

**GENETIC EVALUATION OF BREEDING LINES OF
WHEAT (*Triticum aestivum* L. em. Thell)
FOR YIELD AND QUALITY IN BORON DEFICIENT SOIL**

A Thesis
submitted to the
Bidhan Chandra Krishi Viswavidyalaya
in partial fulfilment of the requirements
for the award of the Degree of Doctor of Philosophy
in
AGRICULTURE
(GENETICS AND PLANT BREEDING)

BY

TULSI SARAN GHIMIRAY

DEPARTMENT OF GENETICS AND PLANT BREEDING
FACULTY OF AGRICULTURE
BIDHAN CHANDRA KRISHI VISWAVIDYALAYA
MOHANPUR, NADIA, WEST BENGAL

1998



Dedicated
to
My Beloved
Buba
Muma
Suchu di
&
Pari di

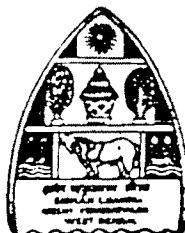
**APPROVAL OF EXAMINERS FOR THE AWARD OF THE
DEGREE OF DOCTOR OF PHILOSOPHY IN AGRICULTURE
(GENETICS AND PLANT BREEDING)**

We, the undersigned, having been satisfied with the performance of Sri. Tulsī Saran Ghimiray in the *viva voce* examination conducted today, the1998 recommend that the thesis be accepted for the award of the Degree.

Name		Signature
1. Dr. K. K. Sarkar	Chairman, Advisory Committee
2.	External Examiner
3. Dr. M. Hossain	Member, Advisory Committee
4. Prof. K. K. Ghosal	Member, Advisory Committee
5. Prof. R.L. Nayak	Member, Advisory Committee
6.	Head of the Department
7.	Teachers' Nominee

Bidhan Chandra Krishi Viswavidyalaya
Faculty of Agriculture
Department of Genetics & Plant Breeding

Dr. K.K. Sarkar, Ph. D.
Reader



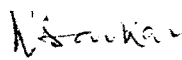
Mohanpur,
Nadia - 741 252
W. B. (India)

Dated, The 17.03.1998

CERTIFICATE

This is to certify that the work recorded in the thesis entitled “**Genetic evaluation of breeding lines of wheat (*Triticum aestivum* L. em. Thell) for yield and quality in boron deficient soil**” submitted by Sri Tulsi Saran Ghimiray in partial fulfilment for the award of the Degree of Doctor of Philosophy in Agriculture (Genetics and Plant Breeding) of Bidhan Chandra Krishi Viswavidyalaya , is the faithful presentation of the bonafide research work carried out under my personal supervision and guidance.

The results of the investigation reported in the thesis have not so far been submitted for any other Degree or Diploma. The assistance and help received during the course of investigation have been duly acknowledged.


(K.K. Sarkar)

ACKNOWLEDGEMENTS

I take a good deal of pleasure in expressing infinite gratitude and profound regards to Dr. K.K. Sarkar, Reader, Department of Genetics and Plant Breeding, Faculty of Agriculture, Bidhan Chandra Krishi Viswavidyalaya (BCKV) for the auspicious guidance *in initio* till completion of this research pursuit. I thank him for his painstaking help and letting me try out my wings as well as his prompt revisions of my manuscript.

I take this opportunity to express my sincere regards and gratefulness to the members of the advisory committee, Dr. M. Hossain (Head) and Prof. K.K.Ghosal (Department of Genetics and Plant Breeding), and Prof. R.L. Nayak (Department of Agronomy) for their valuable suggestions, encouragement and sincere help as well as their keen interest in sharing me their vast knowledge throughout the course of my investigation.

This is my proud prerogative to express my sincere gratitude to Dr. Subir Sen, retired Professor, for his constructive suggestions and allowing me the privilege of having frequent recourse to his expertise and command over the subject in the preparation of this manuscript.

I express my grateful thanks and respect to all my teachers in the Department for their kind support and co-operation during the course of my work. I am also thankful to the authorities of BCKV for providing financial assistance during the tenure of my investigation.

I am deeply indebted to Prof. T. P. Mukhopadhyay, the then Professor-In-Charge, North Bengal Campus and present Dean, Faculty of Horticulture, BCKV for providing me with all sort of facilities during my field trials at North Bengal Campus.

Sincere thanks are also due to all the non-teaching staff of this Department and field staff of the Instructional farm, North Bengal Campus for their unstinted co-operation and

necessary help during the entire course of my thesis work. I highly acknowledge the help rendered by Mr. A. Khan and Mr. S. Biswas during my field work and laboratory analysis, respectively.

My thanks are due to Dr. T.K. Gupta, former Professor of Agricultural Statistics, BCKV for his kind help and critical suggestions in working out different calculations for this thesis.

Assistance rendered by Mr. Tapan Roy and M/S Azure Software Pvt. Ltd., through their painstaking efforts in typing the manuscript carefully, and M/S Dhar Brothers for their meticulous binding are duly acknowledged.

During the years of my research work, I have come in contact with lot of people who have contributed to this thesis. Among them I wish to express my heartfelt thanks to Navin, Krishna, Jangbir, Ganesh, Tashi, Feroze, Kishore and Avijit for their generous help, co-operation and being positive about my research when I felt otherwise.

I am also truly thankful to U.C.Thapa (Lecturer, Faculty of Horticulture, BCKV), S. Pradhan, R. Sadhukhan, S. Kundu, S. Mukherjee, P.K. Panda, M. Nanda, S. Rai, S.P.Singh, R. Prasad and S. Ali and all my younger brothers of Lake Hall for their supportive attitude and co-operation during the entire course of my thesis work.

Finally, the contribution of my adorable parents, courageous sisters and loving brother-in-laws in the successful completion of this thesis cannot be measured in material terms. I am indeed obliged to them for their continuous encouragement, passionate feelings, silent prayers and well wishes always.

Dated, The 19th Aug...1998

Tulsi Saran Ghimiray
(Tulsi Saran Ghimiray)

CONTENTS

PARTICULARS	PAGE NO.
<i>Abstract</i>	
Chapter 1 Introduction	1
Chapter 2 Review of literature	5
2.1 Effect of boron on wheat	6
2.1.1 Effect of boron on growth parameters, yield and yield components	6
2.1.2 Differential response of wheat varieties to boron	7
2.2 Heritability and Genetic Advance	8
2.3 Nature of Gene Action and Heterosis	10
2.3.1 Nature of gene action	10
2.3.2 Heterosis	15
Chapter 3 Materials and methods	
3.1 Experimental site	18
3.2 Experimental soil	18
3.3 Experimental material	19
3.4 Field trials	19
3.4.1 Screening for tolerance to boron deficiency	19
3.4.2 Crossing programme	22
3.4.3 F ₁ generation trial	22
3.5 Laboratory analysis	23
3.6 Statistical methods	23

Chapter 4 Results	
4.1 Screening for tolerance to boron deficiency	29
4.2 Estimation of genetic parameters	33
4.3 Combining ability analysis	36
4.3.1 Growth parameters, yield and yield components	36
4.3.2 Protein and gluten content	50
4.4 Heterosis	57
4.4.1 Growth parameters, yield and yield components	57
4.4.2 Protein and gluten content	69
Chapter 5 Discussion	
5.1 Screening for tolerance to boron deficiency	73
5.2 Estimation of genetic parameters	75
5.3 Combining ability analysis and heterosis	76
5.3.1 Growth parameters, yield and yield components	76
5.3.2 Protein and gluten content	82
Chapter 6 Summary and Conclusion	85
Chapter 7 Future Scope of Research	95
Bibliography	i - xiii

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
1	List of genotypes and their source of collection	21
2	Effect of boron on growth parameters, yield and yield components	30-31
3	Estimates of genetic parameters for seven characters of wheat grown under boron deficient (B_0) and under boron supplemented (B_1) condition	34
4	Mean performance of parents and crosses for growth parameters, yield and yield components under boron deficient condition	37
5	Mean performance of parents and crosses for growth parameters, yield and yield components under boron supplemented condition	38
6	Combining ability analysis for growth parameters, yield and yield components under boron deficient condition	39
7	Combining ability analysis for growth parameters, yield and yield components under boron supplemented condition	40
8	Estimates of general combining ability (<i>gca</i>) effects for growth parameters, yield and yield components under boron deficient condition	42
9	Estimates of general combining ability (<i>gca</i>) effects for growth parameters, yield and yield components under boron supplemented condition	43
10	Estimates of specific combining ability (<i>sca</i>) effects for growth parameters, yield and yield components under boron deficient condition	44

11	Estimates of specific combining ability (<i>sca</i>) effects for growth parameters, yield and yield components under boron supplemented condition	45
12	Mean performance of parents and crosses for protein and gluten content under boron deficient and boron supplemented conditions	51
13	Combining ability analysis for protein content and gluten content under boron deficient condition	52
14	Combining ability analysis for protein content and gluten content under boron supplemented condition	53
15	Estimates of general combining ability (<i>gca</i>) effects for protein content and gluten under boron deficient (B_0) and boron supplemented (B_1) conditions	55
16	Estimates of specific combining ability (<i>sca</i>) effects for protein content and gluten content under boron deficient (B_0) and boron supplemented (B_1) condition	56
17	Percent heterosis for plant height (cm)	58
18	Percent heterosis for number of tillers/plant	60
19	Percent heterosis for spike length (cm)	62
20	Percent heterosis for number of spikelets/spike	63
21	Percent heterosis for number of seeds/spike	65
22	Percent heterosis for 250 grain weight (g)	67
23	Percent heterosis for grain yield/plant (g)	68
24	Percent heterosis for protein content (%)	70
25	Percent heterosis for gluten content (%)	72

ABSTRACT

Twenty five genotypes (viz, **HP 1685, HP 1705, K 8905, HP 1633, BAW 171, HD 2285, Sonora 64, Kanchan, Akbar, Aghrani, Fang 60, BAW 452, HDR 77, HUW 234, HD 2684, HP 1728, Wheat Local, C 306, Siren, BL 1022, Glennsen, HP 1704, DL 784-3, UP 262 and Sonalika**) of wheat were used for evaluation of seven agronomic characters under boron deficient and boron supplemented conditions. On the basis of relative performance under boron deficient condition, eight genotypes (viz., **DL 784-3, HD 2285, UP 262, Sonalika, Sonora 64, Fang 60, Aghrani and Akbar**) were selected for a 8 x 8 diallel experiment.

All the field experiments were conducted during 1994-95, 1995-96 and 1996-97 at the Instructional Farm, BCKV, North Bengal Campus, Pundibari (WB) following the recommended package of practices for wheat cultivation. Standard statistical methods were followed for comparison of performance of seven agronomic characters viz., plant height (cm), number of tillers/plant, spike length (cm), number of spikelets/spike, number of seeds/spike, 250 grain weight (g) and grain yield/plant (g). The range, mean, phenotypic and genotypic co-efficient of variations, heritability (broad sense) and genetic advance were also estimated for the above-mentioned characters under both situations. Griffing's (1956) Model I, Method II were used for analysis of results from 8 x 8 diallel on nine characters viz., plant height, number of tillers/plant, spike length (cm), number of spikelets/spike, number of seeds/spike, 250 grain weight (g), grain yield/plant (g), crude seed-protein content (%) and gluten content (%). Percent heterosis were also computed for these characters.

With boron supplementation, significant increase was noted for almost all the characters except spike length and 250 grain weight. Increased yield in most of the genotypes with boron application was mainly due to increase in number of seeds/spike. **Fang 60** and **Sonalika** outyielded the remaining genotypes under boron deficient condition. **Fang 60, Sonalika, Sonora 64** and **Wheat local** revealed stability in yield under the two situations. This suggests that evaluation of the performance of these genotypes under boron deficient condition may provide results of practical value.

The present study revealed greater relative variability for number of seeds/spike, grain yield/plant and number of tillers/plant under boron deficient condition. However, grain yield/plant under boron supplemented condition showed least relative variability. Phenotypic co-efficient of variation were, in general, higher than genotypic co-efficient of variation for all the characters studied except plant height, indicating greater influence by the environment on these characters. High heritability and genetic advance along with comparable genotypic co-efficient of variation were evident for number of tillers/plant and number of seeds/spike under boron deficient condition. This association indicated the importance of additive gene effects in the inheritance of these characters and, hence, selection of these characters would be highly effective under boron deficient condition.

The combining ability studies indicated the importance of additive genes action only for plant height and gluten content. Both additive and non additive components of gene action contributed significantly in the inheritance of all other characters studied. Predominance of one or the other genetic component varied from character to character and on boron level. In view of this, selective diallel mating system may prove fruitful in creating variability upon which effective selection for desirable characters could be made.

Sonalika, **Fang 60** and **Sonora 64** were good general combiners for grain yield/plant and a cluster of important characters. **Sonalika** and **Fang 60** were also found to be good general combiner for protein and gluten content. The cross combinations **DL 784-3 x Sonalika**, **DL 784-3 x Fang 60**, **DL 784-3 x Sonora 64** and **Fang 60 x Akbar** involving susceptible x tolerant or tolerant x susceptible (to boron deficiency) types are expected to throw up desirable transgressive segregants, which could be exploited for further breeding work. The cross combinations **DL 784-3 x Sonalika** and **Aghrani x Akbar** would provide scope for advantageous association of grain yield and gluten content or grain yield and protein content under boron deficient condition.

Manifestation of heterosis for grain yield/plant seemed to be mainly through heterosis for number of tillers/plant.

Chapter 1

INTRODUCTION

Bread, made from wheat (*Triticum aestivum* L. em.Thell), has been the staff of life for countless numbers of human beings, right from the dawn of history when man first turned from an arboreal or nomadic life to settled agriculture, based on the cultivation of plants and domestication of animals.

Wheat and wheat products contribute substantially to the world's food supply and constitute an important source of carbohydrates in human diet. Its pre-eminence over most cereals is largely due to its baking quality. In India, nearly 85-90% of it is used in the form of **chappatees** and in culinary preparations such as **tandoori roti, nan, paratha** and **poori**. The flour from soft wheat is chiefly used for making cakes, biscuits, pastries, crackers and other products, while hard wheat provides excellent flour for bread making. The grains of *duram* wheat are preferred by the manufacturer of macaroni, spaghetti, vermicelli and similar products as noodles. Small amounts of wheat are converted into breakfast food e.g., wheat flakes, puffed wheat and shredded wheat.

As far as the nutritional value of wheat is concerned, besides starch it also supplies proteins, minerals and important vitamins. Wheat proteins are of special significance. Besides their importance in nutrition, they are principally concerned in providing the characteristic substance, gluten, which is so well known to millers and bakers. It is this particular substance which provides the structural framework for the spongy, cellular texture of bread and a wide variety of other baked products thus assuring its continuing role in society.

Industrial uses of wheat include the manufacture of starch, gluten, distilled spirits, malt, pasta etc. Wheat starch is preferred by many laundries for use in finishing clothes. Gluten is used for the production of monosodium glutamate, a product that intensifies the flavour of food.

Wheat is an important cereal in India, occupying 52.8% of the total *rabi* foodgrains. About one-tenth of the global wheat comes from India. During the crop year 1997, India produced 68.7 mt of wheat from 25.4 m ha. By increasing the per ha productivity, wheat productivity can be raised to 109 mt by 2020 A.D. (Nagarajan, 1997).

High yielding dwarf varieties of wheat were introduced in 1965 and since then continuous increase in both production and productivity without any substantial increase in area have been noted. During the last 25 years, through plant breeding, there has been one percent annual genetic gain in yield due to development of new varieties (Nagarajan, 1996). Continuous varietal improvement and their adoption has pushed productivity to higher levels.

It is not out of place to point out that the potentiality of these high yielding varieties are difficult to realise in some areas, particularly in the terai zone of West Bengal, for their inherent adapho-climatic problems. The climate of this region, in general, is sub tropical humid in nature with high rainfall, high relative humidity accompanied by low temperature. The soil is mostly sandy to sandy loam in texture, porous and greyish black in colour. As a consequence of leaching of bases due to heavy rainfall (2000-3500

mm) in this region, soil reaction is moderate to strongly acidic (pH 4.0 to 6.0). The organic matter content is medium to high and sometimes is of raw humus type. High rainfall in this region favours high rate of leaching of plant nutrients causing deficiency of Ca, Mg and some of the micronutrients like Zn, Mo, B which calls for correction to sustain yield potentiality of crops including wheat (Anon, 1989).

Wheat is the most important *rabi* cereal crop in this zone. However, wheat varieties which generally perform quite creditably in other parts of the state give reduced yield in terai zone. The major constraint is the widespread deficiency of micronutrients, particularly boron (B).

Among the micronutrients, B has been reported to influence the grain setting and yield in wheat (Singh *et al.*, 1976; Ahmed *et al.*, 1979; Sharma and Das, 1982; Mandal and Ghosal, 1985; Mitra and Jana, 1991). In this region, the general practice is the application of boron to sustain increased yield. However, yield loss can also be prevented by identifying cultivars tolerant or resistant to boron deficiency. Genetic resistance is the cheapest and best method to overcome the barrier against floret fertility and helps to sustain productivity more efficiently. To achieve this objective, standard genetic experiments should be intensified to improve resolving power of the genetic system of the mating parents to generate and isolate high yielding stress resistant recombinants.

One of the recent approaches of breeding is to develop nutritionally balanced varieties. The objective is to combine in one plant all the main nutrients in correct proportions for a well balanced diet. Reshaping a species which mainly yields carbohydrates into one which would also supply adequate protein and fat is a task of great magnitude.

In wheat breeding programme, much emphasis is given to increase the total protein content or altering the protein composition of grains so that improvement with respect to certain aminoacids, particularly lysine can be achieved. Gluten content in appreciable amount is desirable as it improves the baking quality and dough making properties of wheat flour. But these quality breeding aspects are a challenge to the plant breeder

because of existence of negative genetic relation between yield and quality parameters, especially protein content (Raina *et al.*, 1982; Kibita and Evans, 1984; Day *et al.*, 1985). Osanai *et al.* (1977), however, suggested that to achieve success in simultaneous improvement of quality and yield, the growing conditions of the experimental population must be critically assessed to discover the favourable, natural selection pressure in a given environment. Artificial selection may be practised in the same direction as that of natural selection or may be used as an aid to compensate for the negative effect of natural selection.

Considering all these aspects, the aim of the present investigation was to evaluate the wheat genotypes collected from different sources for identification of tolerant or resistant genotypes to boron deficiency, to test the performance of parents in different cross-combinations, to characterise the nature and magnitude of gene action in the expression of different quantitative and qualitative characters, and to estimate the promises of advantageous recombinants for balanced quality and high yield that are ideal for growing in terai soils of West Bengal.

Chapter 2

REVIEW OF LITERATURE

The role of boron (B) on floret fertility had been realised by various workers through their experiments on different crops conducted in boron deficient condition. They had attempted to give plausible explanations behind the role of B in overcoming floret sterility and thereby maintaining the yield potentiality of the so-called susceptible varieties.

Lewis (1980) reported that high B level should be maintained in the stigma for effective pollen tube growth which may presumably inactivate the callose by forming the borate-callose complex at the pollen tube-style interface. Dugger (1983) emphasised that B is essential for pollen germination of pollen tube growth, and the deficiency of this micro-element reduces the effective fertilization thereby restricting the seed development. He also suggested that B is responsible for translocation of carbohydrate by forming

carbohydrate-borate complex to maintain growth and grain filling. Sherell (1983) observed that due to B deficiency grain production is much more affected than vegetative growth.

Mandal and Chakraborty (1988) attributed the failure of fertilization in certain wheat varieties, grown in boron deficient soil, to either limited growth of pollen tube or non-germination of pollens. Cheng and Rerkasem (1992) suggested that due to deficiency of B the pollen development may be affected right from the pollen mother cell stage. Improvement in both pollen germination and pollen tube growth could be made through application of B as reported by Mandal *et al.* (1994).

2.1 Effect of boron on wheat

The available literature on wheat are reviewed in this section to find out the effect of boron on various quantitative characters as well as the differential response of wheat varieties to boron application.

2.1.1 Effect of boron on growth parameters, yield and yield components

Among the micronutrients, boron has been reported to influence the grain setting and yield in wheat (Singh *et al.*, 1976; Ahmed *et al.*, 1979; Sharma and Das, 1982). Dani *et al.* (1970) reported that an additional application of boron in soil not only enhances the yield in wheat but also the starch content by 5 to 6% over control. Studies by Singh and Singh (1976) found increased grain carbohydrate content, grain and dry matter yield by boron application.

Ganguly (1979) first reported that boron deficiency causes seedlessness in certain wheat varieties grown in terai zone of West Bengal. Chatterjee *et al.* (1980) reported increased grain yield in wheat varieties with boron application. Mandal and Ghosal (1985) evaluated several varieties in terai soils of West Bengal, where boron deficiency is an acute problem, and reported increased yield with boron application. They observed that the yield of some varieties increased upto 325% when 20 kg borax/ha was applied. Increased yield with boron application have also been reported by various workers (Mandal and Das, 1988; Ali and Manoranjan, 1989; Singh *et al.*, 1992; Roy and Pradhan, 1994).

Yield attributes like number of effective tillers, number of grains/panicle and 1000 grain weight were significantly increased by boron application upto 20 kg/ha as reported by Mitra and Jana (1991). Improvement in seed setting and 1000 grain weight by boron application were also reported by Singh *et al.* (1976) and Ahmed *et al.* (1979).

Mandal (1993) reported positive response of varieties to boron application with respect to grain yield, number of grains/spike and spike length. They also found that increase in grain yield was basically through increase in number of grains/spike. Gandhi *et al.* (1963) had also reported increased yield to be associated with increased number of seeds/spike. Results of Hossain *et al.* (1994) showed that added boron had a positive effect on the number of grains /spike and grain yield. Similar observations were drawn by Jahiruddin *et al.* (1992). Hossain *et al.* (1994) further stated that added boron significantly increased nitrogen and boron contents in grains indicating that boron probably helped protein synthesis.

2.1.2 Differential response of wheat varieties to boron

Reports are available indicating varietal differences with respect to tolerance to boron deficiency. Mandal and Ghosal (1985) identified **Sonalika** and **HD 2233** to have fair tolerance to boron deficiency while **HD 2214** was found to be susceptible. Studies by Mandal and Ghosal (1988) further identified **UP 262**, **HUW 187**, **Sonalika** and **BR 2053** as potential parents in breeding for tolerance to boron deficiency. Studies by Mandal and Singharoy (1989) found **DL 153-2**, **H 1952**, **CPAN 1798**, **Sonalika** and **HP 1470** tolerant to boron deficiency.

Rerkasem and Saunders (1993) found a wide variation in tolerance to boron deficiency between different genotypes. **Fang 60** with grain set index of 71% when given no boron was among the most tolerant to boron deficiency, while several sensitive genotypes completely failed to set grain in the absence of boron. Rerkasem and Loneragen (1994) reported reduction in grain number and yield by boron deficiency in wheat cv. **SW**

41 but remained unaltered in tolerant cv. **Sonora 64** indicating its tolerance to boron deficiency.

Comparatively large volume of works on the genetic parameters of wheat have been reported by various workers. In the following sections, an attempt has been made to present a comprehensive and up-to-date work done in this crop with respect to heritability and genetic advance, nature of gene action and heterosis which are relevant to the present investigation.

2.2 Heritability and genetic advance

Burton (1952) suggested that genetic variability along with heritability should be considered for assessing accurate effect of selection. Studies on genetic parameters like genotypic co-efficient of variation, heritability and genetic advance should be considered as a guide for initiating selection of suitable genotypes to be used as varieties or for further breeding work.

High heritability estimates generally enables the breeder to select plants on the basis of phenotypic expression (Johnson *et al.*, 1955). Genetic advance is still a more useful estimate. Johnson *et al.* (1955) suggested that heritability estimates in combination with genetic advance would be more reliable than heritability alone for predicting the effect of selection. According to Hanson (1961), heritability and genetic advance are complementary aspects. Thus, values of heritability can also be used for computing the expected gain progress possible through selection.

✓Biever *et al.* (1966) reported high heritability estimates for plant height, ear length and kernal weight. Johnson *et al.* (1966) also found high heritability estimates for ear length and kernel weight.

✓Ketata *et al.* (1976) found moderately high heritability for kernel weight and plant height, but low heritability for spikelets/ear and grain yield. They, however, reported inconsistency in the magnitude of heritability and genetic advance for tiller number. Similar observations were made by Ahmed *et al.* (1977) for plant height, 1000 grain weight and

tiller number in wheat. Islam (1976) found high heritability accompanied by high estimates of genetic advance for plant height, tiller number, ear length and grain/spike while for 1000 grain weight there was inconsistency in the magnitude of the two parameters. Singh *et al.* (1978) reported high genetic advance associated with high heritability for grain weight but low genetic advance with low heritability for plant height. Bhatia *et al.* (1978) observed high heritability estimates and appreciable genetic advance in F₄ with regard to plant height, tillers/plant, days to maturity, ear length, number of grains/ear and 100 kernel weight.

✓ Srivastava *et al.* (1982) reported low estimates of heritability for tillers/ plant, grains/ear, grain yield/plant and 1000 grain weight. Brojevic (1984) observed heritability estimates ranging between 50 - 60% for plant height, spike length, number of grains/ear, grain weight/spike, 1000 grain weight and number of spikelets/spike and harvest index while Das and Rahman (1984) reported high heritability estimates for these traits.

✓ Pathak *et al.* (1986) observed high heritability associated with high genetic advance for grain yield/ear but low heritability with high genetic advance for grain yield/plant. Singh *et al.* (1987) found number of grains/ear and 1000 grain weight, in general, had high heritability estimates but the genetic advance was low. Their studies revealed low heritability estimates for grain yield in the crosses. This indicates that direct selection on yield *per se* would not be proper, and due weightage may be given to different yield components.

✓ Kheiralla (1993) found high estimates of heritability for spike length, grains/spike and 1000 grain weight but moderate for spikes/plant and grain yield/plant. Yadav and Mishra (1993) observed high heritability and high genetic advance for 100 grain weight, number of tillers /plant and grain yield/plant. Kumar *et al.* (1996) reported moderate estimates for plant height, tillers /plant and grains/ear indicating the presence of both additive and nonadditive gene actions for their expression. Sharma *et al.* (1991) had also reported moderate values of heritability for plant height and tillers/plant.

