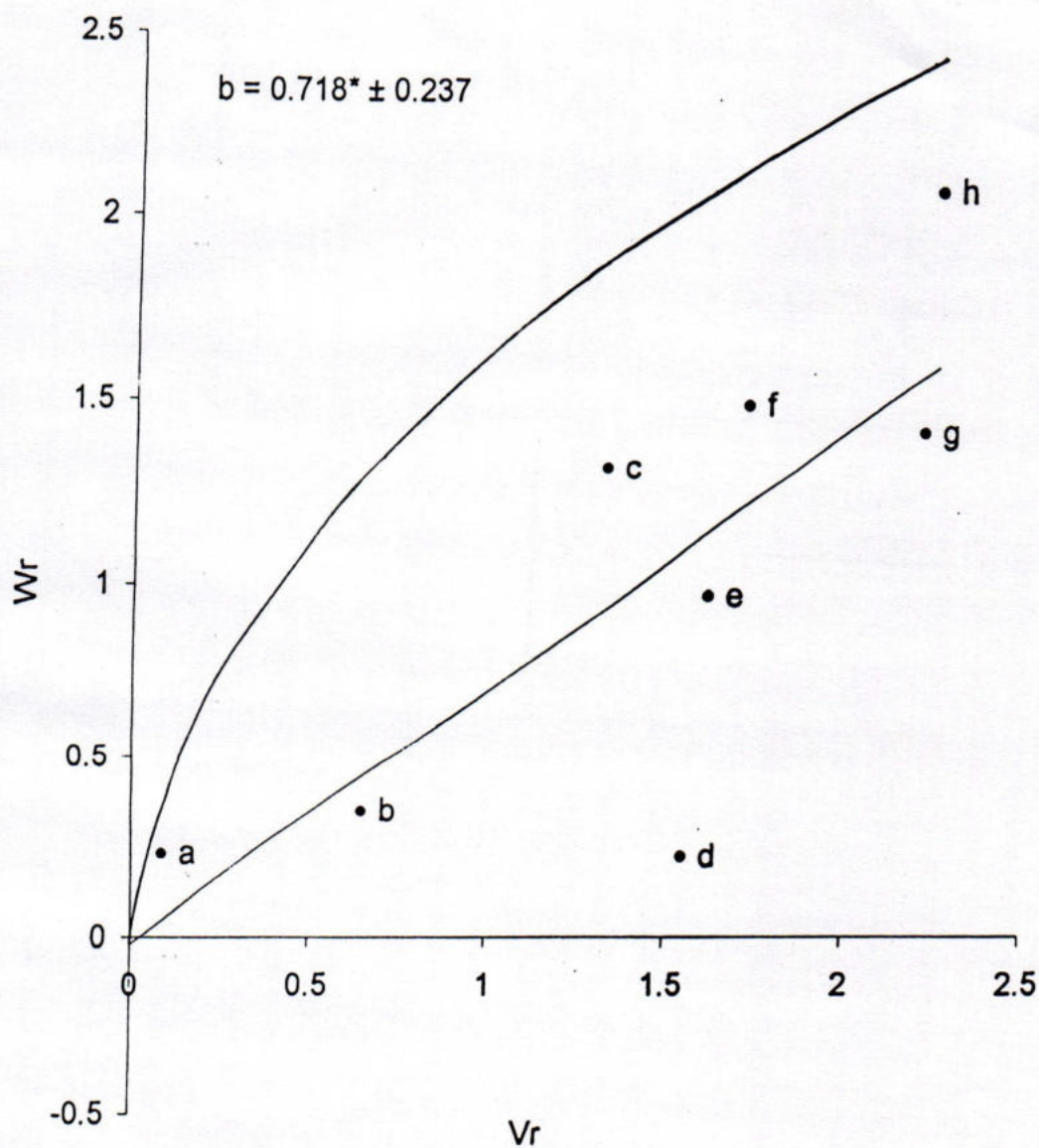


Fig.4.4 W_r - V_r graph for spikelets per spike

dominant alleles. Whereas the parent Kheri (h) had the most recessive alleles and consequently took the distant position from the origin.

The non significant correlation coefficient ($r = 0.60$) was obtained between the parental mean Y_r and $(V_r + W_r)$. This suggests that recessive alleles in the parents were responsible for increasing spikelets per spike.

Loric (1998) reported partial dominance for this character in bread wheat. Altinbas and Bilgen (1996) reported dominance effects for this character. Walia et al. (1994) reported additive and dominance components for this character. Whereas Shamsuddin and Abi-Antoun (1986) reported over dominance gene effect and presence of epistasis.

Grains per spike

For grains per spike there is evidence of epistasis as the regression slope ($b = 0.47 \pm 0.24$) was not significantly different from zero (Fig. 4.5). Distribution of the parents along the regression line showed that parent Sonalika(a) contained the larger proportion of dominant alleles, whereas the parent Chyria(f) had the most recessive alleles and consequently took the distant position from the origin.

The correlation coefficient between parental measurement (Y_r) and parental order of dominance ($V_r + W_r$) was non significant ($r = -0.05$) indicating that direction of dominance was ambiguous.

Shamsuddin and Abi-Antoun (1988) reported epistatic gene action for grains per spike. Rajara and Maheshwari (1996) and Patil *et al.* (1977) reported non-additive gene action for this trait.

