COMBINING ABILITY ANALYSIS ON HEAT TOLERENT WHEAT

GENOTYPES (*Triticum aestivum* L.)

A Thesis
By

Student No: 0905023

Registration No: 0905023

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MASTER OF SCIENCE (M.S.)
IN
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DEPARTMENT OF GENETICS AND PLANT BREEDING
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Dedicated to my Parents

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ABSTRACT

Studies on combining ability including components of genetic variance and magnitude gene action in wheat were done in six diallel crosses including reciprocals. The experiment was conducted at the experimental field of Wheat Research Centre, BARI, Nashipur, Dinajpur during 2007-2008 and 2009-2010 winter season. The parental genotypes were six high yielding viz. Shatabdi, Sufi, Bijoy, Prodip, Line-1040 & Line-1018. The study covered yield and contributing characters along with morphological marker for DUS test.

Combining ability studies on 11 economic characters had significant mean squares for general combining ability (gca), specific combining ability (sca), and reciprocals. Both general combining ability (GCA) and specific combining ability (SCA) variances were significant for all the characters except spike length Preponderance of additive gene action was noticed for these characters. The parent Shatabdi was the best general combiner for grain yield and some other yield contributing characters. 'Shatabdi x Sufi' and 'Bijoy x Prodip' were the best specific crosses for attaining higher grain yield per plant. The cross combination 'Bijoy x Prodip, Shatabdi x Sufi the best specific crossess which could be exploited to produce prospective genotypes with desirable spike architecture. Significant positive reciprocal effects were obtained from 'Shatabdi x Sufi, Bijoy x Line1040' and 'Shatabdi x Bijoy for 1000-grain weight .The partial dominance was estimated for plant height, spikes /plant and spike length. Gourob possessed most of the recessive genes for spikes/plant, 1000-grain weight and grain yield/plant. Shatabdi possessed most of the dominant genes for grains/spike, 1000-grain weight, harvest index and grain yield. Estimates on the component of variance revealed that dominant and recessive alleles were unequally distributed in the parents for all the traits and satisfying the additive-dominance genetic model. Number of dominant gene block was the highest in grains/spike and the lowest in spikelet/spike.

SYMBOLS AND ABBREVIATIONS

<	= smaller than
>	= greater than
a	= additive genetic component
ANOVA	= analysis of variance
BARI	= Bangladesh Agriculture Research Institute
cm	= centimeter
Df	= degree of freedom
E	= expected environmental component of variation
Expt	= experiment
Fig.	= figure
g	= gram
GCA, gca	= general combining ability
h^2	= net dominance effect
h^2_{ns}	= heritability in narrow sense
HI	= harvest index
kg	= kilogram
Me	= mean square due to error
Mg	= mean square due to gca
Ms	= mean square due to sca
MS	= mean square
RCB	= randomized completely block
SCA, sca	= specific combining ability
SE	= standard error

CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Chronic food deficits coupled with increasing population pressure and frequent low production or crop failure due to natural calamities warrant maximizing food production in Bangladesh. Wheat is the second most important cereal crop in Bangladesh next to rice constituting15.2%of the staple cereal food. Currently wheat is grown in an area of 0.4 million hectares during 2009-2010 with production of 1 million ton (Anonymous, WRC, BARI, Nashipur, Dinajpur). Wheat although is an introduced crop, Bangladesh has already achieved an important headway in its production (CIMMYT, 1982). The varieties grown in Bangladesh belong to heat tolerant bread wheat (*triticum aestivum* L.). Though the crop has a long international history of extensive breeding research and genetic studies (Vogel *et. al.*1956 and Sing *et. al.*1984), yet it is important to continue research for its improvement under Bangladesh condition.

Grain yield in heat tolerant wheat is a polygenic character resulting from the interaction of yield contributing characters influenced by environmental influences. Selection is an important tool in crop improvement programme. Selection depends upon the nature and magnitude of gene effects involved in the inheritance and also on heritability of the characters. Combining ability is also a powerful tool in identifying the best combiners that may be used in crosses either to exploit heterosis or to accumulate fix genes and obtain desirable segregates. It will help to understand the genetic architecture of various characters that enable the breeder to design effective breeding plan for future up gradation of the existing materials. This information may also be useful to breeders for identifying and genetic improvement of morphological markers essential for DUS test to release a variety. Studies on the inheritance of environmental characters suggest that they were controlled by both additive and non-additive gene actions (Paroda & Joshi, 1970). Breeding programmed differs in exploiting additive gene action than that of non-additive gene action. Many researchers have investigated combining ability for yield and yield components in wheat but information on combining ability of morphological markers is scanty. Studies on many parameters were done extensively in heat tolerant wheat for planning its improvement programmed. But the results varied from population to population due to differences in genetic background of them and the environmental conditions where such studies have been made.

Grain yield of heat tolerant wheat is a poorly heritable character, while the yield contributing characters are usually highly heritable. Selection for yield is not effective in early segregating generation. So yield contributing character s is chosen and selection indices are made to improve yield in breeding programmed (Grafius, 1964). For this reason, the relationships between different environmental traits have extensively studied by many authors (Das, 1972; Uddin, 1998).

Assuming significant genetic diversity for a trait is established, the question of how its use as a selection criterion would improve breeding efficiency can be addressed. Without experimentation, this cannot be predicted with any certainty; any more a breeder can know in advance which of many crosses will produce the desired variety. From the above information it appears that the inheritance of yield and yield contributing characters in heat tolerant wheat is important for planning a fruitful breeding programmed.

Therefore the present work has been under taken in heat tolerant wheat aiming the following objectives:

1. To determine the interrelationship between the yield other environmental traits of F1 hybrids and their parents.
2. To assess the nature and extent of combining ability for newly released wheat varieties.
3. To identify morphological markers for DUS test.

CHAPTER 2

REVIEW OF LITERATURE

2.1. Diallel analysis: concept and methodology

The method of diallel crossing system was introduced first by Schmidt (1919) in each of a group of males was crossed to each of a group female. Diallel cross was analyzed with statistical technique first by Sprague and Tatum (1942).

Diallel analysis involves crossing in all possible combining among asset of genotypes. It operates on the following genetically assumptions (Hayman, 1954):

1. Diploid segregation; 2. Only environmental difference between reciprocal crosses; 3. Independent action of non-allelic genes; 4. No multiple allelism; 5. Homozygosity of parental lines and 6. Independent distribution of genes.

But it is practically very difficult to satisfy all of these assumptions in biological populations except diploid segregation, absence of multiple allelism (until f2) and homozygosity of the parents. More than one weakness of diallel cross mating is, therefore, perceptible in practice. However, the advantages of diallel analysis as stated by Sharma (1998) are as follows:

1. It is almost balanced and systematic experimental design to examine continuous variation.

2. The genetic information related to parental populations becomes available quite in early generation (F1 itself), thus useful to define breeding strategy without much time.

3. Now there is no need for parent's to be strictly inbred or to have uniform F=1.parents as divergent as homozygous lines, clones, open pollinated varieties can be studied by diallel cross system.

Diallel analysis is most worthwhile for highly heritable traits and less useful for traits with low heritability. Diallel analysis allow for every conceivable variation in experimental design, including presence or absence of parental lines and reciprocal crosses (Yates, 1947; Hayman, 1954a; Graffing, 1956a; Jone, 1965) and varying degrees of replication of diagonal (parents) and off diagonal (f1s) entries in the diallel table (Jones, 1965). Jinks and Hayman (1953) proposed numerical approach to estimate genetic parameters based on mother's notation. They outlined four components viz.D.H1, H2and F assuming additive and dominant effects of genes but no epitasis or nonallelic interaction. Heyman (1954b) presented in detail the theory and algebraic basis of analysis and added two more statistics, h2 and fr to those suggested by Jinks and Heyman (1953). Jinks also defined the relationship between parent- offspring array variance (Vr) and covariance between offspring and non-recurrent parent (Wr). Hayman devised a graph almost similar to one developed by Jinks (1954) for determining the order of dominance and types of gene action.

2.1.1. Inheritance of grain yield and its different contributing characters in heat tolerant wheat

Any crop improvement programmed requires information of genetic control of yield and its different contributing characters .In bread wheat inheritance of yield and yield contributing characters were studied through array of analysis of the data and their implication in wheat improvement have been discussed.

2.1.1.1. Days to heading

Days to heading are an important character considered for breeding short duration crop varieties of wheat. Ghulam Hassan *et. al.* (2006) stated that early heading provided enough periods for grain filling and ultimately bold grain formation resulted. Therefore, negative combining ability effects for days to heading are desirable Kumer *et. al.* (2003) stated that magnitude of non-additive gene action was higher than the additive gene action for days to flowering and maturity. Rajesh *et. al.* (2002) observed additive gene action controlled additive gene action. Sharma *et. al.* (2001) observed that a duplicate type of epistasis controlled days to heading. Sheikh and Sing (2000) reported role of the additive genetic component in the inheritance flowering and maturity by days. Rahman *et. al.* (2000) reported both additive and non-additive gene action for days to heading. They observed comparatively high estimates of additive genetic variance over non- additive genetic variance for this trait. Shamsuddin (1988) reported additive and dominant gene actions for this trait, where additive gene action was preponderant over dominant gene action. Khalifa *et. al.* (1997) studied inheritance of this character in heat tolerant wheat and observed partial dominance for earliness.

2.1.1.2. Days to 90% maturity

Days to maturity are an important character considered for breeding of heat tolerant wheat. Days to heading are an important character considered for breeding short duration crop varieties of wheat. Kumer *et. al.* (2003) stated that magnitude of non- additive gene action for maturity. Rajesh *et. al.* (2002) observed additive gene action controlled additive gene action. Sheikh & Sing (2000) reported role of the additive genetic component in the inheritance flowering and maturity by days. Rahman *et. al.* (2000) Reported both additive and non-additive gene action for days to maturity. They observed comparatively high estimates of additive genetic variance over non- additive genetic variance for this trait. Shamsuddin (1988) reported additive and dominant gene actions for this trait, where additive gene action was preponderant over dominant gene action. Khalifa *et. al.* (1997) studied inheritance of this character in heat tolerant wheat and observed partial dominance for early maturity.

2.1.1.3. Plant height

Plant height is an important morphological yield contributing character in heat tolerant wheat. Hassan *et. al.* (2006) stated that additive gene effect were greater than non additive gene effect indicating the additive genetic control of the plant height. This character observed to be controlled by both additive and non-additive gene actions (Yae *et. al.* 2004; Lie *et. al.* 2003; and shamsuddin *et. al.* 1993). Predominance of additive gene action was reported by Rahman *et. al. (*2000); Patil *et. al. (*1995) and Malik *et. al.* (1988).