2.3 Nature of gene action and heterosis

Estimation of combining ability is imperative to choose parental lines and their crosses for initiation of breeding programme. Information on the inheritance of a character would indicate the ease or difficulty with which the character could be introduced into breeding lines. The available literature on wheat are reviewed in this section to find out the nature of gene action in general, and that under boron deficient condition in particular, along with heterosis for various quantitative characters and quality parameters such as protein content and gluten content.

2.3.1 Nature of gene action

2.3.1.1 Growth parameters, yield and its components

Kronstad and Foote (1964) reported that a large part of total genetic variation for grain yield and its component and plant height was associated with significant *gca* effects while *sca* had small effects on grain yield. Brown *et al.* (1966) found that most of the genetic variability in yield and its components was associated with high *gca*. They reported that *sca* effects did not exist in wheat. However, Singh and Gupta (1969) found both *gca* and *sca* variances to be significant for yield contributing traits. They also noted that the parents, which were high combiners for grain yield, were also high combiners for atleast two of the three yield components. The combining ability for yield seemed to be influenced by the combining ability for its components.

Walton (1969) observed predominance of additive gene action for ear length and yield while Jarnail and Anand (1971) reported additive gene action predominating for grains/ear. Gill *et al.* (1972) revealed the importance of both additive and dominance genetic variance for 100 grain weight, tiller number and ear length. However, predominance of additive genetic variance was observed for grains/ear and plant height. Hanna (1973) also observed the importance of both additive and non additive gene actions for ear length and ear number. Additive gene effects were also found to be significant for spikelets/ear, grains/ear, 100 grain weight, ear length (Sharma *et al.*, 1975), plant height, number of tillers/unit area and kernel weight (Edward *et al.*, 1976).

Gill *et al.* (1979) found pronounced additive gene effect for number of grains/ear while additive, dominance and epistatic effects were all important for seed size and grain yield. Studies of Jatasra and Paroda (1983) revealed non-additive gene effects for grain yield whereas additive gene effects predominated for tillers/plant, grains/ear, grain weight/ear and 100 grain weight. However, Nanda *et al.* (1983) indicated the importance of both additive and non additive components for grain yield, tillers/plant grains/ear and seed size. Sharma *et al.* (1978) and Singh *et al.* (1982) had also observed similar effects in the expression of most of the metric traits in bread wheat. On the other hand, Singh *et al.* (1983) reported non additive gene action to influence yield and most of its components.

Chaudhry *et al.* (1985) reported additive gene action for plant height and non additive for grain yield while both were important for spike length, spikelets/spike and 1000 grain weight. Khan *et al.* (1986), on the other hand, reported additive gene action for number of spikelets/spike, 1000 grain weight and yield/plant. They found that the characters seeds/spike, tiller number and spike length were governed by both additive and non additive type of gene actions.

Studies of Raghavaiah and Joshi (1986) indicated additive effects predominating not only for yield but also for spike length, while non-additive effects were predominant for grain weight/ear and effective tillers/plant. Both the type of gene actions were observed for spikelet number/spike, plant height, number of grains/ear, spike weight and 1000 grain weight. Sarkar *et al.* (1987), however, reported additive gene action governing these characters. Dasgupta and Mandal (1988) noted preponderance of additive gene effects for ear length and spikelets/ for spike while non additive gene effects were more important for seed yield and number of productive tillers/plant.

Li *et al.* (1989) revealed additive gene effects for 1000 grain weight, plant height and fertile florets while seed weight/plant and seed number /plant were under the control of both additive and non additive gene actions. Yadav and Singh (1989) observed preponderance of additive gene effects for plant height, number of grains/ear and 1000

grain weight while tiller number and grain yield were under the control of non additive gene action.

Bhowmik *et al.* (1991) found pronounced additive gene effect for plant height and spike length while spikes/plant and seed weight/plant were mainly controlled by non additive genes. Similar observations were made by Li *et al.* (1991) for these characters. On the other hand, Vitkare and Atale (1991) observed additive gene action controlling spikelets/spike only, while non-additive gene action was more important in the inheritance of plant height, tillers/plant, ears/plant and grain yield/plant. However, Chaudhry *et al.* (1992) indicated preponderance of additive gene effects for plant height, tillers/plant, 100 grain weight and yield/plant.

Studies of Singh and Yunus (1993) indicated greater influence of both additive and non-additive gene action for grain yield. Walia *et al.* (1993), on the other hand, reported predominance of additive gene action in controlling grain yield.

Gill *et al.* (1994) reported predominant role of additive gene action controlling grains/spike and 100 grain weight, non additive for grain yield and both the type of gene action for spikes/plant. Mishra *et al.* (1994), however, found predominant role of additive gene for the expression of yield characters while non-additive gene effects were more important for plant height and yield/plant.

Patel *et al.* (1995) reported that both additive and non additive effects were important in the expression of the yield contributing characters as was also observed by Borghi and Perenzin (1994). However, the magnitude of additive effect was greater for these characters except for spike length suggesting preponderance of additive gene effects as was also reported by other investigators (Malhotra and Jain, 1973; Singh *et al.*, 1982; Singh *et al.*, 1986).

Hassan *et al.* (1996) also found that both additive and non additive genetic variance were responsible for the inheritance of ear length, grain weight/ear, grains/ear and

1000 grain weight. Singh and Singh (1978), Pawar *et al.* (1988) and Vitkare and Atale (1996) also came to the same conclusion.

Combining ability studies by Singh and Chatrath (1997) under salt stress environments revealed the importance of additive gene effects in the inheritance of plant height, non additive for grain yield and number of productive tillers/plant and both for ear length, number of spikelets/spike, grains/spike and 100 grain weight. Additive gene action for plant height was also reported by Sharma and Tandon (1997).

Mandal (1988) studied the effect of boron on combining ability in bread wheat. He found the character such as yield/ plant, grain/spike, spike length and tillers/plant to show significant differences in response to boron. At deficient level of B, variance due to *gca* were highly significant for except tillers/plant whereas at standard B level *gca* variances were significant for all the characters. However, *sca* variances were significant for all characters at both levels. The values for *gca* and *sca* effects at different B levels were variable both in direction and magnitude.

On the basis of combining ability analysis, Mandal and Ghosal (1988) identified **UP 262**, **HUW 187**, **Sonalika** and **BR 2053** as potential parents in breeding for tolerance to boron deficiency. The analysis showed preponderance of additive gene effect in majority of the characters like effective tillers, ear lengths, spikelet number, grain number, 100 grain weight and yield/plant but presence of non-additive gene action was also observed.

Jamjod *et al.* (1991) in their study of seven parent diallel (differing in tolerance to B deficiency) found both *gca* and *sca* to be highly significant. The *gca* effects were seven times greater than *sca* effects. The *sca* effect was positive in six susceptible x tolerant and tolerant x tolerant crosses, respectively. This indicates that it may be possible to transfer the tolerance character to susceptible lines through back crossing. The positive *gca* effects of tolerant lines suggest that these lines may be useful in breeding for more tolerance in problem areas.

Studies by Mandal and Maity (1992) in a six parent diallel over two environments (0 and 10 kg borax/ha) revealed the greater importance of additive gene action for controlling grains/spike while non additive gene action was important in the control of seed yield/plant.

2.3.1.2 Protein and gluten content

The demonstration that improvement in nutritional quality could result from single gene alterations in maize (Mertz *et al.*, 1964) has indicated the prospects of enriching protein quality of other cereal grains through simple genetic manipulations. Reports of changes in the total protein and lysine contents in the mutant of **Sonora 64** (Varughese and Swaminathan, 1967) point to the possibilities of qualitative and quantitative improvement of protein content in wheat by simple genetic manipulation. Simultaneous improvement of grain yield and the nutritional quality has become the main objective in many wheat improvement programme (Borlaug, 1968; Singhal *et al.*, 1977). However, increasing grain protein percentage without a reduction in grain yield is a difficult task in view of the inverse relationship commonly found between these two traits (Terman *et al.*, 1969, McNeal *et al.*, 1972; Ellison *et al.*, 1977; Raina *et al.*, 1982; Kibita and Evans 1984; Day *et al.*, 1985). Kibita and Evans (1984) postulated that these inverse relationship were not determined directly by genetic factors, but mostly by environmental or physiological ones, such as source-sink interactions, and dilution of grain protein by carbohydrates. Studies by Gharzai *et al.* (1983) revealed that although protein content was negatively correlated with yield in the crosses, regressions of F_5 on F_4 and F_4 on F_3 for yield and protein content were generally positive, suggesting that simultaneous selection for these characters is possible.

Goswami (1967) and Ranga Rao and Murthy (1970) reported the presence of both additive and non additive gene actions for controlling protein content. On the other hand, Tandon (1967) observed that additive gene effects were important in controlling the inheritance of grain protein content. However, they also found additive x additive and dominance x dominance effects to be of considerable magnitude. Chapman and McNeal (1970), also found the additive gene effect to be highly significant for grain protein.

Bhuller *et al.* (1974) and Gill *et al.* (1974) found slightly greater magnitude of additive genetic variance than non additive genetic variance for protein content. Srivastava and Ram (1974) observed the *gca* variance to be significantly higher than *sca* variance.

Jatasra *et al.* (1978) reported additive gene action for protein in crosses between varieties from India and Mexico. Studies of Raina *et al.* (1979), however, indicated the importance of both additive and non additive genetic variance in the inheritance of quality traits viz., protein content, Pelshenke value, lysine and tryptophan content in wheat. They observed that most of the crosses showing significant positive *sca* effects involved one good and one poor, or even negative general combiners.

Nedelea and Moisuc (1982) observed additive gene effects to be important for gluten content and sedimentation value.

Thakral *et al.* (1986) revealed the predominant action of additive genes for protein content as was also observed by Ram and Srivastava (1983). On the other hand, Milanko (1988) reported the importance of both additive and non additive gene action for protein content. Singh *et al.* (1978) had also drawn similar conclusion.

Li *et al.* (1992) indicated the predominance of non-additive gene action for the inheritance of protein and gluten content as was also reported by various investigators (Arora and Chandra, 1980; Thakre, 1982; Vitkare and Atale, 1990). On the other hand, Mandal and Maity (1992) revealed predominance of additive gene action controlling protein content as was also reported by Li *et al.* (1991).

The results of Jin *et al.* (1995) showed that the protein content in grain was mainly determined by the additive genetic effects in the offspring of wheat, and in the advanced generations the effect of this genetic components would become more pronounced.

2.3.2 Heterosis

It has been observed that the frequency and extent of heterosis were greater for such characters as number of spikes/plant and total grain yield than for the characters

which are less changing such as plant height, number of seeds/ spike and 100 grain weight (Saakyan, 1975; Redhu *et al.*, 1986). Considerable heterosis for tillers/plant and yield/plant have also been reported by Kumar *et al.* (1977) and Vitkare and Atale (1991).

Redhu *et al.* (1986) reported that heterotic crosses for yield had heterosis for more than one component characters. Similar observations were made by Maurya and Singh (1978). Palve *et al.* (1986) found appreciable heterosis over mid parent and better parent for yield/plant followed by grain weight/ear, grain number/ear and number of productive tillers/plant. Yadav and Singh (1989) observed the number of tillers, total biomass and number of grains/ear to be major contributors for heterotic yield. Similar observations were drawn by Sindhu and Singh (1975) and Sharma *et al.* (1986).

Krishna and Ahmed (1992) obtained highest mean heterosis for grain weight/spike followed by 1000 grain weight, grain yield and harvest index, while Walia *et al.* (1993) reported significant heterosis for grain yield/plant, number of spikelets/spike and number of ears/plant.

Rathore and Chauhan (1986) reported maximum heterosis for 100 grain weight followed by grain yield/ plant. On the other hand, Yin *et al.* (1997) reported highest heterosis for number of tillers/plant followed by grain yield. Yadav and Murty (1976) had also drawn similar conclusions. However, Chakraborty and Tiwari (1995) reported high heterosis for 100 grain weight while heterosis was low for tillers/plant.

Singh *et al.* (1984) observed high heterosis for grain yield. Results of Ibrahim (1994) indicated that heterosis was generally more pronounced for grain yield/plant than any of its components. Sharma and Menon (1996) also reported high and significant positive heterosis for grain yield while the magnitude of heterosis was not high for its contributing characters.

With respect to protein and gluten content, studies of various investigators revealed negative heterosis. Negative heterosis for protein and gluten content were reported by Thakre (1982), Li *et al.* (1992) and Atale and Vitkare (1996). Uddin *et al.*

(1992) obtained negative heterosis for protein content while Matuz and Bebe (1996) found negative heterosis for wet gluten content.

Chapter 3

MATERIALS AND METHODS

3.1 Experimental site

The present investigation was conducted during the *rabi* seasons of 1994-95, 1995-96 and 1996-97 at the Instructional farm, Bidhan Chandra Krishi Viswavidyalaya , North Bengal Campus, Pundibari, Coochbehar (West Bengal). The farm is located at the terai zone of West Bengal at 26° 19' N latitude, 85°23' E longitude and at an elevation of 43 metres above mean sea level.

3.2 Experimental soil

The topography of the land, where the investigation was conducted, was medium in situation, endowed with good drainage facility. The soil of the experimental site was sandy to sandy loam in texture and acidic (pH 5.6) in nature. The available boron, organic matter content and cation exchange capacity were 0.210 ppm, 0.60% and 9.60 m eq/100 gm, respectively.

3.3. Experimental material

The experimental material consisted of twentyfive genotypes of wheat of which, sixteen genotypes were made available by courtesy of All India Co-ordinated Wheat Improvement Project (AICWIP), BCKV, N.B. Campus, Pundibari (W.B.) and the remaining nine genotypes by courtesy of Dr. B. Rerkasem, Faculty of Agriculture, Chiang Mai University (Thailand), through AICWIP, BCKV, N.B. Campus, Pundibari. The various collections used in the present study are presented in Table 1.

3.4 Field trials

3.4.1 Screening for tolerance to boron deficiency

The experiment was conducted during the *rabi* season of 1994-95 with twentyfive genotypes and two levels of boron (0 and 10 kg borax/ha) in a split - plot design with three replications. The size of main plot assigned to borax was 12 m x 7m. Each genotype was accommodated in subplots of 2m x 1m size maintaining a distance of 30 cm between rows and 10 cm between plants. Recommended doses of major nutrients (N,P and K) were applied. Normal cultural practices were followed. No protection measure against pest and diseases was required. Observations were recorded on ten randomly selected plants from the central rows in each plot. The growth and yield characters studied were as follows:

Plant height (cm):

It was measured as the length of the plant from its base to the top of the main spike at harvesting stage.

Number of tillers/plant:

It was recorded as the total number of spike bearing tillers from each of the randomly selected plants.

Table 1 List of various genotypes and their source of collection

Sl. No.	Genotypes	Source of collection
1	HP 1685	AICWIP
2	HP 1705	AICWIP
3	K 8905	AICWIP
4	HP 1633	AICWIP
5	BAW 171	F/ Ag, Chiang Mai University, Thailand
6	HD 2285	AICWIP
7	Sonora 64	F/ Ag, Chiang Mai University, Thailand
8	Kanchan	AICWIP
9	Akbar	F/ Ag, Chiang Mai University, Thailand
10	Aghrani	F/ Ag, Chiang Mai University, Thailand
11	Fang 60	F/ Ag, Chiang Mai University, Thailand
12	BAW 452	F/ Ag, Chiang Mai University, Thailand
13	HDR 77	AICWIP
14	HUW 234	AICWIP
15	HD 2684	AICWIP
16	HP 1728	AICWIP
17	Wheat local	AICWIP
18	C 306	AICWIP
19	Siren	F/ Ag, Chiang Mai University, Thailand
20	BL 1022	F/ Ag, Chiang Mai University, Thailand
21	Glennsen	F/ Ag, Chiang Mai University, Thailand
22	HP 1704	AICWIP
23	DL 784-3	AICWIP
24	UP 262	AICWIP
25	Sonalika	AICWIP

Spike length (cm) :

It was measured as the length from the basal spike node to the tip of the spike (excluding awns) borne by the main culm.

Number of spikelets /spike:

It was recorded as the total number of spikelets borne by the spike of the main culm.

Number of seeds/spike:

It was counted from randomly selected spikes from each plant.

250 grain weight (g):

It was recorded as the mean value of the weight of 250 seeds collected separately from each of the randomly selected plants.

Grain yield/plant (g):

It was recorded as the average grain yield of ten randomly selected plants.

3.4.2 Crossing programme

In 1995-96, eight genotypes (viz., **DL 784-3**, **HD 2285**, **UP 262**, **Sonalika**, **Sonora 64**, **Fang 60**, **Aghrani** and **Akbar**), selected after the first year trial, were crossed in all possible combinations (excluding reciprocals) to obtain 8 x 8 half diallel set. These genotypes were selected on the basis of their tolerance or susceptible nature in response to boron deficiency. Of these, three genotypes (**Sonalika**, **Sonora 64** and **Fang 60**) were tolerant, three (**HD 2285**, **UP 262** and **Aghrani**) were moderately tolerant and two (**DL 748-3** and **Akbar**) were susceptible.

Wheat flowers were emasculated by removing anthers prior to shedding of pollen on stigma from anthers. In order to facilitate removal of anthers, 1/4th to 1/3rd of the upper part of spike was clipped and a few immature, basal and central florets were removed. After this, emasculation was carried out in the remaining florets clipping the glumes, and anthers were removed with the help of pointed forcep. Immediately after these operations, wheat spikes were covered with butter paper packet in order to exclude any foreign pollen. All these operations were done between 2.00 to 5.00 P.M. on the day before pollination. For preparing male spike, a spike showing a few protruding anthers was removed from the male parent. Its glumes were cut without any damage to the anthers, and held in vertical position under sunlight for a few minutes. During this process, anthers emerged out of the cut glumes. The male spike shedding pollen was inserted and shaken over the emasculated spike by twirling motion after removing the covered butter paper packet from spike. The spikes were again covered back to exclude foreign pollens. These crossed spikes were then properly labelled, indicating the specific parents along with date of pollination. The matured spikes from each cross combination were collected separately.

3.4.3 F₁ generation trial

The parents and twentyeight F₁ generations of wheat were grown in a randomised block design with three replications under both boron deficient and boron supplemented condition. Two rows of F₁ generations and four rows of parents were included in the experiments, keeping 1.5 m as row length. The spacing between and within the rows were

30 cm and 10 cm, respectively. The recommended doses of major nutrients were applied. Boron in the form of borax was applied @ 10 kg/ha. Normal cultural practices were followed. No protection measure against pest and diseases was required. Observations were recorded on ten randomly selected plants for each treatment. All other details pertaining to recording of data on various characters were same as those mentioned in section 3.4.1.

3.5 Laboratory analysis

Protein content (%) and gluten content (%) of the parents and their 28 F₁s were estimated. The modified Kjeldahl method (Jackson, 1967) was used to determine the total nitrogen in the flour and this was multiplied by the factor 5.7 to obtain percentage of protein. Gluten content was analysed and expressed in percentage as per the method outlined by Ram and Singh (1994).

3.6 Statistical methods

The data collected from the field trials in the first year were subjected to statistical analysis appropriate to the design (split plot design) and the treatment variations were tested for significance by 'F' test (Gomez and Gomez, 1983). The standard error of mean and critical difference (C.D) are indicated in the appropriate tables.

For estimation of genetic parameters, the data obtained from the same field trial of first year were analysed as per the procedure of Panse and Sukhatme (1954) appropriate to randomised block design (RBD). The different parameters worked out were :

Genotypic and phenotypic co-efficient of variations:

Genotypic co-efficient of variation (GCV) and phenotypic co-efficient of variation (PCV) were calculated by the formulae given by Burton (1952)

$$\text{GCV (\%)} = \frac{\text{Genotypic Standard Deviation}}{\text{Grand mean}} \times 100$$

$$\text{PCV (\%)} = \frac{\text{Phenotypic Standard Deviation}}{\text{Grand mean}} \times 100$$

Heritability (% ,broad sense):

The percentage of heritability (H) was estimated by the formula suggested by Hanson *et al.* (1956)

$$\text{H (\%)} = \frac{\text{Genotypic Variance}}{\text{Phenotypic Variance}} \times 100$$

Genetic advance (as percentage of mean):

The expected genetic advance (GA), as percentage of mean, was computed according to the following formula as suggested by Johnson *et al.* (1955).

$$\text{GA (\%)} = K. H. p \times \frac{100}{\bar{X}}$$

Where, K = Selection differential in standard units, which is 2.06 for 5% selection intensity;

H = heritability (in broad sense);

p = Phenotypic standard deviation;

\bar{X} = Grand mean.

The data obtained from 8 x 8 half diallel set in the third year were analysed as per the procedure of Panse and Sukhatme (1954). The significance of different sources of variance was tested by Fisher Snedecor's 'F' test of probability levels at 5% and 1%, respectively. The standard error of mean and critical difference are indicated in the appropriate tables.

The data pertaining to parents and F₁ s of 8 x 8 diallel sets were subjected to combining ability analysis. The analysis was carried out as per the procedure given by Griffing (1956). Model I, Method II was considered the most appropriate for the material under study. Model I assumed that variety and block effects are constant but environmental effect was variable and the experimental effect was the population about

which inferences were to be made. Method II was applicable to the present study as parents and one sets of F_1 s (without reciprocals) were included. The method helps compare combining ability of parents, where parents themselves are used as testers. Error was independently distributed with mean zero and variance σ^2e .

The mathematical model for the combining ability in model I is assumed to be

$$Y_{ij} = \mu + g_i + g_j + S_{ij} + \frac{1}{bc} \sum_{k=1}^b \sum_{l=1}^c e_{ijkl}$$

$$i, j = 1, 2, \dots, n$$

$$k = 1, 2, \dots, b$$

$$l = 1, 2, \dots, c$$

Where,

Y_{ij} is the mean of $i \times j^{\text{th}}$ genotype over k block and l observations,

μ is the population mean,

g_i is the general combining ability (*gca*) effect of the i^{th} parent,

g_j is the general combining ability (*gca*) effect of j^{th} parent,

S_{ij} is the specific combining ability (*sca*) effect such that $S_{ij} = S_{ji}$.

$\frac{1}{bc} \sum_{k=1}^b \sum_{l=1}^c e_{ijkl}$ is the error mean effect ,

n is the number of parents,

b is the number of blocks,

and c is the number of observations for each plot.

Estimation of sum of squares (SS)

SS due to *gca*

$$S_g = \frac{1}{n+2} \left[(Y_{i.} + Y_{.i})^2 - \frac{4}{n} Y_{..} \right]$$

SS due to *sca*,

$$S_s = \sum_{i \leq j} Y_{ij}^2 - \frac{1}{n+2} \sum_i (Y_{i.} + Y_{.i})^2 + \frac{2}{(n+1)(n+2)} Y_{..}^2$$

Where Y_i = Total of array of the i^{th} parent

Y_{ii} = Mean value of the i^{th} parent

$Y_{..}$ = Grand total of $\frac{1}{2} n(n-1)$ progenies and n parents

Y_{ij} = Mean value in the diallel table

EMS for ANOVA of combining ability

Source	Degrees of freedom	S.S.	MS.	EMS
<i>gca</i>	(n-1)	S _g	M _g	$\sigma^2 + (n+2) \left(\frac{1}{n+2} \right) \sum_i g_i^2$
<i>sca</i>	$n(n-1)/2$	S _s	M _s	$\sigma^2 + \frac{2}{n(n-1)} \sum_{i,j} S_{ij}^2$
Error	m	S _e	M'e	$\sigma^2 e$

The error mean square (M'e) of combining ability analysis was obtained by dividing error mean square obtained from simple RBD analysis of diallel experiment by number of replications. For 'F' test, each mean squares was tested against M'e

Estimation of genetic components

The additive ($\hat{\sigma}^2 A$) and non additive variance ($\hat{\sigma}^2 D$) were estimated from the combining ability components as follows:

$$\hat{\sigma}^2 A = 2 \sigma^2 g \quad \text{where, } \sigma^2 g = \frac{1}{n+2} (Mg - Ms)$$

$$\hat{\sigma}^2 D = \sigma^2 s \quad \text{where, } \sigma^2 s = Ms - Me$$

$$\text{and } \hat{\sigma}^2 e = M'e$$

Additive genetic variances ($\hat{\sigma}^2 A$) were also expressed as proportions of the total genetic variances ($\hat{\sigma}^2 A + \hat{\sigma}^2 D$) --- the predictability ratio of Baker (1978)

$$\text{Predictability ratio} = \hat{\sigma}^2 A / \hat{\sigma}^2 A + \hat{\sigma}^2 D$$

Estimation of effects

The *gca* effects are defined as follows

$$g_i = \frac{1}{n+2} [\sum(Y_{i.} + Y_{.i}) - \frac{2}{n} Y_{..}]$$

The *sca* effects are defined as follows

$$S_{ij} = Y_{ij} - \frac{1}{n+2} (Y_{i.} + Y_{.i} + Y_{.j.} + Y_{j.}) + \frac{2}{(n+1)(n+2)} Y_{..}$$

Variance of estimates

The variance of the various estimates were calculated as follows

$$\text{Variance } (X_{ij}) = \sigma^2 = M'e$$

$$\text{Variance } (g_i) = \frac{n-1}{n(n+2)} \sigma^2$$

$$\text{Variance } (S_{ij}) = \frac{n(n-1)}{(n+1)(n+2)} \sigma^2 \quad (i \neq j)$$

Test of significance

The standard error computed as the square root of the variance of the estimates were used in the test of significance, where degrees of freedom will be equal to that of error component.

Estimation of heterosis

Heterosis (H), expressed as percentage of increase or decrease of F_1 s over mid parent (MP) and better parent (BP) were calculated as suggested by Matzinger *et al.* (1962)

$$\text{H over MP} = \frac{\overline{F_1} - \overline{\text{MP}}}{\overline{\text{MP}}} \times 100$$

$$\text{H over BP} = \frac{\overline{F_1} - \overline{\text{BP}}}{\overline{\text{BP}}} \times 100$$

Where, $\overline{F_1}$ = mean value of F_1 ,

$\overline{\text{MP}}$ = mean value of mid parent,

$\overline{\text{BP}}$ = mean value of better parent (i.e. higher scoring parent of the hybrid; but in case of plant height BP was lower scoring parent).