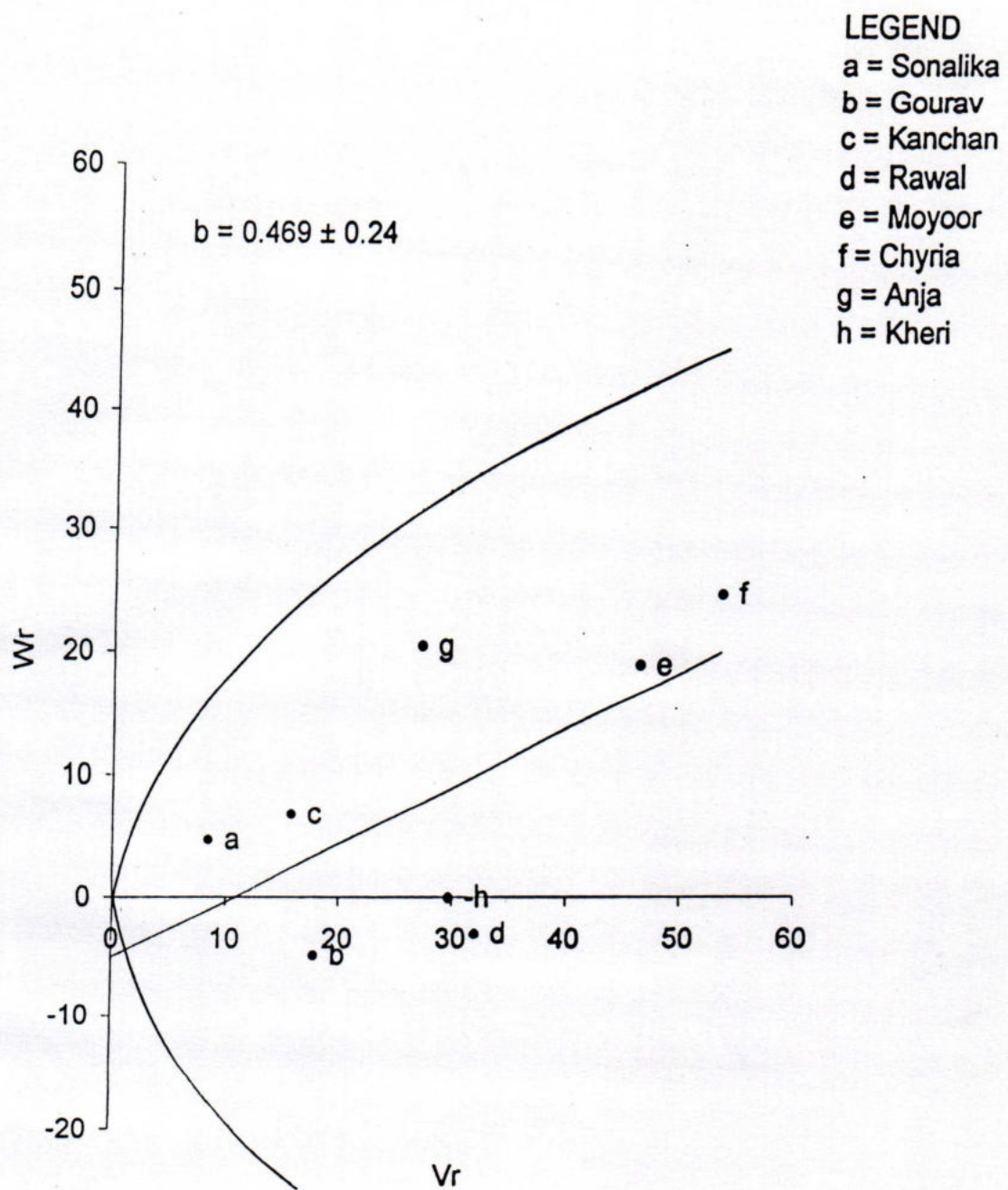


Fig. 4.5 W_r - V_r graph for grains per spike

100-grain weight

Wr/Vr graph for 100-grain weight gave a regression co-efficient ($b = 0.55^{**} \pm 0.12$), which was significant different from zero (Fig. 4.6) at $p < 0.05$. This indicates that additive dominance genetic model to be adequate without complicity of non allelic interaction for 100-grain weight.

The regression line cut the Wr axis above the origin and took the position close to the limiting parabola (Fig. 4.6). This suggests that the character was predominantly controlled by additive gene action. Distribution of the parents along the regression line showed that the parent Sonalika (a) took the position close to the origin. This indicates that the parent contained most of the dominant alleles for the character. Whereas the parent Anja (g) took distant position from the origin, suggesting that the recessive alleles were contained by this parent. The other parents were between these two alleles, indicating that they contained both dominant and recessive alleles.

The correlation value between Yr and ($Vr + Wr$) was negatively non-significant ($r = -0.43$) indicating that direction of dominance was ambiguous.

Shamsuddin adn Abi-Antoun (1986) reported partial dominance under space planting condition, but under solid seeding condition they observed complete dominance. Shamsuddin and Rahman (1998) reported that 100-grain weight was controlled by additive, dominance and all types of epistasis. Rajara and Maheshwari (1996) reported predominance of non-additive gene action for 1000-grain weight. On the other hand Chowdhury *et al.* (1999) reported over dominance for this character.