2.1.1.4. Spikes per plant

Arif *et. al.* (2007) stated that the additive gene effects operate spikes per plant. Spikes per plant are sometimes studied as tiller per plant and is one of primary yield components of bread wheat. The character is under polymeric control. Rajesh *et. al.* (2002) reported that on additive gene action regulated spikes per plant. Chawdhury *et. al. (*1999) carried out an experiment and found nature of gene action for fertile tillers per plant was controlled by partial dominance with additive gene action. The character reported to be controlled by both additive non-additive gene actions (Ali and Khan, 1998). Yadave *et. al.* observed genes controlling spikes per plant were dominant and recessive in two crosses they made. They found both additive and non-additive gene effects important for the trait in bread wheat. Patil *et. al.* (1995) and Shamshuddin *et. al.* (1993) reported that additive and non additive gene action an emphasized on importance of additive gene action for the character.

2.1.1.5. Spike length

Spike length is an important sink character in wheat. Hassan *et. al.* (2006) stated that both additive and non-additive genetic variability necessitate studies of spike length.

Long spike contain higher number of spike lets than the shorter ones. Yoe *et. al.* (2004) stated that inheritance of spike length in wheat was controlled by both additive and non-additive genes. Sharam *et. al.* (2003) stated that additive gene effect was significant for spike length. Masud and Kronstad (2000) reported that both additive and non-additive gene effects, where as Dasgupta and Mondal (1988) obtain only additive gene effects for spike length.

2.1.1.6. Spikelet per spike

Valério *et. al.* (2009) reported the higher GCA and SCA mean square values found in this study suggest that additive gene effects are more important, stabilizing the expression of the trait spikelet per spike in the F2 generation.

2.1.1.7. Grain per spike

Grain per spike is an important primary yield contributing character. Pareek and Grag (2004) reported that grains per spike were governed by preponderance of non-additive gene action. Sing *et. al.* (1998a) made 19 crosses in bread wheat and observed the presence of additive gene effect for this trait. Sing *et. al.* (1986b) reported that predominance of additive gene action for grain per spike. Both additive and dominance effect were a reported by Walton (1971).

2.1.1.8. 1000-grain weight

1000-grain weight is an important character, which belongs one of the primary yield components. Khaliq *et. al.* (2006) stated that 1000-grain weight purely controlled by dominant genes. Yoe *et. al.* (2004) reported thatboth additive non-additive genes regulated the inheritance of 1000-grain weights and the additive effects were predominant in bread wheat. Lie *et. al.* (2003) found both additive and non-additive gene effects controlling the 1000-grain effects. Additive gene action for 1000 grain weight in bread wheat was reported by Rajesh *et. al.* (2002). Chawdhury *et. al.* (1999) studied the nature of gene action under two different environmental conditions and found 1000-grain weight expressed over dominance under irrigated condition but under drought condition the trait exhibited partial dominance type of gene action. Pandey *et. al.* (1999) reported that the inheritance of 1000-grain weight in heat tolerant wheat and it was directed by simple additive genetic system.

2.1.1.9. Harvest index

The harvest Index is an important character, which is pre-requisite for high yielding crop improvement programme. Rahman (2000) studied inheritance of this character and observed partial dominance for this trait. Prasad *et. al.* (1998) reported both additive and non-additive gene action for harvest index. Knobel *et. al.* (1997) reported additive gene action was preponderant over dominant gene action.

2.1.1.10. Spad value

Khan *et. al.* (2007) reported the additive gene effects were operating in spade value and grain yield/plant while number of tillers plant and 1000-grain weight was controlled by non-additive gene effects.

2.1.1.11. Yield per plant

Arif khan *et. al.* (2007) reported that the additive gene effects were operating in grain yield plant. Pareek and Grag (2004) reported that grain yield per plant-exhibited preponderance of non-additive gene action in bread wheat. Yoe *et. al.* (2004) informed that inheritance of grain yield per plant was controlled by both additive and non-additive gene effects. Wang *et. al.* (2003) reported grain yield per plant in wheat was controlled by additive and non-additive genes. Rajesh *et. al.* (2002) mentioned additive gene action was predominant for grain yield per plant. The inheritance of grain yield per plant in heat tolerant wheat reported to be controlled by both additive and non-additive gene action (Hill *et.al.*2001). Mehla *et. al.* (2000) Stated that additive x additive, dominance x dominance epitasis were involved in the inheritance of grain yield. Chawdhury *et. al.* (1999) reported that grain yield was controlled by dominance and partial dominance type of gene actions under irrigated drought conditions. Respectively, among the different components of non-additive gene action was also noticed in controlling grain yield in bread wheat. Sing *et. al.* (1986b) reported that additive gene action was predominant for this trait in wheat. Rahman *et. al.* (1986) observed both additive and non-additive gene action for the character. About predominance of non-additive gene action also reported by some authors (Singh *et. al.* 1974; Ahmed *et. al.* 1977; Shamshuddin *et. al.* 1993). Yadav and Iqbal (1987) reported only non-additive gene action for this trait.

In crosses HD2009/Sonolika and Kalyansona/Sonalika, Srivastava *et. al.* (1992a) reported gene effect and epistatic effects such as additive x additive and additive x dominance type for grain yield per plant. Yadav *et. al.* (1997) observed additive x additive and dominance x dominance type for this trait in bread wheat.

2.2. Combining ability studies

The main feature of diallel analysis is combining ability. The term combining ability introduced by Sprague and Tatum (1942) where they used general combining ability (gca) to designate "those crosses in which certain combinations that do relatively better or worse than would be expected on the basis of the average performance of the lines involved". They attributed gca to additive effect of genes and sca to dominant deviations and epistatic interactions.

The statistical concept of general and specific combining ability effects and variances using diallel crosses presented by Griffing (1956a, 1956b). By using a suitable statistical model the component of variances due to gca and sca are estimated which, in turn may be translated into genetical components such as σ^2 A and σ^2 D under certain assumptions. In diallel analysis, three sets of materials are involved namely parents, F_1 crosses, and reciprocals. Griffing (1956a) has given four methods of dialed depending on the materials involved in the analysis. The methods and materials involved are as follows:

Method 1: nxn (n^2) – full diallel set involving all the above three kinds of progenies

Method 2: n(n+1)/2 – half diallel set involving parents and F_1s only

Method 3: n(n+1)/2 – half-diallel set involving F_1 s only

Method 4: n(n+1) – half diallel set involving F_1s and reciprocals only

Graffing (1956a) also suggested dialed analysis based on two models associated with the types of materials (parents) involved in the mating and about whom inferences are to be drawn as under:

(i) Model I (Fixed effects): Where the experimental materials regarded as population about which inferences are to be made.

(ii) Model II (Random effects): Where random samples drawn as parents from some populations are deal with and inferences do not apply to the sample but to the parental population from which samples are drawn.

However, in most plant breeding experiments, situations corresponding to Model II prevail and out of the four experimental methods only the first two, plant breeders most extensively use i.e. Method I and II. The contribution of each parent to general combining ability was measured by the estimates of gca effects (g_i), and the contribution of each parent to hybrids was given by the estimates of sca effects (s_{ij}). Many authors studied combining ability for yield and yield contributing characters in bread wheat in order to identify the best parents or crosses for breeding program.

2.2.1. Days to heading

Joshi *et. al.* (2004) studied combining ability of bread wheat and reported that GCA and SCA effects were highly significant for days to heading. However the GCA; SCA titled normally favor of GCA for days to heading indicating the preponderance of additive effects in the genetic control of this trait. Sing and Sing (2003) studied general and specific combining in bread wheat and reported the pre dominance of non-additive gene action in the inheritance of this trait. Variance of general combining ability (GCA) was highly significant for days to heading as stated by Soylu (2003). General combining was comparatively higher for days to flowering was reported by Rajesh *et. al.* (2003). Rahman *et. al.* (2000) found that mean squares for both GCA and SCA were highly significant. This indicated both additive and non-additive gene effects for the trait. The varieties due to GCA were higher than SCA, showing more importance of additive action for this character.

2.2.2. Days to 90% maturity

Hassan (2006) stated that both GCA and SCA mean squares were highly significant for days to maturity. Rahman *et. al.* (2000) and Ali and Khan (1998) studied combining ability and reported significant variance of GCA and SCA for 90% days to maturity indicated the importance of both additive and non-additive gene effects for the trait.

2.2.3. Spikes per plant

Khan *et. al.* (2007) stated that the additive gene effects were operating spikes per plant Meena and Satry (2003) observed significant general and specific combining ability variance for spikes per plant. Joshi *et. al.* (2002) reported that both GCA and SCA variance were highly significant for spikes per plant. They noticed GCA: SCA titled normally in favour of GCA in this trait indicating the more importance of additive effects in the genetic control of this traits. Srivastava *et. al.* (1992b) crossed nine varieties in half diallel system and found mean squares for both GCA and SCA were highly significant for spikes per plant. This indicated both additive and non-additive gene effects for the trait. The varieties due to GCA were higher than SCA, showing more importance of additive action for this character. Patil *et. al.* (1995) reported higher magnitude of GCA variances in bread wheat. Ivanovska *et. al.* (2000) ann Zalewski (2000) also reported higher estimates of GCA mean squares for the character in bread wheat. Deshpande and Nayeem (1999) estimated significant GCA effects in parents Hindi 61 and Ajatha for the character.

2.2.4. Plant height

Khan *et. al.* (2007) stated that the additive gene effects were operating in plant height was controlled by non-additive gene effects. Hassan *et. al.* (2006) reported that significant differences were revealed for GCA and SCA mean squares for plant height. However, GCA effects were much greater than SCA effects showing the preponderance of additive genetic effects for plant height. Reciprocal combining ability (RCA) was significant for plant height. Joshi *et. al.* (2004) observed that GCA and SCA effects were highly significant for plant height. However, the GCA: SCA titled favour of GCA for this trait indicating the pronounced effect of additive gene action for this trait. The ratio of specific combing normally in ability variance and general combining ability variance indicated non-additive type of gene action for plant height (Sing *et. al.* 2003). Rahman *et. al.* (2002) reported SCA variance was larger than GCA variance directing the non-additive gene action for plant height in heat tolerant wheat. Sharma & Singh (1998) studied combining ability for plant height and reported that both GCA and SCA variances were significant in spring wheat. Khan and Ali (1998) also reported significant GCA and SCA mean squares for the character. Rahman *et. al.* (2000) reported both GCA and SCA variances were significant for plant height. They reported comparatively higher estimates of additive genetic variance over non-additive genetic variance. Among the parent they studied, Rawal, Nk-5 and SA-92 had high and positive GCA effect for the character.