Test of significance was done following Bitzer *et al.* (1967)

$$\text{S.E. of H over MP} = \sqrt{3 M'e / 2r}$$

$$\text{S.E. of H over BP} = \sqrt{2 M'e / r}$$

Where M_e = error mean square obtained from RBD analysis,

r = number of replications.

't' tests of heterosis over mid parent and better parent were done with their respective standard errors, where the degrees of freedom were same as that of error in ANOVA.

Chapter 4

RESULTS

4.1 Screening for tolerance to boron deficiency

Analysis of variance revealed significant differences for all the characters studied for both the factors (boron and genotype). The interactions between boron and genotype were significant for plant height and number of spikelets/spike, and highly significant for number of tillers /plant, number of seeds/spike and grain yield/plant while spike length and 250 grain weight showed non-significant effects.

The effect of boron on seven characters of wheat genotypes considered in the experiment have been presented in Table 2. The findings for each of the characters are presented separately as follows:

Table 2 Effect of boron on growth parameters, yield and yield components

Genotypes	Plant height (cm)			Number of tillers/plant			Spike length (cm)			Number of spikelets/spike		
	B ₀	B ₁	Mean	B ₀	B ₁	Mean	B ₀	B ₁	Mean	B ₀	B ₁	Mean
HP 1685	97.30	95.66	96.48	4.0	4.5	4.25	9.00	9.30	9.15	15.30	19.60	17.45
HP 1705	89.10	90.33	89.71	3.2	3.9	3.55	8.38	8.90	8.64	16.40	18.10	17.25
K 8905	82.60	86.30	84.45	3.1	4.0	3.55	8.05	9.50	8.77	18.70	20.30	19.50
HP 1633	90.60	94.30	92.45	2.9	4.0	3.45	9.00	10.5	9.75	14.00	16.20	15.10
BAW 171	86.80	89.50	88.15	3.0	4.3	3.65	8.40	11.0	9.70	16.70	18.80	17.75
HD 2285	81.20	81.60	81.40	4.0	4.3	4.15	8.20	10.0	9.10	15.00	16.20	15.60
Sonora 64	78.30	79.60	78.95	4.1	4.2	4.15	9.20	9.60	9.40	14.50	15.03	14.76
Kanchan	95.50	96.50	96.00	3.4	4.0	3.7	8.50	10.0	9.25	16.20	17.00	16.60
Akbar	85.83	87.66	86.74	3.9	4.3	4.1	10.6	11.5	11.05	15.53	16.00	15.70
Aghrani	80.80	82.00	81.40	3.5	4.0	3.75	9.90	10.6	10.25	15.00	16.00	15.50
Fang 60	89.33	91.60	90.46	4.0	4.2	4.1	10.2	10.5	10.35	15.56	16.20	15.80
BAW 452	85.45	86.83	86.14	4.0	4.5	4.25	7.50	8.5	8.00	16.70	18.10	17.40
HDR 77	81.60	83.66	82.63	3.6	4.3	3.95	9.4	10.2	9.80	16.50	17.80	17.15
HUW 234	77.33	78.50	77.91	4.0	4.5	4.25	8.35	9.5	8.90	15.60	16.40	16.00
HD 2684	83.63	85.00	84.31	3.3	4.1	3.70	8.8	10.2	9.50	17.40	19.60	18.50
HP 1728	85.70	86.60	86.15	4.0	4.5	4.25	8.9	9.8	9.35	19.10	21.40	20.25
Wheat local	92.36	93.50	92.93	6.1	7.3	6.7	6.8	7.2	7.00	20.10	20.30	20.20
C 306	110.36	115.5	112.93	4.0	4.02	4.01	9.1	9.5	9.30	17.30	18.10	17.70
Siren	76.06	78.93	77.49	3.8	4.0	3.9	9.2	9.65	9.43	17.80	19.10	18.45
BL 1022	80.86	83.66	82.26	4.0	5.08	4.54	8.0	8.3	8.15	17.60	19.30	18.45
Glennsen	84.33	85.33	84.83	3.2	4.0	3.6	8.7	9.4	9.05	17.10	21.60	19.35
HP 1704	80.90	82.80	81.85	3.0	3.6	3.3	9.1	10.2	9.65	17.80	22.20	20.00
DL 784-3	78.80	80.60	79.70	3.1	4.0	3.55	8.8	9.6	9.20	14.30	15.00	14.65
UP 262	91.50	92.50	92.0	4.0	4.3	4.15	8.1	9.2	8.65	15.70	16.40	16.05
Sonalika	87.00	88.6	87.8	4.0	4.4	4.2	9.8	10.3	10.05	15.00	15.93	15.46
Mean	85.73	87.88		3.73	4.33		8.79	9.72		16.43	18.02	
	S.E.m (±)	C.D. at 5%		S.E.m (±)	C.D. at 5%		S.E.m (±)	C.D. at 5%		S.E.m (±)	C.D. at 5%	
Boron (A)	0.05	0.29		0.01	0.06		0.06	0.36		0.03	0.13	
Genotype (B)	0.78	2.19		0.11	0.30		0.29	0.83		0.55	1.54	
A x B	1.10	3.10		0.15	0.41		0.42	NS		0.78	2.19	
B x A	1.53	3.05		0.20	0.41		0.58	NS		0.79	1.58	

Table 2 Continued

Genotypes	Number of seeds/spike			250 grain weight (g)			Grain yield/plant (g)		
	B ₀	B ₁	Mean	B ₀	B ₁	Mean	B ₀	B ₁	Mean
HP 1685	29.2	45.6	37.4	8.1	9.0	8.55	3.95	6.13	5.04
HP 1705	27.5	40.4	33.9	9.0	9.8	9.4	3.45	6.29	4.87
K 8905	37.1	45.0	41.05	8.0	8.5	8.25	3.68	6.33	5.01
HP 1633	26.7	37.6	32.15	10.2	10.5	10.35	3.20	6.00	4.26
BAW 171	18.2	34.2	26.2	11.0	11.2	11.1	2.36	6.17	4.20
HD 2285	26.1	35.6	30.85	9.0	9.5	9.25	4.3	6.12	5.21
Sonora 64	33.8	36.6	35.2	10.0	10.1	10.05	5.6	6.15	5.87
Kanchan	33.9	38.9	36.4	11.0	11.0	11.0	5.07	6.20	5.63
Akbar	15.0	38.5	26.75	12.0	12.0	12.0	2.9	6.62	4.65
Aghrani	29.5	35.2	32.4	11.0	11.2	11.1	4.6	5.80	5.20
Fang 60	40.0	43.3	41.65	10.5	10.5	10.5	6.1	6.8	6.45
BAW 452	16.2	37.0	26.6	10.5	10.6	10.55	2.98	6.4	4.69
IHR 77	14.2	38.3	26.25	9.0	10.0	9.5	1.95	6.38	4.16
HUW 234	26.2	36.8	31.5	11.0	11.0	11.0	3.5	6.45	4.97
HD 2684	37.2	46.8	42.0	10.0	10.0	10.0	4.02	7.2	5.61
HP 1728	21.9	45.2	33.55	9.0	9.5	9.25	3.32	7.3	5.31
Wheat local	44.0	46.3	45.15	7.5	8.0	7.75	4.3	5.1	4.7
C 306	30.9	41.1	36.0	10.0	10.7	10.35	4.84	6.48	5.66
Siren	33.1	42.8	37.95	9.0	9.5	9.25	4.25	6.44	5.34
BL 1022	18.9	39.3	29.1	7.5	8.0	7.75	2.46	6.18	4.32
Glennsen	21.1	42.8	31.95	8.5	8.8	8.65	2.40	6.00	4.20
HP 1704	14.5	40.8	27.65	9.0	9.0	9.0	1.29	5.47	3.38
DL 784-3	19.8	35.8	31.3	10.0	10.4	10.2	2.67	6.06	4.36
UP 262	31.0	37.0	34.0	10.0	10.2	10.1	4.9	6.43	5.66
Sonalika	34.8	39.1	36.9	12.0	12.0	12.0	6.0	6.5	6.25
Mean	27.2	40.0		9.71	10.0		3.76	6.28	
	S.E.m (±)	C.D. at 5%		S.E.m (±)	C.D. at 5%		S.E.m (±)	C.D. at 5%	
Boron (A)	0.53	2.28		0.06	0.39		0.04	0.26	
Genotype (B)	1.63	4.58		0.27	0.75		0.22	0.63	
A x B	2.31	6.49		0.38	NS		0.31	0.88	
B x A	2.33	4.92		0.54	NS		0.45	0.92	

Plant height (cm)

Plant height ranged from 76.06 cm (**Siren**) to 110.36 cm (**C 306**) under boron deficient condition. The corresponding range under supplemented condition varied from 78.50 cm (**HUW 234**) to 115.50 cm (**C 306**). There was marginal increase in plant height in almost all the genotypes with boron application while **HP 1685, K 8905 HP 1633** and **C 306** showed significant increase with boron application.

Number of tillers/plant

Number of tillers/plant ranged from 2.9 (**HP 1633**) to 6.1 (**Wheat local**) under boron deficient condition. The corresponding range under supplemented condition varied from 3.6 (**HP 1704**) to 7.3 (**Wheat local**). Interaction between boron level and genotypes was significant. However, genotypes such as **HD 2285, UP 262, Sonalika, Sonora 64, Akbar, Fang 60, C 306** and **Siren** did not show significant response to boron application.

Spike length (cm)

Spike length under boron deficient condition varied from 6.8 cm (**Wheat local**) to 10.6 cm (**Akbar**). The corresponding range under supplemented condition varied from 7.2 cm (**Wheat local**) to 11.5 cm (**Akbar**). The interaction between boron level and genotype was non-significant though some genotypes such as **K 8905, HP 1633, BAW 171, HD 2285, Kanchan** and **HD 2684** responded well to boron application.

Number of spikelets/spike

Under boron deficient condition, the number of spikelets/spike varied from 14.0 (**HP 1633**) to 20.1 (**Wheat local**). The corresponding range under supplemented condition was from 15.0 (**DL 784-3**) to 22.2 (**HP 1704**). Only ten genotypes viz., **HP 1685, HP 1705, K 8905, HP 1633, BAW 171, HD 2684, HP 1728, BL 1022, Glennsen** and **HP 1704** responded significantly to boron application. Rest of the genotypes were less influenced with boron application.

Number of seeds/spike

Under boron deficient condition, maximum seed setting was recorded for **Wheat local** (44.0) followed by **Fang 60** (40.0). **HDR 77** produced the least (14.2) which was followed by **HP 1704** and **Akbar** with 14.5 and 15.0 seeds/ spikes, respectively. With boron application, significant increase was observed for almost all the genotypes which varied from 34.2 (**BAW 171**) to 46.8 (**HD 2684**). However, marginal increase was noted in case of **Sonalika**, **Sonora 64**, **Fang 60** and **Wheat local**.

250 grain weight (g)

Wheat local and **BL 1022** recorded lowest 250 grain weight under both boron deficient (7.5g) and supplemented (8.0g) conditions, respectively. **Sonalika** and **Akbar** recorded maximum 250 grain weight of 12.0g each under both conditions. However, the interaction effect was non-significant.

Grain yield/plant (g)

Under boron deficient condition, grain yield/plant varied from 1.29g (**HP 1704**) to 6.19g (**Fang 60**). The corresponding range under supplemented condition varied from 5.1 g (**Wheat local**) to 7.3 g (**HP 1728**). Significant interaction between levels of boron and genotype was noted for this character. However, **Sonalika**, **Sonora 64**, **Fang 60** and **Wheat local** failed to respond to boron application as they showed negligible increase for this character.

A number of genotypes remained unchanged for a number of characters under both boron deficient and supplemented conditions. However, with respect to number of seeds/spike and grain yield/plant, genotypes such as **Sonalika**, **Sonora 64**, **Fang 60** and **Wheat local** remained almost unchanged with boron application.

4.2 Estimation of genetic parameters

The mean, range and estimates of genetic parameters for seven characters of wheat grown under two conditions with respect to boron are presented in Table 3.

Table 3 Estimates of genetic parameters for seven characters of wheat grown under boron deficient (B₀) and under boron supplemented (B₁) conditions

Characters	Environment	Mean	Range	GCV (%)	PCV (%)	Heritability (% Broadense)	Genetic Advance (in percent of mean)
Plant height (cm)	B ₀	85.73 ± 1.09	76.06 - 110.36	8.24	8.53	93.20	16.40
	B ₁	87.88 ± 1.06	78.50 - 115.50	8.34	9.04	(94.70)	17.62
Number of tiller/plant	B ₀	3.73 ± 0.14	2.90 - 6.10	16.76	18.08	85.90	31.90
	B ₁	4.33 ± 0.14	3.60 - 7.30	(13.52)	(14.69)	84.40	(25.63)
Spike length (cm)	B ₀	8.79 ± 0.42	6.80 - 10.60	8.18	11.63	49.90	11.83
	B ₁	9.72 ± 0.41	7.20 - 11.50	8.12	11.00	(54.50)	12.34
Number of spikelets/spike	B ₀	16.40 ± 0.59	14.00 - 20.10	8.89	10.86	66.90	14.93
	B ₁	18.06 ± 0.76	15.00 - 22.20	10.32	12.65	66.50	17.51
Number of seeds/spike	B ₀	27.17 ± 1.82	14.20 - 44.00	30.39	32.53	87.30	59.05
	B ₁	40.00 ± 1.42	34.20 - 46.80	8.78	10.73	66.90	14.80
250 grain weight (g)	B ₀	9.71 ± 0.36	7.50 - 12.00	11.65	13.32	76.50	21.00
	B ₁	10.04 ± 0.33	8.00 - 12.00	11.92	13.27	80.70	22.01
Yield/plant(g)	B ₀	3.78 ± 0.28	1.29 - 6.10	31.26	33.83	85.40	59.38
	B ₁	6.11 ± 0.29	5.10 - 7.50	5.14	6.68	58.68	8.18

GCV = Genotypic Co-efficient Variation

PCV = Phenotypic Co-efficient of Variation

The range and mean values had been consistently higher for all the characters in boron supplemented condition except for the character 250 grain weight, which remained almost unaffected under both boron deficient and supplemented conditions.

The values of phenotypic co-efficient of variations (PCV) were higher than those of genotypic co-efficient of variations (GCV) for all the characters except plant height, which had the magnitude of phenotypic coefficient of variation closer to that of genotypic co-efficient of variation. Under boron deficient condition, the PCV ranged from 8.53% for plant height to 33.83% for grain yield/plant. The GCV was highest for grain yield/plant (31.26%) and lowest for spike length (8.18%). Under supplemented condition, the PCV ranged from 6.68% for grain yield/plant to 14.69% for number of tillers/plant. The range of GCV varied from 5.14% for grain yield/plant to 13.52% for number of tillers/plant. Wider phenotypic and genotypic co-efficient of variations were observed for grain yield/plant, number of seeds/spike and number of tillers/plant under boron deficient condition. For other characters these values were not appreciably different under the two conditions.

Heritability estimates ranged from 49.4% to 93.2% under boron deficient conditions. The corresponding range under supplemented condition varied from 54.4% to 94.7%. Highest heritability was exhibited by plant height while spike length recorded the lowest. Characters like plant height, number of tillers/plant and 250 grain weight gave higher estimates of heritability, while number of spikelets/spike and spike length gave moderate to low estimates under both the conditions. Characters such as number of seeds/spike and grain yield/plant exhibited high estimates of heritability under boron deficient condition only.

The expected genetic advance (GA), expressed as percent of mean, ranged from 11.83% for spike length to 59.38% for grain yield/plant under boron deficient condition. The corresponding range under supplemented condition varied from 8.18% for grain yield/plant to 25.63% for number of tillers/plant. Characters such as spike length and number of spikelets/spike exhibited lower GA while it was higher for plant height, number

of tillers/plant and 250 grain weight under both the condition. Characters like number of seeds/ spike and grain yield/plant exhibited high GA under boron deficient condition only.

High heritability accompanied by appreciable genetic advance was obtained for number of tillers/plant under both the conditions, while number of seeds/spike and grain yield/plant gave such estimates under boron deficient condition only. Plant height exhibited high heritability estimates with high GA, while spike length showed low estimates of heritability and low GA under both boron deficient and supplemented conditions.

4.3 Combining Ability Analysis

4.3.1 Growth parameters, yield and yield components

Mean performance of the parents and crosses under boron deficient condition is presented in Table 4 and that under boron supplemented condition in Table 5. Analysis of variance showed highly significant differences for all the characters studied under both boron deficient and supplemented condition. The mean squares due to general combining ability (*gca*) and specific combining ability (*sca*) were significant for all the characters except plant height where specific combining ability (*sca*) variances were non-significant under both the conditions (Table 6 and 7). The findings recorded in the present investigation are presented separately for each of the character as follows:

Plant height

The parental range varied from 85.33 cm (**Sonora 64**) to 92.00 cm(**Aghrani**) under boron deficient condition. The corresponding range under supplemented condition varied from 86.5 cm (**Sonora 64**) to 91.8 cm (**Aghrani**). Among the crosses, the range varied from 87.10 cm for **DL 784-3 x Sonora 64** to 93.0 cm for **Aghrani x Akbar**, under boron deficient condition. The corresponding range under boron supplemented condition varied from 87.0 for **DL 784-3 x Sonora 64** to 92.6 cm for **DL 784-3 x Akbar**.

The magnitude of *gca* variance was larger than *sca* variance under both conditions. Predictability ratio of 0.98 and 0.94 were observed for this character under

Table 4 Mean performance of parents and crosses for growth parameters, yield and yield components under boron deficient condition

Parents and Crosses	Plant height (cm)	Tillers/plant	Spike length (cm)	Spikelets / spike	Seeds/spike	250 grain wt. (g)	Grain yield/plant(g)
DL 784-3	86.33	2.80	9.38	13.50	19.1	10.00	2.40
HD 2285	88.83	3.73	8.86	16.00	27.2	11.50	4.06
UP 262	89.50	3.56	9.56	16.76	32.0	10.83	4.60
Sonalika	88.00	4.30	9.55	15.13	33.9	11.20	5.83
Sonora 64	85.33	4.13	10.91	14.16	34.6	10.16	5.22
Fang 60	89.20	4.06	10.38	15.76	32.0	10.50	5.80
Aghrani	92.10	4.20	9.46	16.46	30.4	10.50	5.10
Akbar	91.80	4.03	10.66	15.16	16.3	11.60	2.70
DL 784-3 x HD 2285	88.50	5.00	9.76	14.16	22.6	10.66	4.53
DL 784-3 x UP 262	88.00	4.30	9.80	14.86	25.3	10.16	4.35
DL 784-3 x Sonalika	88.03	5.23	10.20	14.56	29.3	10.23	6.12
DL 784-3 x Sonora 64	87.10	4.36	10.20	14.33	30.5	10.33	5.32
DL 784-3 x Fang 60	90.10	4.10	10.13	14.76	30.0	10.33	5.92
DL 784-3 x Aghrani	91.50	4.43	9.56	14.66	24.6	10.76	4.35
DL 784-3 x Akbar	91.00	4.63	10.40	14.76	18.8	11.00	3.40
HD 2285 x UP 262	89.80	4.50	10.15	15.63	29.7	10.33	5.35
HD 2285 x Sonalika	89.00	4.16	10.23	15.70	30.0	11.16	5.20
HD 2285 x Sonora 64	88.00	3.60	10.68	15.60	34.4	10.50	4.95
HD 2285 x Fang 60	90.10	3.63	10.98	15.60	32.0	11.00	5.00
HD 2285 x Aghrani	91.00	4.20	8.61	16.23	28.6	10.66	4.80
HD 2285 x Akbar	91.00	4.23	9.82	15.20	23.5	10.83	3.97
UP 262 x Sonalika	89.00	4.06	10.59	16.10	32.7	11.83	5.31
UP 262 x Sonora 64	87.90	4.63	10.55	16.46	33.8	10.50	6.26
UP 262 x Fang 60	90.30	3.86	10.66	15.66	32.6	10.83	5.05
UP 262 x Aghrani	92.00	3.76	9.75	16.40	31.4	10.33	4.72
UP 262 x Akbar	92.20	4.33	9.12	15.30	26.6	10.56	4.60
Sonalika x Sonora 64	87.60	4.13	10.36	14.76	35.8	11.16	5.90
Sonalika x Fang 60	90.50	4.63	10.53	15.53	34.3	10.66	6.35
Sonalika x Aghrani	90.00	4.30	10.66	15.56	32.8	10.76	5.64
Sonalika x Akbar	91.20	3.73	10.80	14.76	31.6	11.00	4.71
Sonora 64 x Fang 60	90.10	3.93	10.51	15.70	35.5	10.66	5.60
Sonora 64 x Aghrani	92.60	4.03	9.83	15.26	32.5	10.66	5.25
Sonora 64 x Akbar	90.80	3.63	11.51	14.66	30.2	10.80	4.70
Fang 60 x Aghrani	92.20	4.13	9.90	16.13	33.0	10.50	5.45
Fang 60 x Akbar	90.70	4.23	11.18	15.33	29.0	10.93	5.21
Aghrani x Akbar	93.00	4.33	9.96	15.8	28.0	10.66	4.85
SEm(±)	0.939	0.167	0.236	0.240	1.163	0.236	0.252
C.D. at 5%	2.65	0.47	0.66	0.67	3.28	0.66	0.71

Table 5 Mean performance of parents and crosses for growth parameters, yield and yield components under boron supplemented condition

Parents and Crosses	Plant height (cm)	Tillers/plant	Spike length (cm)	Spikelets/spike	Seeds/spike	250 grain wt. (g)	Grain yield/plant(g)
DL 784-3	87.6	4.33	9.7	15.6	31.7	10.33	5.74
HD 2285	90.1	4.56	9.52	15.00	29.4	12.16	6.35
UP 262	90.1	4.33	10.21	16.66	36.6	11.70	6.69
Sonalika	88.2	4.70	10.90	15.60	35.6	13.16	6.83
Sonora 64	86.5	4.36	10.56	15.49	35.4	10.66	6.29
Fang 60	91.5	4.20	10.48	15.20	33.1	10.83	6.40
Aghrani	91.8	4.60	9.73	15.09	32.0	10.66	6.30
Akbar	91.5	4.30	11.18	15.83	32.33	12.06	6.00
DL 784-3 x HD 2285	90.0	4.76	10.53	15.83	32.5	12.16	6.48
DL 784-3 x UP 262	88.5	5.00	10.43	16.10	33.2	10.50	6.84
DL 784-3 x Sonalika	89.0	4.93	10.66	15.83	33.5	11.33	7.11
DL 784-3 x Sonora 64	87.0	4.66	10.46	15.33	32.0	11.33	6.06
DL 784-3 x Fang 60	90.5	4.40	10.3	15.43	32.5	11.16	5.98
DL 784-3 x Aghrani	91.0	4.30	9.89	15.53	31.5	11.50	5.90
DL 784-3 x Akbar	92.6	5.30	10.18	15.5	32.3	12.06	6.90
HD 2285 x UP 262	90.5	4.86	10.33	15.76	33.0	11.66	6.65
HD 2285 x Sonalika	92.0	5.36	10.63	15.86	33.4	10.83	7.02
HD 2285 x Sonora 64	88.6	4.16	11.05	14.16	32.6	10.83	6.16
HD 2285 x Fang 60	92.0	4.33	11.18	15.63	31.9	10.83	5.75
HD 2285 x Aghrani	91.5	4.36	8.96	16.06	32.6	11.40	6.18
HD 2285 x Akbar	91.0	5.50	10.36	15.83	32.9	12.50	6.30
UP 262 x Sonalika	91.2	4.68	10.93	15.60	33.0	11.66	6.80
UP 262 x Sonora 64	88.5	4.83	10.55	16.93	34.8	11.66	7.00
UP 262 x Fang 60	90.0	4.46	11.15	17.30	35.6	11.50	6.31
UP 262 x Aghrani	91.0	4.23	10.58	17.00	34.8	11.86	6.50
UP 262 x Akbar	92.0	4.73	10.41	16.13	33.0	12.83	6.08
Sonalika x Sonora 64	87.9	4.63	11.13	15.90	35.7	10.66	6.97
Sonalika x Fang 60	91.0	4.13	11.16	17.13	37.0	12.33	6.80
Sonalika x Aghrani	90.5	4.66	10.95	16.93	33.4	12.43	6.38
Sonalika x Akbar	91.6	4.43	11.06	16.40	33.8	12.33	6.00
Sonora 64 x Fang 60	88.0	4.03	10.21	15.00	33.6	11.33	6.18
Sonora 64 x Aghrani	90.5	3.70	9.50	15.03	31.5	10.83	5.61
Sonora 64 x Akbar	90.0	4.16	11.81	13.76	32.0	12.00	5.54
Fang 60 x Aghrani	91.8	4.36	10.35	15.60	31.5	11.50	6.00
Fang 60 x Akbar	92.4	4.53	10.68	14.96	32.2	12.36	6.20
Aghrani x Akbar	92.5	4.36	9.93	14.76	32.5	12.50	6.38
SEm(±)	0.831	0.238	0.365	0.288	0.516	0.311	0.305
C.D. at 5%	2.34	0.67	1.03	0.81	1.45	0.87	0.86

Table: 6 Combining ability analysis for growth parameters, yield and yield components under boron deficient condition

Source	Degrees of freedom	Mean Squares									
		Plant height (cm)	Number of tillers/plant	Spike length (cm)	Number of spikelets/spike	Number of seeds/spike	250 grain weight (g)	Grain yield/plant (g)			
<i>gca</i>	7	13.665**	0.271**	1.104**	2.404**	39.980**	0.293**	2.670**			
<i>sca</i>	28	0.926	0.103**	0.247**	0.144**	3.091**	0.122**	0.310**			
Error	70	0.882	0.019	0.056	0.058	1.352	0.056	0.064			
σ^2_g		1.274	0.017	0.086	0.226	3.668	0.017	0.236			
σ^2_s		0.044	0.084	0.191	0.086	1.739	0.066	0.246			
Predictability ratio		0.98	0.28	0.47	0.84	0.81	0.34	0.65			

Table: 7 Combining ability analysis for growth parameters, yield and yield components under boron supplemented condition

Source	Degrees of freedom	Mean Squares								
		Plant height (cm)	Number of tillers/plant	Spike length (cm)	Number of spikelets/spike	Number of seeds/spike	250 grain weight (g)	Grain yield/plant (g)		
<i>gca</i>	7	10.736**	0.313**	0.833**	1.379**	8.186**	1.506**	0.383**		
<i>sca</i>	28	0.750	0.111**	0.213**	0.506**	1.196**	0.395**	0.125**		
Error	70	0.691	0.028	0.107	0.042	0.428	0.059	0.054		
σ^2_g		0.998	0.020	0.062	0.087	0.699	0.111	0.026		
σ^2_s		0.059	0.083	0.106	0.464	0.768	0.336	0.075		
Predictability ratio		0.94	0.16	0.54	0.27	0.64	0.40	0.41		

boron deficient and supplemented conditions, respectively (Table 6 and 7). From the estimates of *gca* effects (Table 8) it may be noted that under deficient condition **Sonora 64** was the best general combiner for dwarfness followed by **DL 784-3** and **Sonalika**. On the other hand **Aghrani** was the poorest combiner. It was followed by **Akbar**. Under supplemented conditions, **Sonora 64** and **DL 784-3** were the best combiners while **Akbar** was the poorest (Table 9).

