COMBINING ABILITY AND HETEROSIS IN SHORT DURATED BORO RICE THROUGH AUS X BORO CROSSING

BY

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CERTIFICATE

This is to certify that thesis entitled, **"COMBINING ABILITY AND HETEROSIS IN SHORT DURATED BORO RICE THROUGH AUS X BORO CROSSING"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **GENETICS AND PLANT BREEDING,** embodies the result of a piece of *bona fide* research work carried out by **MD. ABID HASAN,** Registration No. **11-04701** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated: December, 2013
Place: Dhaka, Bangladesh

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Supervisor

LIST OF ABBREVIATED TERMS

FULL NAME	ABBREVIATION
Additive Variance	δ^2A
Agro-Ecological Zone	AEZ
Amylase Content	AC
Analysis of Variance	ANOVA
And others	*et. al.*
Bangladesh Bureau of Statistics	BBS
Bangladesh Rice Research Institute	BRRI
Better parent	BP
Centimeter	Cm
Co-efficient of Variation	CV
Critical Difference	CD
Days After Sowing	DAS
Degree Celsius	^{o}C
Degrees of freedom	d.f
Dominance Variance	δ^2D
ds/m	Desicemence/ meter
EC	Electric Conductivity
Error Mean Sum of Square	EMSS
Etcetera	etc.
Figure	Fig.
Food and Agriculture Organization	FAO
Gelatinization Temperature	GT
General Combining Ability	GCA
High Yielding Vairety	HYV
Kilometer	Km
Length to breadth ratio	L:B
Male Sterile	MS
Mean Sum of Square	MSS
Mid Parent	MP
Number	No.
Percent	%
Randomized Complete Block Design	RCBD
Sher-e-Bangla Agricultural University	SAU
Specific Combining Ability	SCA
Square meter	m^2
Square	Sq
Standard Error	SE
Transplanted Amon	T. Amon

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ABSTRACT

BY

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This research work was carried out by using number of F_2 population of some inter-varietal crosses of the species *Oryza sativa* in the experimental farm, Sher-e-Bangla Agricultural University (SAU), Dhaka during October 2011 to April 2012 for estimating the mean performance, combining ability (General and Specific) and residual heterosis. Combining ability analysis revealed significant general and specific combining ability for most of the traits studied indicating involvement of both additive and non-additive gene action in the inheritance of yield and yield contributing characters. Significant, desirable and highest SCA effect was observed for days to maturity in cross combination BR21 x BR24 which might be selected as the best specific combiner for earliness. Highest, significant desirable SCA effects was observed for yield and most of the yield contributing characters in cross combination BR26 x BRRI Dhan29 which might be selected as best specific cross combination followed by BRRI Dhan28 x BRRI Dhan29, BR26 x BRRI Dhan36 and BR24 x BR26 for yield and yield contributing characters. These cross combinations also showed heterosis and therefore these cross combinations may be reviewed further for earliness and yield performance. Mean performance revealed that, BR 21 x BRRI Dhan36 required minimum days to flowering and maturity with reasonable yield followed by BR 24 x BRRI Dhan 36. So, these two cross combination could be selected for short duration and high yielding variety development.

TABLE OF CONTENTS

List of Tables

List of Plates

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

Rice is the seed of the monocot plant *Oryza sativa*, of the grass family (Poaceae). As a cereal grain, it is the most important staple food for a large part of the world's human population, especially in tropical Latin America, the West Indies, East, South and Southeast Asia. The worldwide production of rice is second highest after maize. Rice is the staple food of about 160 million people of Bangladesh. It provides nearly 48% of rural employment, about two-third of total calorie supply and about one half of the total protein intakes of an average person in the country. Rice sector contributes one-half of the agricultural GDP and one-sixth of the national income in Bangladesh.

In terms of total rice production; the country now occupies the 4th position in the world. About 46,905,000 t of rice were produced on 11,741,000 ha of land in 2008, with a productivity of 3.99 tha^{-1}(FAO, 2010). Where the China's average yield is around 6.5 tons per hectare. Though Bangladesh is the world's fourth largest rice-producer but yield is relatively low. So developing high yielding short duration rice varieties is one of the ways to satisfy the future demand.