2.2.5. Spike length

Hassan *et. al.* (2006) observed that analysis of variance for combining ability of spike length revealed that mean squares due to both GCA and SCA were highly significant. Magnitude of GCA was, however, greater than SCA variance. Singh and Singh (2003) studied general and specific combining ability and suggested predominance of non-additive gene action in the inheritance for spike length. Soylu (2003) analyzed variance of general and specific combining ability and observed highly significant variation for spike length in bread wheat. Specific combing ability variance and their ratio indicated non-additive type of gene action for spike length as reported by Sing *et al.* (2003). Meena and Satry (2003) observed significant specific and general combining ability variance for spike length. From GCA: SCA ratio they found additive effects were more important for spike length Sing and Sing (2003) studied general and specific combining ability and suggested predominance of non-additive gene action in the inheritance for spike length.

Atale and Vitkare (1990) studied a set of 15x15 diallel cross of bread wheat and found highly significant variance for both GCA and SCA for spike length. However, the GCA/SCA variance ratio was less than unity for the character indicating the predominance of non-additive gene action in the inheritance of it. Patil *et al.* (1995) also reported higher estimates of SCA mean square for this trait. Malik et. al. (1988) and Khan & Ali (1988) reported significant GCA and SCA effects for spike length in heat tolerant wheat. Singh *et. al.* (1982) observed that GCA mean square was higher than SCA mean square indicating the predominance of additive gene action for the character in bread wheat.

2.2.6. Spikelet per spike

Rajesh *et. al.* (2002) reported general combining and specific combining variances were significant for spikelet per spike. Rahman *et. al.* (2000) reported both GCA and SCA mean squares in heat tolerant wheat were significant for this character.

2.2.7. Grain per spike

Khan *et. al.* (2007) stated that the additive gene effects were operating in number of grains/spike. Joshi *et. al.* (2004) observed both GCA and SCA variance were highly significant for grains per spike. Pareek and Grag (2004) reported that the genotypes UP2338, Raj37777, UP2338 and RRL-1-4 were good general combiners and exhibited significant general general combining ability effects of grains per spike. They also found RRL1-4 X Kharchia65, Job673 X Raj1484 and Khanchia65 X Raj1782 were best specific crosses having significantly specific combining effects for this character. Sing *et. al.* (2003) analyzed the specific combining ability ratio and suggested non-additive type of gene action for grains per spike. Rajesh *et. al.* (2002) reported general combining ability and specific combining variances were significant for grains per spike. Rahman *et. al.* (2000) reported both GCA and SCA mean square in heat tolerant wheat were significant for this character. They observed Opata as a good combiner. Both GCA and SCA mean squares in heat tolerant wheat were reported to be significant for the character by Rahman *et. al.* (2000). Ali & Khan (1998) reported highly significant GCA mean squares for grain per spike. Sheikh and Singh (2000) found significant SCA variance for the character in bread wheat.

Srivastava *et. al.* (1992b) studied combining ability for grains per spike in bread wheat and reported that both GCA and SCA mean squares were significant for the character. They obtained higher estimates of GCA mean square and suggested that additive gene action was more important in controlling the character. They reported that the variety WH 147 and HUW 234 were good general combiners. They also estimated significant SCA effects for the character in a good number of crosses. They found Opata as a good general combiner. Three out of 21 crosses showed significant SCA effect for the character. Bhullar *et. al.* (1981) also reported both significant GCA and SCA variances for grain per spike in duram wheat. Singh *et. al.* (1998a) reported only additive effect for the character. Malik *et. al.* (1988) studied combining ability and reported that additive gene action was more important for grain per spike.

2.2.8. 1000-grain weight

Muhammad Arif Khan *et. al.* (2007) stated that 1000-grain weights were controlled by non-additive gene effects. Specific combining ability variance ratio indicated non-additive type of gene action for 1000-grain weight as reported by Sing *et. al.* (2003). Otteler *et. al.* (2003) reported that significant GCA variance for 1000-grain weight in heat tolerant wheat Rahman *et. al.* (2000) mentioned both GCA and SCA effects were significant for 1000-grain weight. Katiyar (1998) reported GCA and SCA mean squares were significant for 1000-grain weight. GCA and SCA variance were significant for and the character showed additive and non-additive gene action as reported by Yadav *et. al.* (1998).

In a combining ability analysis, Taleei & Beigi (1996) reported significant GCA and SCA mean squares for 100-grain weight in bread wheat. Significant GCA and SCA mean squares for the character also reported by Malik *et. al.* (1988) and Ali and Khan (1998). Atale and Vitkare (1990) studied combining ability in bread wheat and found highly significant GCA variance but non-significant SCA variance for 1000-grain weight, which indicated the trait, was mostly governed by additive genetic system. Among the parents they found Rawal and Sebia were the best general combiner for the character. Out of nine parents the variety Lok-1 reported as the best general combiner for the character by Srivastava *et. al.* (1992b).

2.2.9. Harvest index

Hassan *et. al.* (2006) reported Reciprocal combining ability (RCA) was significant for flag leaf area, plant height and harvest index were highly significant. Sarma *et. al.* (1984) studied combining ability of spring wheat and reported significant GCA and SCA variances for harvest index. Srivastaba *et. al.* (1992b) observed both GCA and SCA mean squares were highly significant for grain yield but suggested for SCA variances.

2.2.10. Spad value

Hossain *et. al.* (2006) reported, Mean squares revealed highly significant differences due to general and specific combining ability effects for spade value. Reciprocal combining ability (RCA) was significant for spared value. The GCA and SCA components of variance were significant for all the traits. However, the GCA component of variance was predominant indicating the importance of additive gene effects for the traits studied except flag leaf area for which SCA component of variance was predominant indicating the importance of non-additive gene effects for this trait.

2.2.11. Grain yield

Khan *et. al.* (2007) stated that the additive gene effects were operating in grain yield plant. Joshi *et. al.* (2004) stated HDR2329, Raj1972, HD2428 and HD2285 were the best general combiners for grain yield per plant they also observed CPAN30004X Durgapura 65, Sonalika XHD3229, and Raj3077X CPAN3004 were the best crosses for this character. Rahman *et. al.* (2003) found 4943 was the best general combiner for grain yield per plant and Puja96x4943 was the best specific combiner for this trait. Durgapura65, HD2288Lok-1Raj1972 and HD3229 were the best general combiners for grain yield. 15 crosses showed good specific combiners and also 13 crosses showed positive and significant SCA effects for grain yield per plant as reported by Joshi (2002). Budak-N (2001) studied combining ability in heat tolerant wheat and observed that SCA values were highest for grain yield in the crosses Karakilcik X Edrine-1, Akbas X 97mbvd-11. Iqbal and Sing (1998) conducted an experiment and they observed PBN222 was a good combiner for grain yield per plant.

The GCA and SCA effect for grain yield in heat tolerant wheat reported by Singh and

Gupta (1969) and Rahman et al. (2000). They noticed that significant estimates of GCA effects of the parents for grain yield were associated with significant estimates of some of the yield contributing characters. They suggested that the variety Jaral and Sonalika were good general combiners for grain yield. Malik *et. al.* (1988) and Taleei and Beigi (1996) studied combining ability in bread wheat and reported that both GCA and SCA mean square were highly significant for grain yield per plant. They found higher GCA mean square than SCA mean square suggesting predominance of additive gene effects for the character.

Atale and Vitkare (1990) reported that the ratio of GCA and SCA variance was less than unity, which indicated the predominance of non-additive gene action for grain yield. Predominance of non-additive gene action for grain yield is reported by Jatosra and Paroda (1978).

2.3. Heterosis for yield and its contributing characters

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

2.3.1. Days to heading

Singh (2003) conducted an experiment and observed that positive and significant heterosis for days to heading in the cross UO-301XRaj-3007 and HD-2028X raj-1482 of wheat. The significant heterosis due to epistatic interactions for days to heading was observed by Sharma *et. al.* (2001). Budak-N (2001) mentioned highest value of heterosis for heading (11.2%) in the cross Kundurux 97mbvd-5 and the lowest (4.97%) Sorgul x Kunduru. Rahman (2000) studied heterosis for days to heading in heat tolerant wheat and reported significant positive heterosis for the character. He also studied the components of over all heterosis and found that there were significant average, variety and specific heterosis for the character in heat tolerant wheat.

2.3.2 Days to 90% maturity

Singh (2003) conducted an experiment and observed that positive and significant heterosis for days heading in the cross UO-301XRaj-3007 and HD-2028X raj-1482 of wheat to due to epistatic interactions for days The significant heterosis to heading was observed by Sharma *et. al.* (2001). Budak-N (2001) mentioned highest value of heterosis for heading (11.2%) in the cross Kunduru x 97mbvd-5 and the lowest (4.97%) Sorgul x Kunduru. Deshpande and Nayeem (1999) reported -18.4 to 5.7% heterosis over better parent and -11.8 to 10.0% heterosis over mid parent in bread wheat. Khan and Khan (1996) studied heterosis in bread wheat crosses over mid parent and observed

-11.8% to 10.0% heterosis for days to maturity.

Rahman (2000) studied heterosis for days to maturity in heat tolerant wheat and reported significant positive heterosis for the character. He also studied the components of over all heterosis and found that there were significant average, variety and specific heterosis for the character in heat tolerant wheat.

2.3.3. Spikes per plant

Tareque *et. al.* (2004) conducted an experiment in heat tolerant wheat and estimated heterosis over mid parent in f1 hybrids, which range 24.5 to 107.9% for tillers. Nayeem (1999) reported the highest positive and significant heterosis for this trait in the crosses Hindi 62 x C 306 and Hindi 62 x NI 5439. Prasad et al. (1998) reported heterosis over better parent in the range of -27.4 to 45.5% for the character in different crosses of heat tolerant wheat. Khan & Khan (1997) heterosis in heat tolerant wheat and reported 31.91% and 15.82% heterosis over mid parent and better parent, respectively. Knobel *et. al.* (1996) reported maximum negative heterosis up to -38.0% over better parent for spikes per plant in bread wheat whereas Sharnsuddin (1985) observed 77.31% heterosis for the character in the cross Balaka x Lyallpur. Deshpande and Srivastava *et. al.* (1992a) found that F_1 mean was significantly higher than mid parental value for spikes per plant in the cross HD 2009 x Sonalika. They explained heterosis as a function of dominance gene action.