There were not many crosses with significant *sca* effects. However, the cross **Sonora 64 x Aghrani** showed the highest specific effects for increased height under boron deficient condition (Table 10) while **DL 784-3 x Akbar** and **HD 2285 x Sonalika** had such effects under supplemented condition (Table 11). From dwarfness point of view, **Fang 60 x Akbar** under boron deficient and **Sonora 64 x Fang 60** under supplemented conditions exhibited considerable but non-significant specific effects (Table 10 and 11).

Number of tillers/plant

Maximum tillering was observed under boron supplemented condition. Among parents, **Sonalika** recorded maximum tillering followed by **Aghrani** and **HD 2285**. On the other hand, **Fang 60** had the least number of tillers. Under boron deficient condition, **Sonalika** exhibited the largest tillering capacity while **DL 784-3** had the least number of tillers. For the crosses under supplemented condition, maximum number of tillers were exhibited by the cross **HD 2285 x Akbar** followed by **HD 2285 x Sonalika**. On the other hand, **Sonora 64 x Aghrani** had the least. Under deficient condition, maximum tillering was recorded for the cross **DL 784-3 x Sonalika** followed by **DL 784-3 x HD 2285**. The crosses **HD 2285 x Sonora 64**, **HD 2285 x Fang 60** and **Sonora 64 x Akbar** exhibited least number of tillers.

The magnitude of the variance due to *gca* was larger than that of *sca* under both conditions while the general predictability ratios were 0.28 and 0.16 under boron deficient and supplemented conditions, respectively (Table 6 and 7). The estimates of *gca* effects (Table 8 and 9) showed **Sonalika** to be good general combiner under both conditions. **HD**

Table 8 Estimates of general combining ability (*gca*) effects for growth parameters, yield and yield components under boron deficient condition

Parents	Plant height (cm)	Number of tillers/plant	Spike length (cm)	Number of spikelets / spike	Number of seeds/ spike	250 grain weight (g)	Grain yield/ plant (g)
DL 784-3	-1.177**	0.021	-0.340**	-0.885**	-4.681**	-0.032	-0.585**
HD 2285	-0.360	-0.066	-0.271**	0.215**	-1.091**	0.135	-0.272**
UP 262	-0.045	-0.086	-0.169*	0.595**	0.994**	0.042	0.020
Sonalika	-0.735*	0.174**	0.077	0.265**	2.814**	0.142	0.625**
Sonora 64	-1.390**	-0.086	0.424**	-0.192*	3.574**	-0.285**	0.378**
Fang 60	0.440	-0.046	0.359**	0.128	2.424**	-0.088	0.554**
Aghrani	1.785**	0.064	-0.386**	0.582**	0.554	-0.145**	0.062
Akbar	1.483*	0.024	0.304**	-0.182*	-4.586**	0.232**	-0.780**
S.E. (g_i)	0.284	0.044	0.070	0.071	0.344	0.035	0.075

Table 9 Estimates of general combining ability (*gca*) effects for growth parameters, yield and yield components under boron supplemented condition

Parents	Plant height (cm)	Number of tillers/plant	Spike length (cm)	Number of spikelets / spike	Number of seeds/ spike	250 grain weight (g)	Grain yield/ plant (g)
DL 784-3	-0.878**	0.122*	-0.257*	-0.044	-0.770**	-0.328**	-0.042
HD 2285	0.332	0.169**	-0.233*	-0.404**	-1.090**	0.055	0.007
UP 262	-0.082	0.086	0.039	0.696**	1.200**	0.108	0.239**
Sonalika	-0.298	0.163**	0.324**	0.343**	1.240**	0.392**	0.357**
Sonora 64	-1.908**	-0.198**	0.209*	-0.388**	0.440*	-0.452**	-0.107
Fang 60	0.612*	-0.264**	0.158	0.029	0.191	-0.332**	-0.115
Aghrani	0.982**	-0.161**	-0.480**	-0.014	-0.684**	-0.115	-0.161*
Akbar	1.252**	0.083	0.239*	-0.218**	-0.524**	0.672**	-0.176*
S.E. (g _i)	0.246	0.050	0.096	0.060	0.193	0.023	0.068

Table 10 Estimates of specific combining ability (*sca*) effects for growth parameters, yield and yield components under boron deficient condition

Crosses	Plant height (cm)	Number of tillers/plant	Spike length (cm)	Number of spikelets/spike	Number of seeds/spike	250 grain weight (g)	Grain yield/plant
DL 784-3 x HD 2285	0.185	0.883**	0.256	-0.495**	-1.150	-0.194	0.427**
DL 784-3 x UP 262	-0.630	0.203*	-0.157	0.178	-0.585	0.399**	-0.045
DL 784-3 x Sonalika	-0.091	0.876**	-0.291	0.385**	1.595*	-0.634**	1.120**
DL 784-3 x Sonora 64	0.185	0.269**	-0.171	0.078	2.035**	-0.107	0.567**
DL 784-3 x Fang 60	0.985	-0.037	0.007	0.191	2.685**	-0.303	0.991**
DL 784-3 x Aghrani	1.040	0.186	0.171	-0.362*	-0.845	0.185	-0.087
DL 784-3 x Akbar	0.540	0.426**	0.314*	0.502**	-1.505	0.042	-0.195
HD 2285 x UP 262	0.353	0.489**	0.466**	0.512**	0.225	-0.601**	0.642**
HD 2285 x Sonalika	0.241	-0.104	0.305	0.418**	-1.295	0.132	-0.113
HD 2285 x Sonora 64	-0.102	-0.410*	0.408**	0.245	2.345**	-0.107	-0.116
HD 2285 x Fang 60	0.168	-0.417**	0.773**	-0.075	1.095	0.195	-0.242
HD 2285 x Aghrani	-0.276	0.039	-0.848**	0.105	-0.435	-0.081	0.050
HD 2285 x Akbar	0.025	0.113	-0.332*	-0.165	-0.395	0.291	0.060
UP 262 x Sonalika	-0.073	-0.184	0.565**	0.435**	-0.680	0.892**	-0.295
UP 262 x Sonora 64	-0.516	0.643**	0.171	0.728**	-0.340	-0.014	0.902**
UP 262 x Fang 60	0.053	-0.164	0.353*	-0.392**	-0.390	0.122	-0.484**
UP 262 x Aghrani	0.424	-0.374**	0.184	-0.111	0.280	-0.321*	-0.322
UP 262 x Akbar	0.910	0.233**	-1.142**	-0.448**	0.620	-0.464**	0.400**
Sonalika x Sonora 64	-0.128	-0.117	-0.255	-0.108	-0.160	-0.447**	-0.063
Sonalika x Fang 60	0.941	0.673**	-0.024	0.338*	-0.510	-0.144	0.211
Sonalika x Aghrani	-0.903	-0.103	0.854**	-0.082	-0.140	0.012	-0.007
Sonalika x Akbar	0.598	-0.627**	0.297	-0.118	3.800**	-0.131	-0.095
Sonora 64 x Fang 60	1.198	-0.097	-0.387**	-0.568**	-0.070	0.282	-0.292
Sonora 64 x Aghrani	2.353**	-0.107	-0.326*	-0.455**	-1.200	0.339*	-0.150
Sonora 64 x Akbar	0.855	-0.467**	0.666**	-0.292	1.640*	0.096	0.142
Fang 60 x Aghrani	0.123	-0.047	-0.194	0.092	0.390	-0.024	-0.126
Fang 60 x Akbar	-1.075	0.066	0.398**	0.055	1.590*	0.033	0.476*
Aghrani x Akbar	-0.120	0.583**	-0.073	0.068	2.460**	-0.177	0.608**
S.E.(Sij)	0.758	0.115	0.187	0.189	0.917	0.187	0.199

Table 11 Estimates of specific combining ability (*sca*) effects for growth parameters, yield and yield components under boron supplemented condition

Crosses	Plant height (cm)	Number of tillers/plant	Spike length (cm)	Number of spikelets/spike	Number of seeds/spike	250 grain weight (g)	Grain yield/plant
DL 784-3 x HD 2285	0.269	0.059**	0.529**	0.591**	1.182**	0.882**	0.161
DL 784-3 x UP 262	-0.827	0.257*	0.157	-0.241	-0.408	-0.837**	0.289
DL 784-3 x Sonalika	-0.111	0.114	0.105	-0.155	-0.148	-0.287	0.441**
DL 784-3 x Sonora 64	-0.501	0.207	0.021	0.075	-0.848**	0.555**	-0.145
DL 784-3 x Fang 60	0.479	0.007	-0.094	-0.241	-0.098	0.269	-0.217
DL 784-3 x Aghrani	0.609	-0.196	0.133	-0.098	-0.224	0.385**	-0.250
DL 784-3 x Akbar	1.939**	0.561**	-0.292	0.071	0.416	0.165	0.765**
HD 2285 x UP 262	-0.027	0.077	0.033	-0.214	-0.288	-0.054	0.005
HD 2285 x Sonalika	1.689**	0.501**	0.048	0.238	0.072	-1.171**	0.302*
HD 2285 x Sonora 64	-0.101	-0.339**	0.583**	-0.731**	0.072	-0.327*	-0.094
HD 2285 x Fang 60	0.779	-0.106	0.765**	0.318*	-0.378	-0.447	-0.496**
HD 2285 x Aghrani	-0.091	-0.176	-0.814**	0.795**	1.196**	-0.097	-0.020
HD 2285 x Akbar	-0.861	0.714**	-0.133	0.765**	1.336**	0.215	0.116
UP 262 x Sonalika	1.292*	0.084	0.076	-1.128**	2.618**	-0.391**	-0.150
UP 262 x Sonora 64	0.203	0.411**	-0.192	0.935**	-0.818	0.452**	0.514**
UP 262 x Fang 60	-0.817	0.111	0.459*	0.885**	1.032**	0.165	-0.168
UP 262 x Aghrani	-0.187	-0.226*	0.531**	0.628**	1.106**	0.315*	0.070
UP 262 x Akbar	0.542	0.031	-0.355	-0.035	-0.854*	0.495**	-0.336*
Sonalika x Sonora 64	-0.181	0.134	0.106	0.255	0.842*	-0.831**	0.366**
Sonalika x Fang 60	0.399	-0.299**	0.191	1.105**	2.392*	0.751**	0.204
Sonalika x Aghrani	-0.471	0.131	0.612**	0.915**	-0.334	0.599**	-0.169
Sonalika x Akbar	0.359	-0.346**	0.009	0.585**	-0.094	-0.287	-0.534**
Sonora 64 x Fang 60	-0.991	-0.139	-0.643**	-0.331**	-0.208	0.559**	0.048
Sonora 64 x Aghrani	1.139*	-0.476**	-0.722**	-0.255	-1.434**	-0.657**	-0.475**
Sonora 64 x Akbar	0.369	-0.253*	0.874**	-1.318**	-1.094**	0.222	-0.530**
Fang 60 x Aghrani	-0.081	0.257*	0.179	-0.105	-1.184**	0.389**	-0.077
Fang 60 x Akbar	0.249	0.181	-0.207	-0.535	-0.644	0.469**	0.138
Aghrani x Akbar	-0.021	-0.089	-0.317	0.331**	-0.184	0.385**	0.365**
S.E.(Sij)	0.655	0.133	0.257	0.161	0.516	0.192	0.183

2285 and **DL 784-3** were good combiners under supplemented condition while **Sonora 64**, **Fang 60** and **Aghrani** were poor general combiners (Table 9).

Among the crosses, **UP 262 x Sonora 64**, **DL 784-3 x Akbar** and **DL 784-3 x UP 262** showed consistent specific effects under both conditions. On the other hand, **Sonalika x Akbar**, **Sonora 64 x Akbar** and **UP 262 x Aghrani** showed poor specific effects. However, **DL 784-3 x Sonalika**, **DL 784-3 x Sonora 64**, **HD 2285 x UP 262** and **UP 262 x Akbar** showed consistently good specific performance under deficient condition (Table 10). On the other hand, **HD 2285 x Sonalika**, **HD 2285 x Akbar** and **Fang 60 x Aghrani** showed positive and significant specific effects under supplemented condition (Table 11). However, there was no general trend between the performance of the parents and the resulting crosses.

Spike length (cm)

The spike length varied from 9.46 cm (**Aghrani**) to 10.91 cm (**Sonalika**) under boron deficient condition. The corresponding range under boron supplemented condition ranged from 9.52 cm (**HD 2285**) to 11.18 cm (**Akbar**). Among the crosses, the spike length under boron deficient condition varied from 8.61 cm (**HD 2285 x Aghrani**) to 11.51 cm (**Sonora 64 x Akbar**) while under boron supplemented condition, the range varied from 8.96 cm (**HD 2285 x Aghrani**) to 11.81 cm (**Sonora 64 x Akbar**).

The variances due to general and specific combining ability were highly significant, the magnitude of the former being larger in magnitude under both conditions (Table 6 and 7). However, the predictability ratio was less than unity, being 0.47 and 0.54 in the two conditions, respectively. The estimates of the *gca* and *sca* effects are given in Table 8 and 9. **Sonora 64** followed by **Akbar** had positive and significant *gca* effects under both conditions while **Aghrani**, **DL 784-3** and **HD 2285** recorded poor general performance. However, **Fang 60** under boron deficient and **Sonalika** under boron supplemented condition showed significant and positive effects.

There were as many as eight crosses which had significantly better *sca* effects under both conditions. The best specific combiner was **Sonalika x Aghrani**, followed by **HD 2285 x Fang 60** and **Sonora 64 x Akbar**. On the other hand, **HD 2285 x Aghrani**, **Sonora 64 x Fang 60** and **Sonora 64 x Aghrani** showed significantly poor specific effects under both conditions. Rest of the crosses were intermediate and inconsistent over environments (Table 10 and 11).

Number of spikelets/spike

Under boron deficient condition, the parental range varied from 13.50 for **DL 784-3** to 16.76 for **UP 262**. The corresponding range under boron supplemented condition was from 15.00 for **HD 2285** to 16.66 for **UP 262**. Among the crosses, the variation under deficient condition was from 14.16 (**DL 784-3 x HD 2285**) to 16.46 (**UP 262 x Sonora 64**). Under supplemented condition it varied from 13.76 (**Sonora 64 x Aghrani**) to 17.3 (**UP 262 x Sonora 64**). It may be noted that the crosses showing highest spikelets/spike under both conditions involved **UP 262** as one of the parents.

The magnitude of *gca* was larger than that of *sca* under boron supplemented condition (Table 7) while it was much larger under boron deficient condition (Table 6). The predictability ratio was much less than unity (0.27) under supplemented condition while it was 0.84 under deficient condition. The estimate of *gca* effects under the two conditions have been presented in Table 8 and 9, respectively. The best general combiner was **UP 262** followed by **Sonalika** under both conditions. In contrast, **Sonora 64** and **Akbar** recorded poor general performance. However, **Aghrani** and **HD 2285** under deficient condition gave consistently good general effects.

Only two crosses viz., **UP 262 x Sonora 64** and **Sonalika x Fang 60** gave significant *sca* estimates under both conditions (Table 10 and 11). It may be noted that in the above two crosses, one of the parents involved was good general combiner for this character. On the other hand, **Sonora 64 x Fang 60**, **Sonora 64 x Aghrani**, **UP 262 x Akbar**, **Sonora 64 x Akbar** and **DL 784-3 x Aghrani** showed poor specific effects. Among the four crosses which gave significant *sca* effects under deficient condition, three

of them involved **Sonalika** as one of the parents. Rest of the crosses were intermediate and inconsistent over the environments.

Number of seeds/spike

The expression of this character was optimum under boron supplemented condition, the range of the parents being 29.4 (**HD 2285**) to 36.6(**UP 262**). **Akbar** was characterised by least number of seeds under boron deficient condition. Under such condition, **Sonora 64** had the maximum number of seeds/ spike. Among the crosses, the range under supplemented condition varied from 31.5 (**DL 784-3** x **Aghrani**, **Sonora 64** x **Aghrani** and **Fang 60** x **Aghrani**) to 37.0 (**Sonalika** x **Fang 60**). The corresponding range under deficient condition varied from 18.8 (**DL 784-3** x **Akbar**) to 35.8 (**Sonalika** x **Sonora 64**).

The magnitude of *gca* was larger than *sca* under both conditions. The predictability ratio was 0.81 under boron deficient condition while it was 0.64 under supplemented condition (Table 6 and 7). Based on the estimates of the general combining ability effects (Table 8 and 9) the parents **Sonalika**, **Sonora 64**, **UP 262** and **Fang 60** could be considered consistently as good combiners under both conditions. **DL 784-3**, **Akbar** and **HD 2285** were found to be poor general combiners.

None of the crosses gave significant *sca* effect for this character over the two conditions simultaneously. However, only one cross **HD 2285** x **Sonora 64** gave positive significant *sca* effects under boron deficient condition, and positive but non-significant effects under supplemented condition. There were some crosses which showed significant effects either in boron-deficient or in supplemented condition (Table 10 and 11).

250 grain weight

The parental range under boron deficient condition varied from 10.00 g (**DL 784-3**) to 11.60 g (**Akbar**). The corresponding range under boron supplemented condition varied from 10.33 g (**DL 784-3**) to 13.16 g (**Sonalika**). Among the crosses grown under deficient condition, the range varied from 10.16 g (**DL 784-3** x **UP 262**) to 11.83 g (**UP**

262 x Sonalika). The corresponding range under supplemented condition varied from 10.50 g (**DL 784-3 x UP 262**) to 12.80 g (**UP 262 x Akbar**).

The magnitude of *gca* was larger than *sca*. However, the predictability ratio varied from 0.34 under boron deficient condition to 0.40 under boron supplemented condition (Table 6 and 7). The estimates of general combining ability effects (Table 8 and 9) indicated that only one parent **Akbar** gave significant effects under both conditions, while **Sonalika** gave such effects under supplemented condition. **Sonora 64** was found to be the poorest general combiner under both conditions.

The crosses with significant estimates of specific combining ability effects under boron deficient condition (Table 10) were **UP 262 x Sonalika**, **DL 784-3 x UP 262** and **Sonora 64 x Aghrani**, while five crosses gave significant effects in negative direction. There were as many as twelve crosses which had significantly better effects under boron supplemented condition (Table 11). However, none of the crosses gave significant and positive *sca* effects under both conditions.

Grain yield/plant

As expected, grain yield was more under boron supplemented condition. Under such condition, the parental yield ranged from 5.74 g for **DL 784-3** to 6.83 g for **Sonalika**. The corresponding values under boron deficient condition were 2.40g and 6.83 g for the same parents, respectively. Among the crosses, the grain yield/plant under supplemented condition varied from 5.61g for **Sonora 64 x Aghrani** to 7.11 g in case of **DL 784-3 x Sonalika**. The corresponding range under deficient condition varied from 3.40 g (**DL 784-3 x Akbar**) to 6.35g (**Sonalika x Fang 60**).

The magnitude of *gca* was larger than *sca* under boron supplemented condition and much larger under boron deficient condition. The predictability ratio under deficient condition was 0.65 while under supplemented condition it was found to be 0.41 (Table 6 and 7). The estimates of *gca* effects are presented in Table 8 and 9. Based on both the conditions, **Sonalika** was the only parent which gave significant *gca* effects while **Akbar**

recorded poor general performance. However, **Sonora 64** and **Fang 60** under deficient condition and **UP 262** under supplemented condition gave significant *gca* effects.

The estimates of *sca* effects (Table 10 and 11) indicated that only three crosses viz., **DL 784-3 x Sonalika**, **UP 262 x Sonora 64** and **Aghrani x Akbar** showed significant and positive specific effects under both the conditions. There were six crosses which had significant effects under boron deficient condition only. An interesting situation was exhibited by the combination **UP 262 x Akbar**. It had significantly positive specific effects under deficient condition but the performance was completely reversed under supplemented condition. Similar situation was observed for the crosses **DL 784-3 x Sonora 64** and **DL 784-3 x Fang 60** though the *sca* effects were negative but insignificant under supplemented condition. Under supplemented condition three crosses viz., **DL 784-3 x Akbar**, **Sonalika x Sonora 64** and **HD 2285 x Sonalika** showed a consistent good performance. However, they exhibited negative but insignificant effects under boron deficient condition. Rest of the crosses were inconsistent and showed varying performance over environments.

4.3.2 Protein and Gluten content

Mean performance of parents and their crosses for these two characters are presented in Table 12. Analysis of variance showed highly significant differences for these characters under both boron deficient and supplemented conditions. The mean squares due to both general and specific combining abilities were significant for protein content while for gluten content only the former was significant under both boron deficient and supplemented conditions (Table 13 and 14). The findings are presented separately for these two characters as follows:

Protein content

Protein content varied from 9.80% to 11.40% under boron deficient condition. The corresponding range under boron supplemented condition varied from 9.92% to 11.90%. Parents with minimum (**HD 2285**) and maximum protein content (**Sonora 64**) were the same under both the condition. Among the crosses, the range under deficient

Table 12 Mean performance of parents and crosses for protein and gluten content under boron deficient and boron supplemented conditions

Parents and Crosses	Boron deficient condition		Boron supplemented condition	
	Protein %	Gluten %	Protein %	Gluten %
DL 784-3	10.2	9.2	10.4	9.6
HD 2285	9.8	9.0	9.9	9.2
UP 262	10.9	9.8	11.1	10.0
Sonalika	11.4	10.1	11.9	10.7
Sonora 64	11.0	9.4	11.4	9.6
Fang 60	10.3	10.0	10.8	10.1
Aghrani	10.5	9.0	10.6	9.4
Akbar	10.0	9.4	10.2	9.8
DL 784-3 x HD 2285	9.4	9.0	9.7	9.3
DL 784-3 x UP 262	10.0	9.6	10.1	9.6
DL 784-3 x Sonalika	10.2	9.4	10.3	10.0
DL 784-3 x Sonora 64	10.4	9.4	10.3	9.5
DL 784-3 x Fang 60	10.1	9.6	10.2	9.8
DL 784-3 x Aghrani	10.4	9.2	10.5	9.4
DL 784-3 x Akbar	10.2	9.2	10.3	9.6
HD 2285 x UP 262	9.9	9.5	10.0	9.4
HD 2285 x Sonalika	10.2	9.2	10.2	9.8
HD 2285 x Sonora 64	10.8	9.2	10.6	9.4
HD 2285 x Fang 60	9.9	9.6	10.1	9.6
HD 2285 x Aghrani	9.9	9.2	9.8	9.2
HD 2285 x Akbar	10.1	9.2	9.9	9.5
UP 262 x Sonalika	10.4	10.0	10.7	10.4
UP 262 x Sonora 64	10.6	9.5	11.0	9.8
UP 262 x Fang 60	10.6	9.9	10.7	10.0
UP 262 x Aghrani	10.8	9.7	10.9	9.9
UP 262 x Akbar	10.1	9.5	10.4	9.8
Sonalika x Sonora 64	11.3	9.7	11.7	9.9
Sonalika x Fang 60	11.0	10.0	11.4	10.5
Sonalika x Aghrani	10.4	9.4	10.7	9.5
Sonalika x Akbar	10.2	10.0	10.1	9.9
Sonora 64 x Fang 60	11.0	9.7	11.2	9.8
Sonora 64 x Aghrani	10.7	9.3	10.6	9.4
Sonora 64 x Akbar	10.4	9.3	10.5	9.8
Fang 60 x Aghrani	10.3	9.6	10.7	9.6
Fang 60 x Akbar	10.0	9.6	10.3	9.8
Aghrani x Akbar	10.4	9.1	10.2	9.7
SEm(±)	0.122	0.115	0.236	0.258
C.D. at 5%	0.34	0.32	0.66	0.73

Table 13 Combining ability analysis for protein content and gluten content under boron deficient condition

Source	Degrees of freedom	Mean Squares	
		Protein content	Gluten content
<i>gca</i>	7	0.678**	0.425**
<i>sca</i>	28	0.072**	0.016
Error	70	0.015	0.013
σ^2_g		0.061	0.041
σ^2_s		0.057	0.003
Predictability ratio		0.68	0.96

Table 14 Combining ability analysis for protein content and gluten content under boron supplemented condition

Source	Degrees of freedom	Mean Squares	
		Protein content	Gluten content
<i>gca</i>	7	1.001**	0.530**
<i>sca</i>	28	0.090**	0.034
Error	70	0.018	0.027
σ^2g		0.091	0.049
σ^2s		0.072	0.007
Predictability ratio		0.71	0.93

condition varied from 9.40% (**DL 784-3 x HD 2285**) to 11.30% (**Sonalika x Sonora 64**). Under supplemented condition, the range varied from 9.70% (**DL 784-3 x HD 2285**) to 11.70% (**Sonalika x Sonora 64**). However, with boron application marginal increase in protein content was noted.

The variances due to *gca* and *sca* were highly significant under both boron deficient and supplemented conditions (Table 13 and 14). The magnitude of the variance due to *gca* was much larger than that of *sca*. The predictability ratio of under boron deficient and supplemented conditions were 0.68 and 0.71, respectively. The estimates of the *gca* effects showed **Sonora 64**, **Sonalika** and **UP 262** to be good general combiners over both the environments (Table 15). **Fang 60** was good general combiner under supplemented condition. On the other hand, **HD 2285** was uniformly the poorest general combiner. Other poor combiners were **DL 784-3** and **Akbar**. There were only five crosses viz., **DL 784-3 x Aghrani**, **DL 784-3 x Akbar**, **UP 262 x Aghrani**, **Sonalika x Sonora 64** and **Sonalika x Fang 60** which showed high *sca* effects under both the conditions (Table 16). However, four other crosses viz., **HD 2285 x Sonora 64**, **HD 2285 x Akbar**, **Sonora 64 x Fang 60** and **Aghrani x Akbar** gave such effects under boron deficient condition. Rest of the crosses were non-significant or gave significant but negative *sca* effects.