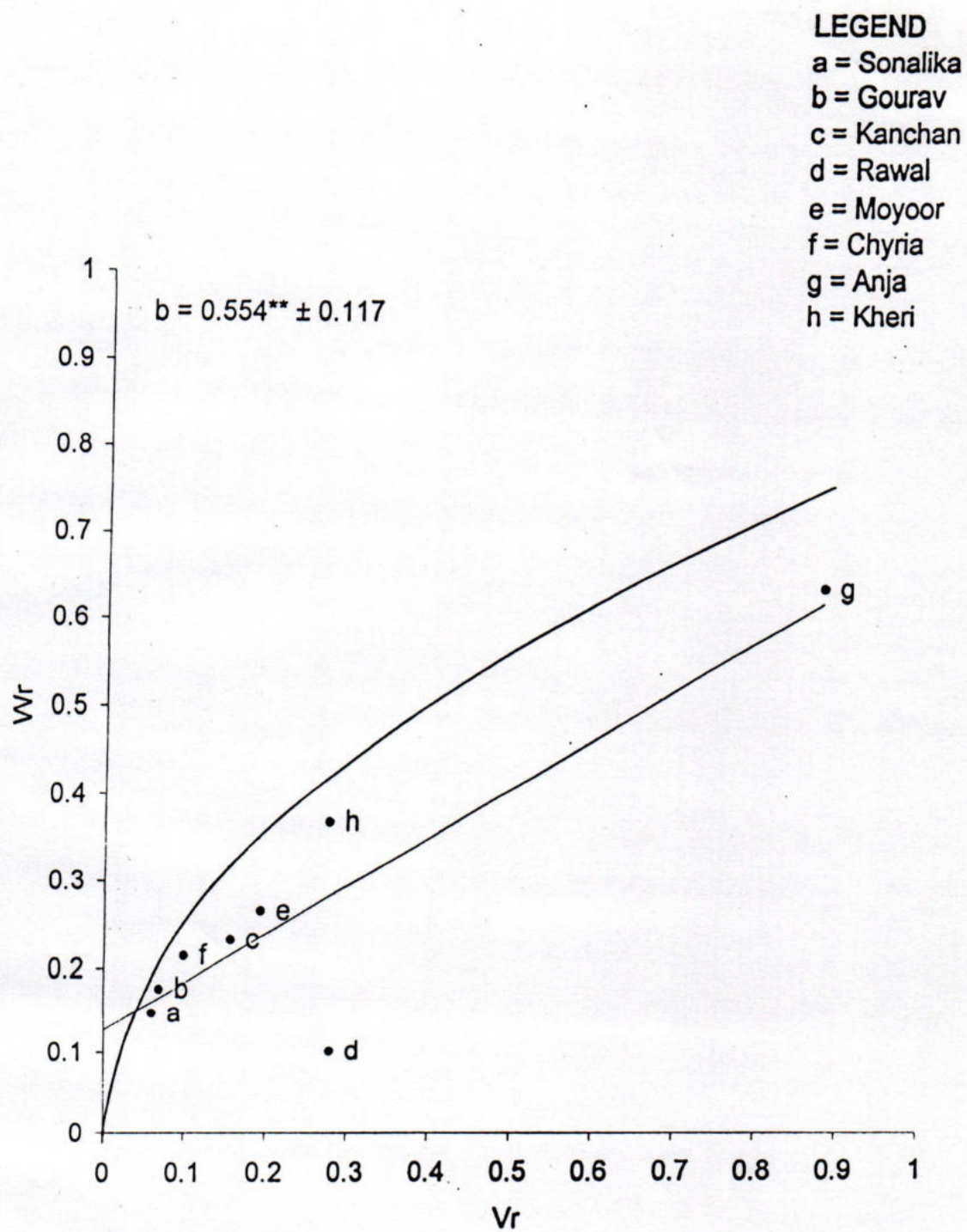


Fig.4.6 Wr-Vr graph for 100-grain weight

Grain yield per plant

For grains yield per plant there is evidence of epistasis as the regression coefficient ($b = 0.01 \pm 0.05$) was not significantly different from zero (Fig. 4.7) This suggests that there was non-allelic interaction among the parents for this character. Therefore, the additive dominance model is not adequate for this character. The yield contributing characters tillers per plant, grains per spike had epistatic gene action, which might have projected their effects through grain yield which caused non-additiveness for the character.

It was also reported that grain yield per plant was controlled by both additive and non additive gene action (Aglodiya and Shukla, 1994; Rajara *et al.* 1996 and Patil *et al.* 1997). Shamsuddin *et al.* (1993) and Atale and Vitkare (1990) also reported that grain yield per plant was predominantly controlled by non-additive gene.

From the study of combining ability and gene action, the characters plant height, spike length, spikelets per spike and 100-grain weight were additive gene actions and they would give good response to selection. However presence of non additive gene action was observed for grain yield per plant could be exploited by recurrent selection.

4.1.6 Heritability for yield and yield contributing characters.

Estimates of heritability in broad and narrow sense and parents offspring regression for yield and yield contributing characters in spring wheat are presented in the Table 4.9. High heritability estimates in both broad and narrow sense were obtained for plant height, spike length, spikelets per spike and 100- grain weight. Medium heritability in broad sense but poor heritability in narrow sense were observed for spikes per plant and grains per spike. Grain yield per plant was highly heritable in broad sense and poorly heritable in narrow sense.