2.3.4. Plant height

Bielawska and Zalewski (1999) reported that heterosis was very frequent for plant height in bread wheat crosses. Prasad *et. al.* (1998) studied heterosis for plant height and reported -8.6 to 23.0% heterosis over tall parent. Deshpande & Nayeem (1999) reported -22.0 to 23.8% mid parent heterosis and -28.4 to 21.8% better parent heterosis for the character in different crosses of heat tolerant wheat.

Khan and Khan (1996) reported positive heterosis over mid parent for plant height in bread wheat. Positive heterosis for the character also reported by Shamsuddin *et. al.* (1993), Wang *et. al.* (1997) and Patil *et. al.* (1998). On the other hand Shamsuddin and Rahman (1989) reported significant negative heterosis (-14.21%) for plant height in the cross Nobre x Pitic 62.

2.3.5. Spike length

Muhammad and Ihsan (2004) conducted an experiment on F1 hybrids of 20 heat tolerant wheat varieties. Wanchan *et. al.* (2003) reported that heterosis for grain yield increase 90000 to 10500kg/m2 from 9 parental diallel cross. Shamshuddin & Rahman (1989) and Yagdi *et. al.* (2000) reported both positive and negative heterosis for spike length in heat tolerant wheat. Deshpande and Nayeem (1999) studied heterosis for spike length in bread wheat and reported highly significant and positive heterosis over better parent for the character in the cross C 306 x Kalyansona. Atale and Vitkare (1990) reported considerably high mid parent and better parent heterosis for spike length in two crosses NI 5439 x UP 215 and C 306 x CPAN 1581.

On the other hand, Shamsuddin and Rahman (1989) reported both positive and negative heterosis in the range of-12.88 to 41.34% for spike length in different crosses of spring wheat. Prasad *et. al.* (1998) also reported -25.1 to 16.9% heterosis for this trait.

2.3.6. Spikelet per spike

Dsehppande and Nayeem (1999) noticed highly significant positive heterosis for spikelet per spike (37.8%) over better parent in the cross of ajanth x cc464. Shamshuddin *et. al.* (1991) reported positive heterosis for this character.

2.3.7. Grain per spike

Dou *et. al.* (2002) reported high heterosis for grain per spike in heat tolerant wheat. Singh *et. al.* (1998a) studied heterosis in heat tolerant wheat and observed significant heterosis over better parent for grains per spike in the crosses of the variety WL 711 with HD 2258, Tanori 71, UP 301, WH 171 and Kalyansona. These crosses showed considerable dominance gene action and they suggested that dominance was involved in heterosis of the crosses. Deshpnnde and Nayeem (1999) observed significant and positive heterosis over mid parent for this trait in the crosses Ajantha x CC464 (39.6%) and Hindi 62 x Ajantha (29.5%).

Srivastava *et. al.* (1992a) found significantly higher F_1 mean than mid parental value for grains per spike in heat tolerant wheat. Prasad *et. al.* (1998) observed heterosis in the range of -33.0 to 26.7% for this trait. They noticed that heterosis for grains per spike were independently associated with heterosis for grain yield per plant. Shamsuddin (1990) studied heterosis in heat tolerant wheat and observed significant variety heterosis for grains per spike.

2.3.8. 1000-grain weight

Mohammad and Ihsan (2004) observed that the highest heterotic effects of 29.65 and 17.33% over mid parents respectively for 1000 grain weight in the cross Inqulab91XM11.97. 62.77% heterosis over mid parent for 1000 grain weight of inter specific hybrid of wheat was observed by cui et al. (2001), Ijaz *et. al.* (2002) observed –2.14% heterosis over mid parent for 1000-grain weight in bread wheat. Rahman (2000) partitioned overall heterosis into components and reported significant average, variety and specific heterosis for 1000-grain weight inheat tolerant wheat.

Deshpande and Nayeem (1999) studied heterosis for 1000-grain.weight and found significant heterosis in hybrid combination of heat tolerant wheat Kalyansona x

CC464. Singh *et. al.* (1998a) studied heterosis for 1000-grain weight in F_1 over better parent in heat tolerant wheat and observed that the crosses of the variety WL 711 with WL 1562, WH 171 and Sonalika exhibited significant heterosis. Positive significant heterosis for the character was also reported by Gupta *et. al.* (1989), Krishna and Ahmad (1992) and Khan *et. al.* (1995). Atale and Vitkare (1990) obtained significant heterosis over better parent for 1000-grain weight in the cross NI 5439 x UP 215. Significant mid parent and better parent heterosis for this trait were reported by Jatasra *et. al.* (1980) and Kumar *et. al.* (1977). Shamsuddin *et. al.* (1991) reported both positive and negative heterosis for 1000-grain weight in heat tolerant wheat. Shamsuddin (1990) studied heterosis in heat tolerant wheat and observed significant variety heterosis for 1000-grain weight.

2.3.9. Harvest index

Prasad *et. al.* (1998) studied heterosis in heat tolerant wheat and reported -16.4 to10.7% heterosis over better parent. Knobel *et. al.* (1997) reported significant negative heterosis of -63.1 % over mid parent for harvest index. Krishna and Ahmad (1992) obtained maximum 9.72% heterosis for this trait in heat tolerant wheat.

Sharma *et. al.* (1984) studied different components of heterosis reported significant specific heterosis and insignificant average and variety heterosis for harvest index. Rahman (2000) studied components of heterosis and reported only significant average heterosis for harvest index. They also observed positive relation between heterosis of the crosses with their SCA effects for this trait.

2.3.10. Spad value

Pandey *et. al.* (1999) reported that the inheritance of spade value of leafy content of heat tolerant wheat and it was directed by simple additive genetic system.

2.3.11. Grain yield

Budak-N (2001) observed heterosis value for grain yield was the highest (87%) in Akbas x 97mbd-11. Grain yield in heat tolerantwheat is the ultimate objective of any breeding programme. Heterosis for grain yield was studied with heterosis for its different contributing characters. Deshpande and Nayeem (1999) studied heterosis for grain yield in bread wheat and observed both positive and negative heterosis over mid and better parental values. They obtained significant positive heterosis over mid parental value in 10 out of 20 crosses. In the cross Hindi 62 x Ajantha they obtained maximum mid parental heterosis of 50.8% for the character. Over better percent they obtained highest heterosis in the same cross that was 28.3%. In their study they obtained maximum negative heterosis (-45.4%) over better parent. Shamsuddin *et. al.* (1991) studied heterosis in spring wheat and observed positive heterosis up to 151.31% for grain yield. They also reported positive relation between heterosis for grain yield and heterosis for some yield components. Singh and Kandola (1969) and Singh and Singh (1978) estimated higher heterosis for grain yield than any other character studied.

Prasad et. al. (1998) studied heterosis in bread wheat and observed both positive and negative heterosis over better parent. They observed maximum heterosis over better parent reached up to 59.7%. In addition they studied heterosis over standard variety and got maximum value 27.3% heterosis for the character grain yield per plant. They also observed that heterosis for grain yield was higher than those of the yield contributing characters. Prasad et. al. (1998) observed that heterosis for number of grain per spike and that for 100-grain weight was independently contributed to heterosis for grain yield per plant in bread wheat Srivastava et. al. (1992a) reported F_1 mean was significantly higher than mid parental value for grain yield per plant in cross Kalyansona x Sonalika. They explained heterosis as the function of dominance gene action.

Gupta *et. al.* (1989) observed poor heterosis below 5% over mid parent for grain yield per plant. Heterosis for yield in wheat was explained as the function of heterosis for yield contributing character, specifically primary yield components. Boyce (1948) explained heterosis of grain yield in wheat was the product of the heterosis of its component characters and that was the cause behind higher estimate of heterosis for grain yield per plant.

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

CHAPTER 3

MATERIALS AND METHODS

3.1. Experimental site and experimental Duration

This research work was carried out at the Field of the Wheat Research Centre, BARI, Nashipur, Dinajpur in two consecutive Rabi seasons of 2007-2008 and 2009-2010 The site is at 25.38^0N latitude and 88.41^0E longitude with an elevation of 39 meter of sea level. The hybridization programme was carried out during Rabi, 2009-2010 seasons and the evaluation of F_1 was done in next Rabi season, 2009-2010.

3.2. Climate and Soil

The experiment site is under the sub tropical climatic zone. The meteorological data including maximum and minimum mean monthly temperature (^{0}C), average rainfall (mm), relative humidity and sunshine (hrs/day) during the hybridization programme and the experimental period may be seen in Appendix I. The selected land was medium high. The texture of the soil was sandy loam and with pH around 5.5. The nutrient status of the experimental soil as tested by the Soil science Laboratory of Wheat Research Centre, BARI, Nashipur, Dinajpur.

Table 1: Nutrient status of experimental field

SI. No.	Soil properties	Results
i)	Organic Carbon	0.52
ii)	Total Nitro *et. al.*gen	0.06
iii)	Exchangeable Potassium (meq/100g)	0.065
iv)	Sulphur (ppm)	10
v)	Phosphorus (ppm)	14.84
vi)	Ph	5.5

3.3. Hybridization programme

3.3.1. Materials used

The study included six genotypes of heat tolerant wheat used in 6X6 diallel cross. The parentage, origin and source of the parental genotypes are shown in Table 1. All possible cross combinations (F_1s) including reciprocals were generated from these six genotypes.

Table 2: List of genotypes and their origin

Sl. No.	Genotype	Origin	Source
1.	Shatabdi	Bangladesh	
2.	Sufi	Bangladesh	
3.	Bijoy	Bangladesh	Wheat Research Centre, Nashipur,
4.	prodip	Bangladesh	Dinajpur.
5.	BL 1040	Bangladesh	
6.	BL1018	Bangladesh	

3.3.2. Land preparation and fertilization

The land was prepared by ploughing with tractor and power tiller followed by laddering. The weeds and stubbles were removed as far as possible. A recommended dose of manures and fertilizers were given in the field (Table 3.3.2.).

Applied doses of fertilizers and manure	
Name	**Rates (kg/ha)**
Urea	220
TSP	100
MP	80
Gypsum	100
Boric acid	4.5
Cowdung	5000

At the time of final land preparation, the whole amount of cow dung, TSP, MP, boric acid and two-third of urea were applied to the soil. The remaining one-third of urea was given as top dressing at tillering stage. Basudin was given to reduce the attack of cutworm at seedling stage.

3.3.3. Sowing and intercultural operation

Six parents were selected from crossing block of WRC, which were sows in November 18, 2009. Each genotype was grown in three-row plot of 2.5m long in four replications with maintained seven days interval for each replication. The spacing was 25cm between rows. Weeding was done at the tillering and booting stage. The experimental plot was irrigated three times.