Gluten content

The range of gluten content under boron deficient condition varied from 9.0% (**HD 2285**) to 10.1% (**Sonalika**). The corresponding range under boron supplemented condition varied from 9.2% (**HD 2285**) to 10.7% (**Sonalika**). Among the crosses, the range under deficient condition varied from 9.0% (**DL 784-3 x HD 2285**) to 10.0% (**UP 262 x Sonalika**, **Sonalika x Fang 60** and **Sonalika x Akbar**). Under supplemented condition, the range varied from 9.2% (**HD 2285 x Aghrani**) to 10.5% (**Sonalika x Fang 60**).

The variances due to *gca* were highly significant while the *sca* variances were non-significant under both boron deficient and supplemented conditions, respectively (Table 13

Table 15 Estimates of general combining ability (*gca*) effects for protein content and gluten content under boron deficient (B_0) and boron supplemented (B_1) conditions :

Parents	Protein content		Gluten content	
	B_0	B_1	B_1	B_0
DL 784-3	-0.238 **	-0.268**	-0.157**	-0.117*
HD 2285	-0.366**	-0.473**	-0.247**	- 0.297**
UP 262	0.086*	0.112*	0.192**	0.132*
Sonalika	0.306**	0.402**	0.252**	0.382**
Sonora 64	0.372**	0.383**	-0.047	-0.077
Fang 60	0.002	0.132**	0.262**	0.173**
Aghrani	0.046	-0.028	- 0.187**	-0.207**
Akbar	-0.208**	-0.258**	-0.068	0.012
S.E. (g_i)	0.036	0.041	0.034	0.048

Table 16 Estimates of specific combining ability (*sca*) effects for protein content and gluten content under boron deficient (B_0) and boron supplemented (B_1) conditions

Crosses	Protein content		Gluten content	
	B_0	B_1	B_0	B_1
DL 784-3 x HD 2285	-0.391**	-0.100	-0.082	-0.020
DL 784-3 x UP 262	-0.233**	-0.286**	0.078	-0.150
DL 784-3 x Sonalika	-0.256**	-0.376**	0.182**	0.000
DL 784-3 x Sonora 64	-0.121	-0.356**	0.118	-0.040
DL 784-3 x Fang 60	-0.051	-0.206*	0.008	0.010
DL 784-3 x Aghrani	0.204**	0.254**	0.058	-0.010
DL 784-3 x Akbar	0.259**	0.304**	-0.062	-0.030
HD 2285 x UP 262	-0.213**	-0.180*	0.068	-0.170
HD 2285 x Sonalika	-0.136	-0.270**	-0.292**	-0.020
HD 2285 x Sonora 64	0.399**	0.149	0.008	0.040
HD 2285 x Fang 60	-0.131	-0.100	0.098	-0.010
HD 2285 x Aghrani	-0.176*	-0.240**	0.148	-0.030
HD 2285 x Akbar	0.279**	0.109	0.028	0.050
UP 262 x Sonalika	-0.378**	-0.356**	0.068	0.150
UP 262 x Sonora 64	-0.243**	-0.036	-0.132	0.010
UP 262 x Fang 60	0.127	-0.086	-0.042	-0.040
UP 262 x Aghrani	0.282**	0.274**	0.208**	0.240*
UP 262 x Akbar	-0.163*	0.024	-0.112	-0.080
Sonalika x Sonora 64	0.234**	0.374**	0.008	-0.140
Sonalika x Fang 60	0.304**	0.324**	-0.002	0.210*
Sonalika x Aghrani	-0.291**	-0.216**	-0.152*	-0.410**
Sonalika x Akbar	-0.286**	-0.566**	0.328**	-0.230*
Sonora 64 x Fang 60	0.239**	0.144	-0.002	-0.030
Sonora 64 x Aghrani	-0.106	-0.296**	0.048	-0.050
Sonora 64 x Akbar	-0.151	-0.146	-0.072	0.130
Fang 60 x Aghrani	-0.136	0.054	0.038	-0.100
Fang 60 x Akbar	-0.181*	-0.090	-0.082	-0.120
Aghrani x Akbar	0.174*	-0.030	-0.132	0.160
S.E. (Sij)	0.096	0.108	0.091	0.129

and 14). The magnitude of *gca* variance was much larger than that of *sca* variance. The predictability ratio under boron deficient and supplemented conditions were 0.96 and 0.93, respectively. The estimates of the *gca* effects showed **Sonalika**, **Fang 60** and **UP 262** to be good general combiners over environments (Table 15). On the other hand, **HD 2285** was uniformly the poorest general combiner. Other poor combiners were **DL 784-3** and **Aghrani**.

There were not many crosses with significant *sca* effects. The estimates of the *sca* effects (Table 16) indicated that only one cross, **UP 262** x **Aghrani** showed significantly better specific effects under both conditions. The crosses like **DL 784-3** x **Sonalika** and **Sonalika** x **Akbar** exhibited significant *sca* effects under boron deficient condition while the cross **Sonalika** x **Fang 60** gave positive and significant *sca* effect under supplemented condition only. The cross **Sonalika** x **Aghrani** showed consistently poor specific performance under both the conditions. An interesting situation was exhibited by the combination **Sonalika** x **Akbar**. It had significantly positive specific effects under boron deficient condition but the performance was completely reversed under supplemented condition.

4.4 Heterosis

4.4.1 Growth parameters, yield and yield components

Plant height

Percent heterosis for plant height (cm) is presented in Table 17. Heterosis over mid parent ranged from -0.05 to 4.37 while the corresponding range over better parent was from 0.98 to 8.52 under boron deficient condition. However, none of the crosses showed significant heterosis in desirable direction. Only one cross **Sonalika** x **Aghrani** showed negative but insignificant heterosis over midparent only. Significant heterosis over mid parent only. The cross **Sonora 64** x **Aghrani** exhibited highly significant *sca* effect together with significant heterosis in positive direction over both MP and BP.

Table 17 Percent heterosis for plant height (cm)

Crosses	Boron deficient condition		Boron supplemented condition	
	MP	BP	MP	BP
DL 784-3 x HD 2285	1.05	2.51	1.29	2.73
DL 784-3 x UP 262	0.10	1.93	-0.39	1.03
DL 784-3 x Sonalika	0.99	1.96	1.25	1.59
DL 784-3 x Sonora 64	1.47	2.07	-0.05	0.57
DL 784-3 x Fang 60	2.66*	4.36**	1.06	3.31*
DL 784-3 x Aghrani	2.56	5.98**	1.44	3.88**
DL 784-3 x Akbar	2.17	5.40**	3.40**	5.70**
HD 2285 x UP 262	0.71	1.09	0.43	0.44
HD 2285 x Sonalika	0.66	1.13	3.19**	4.30**
HD 2285 x Sonora 64	1.05	3.13*	0.34	2.42
HD 2285 x Fang 60	1.22	1.43	1.32	2.11
HD 2285 x Aghrani	0.59	2.44	0.60	1.55
HD 2285 x Akbar	0.76	2.44	0.22	0.99
UP 262 x Sonalika	0.28	1.17	2.29*	3.40*
UP 262 x Sonora 64	0.55	3.01	0.22	2.31
UP 262 x Fang 60	1.06	1.23	-0.88	-0.11
UP 262 x Aghrani	1.32	2.79	0.05	0.99
UP 262 x Akbar	1.70	3.02*	0.54	2.10
Sonalika x Sonora 64	1.07	2.66	0.62	1.61
Sonalika x Fang 60	2.14	2.84	1.27	3.17*
Sonalika x Aghrani	-0.05	2.27	0.55	2.61
Sonalika x Akbar	1.44	3.63	1.94	3.85**
Sonora 64 x Fang 60	3.24*	5.59**	-1.12	1.73
Sonora 64 x Aghrani	4.37**	8.52**	1.51	4.62**
Sonora 64 x Akbar	2.55	6.41**	1.12	4.04**
Fang 60 x Aghrani	1.70	3.36*	0.16	0.33
Fang 60 x Akbar	0.22	1.68	0.98	0.98
Aghrani x Akbar	1.14	0.98	0.93	1.09
S.E.	1.15	1.33	1.02	1.12

Under supplemented condition, the range over MP varied from - 1.12 to 3.40 and that over BP it ranged from -0.11 to 5.70. The trend was similar to deficient condition as none of the crosses exhibited significant heterosis in negative direction. However, four of the total cross-combinations gave insignificant but negative heterosis over the MP only. Significant heterosis with significant *sca* effect were observed in the crosses **DL 784-3 x Akbar**, **HD 2285 x Sonalika** and **UP 262 x Sonalika**.

Number of tillers/plant

Percent heterosis for number of tillers/plant is presented in Table 18. Under deficient condition, the range of heterosis over MP and BP were from -11.02 to 54.14 and from - 13.25 to 34.04, respectively. Significant heterosis over BP in desirable direction was observed in six crosses viz., **DL 784-3 x HD 2285**, **DL 784-3 x UP 262**, **DL 784-3 x Sonalika**, **DL 784-3 x Akbar**, **HD 2285 x UP 262** and **UP 262 x Sonora 64** while five crosses viz., **DL 784-3 x Sonora 64**, **DL 784-3 x Fang 60**, **DL 784-3 x Aghrani**, **UP 262 x Akbar** and **Sonalika x Fang 60** had such effects over MP only. These crosses had significant *sca* effects associated with significant heterosis except in combinations **DL 784-3 x Fang 60** and **DL- 784-3 x Aghrani**. However, significant heterosis in negative direction was shown by **Sonora 64 x Akbar** over both MP and BP while the cross **HD 2285 x Sonora 64** had such effects over BP only.

The corresponding range of heterosis over MP and BP under supplemented condition varied from -17.41 to 24.15 and from - 19.56 to 22.55, respectively. Only five crosses showed significant and positive heterosis over the BP while three crosses exhibited such effects over the MP only. Maximum heterosis was observed for the cross **DL 784-3 x Akbar** over BP and for **HD 2285 x Akbar** over MP. The crosses **DL 784-3 x UP 262**, **DL 784-3 x Akbar**, **HD 2285 x Sonalika**, **HD 2285 x Akbar** and **UP 262 x Sonora 64** also exhibited significant *sca* effects. However, significant heterosis in negative direction was exhibited by the crosses **HD 2285 x Sonora 64** and **Sonalika x Fang 60** over BP and **Sonora 64 x Aghrani** both over MP and BP.

Table 18 Percent heterosis for number of tillers/plant

Crosses	Boron deficient condition		Boron supplemented condition	
	MP	BP	MP	BP
DL 784-3 x HD 2285	54.14**	34.04**	7.08	4.38
DL 784-3 x UP 262	35.22**	20.78**	15.47**	15.47**
DL 784-3 x Sonalika	47.33**	21.62**	9.19*	4.89
DL 784-3 x Sonora 64	25.83**	5.56	7.24	6.88
DL 784-3 x Fang 60	19.53**	0.98	3.16	1.61
DL 784-3 x Aghrani	26.57**	5.47	- 3.69	- 6.52
DL 784-3 x Akbar	35.57**	14.88*	22.82**	22.55**
HD 2285 x UP 262	23.45**	20.64**	9.33*	5.57
HD 2285 x Sonalika	3.61	- 3.25	15.76**	14.04**
HD 2285 x Sonora 64	- 8.39	- 12.83 *	- 6.72	- 8.77*
HD 2285 x Fang 60	- 6.80	- 10.59	- 1.14	- 5.04
HD 2285 x Aghrani	5.92	0.00	- 4.80	- 5.21
HD 2285 x Akbar	9.02	4.96	24.15**	20.61
UP 262 x Sonalika	3.30	- 5.58	3.65	- 0.42
UP 262 x Sonora 64	20.41**	12.11*	11.16**	10.77*
UP 262 x Fang 60	1.31	- 4.92	4.57	3.00
UP 262 x Aghrani	- 3.09	- 10.47	- 5.26	- 8.04
UP 262 x Akbar	14.09**	7.44	9.61*	9.23*
Sonalika x Sonora 64	- 2.00	- 3.95	2.20	- 1.48
Sonalika x Fang 60	10.76*	7.67	- 7.19	- 12.12**
Sonalika x Aghrani	1.17	0.00	0.21	- 0.85
Sonalika x Akbar	- 10.44	- 13.25	- 1.55	- 5.74
Sonora 64 x Fang 60	- 4.02	- 4.84	- 5.84	- 7.79
Sonora 64 x Aghrani	- 3.24	- 4.04	- 17.41**	- 19.56**
Sonora 64 x Akbar	- 11.02*	- 12.10*	- 3.92	- 4.58
Fang 60 x Aghrani	0.00	- 1.66	- 0.90	- 5.21
Fang 60 x Akbar	4.57	4.18	6.58	5.34
Aghrani x Akbar	5.22	3.09	- 2.02	- 5.21
S.E.	0.20	0.24	0.17	0.19

It may be noted that the crosses **DL 784-3 x UP 262**, **DL 784-3 x Akbar** and **UP 262 x Sonora 64** exhibited positive significant heterosis both over BP along with significant *sca* effects under both the condition.

Most of the significant heterotic crosses were poor general combiners except those involving **DL 784-3** and **HD 2285** under supplemented condition, and **Sonalika** under both conditions.

Spike length

Percent heterosis for spike length is presented in Table 19. Under boron deficient condition, the range over MP varied from - 9.79 to 14.13 and over BP it varied from - 14.44 to 11.66. Significant and positive heterosis over MP was shown by nine crosses while only three crosses viz., **HD 2285 x Sonalika**, **UP 262 x Sonalika** and **Sonalika x Aghrani** exhibited such effects over both MP and BP. Of these, eight crosses viz., **HD 2285 x Sonalika**, **HD 2285 x Sonora 64**, **HD 2285 x Fang 60**, **UP 262 x Sonalika**, **UP 262 x Fang 60**, **Sonalika x Aghrani**, **Sonora 64 x Akbar** and **Fang 60 x Akbar** also exhibited significant *sca* effects. Significant heterosis in negative direction was shown by **UP 262 x Akbar** over both MP and BP while as many as five crosses exhibited such effects over the BP only.

Under boron supplemented condition, the range over MP and BP varied from -7.90 to 11.80 and from - 12.84 to 8.55, respectively. None of the crosses exhibited significant heterosis over BP while only five crosses viz., **DL 784-3 x HD 2285**, **HD 2285 x Sonora 64**, **HD 2285 x Fang 60**, **UP 262 x Fang 60** and **Sonalika x Aghrani** showed significant heterosis over MP. However, significant *sca* effects were found to be associated with heterotic effect in all the above mentioned crosses.

Number of spikelets/spike

Percent heterosis for number of spikelets/spike is presented in Table 20. Under deficient condition, heterosis ranged from -4.59 to 5.27 and from -13.04 to 2.82 over MP and BP, respectively. However, none of the crosses had significant effects in positive

Table 19 Percent heterosis for spike length (cm)

Crosses	Boron deficient condition		Boron supplemented condition	
	MP	BP	MP	BP
DL 784-3 x HD 2285	7.01*	4.05	9.57*	8.55
DL 784-3 x UP 262	3.48	2.51	4.35	2.15
DL 784-3 x Sonalika	7.76*	6.80	5.23	0.94
DL 784-3 x Sonora 64	0.54	- 6.50*	1.55	- 4.03
DL 784-3 x Fang 60	2.53	- 2.50	2.08	- 1.71
DL 784-3 x Aghrani	2.44	1.05	10.47	1.64
DL 784-3 x Akbar	3.79	- 2.43	- 2.49	- 8.94*
HD 2285 x UP 262	10.20**	6.17	4.71	1.17
HD 2285 x Sonalika	11.13**	7.12*	5.87	0.66
HD 2285 x Sonora 64	8.04**	- 2.10	8.22*	1.37
HD 2285 x Fang 60	14.13**	5.78	11.80**	6.67
HD 2285 x Aghrani	- 6.00	- 8.98*	- 6.90	- 7.91
HD 2285 x Akbar	0.61	- 7.89*	0.09	- 7.33
UP 262 x Sonalika	10.83**	10.77**	5.24	3.50
UP 262 x Sonora 64	3.07	3.29	- 0.04	- 3.21
UP 262 x Fang 60	6.92*	2.69	7.78*	6.39
UP 262 x Aghrani	2.52	1.98	6.11	3.62
UP 262 x Akbar	- 9.79**	- 14.44**	- 2.66	- 6.88
Sonalika x Sonora 64	1.27	- 5.04	3.72	2.11
Sonalika x Fang 60	5.66	1.44	6.08	5.68
Sonalika x Aghrani	12.15**	11.62**	7.44*	3.69
Sonalika x Akbar	6.87*	1.31	1.74	- 1.07
Sonora 64 x Fang 60	- 1.26	- 3.66	- 4.49	- 2.57
Sonora 64 x Aghrani	- 3.48	- 9.89**	- 7.90*	- 12.84**
Sonora 64 x Akbar	6.72*	5.49	6.97	5.63
Fang 60 x Aghrani	- 0.20	- 4.62	2.42	- 1.24
Fang 60 x Akbar	6.27*	4.87	- 1.38	- 4.47
Aghrani x Akbar	- 0.99	- 6.56*	- 5.02	- 11.18**
S.E.	0.29	0.33	0.40	0.46

Table 20 Percent heterosis for number of spikelets/spike

Crosses	Boron deficient condition		Boron supplemented condition	
	MP	BP	MP	BP
DL 784-3 x HD 2285	- 4.00*	- 11.50**	6.95**	1.47
DL 784-3 x UP 262	- 1.78	- 11.30**	- 0.18	-3.36*
DL 784-3 x Sonalika	5.27**	2.82	2.03	1.47
DL 784-3 x Sonora 64	0.10	- 5.28**	- 1.73	- 1.73
DL 784-3 x Fang 60	0.88	- 6.34	0.19	- 1.08
DL 784-3 x Aghrani	- 3.43	- 13.04**	1.40	- 0.44
DL 784-3 x Akbar	3.00	- 2.63	- 1.36	- 2.08
HD 2285 x UP 262	- 4.57*	- 6.74**	2.80	- 5.40*
HD 2285 x Sonalika	4.11*	- 1.87	7.78 **	2.76
HD 2285 x Sonora 64	0.22	- 2.50	- 4.32**	- 9.23**
HD 2285 x Fang 60	- 1.76	- 2.50	7.05**	2.82
HD 2285 x Aghrani	1.22	- 3.73	10.64**	6.85**
HD 2285 x Akbar	- 2.30	- 5.00*	6.13**	0.00
UP 262 x Sonalika	4.13*	- 3.93	- 2.77	- 6.36**
UP 262 x Sonora 64	3.22	- 1.78	4.95**	1.62
UP 262 x Fang 60	- 3.69*	- 6.56**	8.41 **	3.84**
UP 262 x Aghrani	- 2.43	- 2.72	7.28**	2.04
UP 262 x Akbar	- 3.89	- 8.71**	- 0.71	- 3.18
Sonalika x Sonora 64	0.78	- 2.44	2.48	1.92
Sonalika x Fang 60	2.47	- 1.45	11.85**	11.01**
Sonalika x Aghrani	0.32	- 7.71**	11.16**	9.72**
Sonalika x Akbar	0.68	- 2.63	4.92**	3.60*
Sonora 64 x Fang 60	1.65	- 0.38	- 2.59	- 3.84*
Sonora 64 x Aghrani	- 4.59*	- 9.48**	- 1.86	- 3.65*
Sonora 64 x Akbar	- 3.20	- 3.29	- 12.44**	- 13.26**
Fang 60 x Aghrani	- 1.10	- 4.32*	3.20	2.63
Fang 60 x Akbar	- 0.84	- 2.72	- 3.57*	- 5.49**
Aghrani x Akbar	- 1.31	- 6.28**	- 4.34**	- 6.75**
S.E.	0.29	0.34	0.25	0.28

direction over the BP while several crosses showed negative significance. Significant heterosis over MP was observed in only three crosses viz., **DL 784 -3 x Sonalika** **HD 2285 x Sonalika** and **UP 262 x Sonalika** which also exhibited significant *sca* effects.

The corresponding range under supplemented condition varied from - 12.44 to 11.85 over MP and from -13.26 to 11.01 over BP. Significant and positive heterosis over BP was observed in five crosses viz., **HD 2285 x Aghrani**, **UP 262 x Fang 60**, **Sonalika x Fang 60**, **Sonalika x Aghrani** and **Sonalika x Akbar**, while six crosses viz., **DL 784-3 x HD 2285**, **HD 2285 x Sonalika**, **HD 2285 x Fang 60**, **HD 2285 x Akbar**, **UP 262 x Sonora 64** and **UP 262 x Aghrani** showed such effects over MP only. With the exception of the cross **HD 2285 x Sonalika**, all the above-mentioned crosses had significant *sca* effects as well. Only one cross viz., **HD 2285 x Sonalika** showed significant heterosis over MP under both conditions. It may be noted that in majority of the crosses showing significant heterosis one of the parents involved was good general combiner.

Number of seeds/spike

Percent heterosis for number of seeds/spike is presented in Table 21. The range of heterosis under boron deficient condition varied from - 2.15 to 25.89 over MP and from - 20.90 to 3.72 over BP. None of crosses showed significant positive heterosis over BP while few of them exhibited negative significance. However, significant heterosis over MP was observed in seven crosses viz., **DL 784-3 x Sonora 64**, **DL 784-3 x Fang 60**, **HD 2285 x Sonora 64**, **Sonalika x Akbar**, **Sonora 64 x Akbar**, **Fang 60 x Akbar** and **Aghrani x Akbar**. These crosses also exhibited significant *sca* effects. In most of the crosses showing heterosis one of parents involved were good general combiner for this character.

The corresponding range of heterosis over MP and BP under boron supplemented condition varied from - 8.58 to 7.71 and from - 11.01 to 3.93, respectively. The trend was similar to that of deficient condition as none of the crosses had significant heterosis over the BP while 39% of the crosses exhibited significant but negative heterosis over the BP. However, four crosses viz., **DL 784-3 x HD 2285**, **HD 2285 x Aghrani**, **HD 2285 x**

Table 21 Percent heterosis for number of seeds/ spike

Crosses	Boron deficient condition		Boron supplemented condition	
	MP	BP	MP	BP
DL 784-3 x HD 2285	- 2.15	- 16.12**	6.38*	2.52
DL 784-3 x UP 262	- 0.97	- 20.90**	- 2.78	- 9.28**
DL 784-3 x Sonalika	10.56	- 13.56**	- 0.44	- 5.89*
DL 784-3 x Sonora 64	13.59*	- 11.84*	- 4.61	- 9.60**
DL 784-3 x Fang 60	17.41 **	- 6.25	0.31	- 1.81
DL 784-3 x Aghrani	- 0.60	- 19.07**	- 1.06	- 1.56
DL 784-3 x Akbar	6.21	- 1.57	0.89	- 0.09
HD 2285 x UP 262	0.67	- 7.18	0.00	- 9.83**
HD 2285 x Sonalika	- 1.80	- 11.50*	2.76	- 6.17*
HD 2285 x Sonora 64	11.65*	- 0.57	0.61	- 7.90**
HD 2285 x Fang 60	8.47	1.87	2.08	- 3.62
HD 2285 x Aghrani	- 0.67	- 5.92	6.22*	1.93
HD 2285 x Akbar	8.04	- 13.60*	6.59*	1.76
UP 262 x Sonalika	- 0.76	- 3.53	- 8.58**	- 9.83**
UP 262 x Sonora 64	1.50	- 2.31	- 3.33	- 4.91
UP 262 x Fang 60	1.87	1.87	2.15	- 2.73
UP 262 x Aghrani	0.64	- 1.87	1.48	- 4.91
UP 262 x Akbar	10.14	- 16.87**	- 4.25	- 9.83**
Sonalika x Sonora 64	4.52	3.46	0.56	0.28
Sonalika x Fang 60	4.09	1.17	7.71**	3.93
Sonalika x Aghrani	2.02	- 3.24	- 1.15	- 6.17*
Sonalika x Akbar	25.89**	- 6.78	- 0.48	- 5.05
Sonora 64 x Fang 60	6.60	2.60	- 1.89	- 5.08
Sonora 64 x Aghrani	0.00	- 6.06	- 6.50**	- 11.01**
Sonora 64 x Akbar	18.66**	- 12.71**	- 5.50*	- 9.60*
Fang 60 x Aghrani	5.76	3.12	- 3.19	- 4.83
Fang 60 x Akbar	20.08**	- 9.37	- 1.57	- 0.09
Aghrani x Akbar	19.91**	- 7.89	1.07	0.52
S.E.	1.42	1.64	0.80	0.92

Akbar and **Sonalika x Fang 60** showed significant heterosis in positive direction. They also had significant *sca* effects. It may be noted that in most of the crosses showing significant heterosis the parents involved were poor general combiner except the cross **Sonalika x Fang 60**.

250 grain weight

Percent heterosis for 250 grain weight is presented in Table 22. The range of heterosis under boron deficient condition varied from - 7.47 to 7.39 over MP and from - 10.17 to 5.62 over BP. For this character also, none of the crosses exhibited significant heterosis over BP. Most of the crosses had negative effects of which nine of them were significant. Two crosses viz., **DL 784-3 x UP 262** and **UP 262 x Sonalika** showed heterotic effects over the MP along with significant *sca* effect.

The corresponding range under supplemented condition varied from - 14.15 to 12.24 over MP and - 18.99 to 8.03 over BP. With boron supplementation, twelve crosses showed positive and significant heterosis over MP, of which four crosses viz., **DL 784-3 x Fang 60**, **DL 784-3 x Aghrani**, **UP 262 x Akbar** and **Fang 60 x Aghrani** exhibited such effects over the BP as well. Significant heterosis in desirable direction along with significant *sca* effects were observed in as many as eight crosses viz., **DL 784-3 x HD 2285** x **DL 784-3 x Sonora 64**, **DL 784-3 x Aghrani**, **UP 262 x Akbar**, **Sonalika x Fang 60**, **Sonora 64 x Fang 60** and **Fang 60 x Aghrani**.