LEGEND
a = Sonalika
b = Gourav
c = Kanchan
d = Rawal
e = Moyoor
f = Chyria
g = Anja
h = Kheri

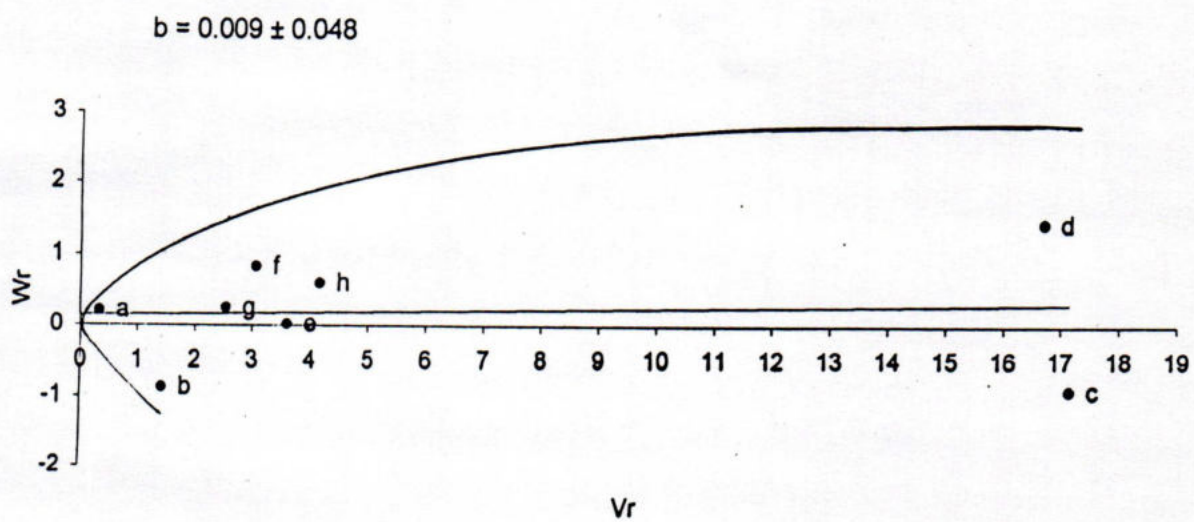


Fig.4.7 W_r - V_r graph for grain yield per plant

Table 4.9 Estimates heritability for yield and yield contributing characters

Characters	Heritability in broad sense	Heritability in narrow sense	Parent-offspring regression (b)
Plant height (cm)	92.45%	87.56%	0.73 ^{**} ± 0.10
Tillers per plant	58.11%	21.51%	0.14 ± 0.21
Spike length (cm)	87.73%	66.77%	0.43 [*] ± 0.17
Spikelets per spike	83.15%	62.97%	0.68 ^{**} ± 0.21
Grains per spike	49.58%	27.68%	0.26 ^{**} ± 0.07
100-grain weight (g)	88.2%	78.45%	0.75 ^{**} ± 0.13
Grain yield per plant (g)	82.38%	12.64%	0.16 ± 0.49

***and** indicate significant at 5% and 1% level of probability, respectively.**

Estimates of parents-offspring regression coefficient indicate heritability in narrow sense. Regression coefficients of offsprings on mid parents were significant for plant height, spike length, spikelets per spike, grains per spike and 100 grain weight. (Table 4.9). This result indicates that these characters were highly heritable in narrow sense. The estimates of parents offsprings regression were non significant for spikes per plant, grain yield per plant, suggesting the characters were poorly heritable.

In the present study, heritability in narrow sense and parents offspring regression confirmed each other. Heritability in narrow sense accounted only the additive components of genetic variation. Significant estimates of both narrow sense heritability and parents-offspring regression for these characters indicate importance of additive gene action and good response to selection for them.

Reports on high heritability for yield contributing characters and poor heritability for grain yield in spring wheat are most frequent. Ehdaie and Wains (1989) reported low heritability in grain yield. Low heritability for grain yield was also reported by Camargo and Oliveria (1983); Pathak and Nema (1985); Kamboj *et al.* (2000) and Afiah *et al.* (2000). Uddin *et al.* (1977) reported high broad sense heritability for 1000-grain weight. Pawar *et al.* (1989) reported high heritability for plant height and 1000-grain weight.

Nessa *et al.* (194) reported high heritability for plant height and spikes per plant. Similar results were reported by Chaturvedi and Gupta (1995), Mehta *et al.* (1998) and Joshi *et al.* (1982) High heritability for spikes per plant and 1000-grain weight was also observed by Rahman *et al.* (1986) and Mann and Sharma (1995). Balchand and Lodhi (1994) reported spike length as a highly heritability character.

In the present study, the results showed that yield and yield contributing characters namely plant height, spike length, spikelets per spike and 100-grain weight were highly heritable in both broad and narrow sense. High heritability estimates for these characters were also reported by other authors. Therefore, selection for this characters would give good response. Grain yield in spring wheat showed poor narrow sense heritability. Selection for this character would not give good response in early segregating generation. However, in the later generation heritability for grain yield may increase due to fixation of alleles. In this context, selection for highly heritable characters such as plant height, spike length, spikelets per spike and 100-grain weight suggested in these materials. Selection for grain yield suggested for later generation.

4.1.7 Relationship between grain yield and its contributing characters.

4.1.7.1 Correlation between grain yield and its contributing characters.

Relationship between grain yield and different yield contributing characters were studied at genotypic and phenotypic levels. The genotypic and phenotypic correlation coefficients are presented in Table 4.7. In general, the values of genotypic correlation were greater than the corresponding phenotypic ones. This suggests the existence of inherent relation between the characters but environmental influence reduced the relationship at phenotypic level. Similarly, higher estimates of genotypic correlation than phenotypic correlation in spring wheat were reported by Razzaque *et al.* (1981) and Khan *et al.* (1994).