3.3.4. Hybridization technique

Female plants were selected having flowering stage just before anthesis stage for emasculation. All spike let from the top of the spike were cut off and young spike let from the bottom also cut off. About half of the remaining spike lets were cut from the distal portion obliquely to expose the anthers. Emasculation was done by hand in the morning after flashing sunshine. The emasculated spikes were covered with glycine paper bags to avoid foreign pollen and to prevent from desiccation. After two days of emasculation the blooming spikes of the respective male parent were collected for pollination. Pollination was done in noon. About one third of each spike let of blooming spike was cut off and kept in to sunshine. After a few minutes, cutting anthers were immersed out. The blooming spikes were then dusted over the emasculated spikes. Bagging and tagging were done in the pollinated plants.

3.3.5. Collection and preservation of F_1 seeds

The mature naked F_1 seed were collected and sun dried. Then the seeds were preserved in cold room. To protect the seeds from the attack of pests, insecticide sevins dust was applied.

3.4. Evaluation of Hybrids

Thirty F_1s along with six parents were evaluated during the Rabi, 2009-2010 seasons.

3.4.1. Land preparation, fertilizer management and sowing

The experimental land preparation and fertilizer management were similar to the previous year. On November 18, 2009 the six parents along with thirty F_1s were sown in a randomized block design with three replications. Each genotype was grown in to row plot of 1m long in each replication. The spacing was 25cm between rows and 5cm between plants of the same row.

3.4.2 Irrigation and intercultural operation

The experimental plots were irrigated three times. One at just after first weeding and rest of irrigation were done at flowering and booting stage. Weeding was done at the tillering and booting stage.

3.4.3. Crop harvesting

The sample plants from all the plots were harvested at 90% maturity observed by eye estimation. The harvested grains were threshed, cleaned and sun dried.

3.5. Characters expression & measurement

3.5.1. Economic characters

A total of 11 yield and yield contributing characters, designated as economic characters, were recorded as follows:

a) Days to heading: Days to heading was recorded at the standing of the crop plants in the field.

b) Days to 90% maturity: Days to 90% maturity was recorded at the standing of the crop plants in the field.

c) Spikes per plant: Total number of spikes in a plant counted for 10 randomly selected plants at the time of maturity.

d) Plant height: Average height (cm) of the main tiller of 10 (random) plants from the base to tip of spike excluding awn was measured in cm.

e) Spike length: The length (cm) of main spike from the base mark to tip excluding awns from 10 random spikes was measured.

f) Spike let per spike: Spikelet per 5spike was taken.

g) Grains per spike: Grains were obtained from ten main spikes of the sample plants, counted and averaged over per spike.

h) 1000-grain weight: One thousand clean sun dried grains were randomly taken out from each plot and weighted it.

i) Harvest index: Harvest index was calculated according to the following formula:

HI=Economic yield/Biological yield

j) Spad value: chlorophyll content of three leaves from each plant was taken.

k) Grain yield per plant: Estimated as the average weight of grain(g)from 10 randomly selected plants.

3.6. Statistical analysis

The replicated data on different characters were subjected to the preliminary ANOVA valid for RCB design. Computer calculated ANOVA and mean by using MSTATC software. The data were then analyzed for combining ability and components of variance.

3.6.1. Combining ability

The statistical analysis of data for 6X6 diallel cross including reciprocals was done as quoted in Sharma (1998). The diallel progenies $\{n^2 = 36\}$ were partitioned into parents (P), crosses (F_1), parents vs. crosses (P vs. F_1), direct crosses (f), reciprocal crosses (l) and direct vs reciprocal items. The parents, crosses, direct cross, reciprocal crosses item tasted the significant differences among the parents, crosses, direct crosses and reciprocal crosses respectively. P vs. F_1 item indicated overall heterosis for the respective character. While f vs. l item indicates presence of reciprocal differences thus necessitates computation of reciprocal differences. For the genetic analysis of diallel population, data were subjected to Griffin's approach. An understanding general and specific combining ability and the genetic system controlling important traits of wheat were thus attempted. The analytical methods and procedures of them, often quoted with worked out examples, could be found in several reference literature (Mather & Jinks, 1982; Singh & Chaudhary, 1985; Dabolker, 1992; Sharma, 1998 Igor Pirez Valerol, 2009). The combining ability analysis of the present study was mainly done following Sharma (1998).

3.6.1.1. Griffing's approach (combining ability analysis)

Griffing's (1956b) method I, Model 2 (Random effect model) was used for combining ability analysis for each of the trait. In model 2, random samples drawn as parents from some populations are dealt with and inference do not apply to the sample but to the parental populations from which samples are drawn. The mathematical model for the combining ability analysis in model 2, method 1 is assumed to be-

$$Xij = \mu + gi + gj + sij + r_{ij} + \frac{1}{bc}\sum_{k}\sum_{1} e_{ijkl}$$

Where, I,j = 1……………p

k = 1…………….b

l = 1…………….c

p = number of parents

b = number of block

c = number of observation in each plot

Xij = mean of X_{ij} th genotypes over k and l

μ = Population mean

gi, g_j = GCA effect

sij = SCA effect

r_{ij} = reciprocal effect

e_{ijkl} = environmental effect particular to the ijklth individual observation

The restriction impose are- $\sum g_i = 0$ and $\sum(s_{ij} + s_{ii}) = 0$ (for each i)

The analysis of variances for combining ability was carried out using block mean of each entry (Diallel family) as follows-

Item	d.f	Sum of squares	Mean square
Gca	$n-1$	$\frac{1}{2n}\sum_{i}(X_{i}.+X.j)^2-\frac{2}{n2}X..^2$	Mg
Sca	$n(n-1)/2$	$\frac{1}{2}\sum\sum X_{ij}(X_{ij}+X_{ji})-\frac{1}{2}\sum(X.j+Xij)^2+\frac{1}{n^2}X..^2$	Ms
reciprocal	$n(n-1)/2$	$\frac{1}{2}\sum\sum(X_{ij}-X_{ji})^2$	Mr
Error	$(r-1)(t-1)$	ESS/r = SSc	Me

Where,

gca = general combining ability

sca = specific combining ability

n = number of parents

r = number of replication

t = number of treatment

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

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

X_{ii} = mean value of the ith parent

$X_{..}$ = Grand total of the n(n +1) crosses and parental lines

X_{ij} = Progeny mean value of the ijth crosses

X_{ji} = Progeny mean value of the jith crosses

ESS =Sum of square due to error (obtain from preliminary ANOVA)

The performance GCA, sca and reciprocal were calculated as follows:

Variance of gca = $\frac{1}{2p}\left[MS_g - MS_e - \frac{2(p-1)MS_s}{P} \right]$

Variance of gca = $(MS_s - NS_e)p^2/[2(p^2 - p+1)]$

Variance of reciprocal= MS_e

The gca, sca and reciprocal effects of each character may be calculated as follows-

gi $= \frac{1}{p2}\left[(Xi. + X.j) - \frac{1}{n^2} X.. \right]$

sij $= \frac{1}{2}[Xij + Xji] - \frac{1}{2p}(Xi. + X.i + Xj. + X.j) + \frac{1}{p^2} X..$

r_{ij} $= \frac{1}{2}(Xij - Xji)$

SE and SEd

S.E.(g_i) = $\left[\frac{P-1}{2P} XMSe \right]^{0.5}$

S.E.(s_{ij}) = $\left[\frac{1}{2p^2}(p^2 - 2p + 2) XMSe \right]^{0.5}$

S.E.(r_{ij}) = $\left[\frac{1}{2} MSe \right]^{0.5}$

SEd (g_i- g_j)= $(MS_e/p)^{0.5}$

SEd(s_{ij}- s_{ik})= $\left[\frac{(p-1)MSe}{p} \right]^{0.5}$

SEd(s_{ij} - s_{kl})= $\left[\frac{(p-2)MSe}{p} \right]^{0.5}$

SEd(r_{ij})= $(MS_e)^{0.5}$

CHAPTER 4

RESULTS AND DISCUSSION

4.1.1. Growth Character

The growth characters studied were days to heading, days to maturity, plant height (cm), spikes per plant, spike length (cm), spikelet per spike, grains per spike, 1000-grain weight (g) spad value harvest index and grain yield per plant (g) for the parents and hybrids (Table 3).

Variation in parents for days to heading was found. The higest day to heading was obtained in variety Shatabdi and the lowest in line 1040; all others had days to heading similar to the parental mean. Prodip showed significantly shorter duration to maturity than the mean value whereas all other parents had about similar longer period to maturity. Parents sufi, bijoy, prodip, showed higher plant height compared to parents shatabdi and line 1018. Lower spikes per plant were produced by parent bijoy whereas all other parents were produced spikes per plant similar to parental mean. The highest spikes length was obtained in the shatabdi and the lowest in bijoy; all others had spikes length similar to the parental mean. Parent bijoy produce significantly lower size of spikelet per spike whereas parent prodip produced spikelet per spike significantly higher than the parental mean. Parents Shatabdi showed a significantly higher potential of producing grain per spikes but the Line-1018 produced significantly lower number of grains per spikes. The high yield contributing parameter 1000-grain weight was highest produced by line shatabdi whereas all others produced 1000-grain weight similar to parental mean. Harvest index were higher in line 1040 and Line-1018 than all other parents.

Mean values of F_1s (Table. 3) showed that the days to heading was the highest in the cross combination 'Shatabdi X' line1018 with higher harvest index. The crosses Shatabdi x line 1040, shatabdi x bijoy took the longest period of the maturity whereas the highest 1000-grain weight was also obtained from the crosses sufi x line 1018, line1018 x sufi & shatabdi x line 1018. From the cross bijoy x line 1040 produce all most lowest spikes per plant. The spikes length produced by cross prodip x sufi was highest whereas the lowest spikes length was produced by the crosses line 1018 x shatabdi & line 1018 x sufi. Harvest index was higher in cross 'prodip x sufi' but cross 'sufi x prodip' was produced harvest index significantly lowest from mean value of the crosses. The highest grain yield was observed in the cross shatabdi x sufi due to high spikes length and highest number of grain per spikes. On the other hand, the lowest grain yield per plant was obtained from 'prodip X line 1040' due to lower spikes per plant, lower number of spikes length and lower grain per spikes. No single parent contained all of the desirable characters. Moreover, these parents could be utilized in the crossing programme depending on the breeding objectives.