Grain yield/plant

Percent heterosis for grain yield/plant is presented in Table 23. Under deficient condition, the range of heterosis over the MP varied from - 2.88 to 48.72 while that over the BP it varied from - 19.21 to 25.92. Among the several cross-combinations, twelve crosses exhibited significant heterosis over the MP of which two crosses had such effects over the BP. Maximum heterosis over MP was shown by the cross **DL 784-3 x Sonalika** followed by **DL 784-3 x Fang 60** while **UP 262 x Sonora 64** produced the maximum effects over the BP followed by **HD 2285 x UP 262**. Significant heterosis along with

Table 22 Percent heterosis for 250 grain weight (g)

Crosses	Boron deficient condition		Boron supplemented condition	
	MP	BP	MP	BP
DL 784-3 x HD 2285	- 0.83	- 7.30*	8.13**	0.00
DL 784-3 x UP 262	7.15**	3.04	- 4.67	- 10.25**
DL 784-3 x Sonalika	- 3.49	- 8.66**	- 3.53	- 13.90**
DL 784-3 x Sonora 64	2.48	1.67	7.95**	6.28
DL 784-3 x Fang 60	0.78	- 1.61	10.71**	8.03*
DL 784-3 x Aghrani	4.97	2.47	9.57**	7.87*
DL 784-3 x Akbar	1.85	- 5.17	3.12	0.00
HD 2285 x UP 262	- 7.47**	- 10.17	- 2.26	- 4.11
HD 2285 x Sonalika	- 1.67	- 2.95	- 14.45**	- 17.70**
HD 2285 x Sonora 64	- 3.05	- 8.69**	- 5.08*	- 10.93**
HD 2285 x Fang 60	0.00	- 4.34	- 1.50	- 10.93**
HD 2285 x Aghrani	- 3.09	- 7.30	0.08	- 6.25*
HD 2285 x Akbar	- 6.23*	- 6.63*	- 0.87	- 2.79
UP 262 x Sonalika	7.39**	5.62	- 6.19**	- 11.39**
UP 262 x Sonora 64	0.04	- 3.04	4.29	- 0.34
UP 262 x Fang 60	1.55	0.00	6.82*	- 1.70
UP 262 x Aghrani	- 3.14	- 4.61	6.08*	1.36
UP 262 x Akbar	- 5.84*	- 8.96**	7.99**	6.38*
Sonalika x Sonora 64	- 4.86	- 9.28**	- 10.49**	- 18.99**
Sonalika x Fang 60	- 1.75	- 4.82	7.26**	- 6.30*
Sonalika x Aghrani	- 0.83	- 3.92	4.36	- 5.54*
Sonalika x Akbar	- 3.50	- 5.17	- 5.94**	- 6.30*
Sonora 64 x Fang 60	3.19	1.52	10.59**	6.28
Sonora 64 x Aghrani	3.19	1.52	3.09	- 3.09
Sonora 64 x Akbar	- 0.73	- 6.89*	5.63*	- 0.49
Fang 60 x Aghrani	0.00	0.00	12.24**	7.87*
Fang 60 x Akbar	- 1.08	- 5.77*	3.47	2.48
Aghrani x Akbar	- 3.52	- 8.10*	10.03**	3.64
S.E.	0.29	0.33	0.29	0.34

Table 23 Percent heterosis for grain yield/ plant (g)

Crosses	Boron deficient condition		Boron supplemented condition	
	MP	BP	MP	BP
DL 784-3 x HD 2285	40.24**	11.57	7.19	2.04
DL 784-3 x UP 262	24.28**	- 5.43	10.05*	2.24
DL 784-3 x Sonalika	48.72**	4.97	13.12**	4.09
DL 784-3 x Sonora 64	39.62**	1.91	0.74	- 3.65
DL 784-3 x Fang 60	44.39**	2.06	- 1.48	- 6.56
DL 784-3 x Aghrani	16.00	- 14.70*	- 1.99	- 6.34
DL 784-3 x Akbar	33.33**	25.92	17.54**	15.00**
HD 2285 x UP 262	23.55**	16.30*	1.99	- 0.59
HD 2285 x Sonalika	5.26	- 10.80	6.52	2.78
HD 2285 x Sonora 64	6.68	- 5.17	- 2.52	- 2.99
HD 2285 x Fang 60	1.41	- 13.79*	- 9.80*	- 10.15*
HD 2285 x Aghrani	4.80	- 5.88	- 2.29	- 2.69
HD 2285 x Akbar	17.45	- 2.21	2.02	- 0.78
UP 262 x Sonalika	1.82	- 8.91	0.59	- 0.43
UP 262 x Sonora 64	27.49**	19.92**	7.85	4.63
UP 262 x Fang 60	-2.88	- 12.93*	- 3.59	- 5.68
UP 262 x Aghrani	-2.68	- 7.45	0.07	- 2.84
UP 262 x Akbar	26.02**	0.00	- 4.17	- 9.11
Sonalika x Sonora 64	6.78	1.20	6.25	2.04
Sonalika x Fang 60	9.20	8.91	2.79	- 0.43
Sonalika x Aghrani	3.20	- 3.25	- 0.09	- 6.58
Sonalika x Akbar	10.43	- 19.21**	- 6.46	- 12.15*
Sonora 64 x Fang 60	1.63	- 3.44	- 2.60	- 3.43
Sonora 64 x Aghrani	1.74	0.57	- 10.88*	- 10.95
Sonora 64 x Akbar	18.68*	- 9.96	- 9.84*	- 11.92
Fang 60 x Aghrani	0.00	- 6.03	- 5.51	- 6.25
Fang 60 x Akbar	22.58**	- 10.17	0.00	- 3.12
Aghrani x Akbar	24.35**	-4.90	3.74	1.26
S.E.	0.31	0.36	0.28	0.32

significant *sca* was exhibited by nine of the crosses except **DL 784-3 x UP 262**, **DL 784-3 x Akbar** and **Sonora 64 x Akbar**.

With boron supplementation a decreasing trend was observed in the percent of heterosis. The range over MP varied from -10.88 to 17.54 while the corresponding range over BP varied from -12.15 to 15.92. Only three crosses viz., **DL 784 - 3 x UP 262** and **DL 784-3 x Sonalika** over MP, and **DL 784-3 x Akbar** over BP showed significant heterosis in desirable direction, which also had significant *sca* effects. It may be noted that in both the crosses one of the parents were good general combiner for this character.

Considering both the conditions, only one cross viz., **DL 784 - 3 x Sonalika** gave significant heterosis over the MP which also exhibited significant *sca* effects.

4.4.2 Protein and gluten content

Protein content

Percent heterosis for protein content is presented in Table 24. Under deficient condition, the range of heterosis over MP varied from - 6.97 (**UP 262 x Sonalika**) to 3.28 (**Sonora 64 x Fang 60**) and that over BP it varied from - 10.54 (**DL 784-3 x Sonalika**) to 1.00 (**HD 2285 x Akbar**). The corresponding range under supplemented condition were from - 8.59 (**Sonalika x Akbar**) to 0.90 (**Sonora 64 x Fang 60**) over MP and from - 15.12 (**Sonalika x Akbar**) to - 0.92 (**Fang 60 x Aghrani**).

Under deficient condition, nine crosses viz., **DL 784-3 x Aghrani**, **DL 784-3 x Akbar**, **HD 2285 x Sonora 64**, **HD 2285 x Akbar**, **UP 262 x Aghrani**, **Sonalika x Sonora 64**, **Sonalika x Fang 60**, **Sonora 64 x Fang 60** and **Aghrani x Akbar** showed positive heterosis, of which only **HD 2285 x Sonora 64** and **Sonora 64 x Fang 60** had significant effects over MP. The remaining crosses exhibited negative heterosis. None of the crosses showed significant positive heterosis over the BP though two crosses viz., **DL 784 -3 x Aghrani** and **HD 2285 x Akbar** showed heterotic effects.

Table 24 Percent heterosis for protein content (%)

Crosses	Boron deficient condition		Boron supplemented condition	
	MP	BP	MP	BP
DL 784-3 x HD 2285	- 6.00**	- 7.84**	- 4.52**	- 6.73**
DL 784-3 x UP 262	- 5.48**	- 8.76**	- 6.04**	- 9.00**
DL 784-3 x Sonalika	- 5.55**	- 10.54**	- 7.62**	-13.44**
DL 784-3 x Sonora 64	- 1.88	- 5.45**	- 5.50**	- 9.64**
DL 784-3 x Fang 60	- 1.46	- 1.94	- 3.77*	- 5.55**
DL 784-3 x Aghrani	0.48	0.95	0.00	- 0.94
DL 784-3 x Akbar	0.99	0.00	0.00	- 0.96
HD 2285 x UP 262	- 4.62*	- 9.67**	- 4.85**	- 9.90**
HD 2285 x Sonalika	- 3.77**	- 10.52**	- 6.50**	- 14.28**
HD 2285 x Sonora 64	3.84**	- 1.82	- 0.56	- 7.01**
HD 2285 x Fang 60	- 1.49	- 3.88*	- 2.51	- 6.48**
HD 2285 x Aghrani	- 2.46	- 5.71**	- 4.48**	- 7.54**
HD 2285 x Akbar	2.02	1.00	- 1.59	- 2.94
UP 262 x Sonalika	- 6.97**	- 8.77*	- 6.95**	- 10.08**
UP 262 x Sonora 64	- 3.46*	- 3.63*	- 2.65	- 3.51*
UP 262 x Fang 60	- 0.28	- 3.28*	- 1.37	- 3.60*
UP 262 x Aghrani	0.65	- 1.46	0.46	- 1.80
UP 262 x Akbar	- 3.62*	- 7.84**	- 2.34	- 6.30**
Sonalika x Sonora 64	0.89	- 0.87**	0.43	- 1.68
Sonalika x Fang 60	1.38	- 3.50**	0.44	- 4.20*
Sonalika x Aghrani	- 4.56**	- 8.33**	- 4.88**	- 10.08**
Sonalika x Akbar	- 4.67**	- 10.52**	- 8.59**	- 15.12**
Sonora 64 x Fang 60	3.28**	0.00	0.90	- 1.75
Sonora 64 x Aghrani	- 0.46	- 2.72	- 3.63*	- 7.01 **
Sonora 64 x Akbar	- 0.95	- 5.45**	- 2.77	- 7.89**
Fang 60 x Aghrani	- 0.96	- 1.90	0.00	- 0.92
Fang 60 x Akbar	- 1.47	- 2.91	- 1.90	- 1.85
Aghrani x Akbar	1.46	- 0.95	- 1.92	- 3.77*
S.E.	0.15	0.17	0.17	0.19

Under supplemented conditions, none of crosses exhibited significant and positive heterosis over both MP and BP. A majority of the crosses gave significant heterosis in negative direction. However, crosses such as **UP 262 x Aghrani**, **Sonalika x Sonora 64**, **Sonalika x Fang 60** and **Sonora 64 x Fang 60** exhibited marginal heterosis in desirable direction over MP only.

Gluten content

Percent heterosis for gluten content is presented in Table 25. The range of heterosis under deficient condition varied from - 3.66 (**HD 2285 x Sonalika**) to 3.19 (**UP 262 x Aghrani**) over the MP while it varied from -6.93 (**DL 784-3 x Sonalika** and **Sonalika x Aghrani**) to 2.22 (**HD 2285 x Aghrani**) over the BP. The corresponding range under supplemented condition varied from -9.52 (**Sonalika x Aghrani**) to 2.06 (**UP 262 x Aghrani**) over the MP while it varied from -11.21 (**Sonalika x Aghrani**) to - 1.00 (**UP 262 x Fang 60** and **UP 262 x Aghrani**) over the BP.

Under boron deficient condition, only one cross **UP 262 x Aghrani** showed significant heterosis in positive direction over the MP only. However, ten crosses viz., **DL 784-3 x UP 262**, **DL 784-3 x Sonora 64**, **DL 784-3 x Aghrani**, **HD 2285 x UP 262**, **HD 2285 x Fang 60**, **HD 2285 x Aghrani**, **UP 262 x Sonalika**, **Sonalika x Akbar**, **Sonora 64 x Aghrani** and **Fang 60 x Aghrani** showed heterotic effect of smaller magnitude which were non-significant. On the other hand, only one cross **HD 2285 x Aghrani** gave positive but insignificant heterosis over the BP while the remaining crosses gave negative heterosis.

Under supplemented condition, none of crosses exhibited significant and positive heterosis over both MP and BP. However, crosses such as **UP 262 x Aghrani** and **Sonora 64 x Akbar** exhibited marginal heterosis in positive direction over the MP only. All the crosses except **Sonora 64 x Akbar**, which did not exhibit any heterosis, gave negative effects.

Table 25 Percent heterosis For gluten content (%)

Crosses	Boron deficient condition		Boron supplemented condition	
	MP	BP	MP	BP
DL 784-3 x HD 2285	-1.09	-2.17	-1.06	-3.12
DL 784-3 x UP 262	1.05	-2.04	-2.04	-4.00
DL 784-3 x Sonalika	-2.59	-6.93**	-1.47	-6.54**
DL 784-3 x Sonora 64	1.07	0.00	-1.04	-1.04
DL 784-3 x Fang 60	0.00	-4.00*	-0.51	-2.97
DL 784-3 x Aghrani	1.09	0.00	-1.05	-2.08
DL 784-3 x Akbar	-1.07	-2.12	-1.03	-2.04
HD 2285 x UP 262	1.06	-3.06	-2.08	-6.00*
HD 2285 x Sonalika	-3.66*	-8.91**	-1.50	-8.41**
HD 2285 x Sonora 64	0.00	-2.13	0.00	-2.08
HD 2285 x Fang 60	1.05	-4.00*	-0.52	-4.95*
HD 2285 x Aghrani	2.22	2.22	-1.07	-2.13
HD 2285 x Akbar	0.00	-2.12	0.00	-3.06
UP 262 x Sonalika	0.50	-1.00	0.48	-2.80
UP 262 x Sonora 64	-1.04	-3.06	0.00	-2.00
UP 262 x Fang 60	0.00	-1.00	-0.49	-1.00
UP 262 x Aghrani	3.19*	-1.02	2.06	-1.00
UP 262 x Akbar	-1.04	-3.06	-1.01	-2.00
Sonalika x Sonora 64	-0.51	-3.96*	-2.46	-7.47**
Sonalika x Fang 60	-0.49	-0.99	0.96	-1.86
Sonalika x Aghrani	-1.57	-6.93**	-9.52**	-11.21**
Sonalika x Akbar	2.56	-0.99	-3.41	-7.47**
Sonora 64 x Fang 60	0.00	-3.00	-0.51	-2.97
Sonora 64 x Aghrani	1.08	-1.06	-1.05	-2.08
Sonora 64 x Akbar	-1.06	-1.06	1.03	0.00
Fang 60 x Aghrani	1.05	-4.00*	-1.53	-4.95*
Fang 60 x Akbar	-1.03	-4.00*	-1.51	-2.97
Aghrani x Akbar	-1.08	-3.19	1.04	-1.02
S.E.	0.14	0.16	0.20	0.23

Chapter 5

DISCUSSION

5.1 Screening for tolerance to boron deficiency

Field tolerance study of wheat genotypes collected from different sources indicated a wide variation for tolerance to boron deficiency, particularly in terms of spike fertility and grain yield/plant.

There was marginal increase in plant height in most of the genotypes while noticeable increase was observed for number of tillers/plant with boron application. Mitra and Jana (1991) had drawn similar conclusion for number of tillers/plant. However, spike length did not vary significantly in most of the genotypes thereby indicating less influence of boron application. On the contrary, Mandal (1993) found positive response to boron for this character. In terms of number of spikelets/spike, some genotypes showed significant response to boron application while several other genotypes were less influenced with boron supplement. However, 250 grain weight, an important component, did not exhibit

significant change in almost all the genotypes. This may be attributed to the fact that optimum improvement had already been achieved through selection. Mandal and Ghosal (1985) also did not find any increase for this character with boron application. However, Mitra and Jana (1991) observed significant increase in grain weight with boron application.

Application of boron significantly increased the number of seeds/spike and yield /plant in most of the genotypes. Boron enhances uptake and translocation of sugars and is implicated also in carbohydrate metabolism (Gauch & Dugger, 1953) which might be the reason for greater number of seeds/ spike. Improvement in grain setting and yield/plant in wheat with boron application were also observed by Ahmed *et al.* (1979), Mandal and Ghosal (1985) and Mitra and Jana (1991). However, genotypes such as **Sonalika**, **Sonora 64**, **Fang 60** and **Wheat local** were able to perform well as they showed either negligible reduction or increase in number of seeds/ spike and grain yield/plant with boron supplementation.

In the present investigation, increased grain yield/plant in most of the genotypes with boron application was mainly due to increase in the number of seeds/spike i.e., increase in floret fertility. This corroborates the earlier findings of Mandal and Ghosal (1985). Jahiruddin *et al.* (1992) and Mandal (1993) had also reported higher grain yield associated with enhanced grain formation. Increased grain yield with boron application have also been reported by Mandal and Das (1988), Ali and Monoranjan (1989), Singh *et al.* (1992), Roy and Pradhan (1994) and Hossain *et al.* (1994).

Mandal and Ghosal (1985) classified varieties into three categories viz., tolerant, moderately susceptible and susceptible on the basis of their relative performance under boron deficient condition. From the foregoing discussions it appears that the genotypes **Sonalika**, **Sonora 64**, **Fang 60** and **Wheat local** performed more or less uniformly under both the conditions and were thus considered tolerant to boron deficiency. On the basis of floret fertility, nine genotypes viz., **BAW 171**, **Akbar**, **BAW 452**, **HDR 77**, **HP 1728**, **BL 1022**, **Glennsen**, **HP 1704** and **DL 784-3** were found to be moderately susceptible. The remaining twelve genotypes viz., **HP 1685**, **HP 1705**, **K 8905**, **HP 1633**, **HD 2285**,

UP 262, Kanchan, Aghrani, HUW 234, HD 2684, C 306 and Siren were considered moderately tolerant to boron deficiency.

5.2 Estimation of genetic parameters

Most of the important characters showed wide variation which may provide enough scope to improve the crop through selection, as improvement in any crop largely depends on the wide range of variability present in that crop, as was suggested by Joshi and Dhawan (1966), Rudraradhya *et al.* (1984) and Singh and Dahiya (1984).

The value of phenotypic co-efficient of variations were higher than those of genotypic co-efficient of variation for number of tillers/ plant, spike length, number of spikelets/spike, number of seeds/spike and 250 grain weight. This indicated that these characters were more influenced by the environment than plant height, which had the magnitude of phenotypic co-efficient of variation closer to that of genotypic co-efficient of variation. The characters number of tillers/plant, number of seeds/spike and grain yield /plant showed moderate to high phenotypic and genotypic co-efficient of variations under boron deficient condition.

However, with the help of genetic co-efficient of variation alone it is not possible to determine the amount of variation that is heritable. The heritable portion of variation can be identified with the help of heritability estimates and genetic gain (Johnson *et al.*, 1955; Gandhi *et al.*, 1964). High heritability estimates generally enables the breeder to select plants on the basis of phenotypic expression (Johnson *et al.*, 1955). Spike length gave low heritability estimates while number of spikelets/spike exhibited moderate heritability estimates. This suggests that less weightage should be given to those components possessing low heritability while fixing selection criteria. The character number of tillers/plant under both the condition and number of seeds/ spike and grain yield/plant under deficient condition gave high heritability estimates. Selection for these characters may prove fruitful under boron deficient condition than under supplemented condition. Kheiralla (1993) reported moderate estimates of heritability for grain yield/plant and high heritability for number of seeds/ spikes while Yadav and Mishra (1993) observed

high heritability for characters number of tillers/plant and grain yield/plant. However, Singh *et al.* (1987) had observed high heritability for yield/plant but this was not reflected in F_1 and successive generations. As this character is non reliable it should not be considered for direct selection and due weightage may be given for different yield components. The present study revealed that there could be lot of scope for the improvement of important characters like number of seeds/ spike and number of tillers/plant exhibiting high heritability.

Burton (1952) suggested that the extent of advance expected from selection can be obtained from a study of the genotypic co-efficient of variation along with heritability estimates, as heritability estimates are often subjected to genotype-environment interactions. In the present investigation, high genetic advance associated with high heritability and with comparable genotypic co-efficient of variation were evident for the characters number of tillers/plant and number of seeds/spike under boron deficient condition. This association would indicate that additive gene effects are probably more important in the inheritance of these characters (Panse, 1957) and hence, selection for these characters would be highly effective under boron deficient condition. Pathak *et al.* (1986) had also drawn similar conclusions.

5.3 Combining ability analysis and heterosis

5.3.1 Growth parameters, yield and yield components

The mean squares due to *gca* and *sca* were significant for all the characters studied except plant height, where the *sca* variances were not significant under both boron deficient and boron supplemented conditions. This indicated the importance of both additive and non additive gene effects for yield/plant and other related traits while plant height was strongly under the control of additive genes. Mandal (1988) had also observed the importance of both additive and non additive gene effects in controlling grains/spike, spike length and yield/ plant while the *gca* variance for tillers/plant was found to be non significant under boron deficient condition. The importance of both additive and non additive gene action in the expression of yield and its contributing characters had also

been reported by Jamjod *et al.* (1991), Mandal and Maity (1992), Patel *et al.* (1995) and Singh and Chatrath (1997).

Baker (1978) suggested that the importance of *gca* and *sca* should be assessed by estimating the components of variance and expressing them as $2\sigma^2_g / 2\sigma^2_g + \sigma^2_s$ ratio. The closer this ratio to unity, the greater will be the magnitude of additive gene effects. The ratio computed for all the characters under boron deficient condition (Table 6) showed that additive gene effects were more important for plant height, number of spikelets/spike and number of seeds/spike, while both additive and non additive gene effects were important for spike length and grain yield/plant. For number of tillers/plant and 250 grain weight, non additive gene effects were more important. On the other hand, under boron supplemented condition (Table 7) characters such as number of tillers/plant, number of spikelets/spike, 250 grain weight and grain yield/plant were found to be under the control of non additive gene actions while both the type of gene actions were important for spike length and number of seeds/spike. The predominant role of non additive gene effect was reflected in characters such as number of tillers/plant and 250 grain weight under both boron deficient and boron supplemented conditions while such effect was found to be predominant for number of spikelets/spike and grain yield/plant under boron supplemented condition only. This may cause difficulties in bringing all desirable genes for these characters through pedigree method for which the use of multiple parents brought together to form a central gene pool might prove useful (Jensen, 1970). Sokol and Baker (1977) had concluded that negative association between genes results in relatively larger estimates of *sca* variances. Under such situations, population improvement programme followed by recurrent selection to accumulate desirable genes, and to facilitate the breaking of linkages would be more appropriate in self pollinated crops as suggested by Frey (1975).

A perusal of *gca* estimates under boron deficient condition (Table 8) indicated that **Sonalika** followed by **Fang 60** and **Sonora 64** were the best general combiners for grain yield/plant. **Sonalika** was also good combiner for number of tillers/plant, number of spikelets/spike, number of seeds/spike and plant height; **Fang 60** for spikelength and

number of seeds/spike while **Sonora 64** was good general combiner for spike length, number of seeds/spike and plant height. Other parents with good general combiners were **UP 262** for number of spikelets/spike and number of seeds/spike; **Akbar** for spike length and 250 grain weight; **HD 2285** and **Aghrani** for number of spikelets/ spike; and **DL 784-3** for plant height. Under supplemented condition (Table 9), **Sonalika** was found to be good general combiner for grain yield/plant along with all other characters studied while **UP 262** was good general combiner for grain yield/plant, number of spikelets/spike and number of seeds/spike. Other parents with good general combiners were **DL 784-3** for plant height and number of tillers/plant; **HD 2285** for number of tillers/ plant; **Sonora 64** for plant height, spike length and number of seeds/spike; and **Akbar** for spike length and 250 grain weight. It has been observed that good general combiners for yield had good *gca* values for atleast one component character. Similar results were obtained by Mandal and Ghosal (1988).

The mean performance of parents for different characters were related with their respective *gca* effects in majority of the cases. Thus, the selection of the lines for a breeding programme could be based on both mean performance and combining ability. It will be an efficient selection if **Sonalika** is included as a parent in any hybridization programme. **Sonalika**, **Fang 60** and **Sonora 64** can be included as parents in breeding for tolerance to boron deficiency. Jamjod *et al.* (1991) had, infact, observed positive *gca* effects of tolerant lines with respect to grain yield/plant and its components, and suggested that through back crossing susceptible lines could be improved satisfactorily.

Majority of the cross combinations showing significant and positive *sca* effects involved one good general combiner for most of the traits under both boron deficient and boron supplemented conditions. However, for number of tillers/plant many crosses under boron deficient condition showed significant *sca* effects, although both the parents were poor general combiners. It was also noted that under boron deficient condition all the characters except number of seeds/spike showed significant *sca* effects in some crosses involving poor combining parents. Sharma *et al.*(1978) explained this phenomenon as a reflection of non additive type of gene activity in making the resultant combinations

unpredictable. In some cases, the F_1 involving parents with high *gca* effects failed to result in high *sca* effects which may probably be due to internal cancellation of gene effects, as was suggested by Jones (1958). Some crosses, inspite of the parents being good general combiners, showed negative *sca* values. Singh and Gupta (1969) tried to explain it as a manifestation of poor genetic diversity between the parents involved. These explanations appears to be valid in the present study also.

Under boron deficient condition, most of the crosses with significant *sca* for grain yield/plant also had significant *sca* for atleast one of the three yield components (Table 10). The cross combinations **DL 784-3 x Sonalika**, **DL 784-3 x Fang 60**, **DL 784-3 x Sonora 64** and **Fang 60 x Akbar** involving susceptible x tolerant or tolerant x susceptible (to boron deficiency) types exhibited significant *sca* effects for grain yield/plant alongwith a cluster of component characters. It needs to be mentioned that in self pollinated crop like wheat, conventional breeding methods could exploit only that portion of genetic variability which is due to additive or additive x additive interaction. The *gca* estimates have revealed that the tolerant parents (**Sonalika**, **Sonora 64** and **Fang 60**) were good general combiners for grain yield/plant and other characters. Such combinations could throw up desirable transgressive segregants giving rise to new population if the additive genetic system present in good combiners and complementary epistatic effects present in the crosses act in the complementary fashion to maximize desirable plant attributes, which could be exploited for further breeding programme. **UP 262 x Sonora 64** involving poor x high general combiners for grain yield/plant had significant *sca* and high grain yield/plant indicating the possibility of obtaining desirable segregants. The cross combinations **HD 2285 x UP 262**, **Aghrani x Akbar**, **DL 784-3 x HD 2285** and **UP 262 x Akbar** had significant *sca* effects for grain yield/plant along with significant *sca* for number of tillers/plant or number of seeds/spike or both. However, none of the parents were good general combiner for grain yield/plant. Such situations are indicative of the presence of additive x dominance or dominance x dominance type of gene effects (Sharma *et al.*, 1978; Yadav and Singh, 1989).