Study of correlation at genotypic level showed that grain yield was positively correlated with spike length, spikelets per spike and 100-grain weight. These are the major characters that constitutes the sink for grain yield in spring wheat. The genotypic correlation of plant height and grains per spike were also high but in

Table 4.7 Estimates genotypic and phenotypic correlation coefficient between yield and yield contributing characters.

Characters	Tillers per plant	Spike length	Spikelets per spike	Grains per spike	100-grain weight	Grain yield per plant
Plant height	Genotypic 0.38	-0.09	0.45	0.49	0.47	-0.43
	Phenotypic 0.40*	0.08	0.56**	0.44**	0.48**	-0.31
Tillers per plant	Genotypic	-0.19	0.57	-0.57	0.09	-0.05
	Phenotypic	0.16	0.44**	0.19	0.56**	-0.03
Spike length	Genotypic		0.28	-0.57	-0.13	0.41
	Phenotypic		0.49**	0.07	0.22	0.27
Spikelets per spike	Genotypic			-0.61	0.29	0.44
	Phenotypic			0.08	0.41*	0.29
Grains per spike	Genotypic				0.36	-0.64
	Phenotypic				0.63**	-0.46**
100-grain weight	Genotypic					0.34
	Phenotypic					-0.06

*and** indicate significant at 5% and 1% level of probability, respectively.

negative direction. Singh *et al.* (1998b) reported positive and significant correlation between grain yield and spikes per plant in bread wheat. Shoran (1995) reported that grain yield per plant had significant and positive association with spikes per plant, grains per spike and 1000-grain weight. Nirala and Jha (1996) reported that days to maturity and spikes per plant were positively correlated with grain yield. Kumar *et al.* (1997) reported significant negative correlation between 1000-grain weight and grain yield and positive correlation between grain yield and plant height, spikes per plant and grains per spike. Razzaque *et al.* (1981) reported that spike length was positively correlated with grain yield per plant in bread wheat.

There were some significant correlations between yield contributing characters (Table 4.7). From the results of phenotypic correlation, it is observed that tillers per plant was positively and significantly correlated with plant height. There were significant and positive correlation between plant height and 100-grain weight. 100-grain weight was also positively correlated with tillers per plant, spikelets per spike. The genotypic correlation between grains per spike and 100-grain weight was a little. This indicated a less compensating effect between them in determining grain yield in the present materials.

Razzaque *et al.* (1981) reported that 100-grain weight was positively correlated with spike length and negatively correlated with spikes per plant. Shen *et al.* (1997) reported negative correlation between grains per spike and 100-grain weight. Mishra *et al.* (2001) reported highly significant negative correlation between plant height and 100-grain weight. Raina *et al.* (1982) and Jaglan *et al.* (1997) reported correlation between grains per spike and 100-grain weight suggesting yield components compensation effect between them.

Correlation between grain yield and yield contributing characters suggested that spike length, spikelets per spike and 100-grain weight were the most important characters, which had positive association with grain yield per plant. Therefore, these characters could be included in selection and screening programme in spring wheat improvement.

4.1.7.2 Path coefficient analysis

Study of correlation showed that the different yield contributing characters were highly and significantly correlated among themselves. This indicated that the relationships between grain yield and different yield contributing characters were influenced by the complex chain of interrelationship among different yield contributing characters. This brings the necessity of detailed study of relationship through path coefficient where the correlation between yield and yield contributing characters can be partitioned into direct and indirect effects. Path coefficient analysis was performed using genotypic correlation and presented in Table: 4.8 and Figure: 4.8. Both table and figure showed that spikelets per spike and 100-grain weight had estimated high positive direct effects on grain yield. The correlation coefficients of spikelets per spike and 100-grain weight with grain yield were high. The negative direct effect of plant height, tillers per plant and grains per spike resulted negative correlation with grain yield.

Barma *et al.* (1991) reported that spike length had the highest direct effect on grain yield. Sheikh and Singh (2001) reported negative direct effects of plant height and 1000-grain weight on grain yield, which partially supported the above results.

Study of the relationship between yield and yield contributing characters through both correlation and path coefficients analysis indicated that spikelets per spike and 100-grain weight were related to grain yield and they contributed directly to grain

Table 4.8 Estimates of path coefficient analysis

Characters	Plant height	Tillers per plant	Spike length	Spikelets per spike	Grains per spike	100-grain weight	Correlation with grain yield per plant
Plant height	-0.77	-0.10	-0.01	0.26	-0.13	0.32	-0.43
Tillers per plant	-0.29	-0.27	-0.01	0.32	0.15	0.06	-0.05
Spike length	0.07	0.05	0.07	0.16	0.15	-0.09	0.41
Spikelets per spike	-0.35	-0.15	0.02	0.57	0.16	0.19	0.44
Grains per spike	-0.38	0.15	-0.04	-0.35	-0.26	0.24	-0.64
100-grain weight	-0.37	-0.02	-0.01	0.17	-0.09	0.66	0.34

The values in diagonals are direct effects and those off-diagonals are indirect effects. Residual effect, $R = -0.102$