The demand for rice is constantly rising in Bangladesh with nearly 2.3 million people being added each year to its population of about 150 million. Desired rice production must be achieved at a faster rate than in most other countries, while the rice growing land is not expanding. In addition, Bangladesh is facing with production constraints such as drought, lack of irrigation facilities, flooding and salinity of soils, coupled with fluctuating commercial rice prices.

Primary constraints to achieving food security are the low yield per unit area and negligible scope for expansion of the area of land for cultivation. Hence, increase in intensity of cultivation and in yields per unit area are the only available options to meet future food needs to feed an ever increasing population. In Bangladesh most of the farmers are growing more than one crop on the same land during one year of production system. Within this concept there are many possible cropping patterns. With the availability of short duration HYV of Boro rice farmers will be able to grow any third crop between T. Aman and Boro rice (L. Hassan & M.A Quddus, 2014)

In Bangladesh, most of the farmers are growing many varieties of boro rice annually in many regions of Bangladesh. Those varieties required long growth duration. So farmers need more irrigation, labor and chemical costing. Due to the lacking in the availability of short duration HYV of Boro rice farmers are reluctant to grow any third crop in between T. Aman and Boro rice. So, it is needed to be reduced the duration of boro rice and developing high yielding rice.

As, people of northern region produce huge amount of potato during October to January. So, short duration rice cultivation in boro season (just after harvest of potato in late January or early February) as additional rice production technology may be a blessing to northern Bangladesh.

For the improvement of rice through breeding program i.e., development of high-yielding varieties with short duration boro rice need to select parent first. But parent selection is so much difficult task because yield is a polygenic character resulting from the interaction of yield contributing characters influenced by environmental fluctuations.

Selection is the important aspect in a crop improvement program, but it is difficult to make improvement through direct selection on the basis of phenotypic performance only. The value of selected progeny would largely depend upon the relative contribution of heritable and non-heritable component. In case of hybrid breeding program, selection of the parent on the basis of phenotypic performance alone is not in sound position since phenotypically superior line may yield poor recombination in the segregating generations. Therefore, the parents should be selected or chosen based on their genetic value for any plant breeding program.

Aus rice takes minimum days to maturity. On the other hand boro rice gives maximum yield among all rice. Considering these two features, F_1 generation was produced by crossing aus and boro rice for combining short duration and high yielding character. BR 21, BR 24 and BR 26 were selected as aus rice. BRRI Dhan 28, BRRI Dhan 29 and BRRI Dhan 36 were selected as boro rice. Present study was carried out on F_2 generation for estimating the mean performance of crosses and parental material, GCA, SCA and also estimating the F_2 heterosis over parent.

Diallel analysis provides an effective means of obtaining rapid information about the genetic features of the homogygous lines. Selection of parental lines in terms of their ability to combine in hybrid combinations and subsequently use them for developing pure line or hybrid varieties depend upon their nature of combining ability. The study of combining ability also offers scope in partitioning the genetic component of characters into additive and non-additive components. General combining ability (GCA) measures the additive and specific combining ability (SCA) measures the non- additive genetic variations. The breeding methods for exploiting these two types of genetic variations are different from each other. The parent with high GCA could be used for developing inbred variety while crosses showing high SCA could be used for developing hybrid varieties.

So the present study has been undertaken with following objectives-

- To select short duration materials of Boro rice.
- To select higher yielding materials of Boro rice.

CHAPTER II

REVIEW AND LITERATURE

2.1. Diallel analysis: concept and methodology

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

Diallel analysis involves crossing in all possible combination among a set of genotypes. It operates on the following genetical assumptions (Hayman, 1954a):

i. Diploid segregation
ii. Only environmental difference between reciprocal crosses
iii. Independent action of non-allelic genes
iv. No multiple allelism
v. Homozygosity of parental lines
vi. 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 F_2) 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:

i. It is a most balanced and systematic experimental design to examine continuous variation.

ii. The genetic information related to parental populations becomes available quite in early generation (F_1 itself), thus useful to define breeding strategy without much time.

iii. Now, there is no need for parents 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; Griffing, 1956a and 1956b; Jones, 1965) and varying degrees of replication of diagonal (parents) and off-diagonal (F_1s) entries in the diallel table (Jones, 1965).