Table 3: Mean value of different growth characters of the hybrid and parents in a six parental diallel cross of wheat

Genotype (code)	Days to heading	Days to maturity	Plant height (cm)	Spike /plant	Spike Length (cm)	Spikelet per spike	Grain /spike	1000 grain weight	Harvest index	Spade value	Grain yield/ plant (g)
1	71.08	114.62	99.29	7.333	12.95	21.87	60.37	48.285	36.27	34.82	47.07
2	68.50	111.54	100.33	6.666	12.47	22.16	59.33	45.560	37.14	34.54	46.43
3	68.50	111.75	101.04	6.208	12.43	21.37	57.70	43.018	35.83	35.15	44.27
4	68.87	110.45	101.29	6.416	12.71	22.54	53.45	43.436	36.24	36.31	44.21
5	68.37	111.83	99.29	6.375	12.91	22.37	53.70	42.658	38.36	36.12	44.08
6	69.58	112.95	99.3	6.666	12.63	22.50	51.91	46.331	38.66	37.30	45.33
1x2	69.5	113.0	98.5	6.0	12.4	21.00	71.00	45.75	38.6	35.50	50.5
1x3	69.0	117.0	115.5	7.0	12.7	20.50	62.00	51.71	34.5	37.70	45.6
1x4	70.0	112.5	115.5	7.5	12.7	24.00	64.00	46.19	362	35.15	47.5
1x5	68.5	113.5	112.5	7.5	12.8	21.00	50.00	50.04	37.3	32.95	44.1
1x6	71.5	116.5	117.0	8.0	12.5	22.00	58.50	47.26	36.3	37.80	47.0
2x1	69.5	115.5	99.0	6.5	12.1	21.00	71.0	47.52	37.2	35.50	50.3
2x3	68.5	109.5	97.0	6.0	12.3	20.5	63.0	34.3	34.0	28.0	41.7
2x4	69.0	110.0	98.0	6.5	12.8	23.5	58.0	46.0	29.6	36.5	46.9
2x5	68.0	112.5	104.5	6.5	12.3	22.0	59.0	36.0	40.3	42.2	48.7
2x6	69.5	112.0	103.5	8.0	12.5	22.0	54.0	53.3	40.3	34.1	47.7
3x1	70.5	115.5	101.5	7.0	12.8	21.5	65.0	52.7	33.5	32.6	46.2
3x2	68.0	116.0	97.0	6.0	12.3	20.5	63.5	34.3	40.6	37.7	41.7
3x4	68.5	108.0	105.5	6.0	12.1	22.5	60.0	46.4	38.9	38.8	45.7
3x5	68.0	112.5	97.5	7.5	13.2	21.5	43.0	46.8	34.5	41.5	43.1
3x6	69.5	114.5	98.5	6.5	12.	21.5	63.0	46.0	39.6	38.1	42.0
4x1	71.5	112.5	97.0	7.5	13.1	23.0	64.0	42.2	39.1	35.1	48.[illegible]
4x2	67.5	109.5	98.0	6.5	13.8	24.5	58.0	43.2	41.0	37.5	47.[illegible]
4x3	68.5	111.5	105.5	6.0	13.1	21.5	61.5	42.2	40.2	38.8	45.7
4x5	68.5	110.5	100.0	6.5	12.1	21.5	43.0	43.26	39.4	34.6	40.2
4x6	69.0	113.5	96.5	6.5	13.0	22.0	45.0	44.3	30.9	38.2	42.7
5x1	70.5	117.0	98.0	7.0	17.1	21.5	50.5	50.6	39.8	32.9	44.1
5x2	67.5	109.5	104.5	8.0	13.6	22.5	56.0	35.8	39.9	42.2	44.4
5x3	68.0	109.0	97.5	6.5	12.3	23.0	55.0	43.5	40.1	41.1	43.2
5x4	67.5	111.5	100.0	6.0	12.25	21.5	43.0	41.6	38.6	34.2	40.3
5x6	69.0	108.5	98.5	3.5	12.5	22.5	55.0	47.6	40.2	37.5	44.7
6x1	71.5	116.5	100.5	8.0	12.0	22.0	58.5	53.3	38.9	37.8	47.9
6x2	69.0	112.0	103.5	7.0	12.0	22.5	54.4	53.3	39.6	34.1	48.2
6x3	68.5	110.5	98.5	7.0	13.10	22.5	43.5	46.8	37.2	38.1	42.8
6x4	68.5	112.0	96.5	6.5	13.20	22.5	45.0	44.9	38.0	41.4	43.5
6x5	69.0	113.5	98.5	5.0	12.60	24.5	55.0	41.8	36.60s	38.0	45.0
SE(±)	0.387	.517	2.09	.820	.466	.737	.378	.363	1.6	2.23	.85
P±SE	69.15+- 0.322	112.194+- 0.431	100.097 +-1.74	6.61+- .683	12.68+- .389	22.13+- .614.	56.08+-	44.98+- .302	37.08 ±0.27	34.72 +- 1.86	45.2 -.713
F_1±SE	69.66+- 0.232	110.50+- .311	100.3+- .492	6.41+- .492	12.20 .208	22.08+- .413	55.58+- .404	44.33+.21 8	37.24 ±1.61	35.91 +-1.34	45.00- -.514

Satabdi=1,sufi=2,bijoy=3,prodip=4,1040=5,1018=6

4.1.2. Preliminary analysis of variance (ANOVA)

The genotypes showed highly significant mean squares for all the growth characters (Table 4). Genotypes have been partitioned into parents (P), hybrids (F_1), direct F_1s (f), reciprocal F_1 (l), f vs l and parent vs F_1 items. Significant mean squares due to parents and F_1s for all the characters indicated significant differences among the parents and the F_1s, which were important for, further study of Griffing's of diallel analysis. Significant mean squares due to direct crosses (f) and reciprocal crosses (l) indicate significant differences among direct crosses (f) and reciprocal crosses (l) respectively. Again significance of f vs l mean squares indicated reciprocal differences for the characters harvest index, spad value except days to maturity, plant height, spike length and spikelet per spike, 1000-grain weight and all other remaining characters necessitating computation of reciprocal effects. The parents vs crosses item for the characters 1000-grain weight harvest index and spad value were significant except spike length and spikes per plant and all others remaining characters. This detected the presence of significant on heterosis in cross combination.

Table 4: Preliminary analysis of variances for growth characters in a six parental diallel crosses

Source of variation	df	Days to heading	Days to maturity	Plant ht. (cm)	Spikes per plant	Spike length (mm)
Rep	1	0.013	0.222	.138	.888	0.845
Diallel progenies	35	4.823**	0.483	17.509**	1.914	1.670
Parent (P)	5	4.484**	3.2*	3.971*	0.671	0.20
Fl	29	0.649	4.695**	4.695**	0.458	0.449
Direct Fls (f)	15	0.364	5.21**.	5.21**	4.695	0.064
Reciprocal Fls (l)	15	0.891	4.07**	4.07**	0.483	0.799
f vs l	1	0.004	6.3375	6.33	0.037	0.925
P vs Fl	1	0.947	4.013	4.013	0.277	0.885
Error	71	0.299	9.40	12.05	12.50	1.587

*P=0.05, **P=0.01

Table 4: Contd.

Source of variation	df	Spikelet per spike	Grains per spike (No.)	1000 grain wt. (g)	Harvest Index	Spade value	Yield per plant (g)
Rep	1	0.888	0.222	0.544	17.225	11.440**	.579
Diallel progenies	35	2.560	111.47**	57.372**	35.460**	17.417**	13.899**
Parent (P)	5	0.911	9.425**	10.973**	5.575	1.909	1.70
Fl	29	0.86	32.046**	16.071**	40.213**	4.810**	3.891**
Direct Fls (f)	15	1.129	32.354**	18.22**	53.339**	2.147*	4.157**
Reciprocal Fls (l)	15	0.657	31.546**	16.68**	26.065**	6.333**	3.902**
f vs l	1	0.037	0.104	2.424	54.538*	12.194**	0.044
P vs Fl	1	0.277	0.440	201.547**	47.029*	3.441**	0.200
Error	71	0.883	0.907	18.028	9.839	10.034	1.465

*P=0.05, **P=0.01

4.1.3. Griffing's Approach

4.1.3.1. Analysis of variances (ANOVA) for combining ability

The ANOVA for combining ability showed that the mean squares due to general, specific combining ability and reciprocals were highly significant for all the traits except spike length (Table 5). The results indicated that both additive and nonadditive gene actions were involved in the inheritances of these traits. Grain yield and its contributing characters were suggested to be controlled by both additive and non-additive gene action in bread wheat. Srivastava *et. al.* (1992b) reported both additive and non-additive gene action with higher estimates of GCA variance than SCA variance, showing a more importance of additive gene action for grains per spike, 100-grain weight, harvest index and grain yield per plant except plant height & spike per plant Singh *et. al.* (1998a) reported only additive effect for grains per spike in heat tolerant wheat. Malik *et. al.* (1988) studied combining ability and reported that additive gene action was more important for plant height, spike length and grains per spike. Atale & Vitkare (1990) studied combining ability in a 5 x 5 diallel cross and reported additive genetic system for 100-grain weight but predominance of non-additive genetic system for spike length and grain yield per plant. They suggested that it might be due to the fact that the parental materials including in the study were highly selected for yield. Masood & Kronstad (2000) reported both significant GCA and SCA variances for plant height, spikes per plant, spike length and significant SCA variance for grain yield per plant alone. They observed GCA/SCA variance ratio was more than unity for spikes per plant, 1000 grain weight & days to heading.

Table 5: Analysis of variance for combining ability of different characters of wheat in a 6x6 diallel cross

Source of variation	df	Days to heading	Days to maturity	Plant height (cm)	Spike per plant	Spike length (cm)
GCA	5	26.144**	49.244**	20.427**	3.761*	1.117ns
SCA	15	1.623**	8.203**	21.545**	2.737*	1.938ns
Reciprocal cross	15	0.916 **	9.400**	12.500**	0.483ns	1.587ns
Error	35	0.299	0.536	8.785	1.346	0.436
Variance components						
σ_{gca}		1.023	1.720	-0.029	0.044	-0.032
σ_{sca}		0.384	2.225	3.704	0.403	0.436
σ_{rec}		0.154	2.215	0.928	-0.215	0.287
σ_{gca}: σ_{sca}		16.10	6.00	0.94	1.35	.576

*P=0.05, **P=0.01

Table 5: Contd

Source of variation	df	Spike let per spike	Grain per spike	1000 grain weight (g)	Harvest index	Spad value	Grain Yield / plant (g)
GCA	5	4.811**	295.266**	118.302**	48.848**	26.556**	38.956**
SCA	15	3.487**	160.194**	76.405**	17.496**	21.899**	**17.940
Reciprocal cross	15	0.883ns	1.4833ns	18.028**	49.996**	10.122**	1.494nss
Error	35	1.088	0.907	0.263	7.745	10.034	1.465
Variance components							
σ_{gca}		0.058	5.842	1.848	0.879	0.209	0.897
σ_{sca}		0.696	46.244	22.105	1.887	3.444	4.783
σ_{rec}		-0.051	0.143	4.441	7.041	0.021	0.007
σ_{gca}: σ_{sca}		.0604	.126	.0836	0.466	0.0606	1.465

**P=0.01; *P=0.05

Spike length, spade value & harvest index was less than unity for spikes per plant and 1000 grain weight & days to heading in bread wheat. Predominance of non-additive gene action for grain yield per plant in spring wheat reported by Ahmed *et. al.* (1979). The results of the present experiment suggested that most of the yield contributing characters were predominantly controlled by additive gene action except Spike length and grain yield which were controlled by non-additive gene action In the present study predominance of additive gene action for different yield contributing characters especially for days to heading, days to maturity, plant height spikes per plant, spikelet per spike, grains per spike and harvest index indicated that they would give good response to selection for these characters. However, presence of non-additive gene action for spike length and grain yield per plant could be exploited by recurrent selection.