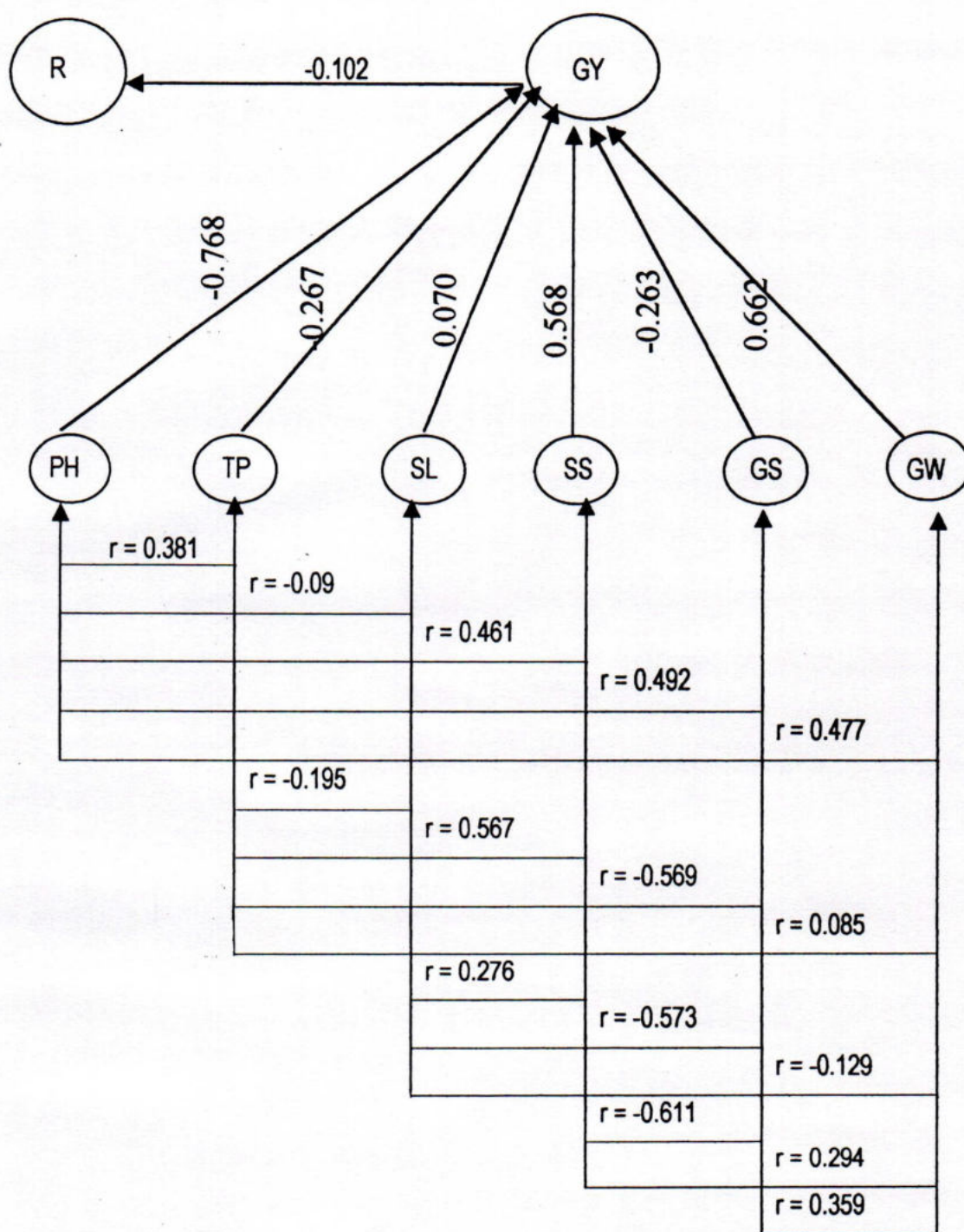


Fig. 4.8 Genotypic path diagram of yield contributing characters on grain yield per plant. Single arrow lines indicate path co-efficient and double arrow lines indicate correlation coefficients. PH = Plant height, TP = Tillers per plant, SL = Spike length, SS = Spikelets per spike, GS = Grains per spike, GW = 100-grain weight, GY = Grain yield per plant and R = Residual effect.

yield. Therefore, these characters could be selected in indices for yield improvement in the present materials.

4.2 Response to selection for yield and yield contributing characters.

Responses to selection for grain yield and its different yield contributing characters were studied in the two crosses NK-5 x Opata and Rawal x SA-92. The different parameters related to response to selection in the cross NK-5 x Opata are given in table- 4.10. The response were estimated in F_3 generation by selecting the plants in F_2 generation. It appears from the table 4.10, the characters tillers per plant, 100-grain weight and grain yield per plant gave good responses to selection. These characters had also positive realized heritability associated comparatively higher coefficients of variation. The others character, like plant height, spike length and grains per spike gave negative response to selection. The plants were selected in the F_2 generation in the year 2000-2001 and selected plants were grown in the next year 2001-2002. Therefore negative response for the above mentioned characters might be due to the cause of genotype-environment interaction, which prevailed in the present study.

Similarly, response to selection in the cross Rawal x SA-92 are given in table 4.11. The response were estimated in F_3 generation by selecting the plants in F_2 generation. It appears from the table- 4.11, the characters tillers per plant, spikelets per spike, grains per spike and grain yield per plant gave good response to selection. These characters estimated also positive realized heritability. The good responses of these characters were associated with their comparatively high coefficients of variation. This suggests that characters with high variation would give response to selection. The other characters like 100-grain weight and grain yield per plant had negative response to selection. The negative response for the

Table 4.10 Response to selection in grain yield and its components in NK-5 X Opata.