Under boron supplemented condition, the cross combinations with significant *sca* for grain yield/plant were **UP 262 x Sonora 64**, **DL 784-3 x Sonalika**, **Sonalika x Sonora 64** and **HD 2285 x Sonalika** (Table 11), and they included at least one parent to be good general combiner for this character (Table 9). However, the combinations **DL 784-3 x Akbar** and **Aghrani x Akbar** gave significant *sca* effects although none of the parents were good general combiner. The explanation for these variations are similar to those presented earlier.

The crosses **UP 262 x Sonora 64**, **Sonalika x Sonora 64** and **HD 2285 x Sonalika** had positive significant *sca* effects for grain yield/plant and at least one related character in which one parent was good general combiner for the said characters. Intermating between them followed by selection may be useful for exploitation of these crosses for yield. This method of breeding provides opportunity for breaking the undesirable linkages and create a broad genetic base against which the rearranged genes may be expressed.

In the present investigation, both additive and non additive gene effects were involved in the inheritance of all the characters studied except plant height. Rapid improvement in the productivity of bread wheat may not be achieved through conventional breeding programmes. Population improvement like concurrent random mating along with mass selection (Redden and Jensen, 1974) in early segregating generations could be a dependable breeding procedure for improvement of yield in the resulting population of bread wheat. Multiple crosses followed by intermating among the desirable selected plants in later segregating generations may also be of much use for simultaneous exploitation of additive and non additive gene effects for developing lines suitable for boron deficient soils.

As regards heterosis, none of the cross combinations exhibited significant heterosis in desirable direction over the better parent for plant height, number of spikelets/spike, number of seeds/spike and 250 grain weight under boron deficient condition (Tables 17,20,21 and 22). For spike length, crosses such as **HD 2285 x Sonalika**, **UP 262 x Sonalika** and **Sonalika x Aghrani** proved outstanding (Table 19). Crosses like **DL 784-3**

x **HD 2285**, **DL 784-3** x **UP 262**, **DL 784-3** x **Sonalika**, **DL 784-3** x **Akbar**, **HD 2285** x **UP 262** and **UP 262** x **Sonora 64** exhibited significant heterosis over better parent for number of tillers/plant (Table 18). It was interesting to note that significant heterosis over mid parent or better parent for grain yield/plant was obtained in several crosses which showed high heterosis for number of tillers/plant. It seems that the manifestation of heterosis for grain yield is mainly through tillers/plant, as was also reported by Hsu and Walton (1971).

Most of the crosses which exhibited significant heterosis over mid parent or better parent for grain yield/ plant were also having high *sca* effects. However the cross **DL 784-3** x **Akbar**, where parents were poor general combiners for grain yield/plant, exhibited high heterosis over the better parent even though the *sca* effect was low. The cross combinations like **DL 784-3** x **HD 2285**, **DL 784-3** x **UP 262**, **DL 784-3** x **Sonalika**, **DL 784-3** x **Sonora 64**, **DL 784-3** x **Fang 60**, **HD 2285** x **UP 262**, **UP 262** x **Akbar**, **Sonora 64** x **Akbar** and **Fang 60** x **Akbar** showed significant heterosis over mid parent and **HD 2285** x **UP 262** over better parent with respect to grain yield/plant accompanied by considerable heterosis for one or more related characters. These crosses will help selection in desirable direction based on cluster of desirable characters under boron deficient condition. The cross **UP 262** x **Sonora 64** showed high heterosis over better parent for grain yield/plant and number of tillers/plant. It can be considered as most appreciable because it may throw advantageous fixable recombinants for presence of significant *sca* effect for grain yield/plant accompanied by high heterosis and moderate to high *gca* effects of these parents.

Under boron supplemented condition, only one cross **DL 784-3** x **Akbar** showed significant heterosis over better parent for grain yield/plant along with one of the component character, number of tillers/plant. However, both the parents were poor general combiners indicating the presence of higher order of gene interaction behind the heterotic effect. The cross combinations **DL 784-3** x **UP 262** and **DL 784-3** x **Sonalika** exhibited high heterosis over mid parent for grain yield/plant accompanied by appreciable heterosis for number of tillers/plant. Both **UP 262** and **Sonalika** were good general

combiners for grain yield/plant. The cross **DL 784-3 x UP 262**, however, failed to show significant *sca* effects inspite of having significant heterosis. The cross **DL 784-3 x Sonalika** which had high heterotic response and high *sca* effect involving one good and one poor general combiner parent could produce desirable segregants. Due considerations may be given to those combinations which showed positive significant heterosis over mid parent for a number of yield contributing characters. The crosses such as **DL 784-3 x HD 2285**, **HD 2285 x Akbar**, **UP 262 x Fang 60** and **Sonalika x Fang 60** were found to be promising and selection from these crosses under boron supplemented condition may produce better results.

5.3.2 Protein and gluten content

The mean squares due to *gca* and *sca* were significant for protein content, while for gluten content only the *gca* variances were significant under both boron deficient and boron supplemented conditions (Table 13 and 14). This indicated the importance of both additive and non additive gene effects for protein content while gluten content was strongly under the control of additive genes. Nedelea and Moisuc (1982) had also observed additive gene effects to be important for gluten content. The importance of both additive and non additive gene action for protein content had also been observed by Raina *et al.* (1979), Milanko (1988) and Vitkare and Atale (1990). However, high predictability ratio was evident for this character indicating the predominant role of additive gene effects as was also reported by other investigators (Ram and Srivastava, 1983; Thakral *et al.*, 1986; Li *et al.*, 1991; Mandal and Maity, 1992; Jin *et al.*, 1995).

A perusal of *gca* estimates (Table 15) indicated that **Sonora 64**, followed by **Sonalika** and **UP 262** were good general combiners for protein content under boron deficient condition while **Sonalika**, **Sonora 64**, **Fang 60** and **UP 262** were good general combiners under boron supplemented condition. For gluten content, **Fang 60** was the best general combiner under boron deficient condition. Other good general combiners were **Sonalika**, **UP 262** and Aghrani. Under boron supplemented condition, **Sonalika** followed by **Fang 60** and **UP 262** were good general combiners.

All the crosses showing significant and positive *sca* effects for gluten content involved one or both parents to be good general combiner for the said character. For protein content also the crosses with high *sca* effects involved the parents good x good or good x poor (poor x good) general combiners, though some crosses with poor *gca* effects also showed significantly high *sca* effects. However, some crosses failed to show significant *sca* effects where one or both the parents were good general combiners. The explanations for these variations were similar to those presented earlier for yield and its components. Crosses such as **HD 2285 x Akbar**, **DL 784-3 x Akbar** **DL 784-3 x Aghrani** and **Aghrani x Akbar** under boron deficient condition, and **DL 784-3 x Akbar** and **DL 784-3 x Aghrani** under boron supplemented condition exhibited positive significant *sca* effects which involved parents of poor general combiners for protein content. However, cross combinations such as **HD 2285 x Sonora 64**, **Sonalika x Fang 60**, **UP 262 x Aghrani**, **Sonora 64 x Fang 60** and **Sonalika x Sonora 64** under boron deficient condition and crosses such as **Sonalika x Sonora 64**, **Sonalika x Fang 60** and **UP 262 x Aghrani** under boron supplemented condition, which had good *per se* performance and significant *sca* effects also had one or both parents to be good general combiner. This indicated the possibility of obtaining desirable segregants from these crosses under the respective environments. Under boron deficient condition, **HD 2285 x Sonora 64** and **Sonora 64 x Fang 60** also showed significant heterosis indicating the possibility of producing highest transgressive segregants from these crosses. However, crosses **UP 262 x Sonalika**, **UP 262 x Sonora 64** and **UP 262 x Fang 60** showed negative *sca* values although both the parents were good general combiners.

As regards gluten content, three crosses viz., **Sonalika x Akbar**, **UP 262 x Aghrani** and **DL 784-3 x Sonalika** under boron deficient condition and two crosses viz., **UP 262 x Aghrani** and **Sonalika x Fang 60** under boron supplemented condition exhibited significant *sca* effects which involved one or both parents to be good general combiner. Intermating between them followed by selection may be useful for exploitation of these crosses for gluten content. The cross **UP 262 x Aghrani** also exhibited significant heterosis over the mid parent under boron deficient condition alongwith good *per se*

performance and high *sca* effects indicating the possibility of this cross to produce better transgressive segregants. However, the cross **Sonalika** x **Aghrani** showed negative *sca* effects though both the parents were good general combiners. The phenomenon of negative *sca* effects in combinations involving good general combiners indicated the manifestation of poor genetic diversity between the parents involved as was explained by Singh and Gupta (1969).

In the present investigation, majority of the crosses which had significant *sca* effects for yield were low specific combiners for protein or gluten content and *vice versa*, which are indicative of inverse relationship commonly found between these two traits (Raina *et al.*, 1982; Day *et al.*, 1985). However, it shall not be out of place to emphasise that the estimates of combining ability as well as heterosis clearly revealed the feasibility of simultaneous genetic improvement for yield and quality characters in some cross combinations. **DL 784-3** x **Sonalika** with significant *sca* involving low x high (L x H) general combiner for yield and gluten content and **Aghrani** x **Akbar** involving low x low (L x L) general combiners for yield and protein content can be used in biparental mating system in a recurrent crossing programme under boron deficient condition. In the same manner, **Sonalika** x **Sonora 64** and **DL 784-3** x **Akbar** can be used for simultaneous improvement in yield and protein content under boron supplemented condition.

Improvement in protein content concomitantly improved gluten content as indicated by significant *sca* effects in certain crosses (Table 16). Under boron deficient condition, the cross **UP 262** x **Aghrani** (H x L) can be considered for biparental mating system for improvement of protein content while the same can be used directly for gluten content through pedigree selection. Under boron supplemented condition, **Sonalika** x **Fang 60** (H x H) can be used for simultaneous improvement of protein and gluten content through pureline selection while **UP 262** x **Aghrani** (H x L) can be considered for biparental mating for improving both protein and gluten content.

Chapter 6

SUMMARY AND CONCLUSION

SUMMARY

An investigation entitled “ **Genetic evaluation of breeding lines of wheat (*Triticum aestivum* L. em. Thell) for yield and quality in boron deficient soil**” was conducted during the *rabi* seasons of 1994-95, 1995-96 and 1996-97 at the Instructional farm of Bidhan Chandra Krishi Viswavidyalaya, North Bengal Campus, Pundibari, Coochbehar.

Twentyfive genotypes of bread wheat were evaluated in the first year for their relative performance under boron deficient and boron supplemented conditions. The characters studied were plant height (cm), number of tillers/plant, spike length (cm), number of spikelets/spike, number of seeds/spike, 250 grain weight (g) and grain yield/plant (g).

Eight genotypes viz., **DL 784-3** (moderately susceptible), **HD 2285** (moderately tolerant), **UP 262** (moderately tolerant), **Sonalika** (tolerant), **Sonora 64** (tolerant), **Fang**

60 (tolerant), **Aghrani** (moderately tolerant) and **Akbar** (moderately susceptible), primarily selected on their relative performance under boron deficient condition, were crossed in diallel combinations (excluding reciprocals) in the second year.)

In the third year, the parents and their 28 F₁s were grown in a randomised block design with three replications under both boron deficient and boron supplemented conditions. Observations were recorded on various quantitative characters viz., plant height (cm), number of tillers/plant, spike length (cm), number of spikelets/spike, number of seeds/spike, 250 grain weight (g) and grain yield/plant (g). Moreover, protein content and gluten content were also estimated for the parents and their F₁s. (All these nine characters were subjected to combining ability and heterosis studies.)

(With boron application, significant increase was noted for almost all the character except spike length and 250 grain weight. Increased yield in most of the genotypes with boron application was mainly due to increase in number of seeds/spike. Grain yield/plant was least affected under boron deficient condition in genotypes **Sonalika**, **Sonora 64**, **Wheat local** and **Fang 60**. **HP 1728** and **HD 2684** performed best under boron supplemented condition with respect to grain yield/plant, which also had maximum number of seeds/spike.)

(In the present investigation, number of seeds/ spike followed by grain yield/plant and number of tillers/plant showed greater relative variability compared to other characters studied under boron deficient condition. However, under boron supplemented condition grain yield/plant showed least relative variability.) (Phenotypic co-efficient of variation were, in general, higher than genotypic co-efficient of variation for all the characters studied except plant height, indicating greater influence by the environment.) Number of tillers/plant, number of seeds/spike and grain yield/plant showed moderate to high phenotypic and genotypic co-efficient of variations under boron deficient condition. These characters also gave high estimates of heritability. Spike length and number of spikelets/spike exhibited low to moderate heritability while number of tillers/plant and plant height had high heritability under both boron deficient and boron supplemented

conditions. High heritability and high genetic advance with comparable genotypic coefficient of variation were evident for number of tillers/plant and number of seeds/spike under boron deficient condition.

In F_1 diallel, the mean squares due to *gca* and *sca* were significant for all the characters except plant height and gluten content, where *sca* variances were non-significant under both boron deficient and boron supplemented conditions. The predictability ratio under boron deficient condition was high for plant height, number of spikelets/spike and number of seeds/spike; moderate for spike length and grain yield /plant; and low for number of tillers/plant and 250 grain weight. Under boron supplemented condition, the ratio was high for plant height; moderate for spike length and number of seeds/spike; and low for number of tillers/ plant, number of spikelets/spike, 250 grain weight and grain yield/plant. The ratio was high for both the quality parameters viz., protein content and gluten content.

It was observed that under boron deficient condition, **Sonalika** followed by **Fang 60** and **Sonora 64** were the best general combiners for grain yield/plant. **Sonalika** was also good general combiner for plant height, number of tillers/plant, number of spikelets/spike and number of seeds/spike; **Fang 60** for spike length and number of seeds/spike; and **Sonora 64** for plant height, spike length and number of seeds/spike. Under boron supplemented condition, **Sonalika** proved to be high general combiner for grain yield/plant along with other characters studied except plant height. **UP 262** was good general combiner for grain yield/plant number of spikelets/spike and number of seeds/spike. For protein content, **Sonora 64**, **Sonalika** and **UP 262** were good general combiners under both boron deficient and boron supplemented conditions while **Fang 60** was found to be good general combiner under boron deficient condition only. For gluten content, **Fang 60**, **Sonalika** and **UP 262** were good general combiners under both conditions while **Aghrani** was good general combiner under boron deficient condition only.

Under boron deficient condition, **DL 784-3 x Sonalika** with the highest *sca* effects for grain yield/plant also had high *sca* for number of tillers/plant, number of spikelets/spike and number of seeds/spike. Crosses such as **DL 784-3 x Fang 60**, **HD 2285 x UP 262**, **Aghrani x Akbar**, **DL 784-3 x Sonora 64**, **Fang 60 x Akbar**, **DL 784-3 x HD 2285** and **UP 262 x Akbar** exhibited high *sca* estimates for grain yield/plant along with significant *sca* for number of tillers/plant or number of seeds/spike or both. The cross **UP 262 x Sonora 64** with significant *sca* and high *per se* performance also had significant *sca* for number of spikelets/spike. Under supplemented condition, **DL 784-3 x Sonalika** had high *sca* with highest grain yield/plant. High *sca* estimates were noted in **UP 262 x Sonora 64** for grain yield/plant, number of tillers/plant and 250 grain weight; **Aghrani x Akbar** for grain yield/plant, number of spikelets/ spike and 250 grain weight; **DL 784-3 x Akbar** and **HD 2285 x Sonalika** for grain yield/plant and number of tillers/plant; and **Sonalika x Sonora 64** for grain yield/ plant and number of seeds/ spike.

The cross-combinations **HD 2285 x Sonora 64**, **Sonalika x Fang 60**, **UP 262 x Aghrani**, **Sonora 64 x Fang 60** and **Sonalika x Sonora 64** under boron deficient condition and **Sonalika x Sonora 64**, **Sonalika x Fang 60** and **UP 262 x Aghrani** under boron supplemented condition, which exhibited significant *sca*, good *per se* performance with one or both parents to be good general combiner, were considered to be promising for protein content (For gluten content, **Sonalika x Akbar**, **UP262 x Aghrani** and **DL 784-3 x Sonalika** under boron deficient condition and **UP 262 x Aghrani** and **Sonalika x Fang 60** under boron supplemented condition had high *sca* effects which involved one or both parents to be good general combiner.)

It was interesting to note that significant heterosis over mid parent or better parent for grain yield/plant was obtained in several crosses which also showed high heterosis for number of tillers/plant and significant *sca* effects for grain yield/ plant (Under boron deficient condition, the cross **HD 2285 x UP 262** showed significant heterosis over the better parent for grain yield/plant and number of tillers/ plant and over the mid parent for spike length along with significant *sca* for grain yield/plant.) However, both the parents were poor general combiners. The cross **UP 262 x Sonora 64** showed significant heterosis

over better parent for grain yield/plant and number of tillers/plant with significant *sca* for grain yield/plant. Both **UP 262** and **Sonora 64** were good general combiners (Under boron supplemented condition, **DL 784-3 x Akbar** exhibited significant heterosis over the better parent for grain yield/ plant and number of tillers/ plant along with significant *sca* effects.) However, both the parents were poor general combiners for grain yield/plant. **DL 784-3 x Sonalika** and **DL 784-3 x UP 262** showed significant heterosis over the mid parent with good *per se* performance along with appreciable heterosis for number of tillers/plant. However, the latter cross failed to show significant *sca* effect. In both these crosses, one of the parent involved was good general combiner.

As regards quality parameters, **HD 2285 x Sonora 64** and **Sonora 64 x Fang 60** showed significant heterosis over the mid parent for protein content. These crosses also had high *sca* with one of the parent being good general combiner. For gluten content, **UP 262 x Aghrani** exhibited significant heterosis over the mid parent, high *sca*, good *per se* performance and involved parents with high *gca* effects.

The present study also revealed the feasibility of simultaneous improvement of yield and protein or yield and gluten in certain cross-combinations.)

CONCLUSION

1. The grain yield/plant of **Fang 60** followed by **Sonalika** and **Sonora 64** were highest amongst the twentyfive genotypes evaluated under boron deficient conditions, while marginal increase was noted with boron application. These genotypes can be regarded as best donors for the development of lines tolerant to boron deficiency.
2. Selection for characters such as number of tillers/plant and number of seeds/spike would be highly effective under boron deficient condition as these characters exhibited high estimates of heritability and genetic advance which are indicative of additive genes.

3. Plant height and gluten content were found to be strongly influenced by additive type of gene action as the *sca* effects were non-significant. Both additive and non additive components of gene actions contributed significantly in the inheritance of all other characters studied. Predominance of one or the other component varied from character to character and boron level.
4. To exploit both additive and non additive gene action, population improvement like concurrent random mating along with mass selection (Redden and Jensen, 1974) in early segregating generations could be a dependable breeding procedure for improvement of bread wheat for tolerance to boron deficiency. Multiple crosses followed by intermating among the desirable selected plants in later segregating generations may also be of much use for simultaneous exploitation of additive and non additive gene effects for developing lines suitable for boron deficient soils.
5. The *gca*, *sca* and heterosis estimates predicted the feasibility of further upgrading of yield along with protein or gluten content from certain cross combinations which would include the genotypes like **Sonalika**, **Fang 60**, **Aghrani** and **Sonora 64**.

Chapter 7

FUTURE SCOPE OF RESEARCH

Sonalika and **Fang 60** outyielded the remaining twenty three genotypes under boron deficient condition. Potentiality of these genotypes needs to be critically evaluated by conducting multilocational trials in different zones having inherent problem of boron deficiency. This will help to recommend highly promising lines suitable for problem areas.

For improvement of bread wheat under boron deficient soils, attention must be paid to those characters showing high heritability and genetic advance which will help selection of desirable genotypes.

Both additive and non additive gene actions needs to be exploited through population improvement like concurrent random mating along with mass selection for improvement of bread wheat under boron deficient condition.

Selection of the appropriate cross-combinations for yield alone or for yield and quality parameters would be the most important aspect for generating improved lines suitable for boron deficient soil conditions. The cross-combinations **DL 784-3 x Sonalika**, **DL 784-3 x Fang 60**, **DL 784-3 x Sonora 64** and **Fang 60 x Akbar** involving susceptible x tolerant or tolerant x susceptible (to boron deficiency) types are expected to throw up desirable transgressive segregants, which could be exploited for further breeding work. The exploitation of **Fang 60**, **Sonalika** and **Sonora 64** should be more extensive, exclusively for boron deficiency tolerance where population improvement should include selection for tolerance against major diseases and pest.

Considering grain yield and quality, the combinations **DL 784-3 x Sonalika** for yield and gluten content, and **Aghrani x Akbar** for yield and protein content are expected to provide advantageous recombinants for simultaneous improvement through appropriate breeding strategy under boron deficient condition. The possibility of simultaneous upgradation of yield and quality may be taken up by including other genotypes having high protein and gluten content.

BIBLIOGRAPHY

- Ahmad, Z., Katiyar, R.P., Ram, L. and Khanna, A.N. (1977) Gene action and selection - parameters in macaroni wheat. *Indian J. Agric Sci.* **47**: 417-421.
- Ahmed, I., Khattak, J.K., Perveen, S. and Jabeen, T. (1979) Effect of boron on the yield and crude protein of wheat. *Pakistan Journal of Scientific and Industrial Research*, **22**(5): 248-250.
- Ali, S.J. and Monoranjan, R. (1989). Effect of NPK and micronutrients in controlling sterility of wheat. *Fertilizer News*, **34**(2): 35-36.
- Anonymous, (1989). Agriculture in northern districts of West Bengal - profile and prospects. A Bidhan Chandra Krishi Viswavidyalaya, N.B. Campus publication, pp 103.
- Arora, S.K. and Chandra, S. (1980). Genetic analysis of some quality characters in wheat. *Indian J. Genet.*, **40**: 316-321.
- Atale, S. B. and Vitkare, D.G. (1996) Manifestation of hybrid vigour in some quality traits in bread wheat. *PKV. Res. J.*, **20**(2): 126-129.
- Baker, R.J. (1978). Issues in diallel analysis. *Crop Sci.*, **18**: 533-536.
- Bhatia, R.S., Ahmed, Z., Sharma, J.C., Srivastava R.R. and Khanna, A.N. (1978) Heritability and genetic advance from F₁ to F₄ diallel generations in spring wheat. *Indian J. Genet.*, **38**: 155-159.
- Bhowmik, A., Sadeque, Z. and Ali, M.S. (1991) Combining ability analysis in wheat (*Triticum aestivum* L.) *Annals of Bangladesh Agriculture*, **1**(1): 13-18.
- Bhuller, G.S., Gill, K.S. and Khehra, A.S. (1974). The diallel analysis of the protein content in successive generations of bread wheat (*Triticum aestivum* L. em. Thell) *Crop Improv.*, **4**(2): 177-183.
- Biever, K.J., Johnson, V.A., Haunold, A. and Schmidt, J.W. (1966), Inheritance of plant height, yield of grain and other plant and seed characteristics in a cross of hard red winter wheat. *Crop Sci.*, **6**: 336-338.
- Bitzer, M.J., Patterson, F.L. and Nyquist, W.E. (1967). Diallel analysis and gene action in crosses of *Triticum aestivum* L. *Agronomy Abstract* (Madison), p 4.

- Borghini, B. and Perenzin, M. (1994) Diallel analysis to predict heterosis and combining ability for grain yield, yield components and bread-making quality in bread wheat (*Triticum aestivum* L). *Theor. Appl. Genet.*, **89** (7/8): 975-981.
- Borlaug, N.E. (1968) Wheat breeding and its impact on world food supply. In: *Proc. 3rd Int. Wheat Genet. Symp.*, pp 1-36.
- Brojevic, K. (1984) Significance of experimental heritability estimates in wheat breeding [Abstract]. In: Efficiency in plant breeding- Proceedings of the 10th congress of the European Association for Research on Plant breeding, EVCARPA, Wageningen, The Netherlands, 19-24 June 1993 (Lange W., Zeven A.C. and Hogenborn N.G.-Eds.) Wageningen, The Netherlands; Pudoc (1984), pp 297.
- Brown, C.M., Weibel, R.P. and Seife, R.D. (1966). Heterosis and combining ability in common winter wheat. *Crop Sci.*, **6**: 382-383.
- Burton, G. W. (1952) Quantitative inheritance in the interpretation of numerical plantation data. *New Zealand J. Sci.* **6**: 39-59.
- Chakraborty, S.K. and Tiwari, V. (1955). Heterosis in bread wheat. *J.Birsa Agri. Univ.* **7**(2): 109-111.
- Chapman, S.R. and McNeal, F.H. (1970). Gene effects for grain protein in five spring wheat crosses. *Crop Sci.*, **10**: 45-46.
- Chatterjee, B.N., Chatterjee, M. and Das, N.R. (1980) Note on the differences in the response of wheat varieties to boron. *Indian J. Agric. Sci.*, **50**(10):796.
- Chaudhry, M. A., Khan, A. S., Ahmed, B. and Shah, M.L. (1985) Diallel analysis for yield and some of its components in bread wheat. *Journal of Agricultural Research. (Pak.)*, **21**(2): 39-45.
- Chaudhry, M.A., Sattar, A., Subhani, G.M. and Khan, G.S.(1992) Combining ability estimates in spring wheat (*Triticum aestivum* L.). *Journal of Agricultural Research (Pak.)* **30**(2):153-160.
- Cheng, C. and Rerkasem, B. (1992) Effects of boron on male fertility in wheat. In: Boron deficiency in wheat-Mann, C.E. and Rerkasem, B. (Eds.). Mexico, DF (Mexico). CIMMYT. 1992, pp 5-7.