4.1.3.2. GCA effects

The gca effects of six parents for different growth characters along with standard error and standard error of difference are presented in Table 6. The parent shatabdi was the best general combiner for grain yield/plant but shatabdi was not good combiners for yield component characters spad value and spike length. The parents' shatabdi, sufi, bijoy was good general combiner for 100-grain weight and spikelet per spike but they had significant negative GCA effects for spike length and almost non significant effect for spad value. Sufi was a negative combiner for days to maturity and plant height. Thus the variety might be useful in developing short duration variety with dwarf characters. Whereas shatabdi, sufi, bijoy, line 1040 and line 1018 might be useful in developing high yielding variety with significant period of days to heading. No single parent contained all of the desirable characters. Moreover, these parents could be utilized in the crossing programme depending on the breeding objectives.

Table 6: Estimates of general combining ability effects (gca) and mean performance of the parents for different characters in wheat

Parents	Days to heading	Days to maturity	Plant height (cm)	Spike per plant	Spike length (cm)
	gca	gca	gca	gca	gca
P_1	0.931**	2.431**	-0.805	0.722*	0.26
P_2	-0.652**	-0.653*	0.236	0.055	-0.209
P_3	-0.652**	-0.444	0.944S	-0.402	-0.256
P_4	-0.277	1.736**	1.19	-0.194	0.028
P_5	0.777**	0.361	-0.805	-0.236	0.228
P_6	0.430*	0.764*	-0.763	0.056	-0.051
SE (g_i)	0.102	0.136**	0.552	0.216	0.123
SE (g_i-g_j)	0.158	0.211	0.855	0.335	0.191
CD $_{(0.05)}$	0.41	0.54	2.19	0.86	0.49
CD $_{(0.01)}$	0.64	0.85	3.44	1.35	0.77

*p<0.01; **<0.05

Table 6: Contd

Parents	Spikelet Per Spike	Grain per spike	1000-grain weight (g)	Harvest index	Spad value	Grain Yield per plant (g)
	gca	gca	gca	gca	gca	gca
P_1	-0.264	4.291**	3.403**	-0.993	1.591	1.83*
P_2	0.0278	3.2508**	0.678*	0.983	0.7708	1.197*
P_3	-0.763*	1.6258**	-1.86**	0.606	-0.558	-0.964*
P_4	0.403	-2.6258**	-1.445**	1.407	0.604	-1.019*
P_5	0.236	-2.3758**	-2.2238*	-1.491	0.41688	-1.151*
P_6	0.361	4.166**	1.4498**	-0.511	-1.1668	0.1008*
SE (gi)	0.177	0.194	0.590	0.423	0.5908	0.225
SE (g_i-g_j)	0.275	0.301	0.194	0.656	0.914	0.349
CD $_{(0.05)}$	0.71	0.77	0.50	1.69	2.34	0.89
CD $_{(0.01)}$	1.11	1.21	0.78	2.64	3.68	1.41

*p<0.05; **<0.01

4.1.3.3. SCA effects

Out of 15 cross combinations three showed significantly positive sca effects and another three showed significantly negative sca effects for days to heading (Table 7). The results indicated that crosses bijoy x prodip, shatabdi x sufi were produced significantly higher yield per plant along with significantly positive sca effect for grains per spike was also obtained from the same cross combination. Again the crosses had significantly negative sca effects for spike per plant. The cross 'shatabdi x sufi' showed significantly higher sca effect negatively for spike per plant which was also produced significantly higher yield per plant. Significantly highest negative effect for yield per plant was obtained from the cross 'sufi x bijoy'.

seven cross combinations viz., 'shatabdi x bijoy', 'shatabdi x line 1040', 'shatabdi x line 1018', 'sufi x bijoy', 'prodip x line 1040', 'prodip x line 1018' & 'line 1040 x line 1018' showed significant sca effects for earliness. The best specific combiners for 100 seed weight were 'sufi x line 1040' while 'sufi x bijoy' highest sca effect but negatively for 1000-grain weight. The crosses shatabdi x prodip & line 1040 line 1018'showed negative highest specific combining ability effects for harvest index.

Table 7: Estimates of specific combining ability effects (sca) and mean performance of the parents for different characters in wheat

Parents	Days to heading	Days to maturity	Plant height (cm)	Spike per plant	Spike length (mm)
	sca	sca	sca	Sca	sca
P_1XP_2	0.9308**	0.277	-0.777S	-1.138*	-0.515
P_1XP_3	-0.6808*	2.0694**	1.263	0. 069	0.080
P_1XP_4	0.055	-0.388	0.76	0.36	-0.052
P_1XP_5	-0.8058**	0.986**	-1.236	0.152	1.747**
P_1XP_6	0.402	1.1118**	1.972	0.61	0.101
P_2XP_3	0.027	1.652**	-3.527*	-0.263	0.7938*
P_2XP_4	0.027	-0.055	-2.027	0.027	0.268
P_2XP_5	0.319	-0.180	2.222	0.819	-0.1777
P_2XP_6	0.319	-0.305	4.180**	0.777S	0.113
P_3XP_4	0.277	-0.263	3.513*	-0.013	0.088
P_3XP_5	0.277	-0.638	1.263	1.027	0.593*
P_3XP_6	0.694**	-0.013	-1.527	0.486	-0.544*
P_4XP_5	-0.097	0.902*	0.513888889**	0.027	-0.074
P_4XP_6	-0.555*	1.527**	-3.277**	-0.180S	0.434
P_5XP_6	0.194	-1.597**	-0.277**	-2.180**	-0.6152*
SE (ij)	0.233	0.311	1.259	0.493	0.281
LSD(0.05%)	0.49	0.66	2.68	1.05	0.59
LSD(1%)	0.69	0.92	3.71	1.45	0.83

*p<0.05; **<0.01

Table 7: Contd

Parents	Spikelet per spike	Grain per spike	1000 grain weiht	Harvest index	Spad value	Grain Yield per plant (g)
	Sca	Sca	Sca	Sca	Sca	Sca
P_1XP_2	-0.902**	7.375**	-3.288**	0.327	1.5916	2.214**
P_1XP_3	-0.111	1.500**	5.770**	-0.197	0.6833	-0.173
P_1XP_4	1.222**	6.250**	-0.3197	-0.355	-1.6541	1.858**
P_1XP_5	-0.8618**	-7.750**	4.295**	-0.672	-2.5416	-1.383*
P_1XP_6	-0.236	2.291**	-2.289**	0.657	0.2083	0.346
P_2XP_3	-0.902**	2.291**	-9.347**	0.664	-4.487**	-3.685**
P_2XP_4	1.430**	1.292**	1.781**	-2.196*	1.100	1.434*
P_2XP_5	-0.152	0.542	0.857**	0.211	3.562*	1.329*
P_2XP_6	-0.277	-0.917*	6.1168**	-0.133	-0.937	1.444*
P_3XP_4	0.722*	5.667**	0.546*	-0.237	1.266	2.548**
P_3XP_5	1.138**	0.1667	-4.975**	-0.976	3.829*	0.083
P_3XP_6	.263	-10.292**	2.391**	-0.692	0.704	-1.913**
P_4XP_5	-1.27**	-8.083**	2.1668**	2.165*	-2.333	-2.904**
P_4XP_6	-0.652*	-4.292**	0.096	2.167*	1.941	-1.176*
P_5XP_6	0399	5.458**	-2.23**	-4.011**	0.029	0.688
SE (ij)	0.251	0.404	0.218	0.962	1.346	0.514
LSD(5%)	0.53	0.86	0.46	2.052	2.86	1.09
LSD(1%)	0.74	1.19	0.64	2.83	3.97	1.51

*p<0.05; **<0.01

SCA effects of the crosses have been reported by many authors in spring wheat. Srivastaba *et. al.* (1992b) reported significant sca effects of the crosses for the grain yield by crossing the parents with low x low and low x average general combiner. Masood & Kronstad (2000) also observed high positive sca effects for grain yield by the crossing the parents with low x low and low x average general combiner in bread wheat.

Overall study on the results of the crosses revealed that shatabdi x sufi & bijoy x prodip had significant sca effects for grain yield associated with some yield contributing characters. This suggested that the sca effects to the crosses could effectively be exploited in hybrid breeding programme in heat tolerant wheat.

4.1.3.4. Reciprocal effects

Out of 15 cross combinations no one showed significantly positive sca effects (Table 8) for grain yield per plant. Significant and negative reciprocal effects for days to heading were obtained from three crosses but three showed significantly positive reciprocal effects. These cross combinations could be exploited to produce early maturing wheat varieties. The positive significant reciprocal effect for plant height was obtained from 'shatabdi x prodip', 'bijoy x line 1040'. The best reciprocal cross combination for thousand grain weight was shatabdi x bijoy while some of others were significantly higher negative reciprocal combiners for the same characters.