Characters	Genetic advance in % of mean.	Realized heritability (%)	Co-efficient of variation (%)
Plant height (cm)	-5.16	-41.3	3.04
Tillers per plant	34.77	34.2	15.19
Spike length (cm)	-3.1	-14.4	4.35
Spikelets per spike	0.89	4.6	2.84
Grains per spike	-7.86	-6.4	30.71
100-grain weight (g)	26.25	21.4	10.62
Grain yield per plant (g)	22.49	39.6	26.44

Table 4.11 Response to selection in grain yield and its components in Rawal X SA-92.

Characters	Genetic advance in % of mean.	Realized heritability (%)	Coefficient of variation (%)
Plant height (cm)	5.18	17.9	3.59
Tillers per plant	23.39	22.5	22.47
Spike length (cm)	6.81	30.98	7.47
Spikelets per spike	11.55	37.55	7.38
Grains per spike	2.35	4.66	14.71
100-grain weight (g)	-7.17	-6.13	6.69
Grain yield per plant (g)	11.49	34.78	7.04

characters might be due to the cause of genotype-environment interaction, because selection was made in F_2 generation and response was estimated in F_3 generation in the next year.

Uddin *et al* (1997) suggested that grain yield per plant, tillers per plant and 1000-grain weight gave the highest relative efficiency over straight selection for grain yield per plant. Jedynski (2001) suggested that number of grains per spike was the most important character in selection for high grain yield. Khan *et al* (1985) studied coefficient of variation, expected genetic advance and heritability for yield per plant in wheat and observed that selection gave in rapid improvement of the studied material. Serrano (1990) reported that selection was more effective for yield increases providing a higher advance per cycle. Baisakh and Nayak (1991) observed high heritability along with strong genetic advance for plant height suggesting that this trait should be effective when selecting for enhanced grain yield.

In the present study, there is a scope for improving grain yield through selection for tillers per plant, 100-grain weight and grain yield per plant in the cross NK-5 x Opata and tillers per plant, spikelets per spike, grains per spike and grain yield per plant in the cross Rawal x SA-92.

CHAPTER 5
SUMMARY

SUMMARY

The present study includes two experiments; the first experiment was under taken with a view to study of combining ability, heterosis and gene actions for yield and yield contributing characters in spring wheat. The second experiment was selection for yield and yield contributing characters in two crosses of spring wheat. The experiments were conducted at the field laboratory of the Department of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh from November 2000 to March 2001 and November, 2001 to March 2002. The characters studies for both experiments are plant height, tillers per plant, spike length, spikelets per spike, grains per spike, 100-grain weight and grain yield per plant.

5.1. Study of combining ability, heterosis and gene actions for yield and yield contributing characters.

5.1.1. Variation among parents and their F_1 hybrids for yield and yield contributing characters.

Analysis of variance for yield and yield contributing characters indicate the significant variations among the genotypes for all characters. The variances due to parents were significant for all characters except grains per spike and grain yield per plant. The variances due to F_1 were significant for all character^b except tillers per plant and grains per spike. The significant variances due to parents vs F_1 s for the characters spikelets per spike, grains per spike and grain yield^{per}/plant indicated the heterotic expression for these characters in F_1 generation.

5.1.2. Combining ability for yield and yield contributing characters.

Combiningⁱⁿ ability analysis revealed that both GCA and SCA variances were significant for all the characters except grains per spike. Plant height showed only

significant SCA variance. These results suggests the presence of both additive and non additive gene actions for all the characters except grains per spike. Grains per spike was controlled by only additive gene action. Estimates ratio between GCA and SCA variance for the characters indicated predominance of additive gene action for plant height, tillers per plant, spike length, spikelets per spike, grains per spike and 100-grain weight. Higher estimates of non-additive gene action was obtained only for grain yield per plant.

The parent Rawal was found to be a good general combiner for grain yield per plant and some other yield contributing characters, such as spike length, spikelets per spike and 100-grain weight. The parent Moyoor was good general combiner for spike length, spikelets per spike and 100 grain weight. The parent Kheri was best general combiner for plant height, spikelets per spike and grains per spike. Mean performance and GCA effects of the parents showed a positive relationship between them.

SCA effect of the crosses showed that the crosses Gourav x Anja, Kanchan x Rawal, Rawal x Moyoor, Moyoor x Kheri and Chyria x Kheri had significant estimates of SCA effect for grain yield per plant. High specific combination for grain yield per plant for the cross Kanchan x Rawal involved low x high general combinations and Moyoor x Kheri involved high x average general combiners.

5.1.3. Heterosis for yield and yield contributing characters.

Among the crosses Gourav x Anja, Rawal x Moyoor and Chyria x Kheri exhibited significant and positive mid parent heterosis for grain yield per plant. Maximum heterosis was 155.94% in Gourav x Anja. There were positive relations between the heterosis of the crosses with their SCA effects for grain yield and its different

yield contributing characters. The crosses Rawal x Anja, Moyoor x Anja and Moyoor x Kheri showing significant and positive heterosis for yield contributing characters.

Analysis of combining ability and heterosis showed that the crosses Gourav x Anja and Rawal x Moyoor expressed both significant heterosis and SCA effects for yield and yield contributing characters. Therefore, in these crosses hybrid variety development programme was suggested.