- Dani, H.M., Saini, H.S. and Sareen, K. (1970). Effect of boron on starch and protein contents of wheat grains. *Curr. Sci.*, **39**(10): 235-236.
- Das, M.K. and Rahman, L. (1984) Estimates of genotypic and phenotypic variability, heritability and genetic gain in common wheat. *Bangladesh Journal of Agricultural Research*, **9**(1) 15-18.
- Dasgupta, T. and Mandal, A.B. (1988). Diallel analysis in wheat. *Indian J. Genet.*, **48**: 167-170.
- Day, G.E., Paulsen, G.M. and Sears, R.G. (1985) Nitrogen relations in winter wheat cultivars differing in grain protein percentage and stature. *J. Plant Nutr.*, **8**: 555-566.
- Dugger, W.M. (1983) Boron in plant metabolism. In: Inorganic plant nutrition - Lauchli, A and Bielecki, R.L. (eds.) *Encycl. Plant Physiol., New Ser.*, Vol. 15 B, Springer Verlag, New York, pp 626-650.
- Edward, L.H., Ketata, H. and Smith E.L. (1976) Gene action of heading date, plant height and other characters in winter wheat cross. *Crop Sci.*, **16**: 275-277.
- Ellison, F.W., Pederson, D.G. and Devera, N. F (1977) Selection of higher yield and grain protein percent in wheat. *SABRAO 3rd Intl. Congr. Pl. Breed. Paper* **2**: 5(a) 36-39.
- Frey, K.J. (1975) Breeding concept and techniques in self pollinated crops In: Proc. 1st. Workshop on Grain Legumes, ICRISAT, Hyderabad. Oct. 9-12, pp 257-258.
- Gandhi, S.M., Nathawat, K. S. and Bhatnagar, M.P. (1963) Influence of nitrogen fertilization on yield and its components in wheat. *Indian J. Genet.*, **23**(3): 241-249.
- Gandhi, S. M., Sanghi, A.K., Nathawat, K. S. and Bhatnagar, M.P. (1964). Genotypic variability and correlation co-efficients relating to grain yield and a few other quantitative characters in Indian Wheat. *Indian J. Genet.*, **24**: 1-8.
- Ganguly, B. (1979) Note on seedlessness in some wheat varieties caused by boron deficiency. *Indian J. Agric. Sci.*, **49**(5): 384-386.
- Gauch, H.G. and Dugger, W.M. (1953) The role of boron in the translocation of sucrose. *Plant Physiol.*, **28**: 457-466.

- Gharzai, M.K., Schmidt, J.W. and Mattern, P.J.(1983). Grain yield and protein inheritance in five generations of hard red winter wheat (*Triticum aestivum* L.) [Abstract]. In-Agronomy Abstracts (Madison), pp 65.
- Gill, K.S., Dhillon, S.S. and Bains, K. S. (1972) Combining ability and inheritance of yield components in crosses involving Indian and Exotic wheat germplasm. *Indian J. Genet.*, **32** (3): 421-430.
- Gill, K.S., Dhillon, S.S. and Arora, B.S. (1974) Line x Tester analysis of combining ability and heterosis in wheat. *Indian J. Genet.*, **34**: 49-55.
- Gill, K.S., Nanda, G.S., Gurdev, S. and Sehgal, K.L. (1979) Inheritance of grain number, grain size, protein content and grain yield in spring x winter wheat crosses. *SABRAO J.*, **11**: 1-7.
- Gill, K.S., Bhuller, G.S., Dhillon, B. S. and Khera, A. S. (1994) Comparative evaluation of combining ability and graphical analysis of diallel cross. *Proc. Indian natl. Sci. Acad.*, B **50** (3): 337-347.
- Gomez, K. A. and Gomez, A. A. (1983). *Statistical Procedures For Agricultural Research*. An IRRI Book, John Wiley & Sons, New York.
- Goswami, K. (1967). Genetic analysis of adaptation of bread wheat. Ph.D. Thesis, (Unpublished.), Division of Genetics, IARI.
- Griffings, B.(1956) Concept of general and specific combining ability in relation to diallel crossing system. *Aust J.Biol. Sci.*, **9**: 463-493.
- * Hanna, A.S.(1973). Diallel analysis of some traits in wheat. *Alex. Agri. Res.*, **21**: 33-40.
- Hanson, W.D. (1951) Heritability in statistical Genetics and Plant Breeding. National Academy of sciences, National Research Council, Washington, pp 125-140.
- Hanson, W.D., Robinson, H.F. and Comstock, R.E. (1956). Biometrical studies of yield in segregating population of Korean Lespedeza. *Agron. J.*, **48**: 268-272.
- Hassan, A.M., Abdel-sabour, M. S., Abdel-Shafi, A.S., Sherif, H. S. and Hamada, A.A. (1996) Genetical analysis of diallel cross in bread wheat under different environmental conditions in Egypt. I. F₁ and Parents. *Indian J. Genet.*, **56**(1) 34-48.

- Hossain, M.A., Jahiruddin, M., Hoque, M.S. and Ali, M.I. (1994) Effect of genotype and sowing date on the response to boron in wheat *Pakistan Journal of Scientific and Industrial Research*, **37**(10): 432-435
- Hsu, P. and Walton, P. D. (1971) Relationship between yield and its components and structures above the flag leaf node in spring wheat. *Crop Sci.*, **11**: 190-193.
- Ibrahim, K. (1994) Heterotic performance and combining ability in factorial crosses of bread wheat. *Annals of Agricultural Sciences*, **32**(3): 1167-1179.
- Islam, M.A., (1976) Genotypic and phenotypic variability in yield and other quantitative characters in common wheat. *Pakistan Journal of Scientific Research*, **28**: 41-44.
- Jackson, M. L. (1967). Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi.
- Jahiruddin, M., Hoque, M.S., Haque, A.K.M.M. and Roy, P.K. (1992) Influence of boron, copper and molybdenum on grain formation in wheat. *Crop Res.*, **5**(1): 35-42.
- Jamjod, S., Mann, C.E. and Rerkasem, B. (1991) Combining ability of the response to boron deficiency in wheat. In: The Fourth International Symposium on Genetic Aspects of Plant Mineral Nutrition, **30** Sep - 4 Oct. 1991. Canberra, Australia, 1993, pp 359-361.
- Jarnail, S. and Anand, S.C. (1971) Inheritance of grain number in wheat. *Indian J. Genet.*, **31**: 177-183.
- Jatasra, D.S. and Paroda, R.S. (1983). Combining ability studies in wheat (*Triticum aestivum* L.). *Haryana Agric. Univ. J. Res.*, **13** (1): 49-54.
- Jatasra, D.S., Solanki, K.R., Singh, D.P. and Yadav, J.S. (1978). Gene action for grain protein in wheat. *Cereal Res. Commun.*, **6** : 273-275.
- Jensen, N.F. (1970). A diallel selective mating system for cereal breeding. *Crop Sci.*, **10**:629-635.
- * Jin, Z., Zhao, X. and Yan, W. (1995) A research on combining ability of protein content in grains of wheat hybrid progeny. *Journal of Northeast Agricultural University (China)*, **26**(2): 120-124.
- Johnson, H. W., Robinson, H. F. and Comstock, R.E. (1955) Estimates of genetic and environmental variability in soybeans. *Agron. J.*, **47**: 314-318.

- Johnson, V.A., Schmidt, J.W., Mattern, P.J. and Haunold, A (1966). Agronomy and quality characteristics of high protein F₂-derived families from a soft red - hard red winter wheat cross. *Crop. Sci.*, **6**: 7-10.
- Jones, D.F. (1958). Plasmagenes and chromogenes in heterosis. In: Heterosis. Iowa State Univ. Press, Ames, Iowa. pp 225-235.
- Joshi, A.B. and Dhawan, N.L. (1966). Genetic improvement in yield with special reference to self fertilizing crops. *Indian J. Genet.*, **26A**: 101-113.
- Ketata, H., Edwards, L.H. and Smith, E.L. (1976) Inheritance of eight agronomic characters in a winter wheat cross. *Crop Sci.*, **16**: 19-22.
- Khan, N., Bajwa, M. A. and Asi, A.G. (1986). Combining ability study in a diallel cross of five wheat varieties. *Journal of Agricultural Research (Pak)*, **6** (4): 248-251.
- Kheiralla, K.A. (1993) Selection response for grain yield and its components in a segregating population of spring wheat. *Assist. J. Agric. Sci.*, **24**(3), 87-93.
- Kibita, S. and Evans, L. E. (1984) Causes of negative correlation between grain yield and grain protein concentration in common wheat. *Euphytica*, **83**: 801-810
- Krishna, R. and Ahmed, Z. (1992) Heterosis for yield components and developmental traits in wheat. *Genetika (Beograd)*, **24**(2): 127-132.
- Kronstad, W.E. and Foote, W.H. (1984) General and specific combining ability in wheat (*Triticum aestivum* L.). *Crop Sci.*, **4**: 616-619.
- Kumar, P., Ahmed, Z., Katiyar, R.P., Gupta, R.R. and Khanna, A.N. (1977). Studies on combining ability and heterosis in macaroni wheat (*Triticum durum* desf.) *Proc. 1st Natl. Sem. Genet.*, (Ludhiana), pp 218-224.
- Kumar, R., Tripathi, I. and Luthra, O.P. (1996) Estimates of variability parameters in wheat. *Haryana Agric. Univ J. Res.*, **26**: 223-226.
- Lewis, D.H. (1980) Are there inter-relations between the metabolic role of boron, synthesis of phenolic phytoalexins and germination of pollen ? *New Phytol.*, **84**: 261-270.
- * Li, G.T., Zhu, J.B. and Zhang, S.Z. (1989) Studies on heterosis and combining ability in wheat (*Triticum aestivum* L.) *Acta Agriculturae Universitatis, Perkinensis*, **15**(3): 259-266.

- * Li, H., Wang, Y. and Lin, P. (1992) Analysis of combining ability of some qualitative traits in spring wheat. *Journal of Jilin Agricultural University (China)*, **14**(4): 9-12.
- * Li, L.Z., Lu, D.B. and Cui, D.Q. (1991) Study on the combining ability for yield and quality characters in winter wheat. *Acta Agriculturae Universitatis Henanensis*, **25**(4) 372-378.
- Malhotra, R.S. and Jain, R.P. (1973) Combining ability and inheritance studies in wheat. (*Triticum aestivum* L.) *Madras Agric. J.*, **60**: 1197-1201.
- Mandal, A.B. (1988) Effect of boron on combining ability in bread wheat. *J. Maharashtra Agric. Univ.*, **13**(3): 268-270.
- Mandal A.B. (1993) Effect of boron on different varieties of bread wheat (*Triticum aestivum* L.). *Crop Research (Hissar)*, **6** (2): 330-334.
- Mandal, A.B. and Chakraborty, S. (1988) Pollen variability, germination and percentage of seed setting in some wheat varieties in Terai soil. *Environment & Ecology*, **6**(2): 475-476.
- Mandal, A.B. and Das, A.D. (1988) Response of wheat (*Triticum aestivum* L.) to boron application. *Indian J. Agric. Sci.*, **58** (9): 681-683.
- Mandal, A.B. and Ghosal, K.K. (1985) Evaluation of wheat varieties in Terai soils. *Exptl. Genet.*, **1** (1): 29-33.
- Mandal, A.B. and Ghosal, K. K. (1988) Combining ability of wheat genotypes in Terai Soils. *Exptl. Genet.*, **4** (1): 1015.
- Mandal, A.B. and Singharoy, A.K. (1989) Selection of some wheat genotypes on terai soil. *Environment & Ecology*, **7** (4): 978-979.
- Mandal, A.B. and Maity, S.S. (1992) Combining ability analysis over micronutrient environments (Boron) in wheat. *Exptl. Genet.*, **8**(1/2): 53-57.
- Mandal, A.B. Chowdhury, P.R. and Sarkar, K.K. (1994) Overcoming incompatibility of bread wheat *Crop Research (Hissar)*, **7**(2) 252-255.
- Matuz, J. and Bebe, B. (1996) Inheritance of quality traits in two durum wheat (*Triticum durum* Desf.) crosses *Cereal Res. Commun.*, **24**(2): 203-210.

- Matzinger, D. F., Mann, T.J. and Cockerham, C.C. (1962). Diallel crosses in *Nicotiana tabacum*. *Crop Sci.*, **2**: 383-386.
- Maurya, D. M. and Singh, D.P. (1978) Heterosis in rice. *Indian J. Genet.*, **38**: 71-76.
- McNeal, F.H., Berg, M.A., Mcguire, C.F., Steward, V.R. and Baldrige, D.E. (1972) Grain and plant nitrogen relationships in eight spring wheat crosses. *Crop. Sci.*, **12** : 599-602.
- Mertz, E.T., Bates, L.S. and Nelson, O.E. (1964) Mutant gene that change protein composition and increase lysine content of maize endosperm. *Science*, **145**: 279-280.
- Milanko, S. (1988) Combining ability for seed protein content in wheat. *Cereal Res. Commun.*, **16** (3-4): 189-193.
- Mishra, P.C., Singh, T.B., Singh, O.P. and Jain, S.K. (1994). Combining ability of grain yield and some of its attributes in bread wheat under timely sown condition. *International Journal of Tropical Agriculture*, **12** (3/4): 188-194.
- Mitra, A.K. and Jana, P.K.(1991) Effect of doses and method of boron application on wheat in acid Terai soils of North Bengal. *Indian J. Agron.*, **36**(1): 72-74.
- Nagarajan, S. 1996. Wheat- All-out effort needed. In: The Hindu Survey of Indian Agriculture (1996), pp 59-65.
- Nagarajan, S. 1997. Wheat - Promise of value added products. In : The Hindu Survey of Indian Agriculture (1997), pp 45-47.
- Nanda, G.S. ,Virk, P.S. and Gill, K. S. (1983). Diallel analysis over environments in wheat - Yield and its environment. *Indian J. Genet.*, **43**: 14-20.
- * Nedelea, G. and Moisuc, A (1982) [Genetic and environmental effects on some aspects of wheat grain quality]. *Effectele genetice si de mediu asupra unor insusiri de calitate la griu. Probleme de Genetica Teoretica Si Aplicata*, **14** (6): 431-436.
- Osanai, S.I., Sasaki, H. and Gotoh, K. (1977). Selection experiment for combining high quality and yield in hard red spring wheat. *SABRAO. 3rd Intl. Congr. Pl. Breed. Paper.* **2**: 43-46.

- Palve, S.M., Thete, R.V., Dumbre, A.D. and Hapse, R. A. (1986) Heterosis in wheat (*Triticum aestivum* L.). *Current Research Reporter* (Mahatma Phule Agricultural University), **2**(2): 179-183.
- Panse, V. G. (1957) Genetics of quantitative characters in relation to Plant Breeding. *Indian J. Genet.*, **17**: 318-328.
- Panse, V.G. and Sukhatme, P.V. (1954). Statistical methods for Agricultural Workers. ICAR, New Delhi.
- Patel, H.S., Manake, B.S., Chavan, V.W. and Kachole, V.G. (1995) Diallel analysis in bread wheat. *Indian J. Genet.*, **55** (3): 320-323.
- Pathak, N.N., Nema, D.P. and Sheopuria, R.R. (1986). Genetic advance in wheat under high temperature and rainfed conditions. *Indian J. Genet.*, **46**(2): 339-344.
- Pawar, I.S., Paroda, R.S. and Singh, S. (1988) Gene effects for six metric traits in four spring wheat crosses. *Indian J. Genet.*, **48** (2): 195-199.
- Raghavaiah, P. and Joshi, M.G. (1986) Combining ability studies in Emmer wheat. *Indian J. Genet.*, **46**(3) 476-483.
- Raina, R., Singh, R.B. and Sharma, G.S. (1979.) Combining ability for grain quality in spring wheat. *Indian J. Genet.*, **39**(2): 225-229.
- Raina, R., Sharma, G.S. and Singh, R.B. (1982). Path co-efficient analysis of some yield and quality characters in normal and EMS treated varieties of bread wheat. *Indian J. Agric. Sci.*, **52**: 53-58.
- Ram, H.H. and Srivastava, J.P. (1983) Inheritance of grain protein and sedimentation value in wheat. *Indian J. Genet.*, **35**(1): 21-25.
- Ram, H.H. and Singh, H. G. (1994). Crop Breeding and Genetics. Kalyani Publishers. India. pp 510.
- Ranga Rao, V. and Murthy, B.R. (1970) Fractional diallel analysis of some quality characters in bread wheat. *Indian J. Genet.*, **30**(3): 716-726.
- Rathore, R.K.S. and Chauhan, S. S. (1986) Heterosis studies in spring wheat. *Madras Agric. J.*, **73**(8): 425-428.
- Redden, R.J. and Jensen, N.F. (1974) Mass selection and mating systems in cereals. *Crop Sci.*, **14**: 345-350

- Redhu, A.S., Singh, R.K. and Luthra, O.P. (1986) Trend of heterosis for grain yield and its components in bread wheat. *Haryana Agric. Univ. J. Res.*, **17** (1) 4-11.
- Rerkasem, B. and Saunders, D.A.(1993). Grain set failure in warm, non traditional wheat growing areas of Asia-The boron reponse. Wheat in heat stressed environments: irrigated dry areas and rice-wheat farming systems. Proceedings of the International Conferences, held at Wad Medani, Sudan, 1-4 Feb. 1993 and Dinajpur, Bangladesh 13-15 Feb. 1993, pp 290-296.
- Rerkasem, B and Loneragen, J.F. (1994) Boron deficiency in two wheat genotypes in a warm, subtropical region. *Agron J.*, **86**(5): 887-890.
- Roy, S.K. and Pradhan, A.C. (1994). Effect of method and time of boron application on wheat (*Triticum aestivum* L.) production in terai soil of West Bengal. *Indian J. Agron.*, **39** (4): 643-645.
- Rudraradhya, M., Habib, A.F. and Joshi, M.S.(1984) Variability studies of some quantitative characters in sesamum. *J. Oilseeds Res.*, **1**: 179-182.
- * Saakyan, G.A. (1975), Heterosis in hybrids of *Triticum aestivum* L. *Referatiunyi Zhurnal*, **12**: 142-144.
- Sarkar, D.D., Joardar, O. J. and Hossain, M. (1987) Combining ability analysis in wheat. *Environment & Ecology*. **5**(4): 809-810.
- Sharma, D., Bhadouria, S.S. and Malik, H.C. (1975) Genetic parameter and their implication in breeding high yielding varieties of wheat. *Indian J. Agric. Sci.*, **45**: 311-316.
- Sharma, J.C., Ahmed, Z. and Khanna, A.N. (1978). Combining ability in relation to wheat breeding. *Indian J. Genet.*, **38**: 78-85.
- Sharma, R.K and Tandon, J.P. (1997). Combining ability analysis in relation to heat stress for some morphological characters in wheat (*Triticum aestivum* L.) *Indian J. Agric. Res.*, **31**(2) : 87-92.
- Sharma, R.N. and Das, N (1982) Response of wheat to application of Zn, B and Mo *J. Maharashtra Agric. Univ.*, **7**(2) 155-157.
- Sharma, S.K., Singh, I and Singh, K.P. (1986). Heterosis and combining ability in wheat (*Triticum aestivum* L). *Crop Improv.*, **13**(1): 101-103.

- Sharma, S.K., Singh, K.P. and Singh, I. (1991) Selection responses for grain weight in some intermated populations of wheat, *Golden Jubilee Symp. of Genet. Res. Edu.*, IARI, New Delhi, **2**:273.
- Sharma, S.N. and Menon, U. (1996) Heterosis over environments in bread wheat. *Crop Improv.*, **23**(2): 225-228.
- * Sherell, C.G. (1983). Effect of boron application on seed production of New Zealand herbage legumes. *New Zealand Journal of Experimental Agriculture*, **11**: 13-117.
- Sindhu, J. S. and Singh, R. B. (1975). Heterosis in wheat. *Indian J. Genet.*, **35**: 467-469.
- Singh, B. and Singh, S.C. (1976) Effect of boron on quality and yield of wheat grains (R.R.21) *Proc. Indian Natl. Sci. Acad.*, **42** (2/3): 130-134.
- Singh, D., Srivastava, R.B. and Singh, V.P. (1982) Combining ability in bread wheat. *Indian J. Agric. Sci.*, **52**: 355-359.
- Singh, G., Nanda, G. S. and Gill, K. S. (1984) Inheritance of yield and its components in five crosses of spring wheat. *Indian J. Agric. Sci.*, **54** (11): 943-949.
- Singh, H. M., Sinha, S.D. and Prasad, R.B. (1976) Effect of boron on seed setting in wheat under North Bihar conditions. *Indian J. Agron.*, **21**(2): 100-101.
- Singh, I. and Yunus, M. (1993) Combining ability analysis over environments in bread wheat. *Haryana Agric. Univ J. Res.*, **23** (2): 119-121.
- Singh, I., Paroda, R.S. and Singh, S. (1987). Estimation of genetic parameters for some quantitative traits in spring wheat. *Haryana Agric. Univ J. Res.*, **17**(4) 364-369.
- Singh, K. B. and Gupta, V.P. (1969) Combining ability in wheat. *Indian J. Genet.*, **29**(2): 227-232.
- Singh, K. N., Ahmed, Z., Gupta, M. P. and Singh, A. K. (1978) Variability, heritability and genetic advance for some metric traits in macaroni wheat. *Indian J. Agric Res.*, **12**: 237-240.
- Singh, K.N., Ahuja, P.S. and Rana, R.S. (1983) Combining ability in alkali soil. *Indian J. Genet.*, **43**(3) 441-441.
- Singh, R.K., Ahmed, Z., Singh, Y. P. and Singh, K.N. (1986) Combining ability for some metric traits in bread wheat. *Indian J. Genet.*, **46**(2) 304-310.

- Singh K. N. and Chatrath, R. (1997) Combining ability studies in bread wheat (*Triticum aestivum* L. em. Thell) under salt stress environments. *Indian J. Genet.*, **57**(2):127-132.
- Singh, S. and Singh, R. S. (1978) A study of gene effects in three wheat crosses. *J. Agric. Sci. (Camb)*. **91**: 9-12.
- Singh, S and Dahiya, M. S. (1984). Detection and estimation of components of genetic variation and genotype x environment interaction in three wheat crosses. *J. agric. Sci. (Camb)*. **103**: 543-547.
- Singh, S. P., Verma, M., Deodhar, A. D. and Gupta, A.K. (1978) Genetics of protein content and proteolytic activity in wheat. *Indian J. Genet.* **38**: 25-30.
- Singh, V., Singh, R.P. and Singh, Vinay (1992). Effect of Mo and B application on yield and their uptake by wheat. *J. Indian Soc. Soil Sci.*, **40** (4): 876-877.
- Singhhal N.C. Jain H.K. and Austin A (1977) Improving bread wheat for protein content. Pl. Breed. Paper 2. 3rd Int. Cong. SABRAO, PP. **5(a)** 39-43.
- Sokol, M. J. and Baker, R.J. (1977). Evaluation of the assumptions required for the genetic interpretation of diallel experiments in self pollinating crops. *Can. J. Plant Sci.*, **57**: 1185-1191.
- Srivastava, J. P. and Ram, H.H. (1974) Consideration on improvement in grain quality characters in wheat. *Indian J. Genet.*, **34**: 610-620.
- Srivastava, R.B., Paroda, R.S., Luthra, O.P. and Goyal, K.C. (1982) Genetic architecture of yield components and yield in durum wheat. *Indian. J. Agric. Sci.*, **52**: 58-62.
- Tandon, J.P. (1967) Inheritance of Protein content in an intervarietal cross of wheat (*Triticum aestivum* L.) *J. Res. Punjab Agric. Univ.*, **4**: 348-352.
- Terman, G.L., Ramig, R.E., Dreier, A.F. and Olson, R.A. (1969). Yield-protein relationships in wheat grain, as affected by nitrogen and water. *Agron. J.*, **61**: 755-759.
- Thakral, S.K., Luthra, O.P, Behl, R.K. and Dhindsa, K. S. (1986). Combining ability analysis for grain protein and quality traits in wheat. *Annals of Biology*, **2**(2): 136-142.
- Thakre, J.T. (1982) Genetic analysis of yield and its components in wheat (*Triticum aestivum* L.). Ph.D. thesis (Unpublished), PKV, Akola.

- Uddin, M. N., Ellison, F. W., O'Brien, L. and Lather, B.D. (1992). Heterosis in F_1 hybrids derived from crosses of adapted Australian wheat. *Aust. J. Agric. Res.*, **43** (5): 907-919.
- Varughese, G. and Swaminathan, M.S. (1967) Sharbati Sonora - a symbol of the age of algey. *Indian Fmg.*, **17**(5): 8-9.
- Vitkare, D.G. and Atale, S.B. (1990). Genetics of quality traits in bread wheat. *PKV Res. J.*, **14**(2): 97-100.
- Vitkare, D.G. and Atale, S. B. (1991) Studies on heterosis for the yield attributes in 15 x 15 diallel in wheat (*Triticum aestivum* L.). *PKV Res J.*, **15**(2): 111-116.
- Vitkare, D.G. and Atale, S.B. (1996). Gene effects of some yield components in bread wheat (*Triticum aestivum* L.). *PKV Res. J.*, **20** (2): 122-125.
- Walia, D.P., Tashi, D., Plaha, P. and Choudhury, H.K. (1993) Gene action and heterosis in bread wheat. In : Heterosis Breeding in Plants-Theory and application: Verma, M.M., Virk, D.S. and Chahal, G.S. (Eds). pp (834-835)
- Walton, P.D. (1969) Heterosis in spring wheat. *Can. J. Pl. Sci.*, **49**: 587-596.
- Yadav, M.S. and Singh, I. (1989). Heterosis and combining ability in bread wheat. *Haryana Agric. Univ. J. Res.*, **19**(2): 149-156.
- Yadav, R.K. and Mishra, R. K. (1993). Genetic analysis of wheat varieties for yield and its components under rainfed conditions. *Agricultural Science Digest* (Karnal), **13** (1): 6-8.
- Yadav, S.P. and Murty, B. R. (1976) Heterosis and combining ability in crosses of different height categories in bread wheat. *Indian J. Genet.*, **36** (2) 184-196.
- * Yin, J., Yin, J. Y. and Chen, Q.S. (1997). A study on the use of wheat heterosis in the Beijing area- an analysis of heterosis in certain important wheat varieties and lines. *Beijing Journal of Agricultural Sciences*, **15** (2): 13-15.

* Original not seen