Table 8: Estimates of reciprocal effects for different economic characters in a six parental diallel cross of wheat

Parents	Days to heading	Days to maturity	Plant height (cm)	Spike per plant	Spike length (cm)
P_1XP_2	0.000	-1.250**	-0.250	-0.250	0.175
P_1XP_3	-0.750*	0.750	0.000	0.000	-0.075
P_1XP_4	-0.750*	0.000	4.250*	0.000	-0.225
P_1XP_5	-1.00**0	-1.750**	-0.750	0.250	-2.125
P_1XP_6	0.000	0.000	0.000	0.000	0.250
P_2XP_3	0.250	-3.250**	0.750	0.000	-0.025
P_2XP_4	0.750*	0.250	1.500	0.000	-0.500
P_2XP_5	0.250	1.500**	-2.750	-0.750	-0.675
P_2XP_6	0.250	0.000	0.250	0.500	0.250
P_3XP_4	0.000	-1.750**	0.250	0.000	-0.475
P_3XP_5	0.000	1.7508**	4.000*	0.500	0.450
P_3XP_6	0.500*	2.0008**	0.250	-0.250	-0.125
P_4XP_5	0.500*	-0.500	1.000	0.000	-0.050
P_4XP_6	0.250	0.750*	0.750	0.000	-0.100
P_5XP_6	0.000	-2.500**	-0.250	-0.750	-0.250
SE (ij)	0.273	0.366	1.482	0.580	0.330
LSD(5%)	0.58	0.78	3.15	1.23	0.70
LSD(1%)	0.80	1.07	4.37	1.70	0.97

*p<0.05; **<0.01

Table 8: Contd

Parents	Spikelet per spike	Grain per spike	1000 grain weight(gm)	Harvest index	Spad value	Grain Yield per plant(g)
P_1XP_2	0.000	0.000	-4.445**	-0.397	-0.250	0.107
P_1XP_3	-0.500	-1.500*	4.672**	-3.995**	-2.750	-0.292
P_1XP_4	0.500	0.000	-1.0008*	-2.068	-1.375	-0.385
P_1XP_5	-0.250	-0.250	2.837**	3.630**	-0.250	-0.385
P_1XP_6	0.000	0.000	-0.075	-2.4258	-1.175	-0.452
P_2XP_3	0.000	-0.250	-15.770**	-0.623	1.500	0.000
P_2XP_4	-0.500	0.000	-4.222**	0.770	-0.250	-0.255
P_2XP_5	-0.250	1.500*	-5.925**	-3.000*	-3.725	2.117
P_2XP_6	-0.250	-0.250	3.007**	-3.502**	1.050	-0.265
P_3XP_4	1.000	-0.750	-4.650**	-3.042*	-1.825	-0.082
P_3XP_5	-0.250	0.500	-10.9508*	-4.272**	-1.750	-0.050
P_3XP_6	-0.500	-0.250	0.090	-2.012	-0.700	-0.380
P_4XP_5	0.000	0.000	3.05000**	-0.953	0.200	0.132
P_4XP_6	-0.250	0.000	1.27750**	0.472	-1.650	-0.432
P_5XP_6	-1.000	0.000	1.8350	-5.533**	-0.250	-0.165
SE (ij)	0.522	0.476	0.256	0.966	1.583	0.605
LSD(5%)	1.11	1.01	0.54	2.05	3.37	1.28
LSD(1%)	1.53	1.40	0.75	2.84	4.66	1.78

*p<0.05; **<0.01

4.1.3.5. Heterosis of the crosses

Heterosis over mid parent for grain yield and its contributing characters in heat tolerant wheat are given in Table 9. Heterosis of the crosses was estimated in method and model 1 of Griffing (1956a) where the parents and reciprocal crosses were excluded. Out of 15 crosses none was shown significant positive heterosis for garin yield. The cross 'sufi x line 1018' showed significant heterosis for plant height. Significant days to maturity was showed by the cross 'Shatabdi x bijoy' whereas none of the cross showed significant heterosis over better parents. The significant positive heterosis over better parents were obtain from the cross 'sufi x bijoy'. Shamsuddin *et. al.* (1991) reported positive relation between heterosis for grain yield and heterosis for some yield components. Prasad *et. al.* (1998) reported that heterosis for grains per spike and 1000-grain weight was independently associated with heterosis for grain yield per plant.

Table 9: Estimates of heterosis in F_1 hybrids over better parent for grain yield and its contributing characters in heat tolerant wheat

Crosses	Days to heading	Days to maturity	Plant height (cm)	Spike per plant	Spike length (cm)
P_1x P_2	-2.2500*	1.250*	-1.750	-1.7500	-0.3750
P_1 x P_3	-1.750*	3.250*	0.500	-1.0000	0.1750
P_1 x P_4	-1.5000*	-0.500	-1.750	-0.5000	0.3250
P_1 x P_5	-2.2500*	2.250*	0.750	-0.7500	2.3250
P_1 x P_6	-1.2500*	3.500*	3.000	-0.5000	-0.7500
P_2x P_3	0.5000	3.250*	-3.250*	0.0000	0.5250
P_2x P_4	-0.2500	0.250	-3.500*	0.7500	1.1000
P_2x P_5	-0.2500	-1.000	1.250	0.5000	0.5750
P_2x P_6	0.2500	-1.000	3.250*	0.750	-0.7500
P_3x P_4	0.2500	1.2500*	2.7500	0.0000	0.3750
P_3x P_5	0.2500	-1.2500*	0.5000	0.5000	0.3500
P_3x P_6	0.2500	-0.5000	-2.2500	-0.2500	-0.0250
P_4x P_5	-0.500	-1.0	-.200	-.5	-0.2000
P_4x P_6	-0.750	-.25	-5.75	-.5	.100
P_5x P_6	0.000	-1.500*	1.500	-2.7	-.075
SE	.517	.517	1.48	.820	.466
CD(5%)	1.10	1.10	3.15	1.74	0.99

*p<0.05; **<0.01

Table 9: Contd.

Crosses	Spikelet per spike	Grain per spike	1000grain weight	Harvest index	Spad value	Grain Yield per plant(g)
P_1x P_2	-2.0000	16.000	-3.145	-2.78	-0.4	5.0150
P_1 x P_3	-1.5000	3.500	5.047	-3.24	-0.7	-0.3125
P_1 x P_4	1.0000	9.000	3.900	-1.21	-2.82	4.1700
P_1 x P_5	-1.7500	-10.750	6.432	-3.46	-2.95	-1.0450
P_1 x P_6	-1.0000	3.000	1.832	-1.84	-0.32	1.4725
P_2x P_3	-2.0000	3.250	-14.095	-0.84	-3.100	-3.887
P_2x P_4	-1.5000	6.000	1.977	-2.90	-0.350	3.682
P_2x P_5	1.0000	-3.500	-1.030	-3.39	4.525	1.605
P_2x P_6	-1.7500	-1.250	6.215	-2.76	-1.750	2.507
P_3x P_4	1.0000	0.750	-0.125	-0.88	0.4250	1.857
P_3x P_5	-0.2500	-5.500	-7.730	-4.51	5.4000	-2.580
P_3x P_6	-1.0000	-16.750	1.622	-3.25	0.5000	-3.790
P_4x P_5	-0.7.5	18	4.355	0.81	-2.2	-3.117
P_4x P_6	-1.50	-0.10	4.270	1.79	0.80	-0.602
P_5x P_6	-0. 500	0.6	-0.147	-7.00	-2.95	-0.710
SE	1.28	0.952	0.363	2.12	3.16	0.284
CD(5%)	2.72	2.028	0.774	4.51	6.733	0.169

*p<0.05; **<0.01

CHAPTER 5

SUMM ARY

The experiment was undertaken to study the combining ability, variances and effects for the determination of type and magnitude of gene action for different economic characters in wheat using a six parent diallel cross including reciprocals. The experiment was conducted at the experimental field of WRC, Dinajpur during rabi season, 2007-2008to rabi 2009-2010 season. The parental genotypes used in the study were spring wheat namely Shatabdi, Sufi, Bijoy, Prodip, Line-1040 & Line-1018. The different environmental characters were investigated.

The results of the investigation are summarized as follows:

5.1. Combining ability (Grffing's approach)

Combining ability analyses following Griffing's approach revealed significant general, specific combining ability and reciprocals mean squares for all the growth characters studied indicating involvement of both additive and non-additive gene action in the inheritance of these characters. The gca variances (σ^2g) were higher than the sca variances(σ^2s) for the characters days to heading, days to maturity, plant height, spike length, spike let per spike grains per spike, 1000-grain weight harvest index indicating predominance of additive gene actions in the inheritance of these growth characters. On the other hand sca variances (σ^2s) were higher than the gca variances (σ^2g) for spike per plant and spike length indicating predominance of non-additive gene actions in the inheritance of these growth characters.

The estimates of gca effects showed no single parent contain all of the desirable characteristics. Variety shatabdi was identified as good general combiner for grain yield per plant. Other good general combiners for other characters were: shatabdi was positive combiner for 1000-grain weight, spikelet per spike and spike length. Shatabdi was good combiner for long growth duration.

The study of sca effects reveled that the best specific combiner 'bijoy x prodip' and 'shatabdi x sufi' for grain yield; 'shatabdi x line 1040' and 'bijoy x line line 1040', 'bijoy x line 1018' & 'line 1040 x line 1018' for long spikes; except 'sufi x line 1040' & 'bijoy x line 1040' all were good combiner for grain per spike; crosses between 'line1040 x line 1018', 'prodip x line 1040' & 'prodip x line 1018' for harvest index.

Significant positive reciprocal effect were obtained from all the crosses except 'shatabdi x line1018', 'line 1040 x line 1018' and 'bijoy x line 1018' for 1000-grain weight. 'Shatabdi x prodip' and 'bijoy x line 1018' are showed significant plant height.

CHAPTER 6

CONCLUSION

- Pedigree (or sort of modified pedigree) method could be used for improvement of the characters showing preponderance of additive genetic effects such as plant height, spike length, spike let per spike.
- The improvement of the characters with greater non-additive genetic component, such as in grain yield/plant, spike /plant, grain per spike, 100 grain weight etc could be improved by recurrent selection.
- shatabdi was good combiner for most for the morphological traits.
- Gene interactions were found important in producing significant specific combining ability.
- 'shatabdi x sufi' and 'bijoy x prodip' were the most promising cross combination which could be exploited for crossing block.

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Appendix I. Meteorological data recorded (a) during hybridization programme (Nov.2007-Mar. 2008) and (b) during the experimental period (Nov.2009-Mar. 2010) at WRC. Nashipur, Dinajpur

Month	Temperature(^{0}C) Maximum	Temperature(^{0}C) Minimum	Average Rainfall (mm)	Average Sunshine (hr)	Average Humidity (%)
(a) Hybridization programme					
November 2007	29.50	18.55	00	7.4	72
December 2007	24.54	12.25	00	7.2	66
January 2008	24.24	9.50	3.24	6.6	74
February 2008	25.75	10.24	00	7.5	64
March 2008	30.50	16.00	9.00	8.6	68
(b) Experimental period					
November 2008	28.00	18.34	00	7.5	70
December 2008	24.88	11.34	00	7.3	66
January 2010	24.00	8.56	00	7.0	65
February 2010	26.78	9.50	7.56	7.9	72
March 2010	32.00	18.56	12.53	8.4	73

Source : Weather Station, WRC, Dinajpur.