5.1.4. Wr – Vr graph analysis for yield and yield contributing characters.

Study of genetic analysis was performed through Wr-Vr graph. This showed that simple additive dominance genetic model was adequate without complicity of non-allelic interaction for plant height, spike length, Spikelets per spike and 100-grain weight. Whereas tillers per plant, grains per spike and grain yield per plant showed presence of epistasis, Partial dominance was observed for plant height, tillers per plant, spike length, 100-grain weight. Complete dominance was noticed for spikelets per spike and over dominance for grains per spike.

In Wr- Vr graph, the distribution of parents along the regression line suggests that the parent Sonalika contained more dominant alleles for tillers per plant, spikelets per spike and 100-grain weight. The parent Moyoor contained more dominant alleles for spike length.

The character spike length showed that the dominant alleles had increasing effect on it. On the other hand dominant alleles had decreasing effects on plant height, Spikelets per spike and grain yield per plant. Whereas ambiguity of results was found in the characters tillers per plant, grains per spike and 100-grain weight.

5.1.5. Relationship between grain yield and its contributing characters

5.1.5.1. Correlation between grain yield and its contributing characters

Estimates of genotypic and phenotypic correlation coefficients between yield and yield contributing characters suggested that in most cases the genotypic correlation coefficients were higher than their corresponding phenotypic ones suggesting the existence of inherent relation between the characters, but environmental influence reduced the relationship at phenotypic level. It appeared that grain yield was significantly correlated with plant height, spike length, spikelets per spike, grains per spike and 100-grain weight.

5.1.5.2. Path coefficient analysis for yield and yield contributing characters.

Path coefficient analysis showed that spike length, spikelets per spike and 100-grain weight contributed to grain yield directly.

Analysis of both correlation and path coefficient suggested that selection for spike length, spikelets per spike and 100-grain weight would give better response in grain yield improvement in spring wheat.

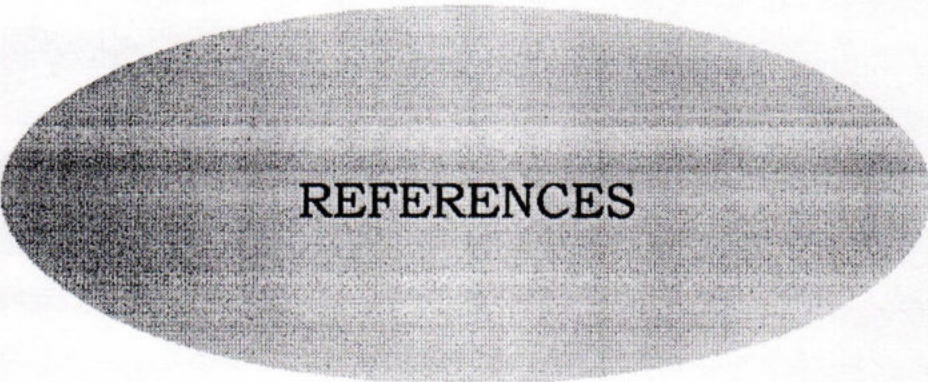
5.1.6. Heritability for yield and yield contributing characters.

High heritability estimates in both broad and narrow sense were obtained for plant height, spike length, spikelets per spike and 100-grain weight. Medium heritability in broad sense but poor heritability in narrow sense were observed for tillers per plant and grains per spike. Grain yield per plant was highly heritable in broad sense and poorly heritable in narrow sense.

5.2. Response to selection for grain yield and yield contributing characters.

The response was studied in F_3 generation by selecting the plants in F_2 generation. In the cross NK-5 x Opata, the characters spikes per plant, 100-grain weight and

grain yield per plant gave good response to selection. These characters had also positive realized heritability. In the cross Rawal x SA-92, the characters plant height, tillers per plant, spike length, spikelets per spike and grains per spike gave good response to selection. These characters had also positive realized heritability. The others characters had negative response to selection might be due to the cause of genotype-environment interaction.



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Appendix I. Meteorological data of the experimental period (November'2000 to March, 2001) at BAU Farm, Mymensingh.

Month	Year	** Air temperature (°C)		** Average humidity (%)	* Total Rainfall (mm)	* Sunshine (hrs)
		Maximum	Minimum			
November	2000	29.76	19.09	82.37	0.00	7.92
December	2000	26.71	13.43	77.00	0.00	7.24
January	2001	24.36	10.66	76.90	0.20	6.23
February	2001	27.33	15.23	74.91	0.11	5.97
March	2001	31.07	18.43	70.39	15.0	6.10

*Monthly total

**Monthly average

Courtesy: Meteorological Section, Department of Irrigation and Water Management, BAU, Mymensingh.

Appendix II. Meteorological data of the experimental period (November'2001 to March, 2002) at BAU Farm, Mymensingh.

Month	Year	**Air temperature (°C)		**Average humidity (%)	*Total Rainfall (mm)	*Sunshine (hrs)
		Maximum	Minimum			
November	2001	29.49	19.55	84.27	10.7	7.42
December	2001	26.52	13.19	80.84	0.00	7.10
January	2002	25.43	12.93	78.00	5.3	6.87
February	2002	27.70	15.39	82.68	Trace	8.84
March	2002	30.00	19.79	73.61	34.4	7.72

*Monthly total

**Monthly average

Courtesy: Meteorological Section, Department of Irrigation and Water Management, BAU, Mymensingh.