Jinks and Hayman (1953) proposed numerical approach to estimate genetic parameters based on Mather's notation. They outlined four components viz. D, H1, H2 and F assuming additive and dominant effects of genes but no epistasis or non-allelic interaction. Hayman (1954b) presented in details the theory and algebraic basis of analysis and added two more statistics, h^2 and F to those suggested by Jinks and Hayman (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.

2.2. Combining ability studies

The main feature of diallel analysis is combining ability. The term combining ability was introduced by Sprague and Tatum (1942) where they used general combining ability (GCA) to designate "average performance of a line in hybrid combination" and specific combining ability (SCA) as "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 was 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 δ^2A and δ^2D 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 diallel depending on the materials involved in the analysis. The methods and materials involved are as follows;

Method 1: n x n (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_1s only

Method 4: n (n-1) - Full diallel set involving F_1s and reciprocals only

Griffing (1956a) also suggested diallel 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 are 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 dealt 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, i.e. Method I and Method II are most extensively used by plant breeders. The contribution of each parent to general combining ability was measured by the estimates of GCA effects (gi), and the contribution of each parent to hybrids was given by the estimates of SCA effects (sij).

2.3. Combining ability in rice

Singh *et al.* (1993) conducted an experiment and gave information on combining ability for yield and 6 of its components in 8 genotypes and their F_1 hybrids from a diallel cross without reciprocals. ARC10550 performed as a good general combiner for most of the traits.

Ali *et al.* (1994) evaluated F_1 hybrids resulting from a half-diallel cross involving cultivars Basmati 370, Basmati 385, Basmati 4048 and Basmati 198 for anther length, 100-anther weight, pollen grain size and percentage filled spikelet. Both GCA and SCA were significant for all traits except pollen grain size. The GCA mean square was considerably higher than SCA mean square for anther length and 100-anther weight, whilst the reverse was found for percentage filled spikelet. This indicated additive gene effects for anther length and 100-anther weight, and dominance gene effects for percentage filled spikelet. Basmati 198 displayed positive and significant GCA effects for anther length and 100-anther weight, Basmati 370 was the best general combiner for percentage filled spikelet and 1000 grain weight. 4048 x Basmati 198, Basmati 370 x 4048 and Basmati 370 x Basmati 385 were the best specific combiners for anther length, 1000 grain weight and percentage filled spikelet, respectively.

Geetha *et al.* (1994) studied genetic variance and combining ability on yield and 6 of its components in a 4 x 4 half diallel involving cultivars ADD38, ADT39, Co45 and White Ponni. Variance due to GCA and SCA was significant. There was a preponderance of additive gene action for plant height, grain length, grain breadth and 100-grainweight, andgene action or panicles per plant and grain yield per plant. ADT38 and White Ponni were the best combiners for grain yield due to increases in panicles per plant and number of grains per particle, respectively. White Ponni and ADT39 were the best contributing parents for slender grain type.

Honarnejad *et al.* (1994) studied the combining ability of 6 yield components in 6 Iranian rice genotypes and their F_1 hybrids from a half-diallel cross. There were significant differences between genotypes and high GCA and SCA effects for the yield components studied. Tillers per plant, plant height and grain length to breadth ratio were mostly controlled by additive gene action and partial dominance. These characters had high heritability and were suitable for selection. Earliness, length of panicles and percentage of empty gains per panicle were controlled by over dominance.

Heand Zheng (1994) analyzed the leaf number on the main stem at various growth stages in 6 cultivars and 15 F_1 progeny of rice. The inheritance of the rate of leaf increase varied with growth stage, but dominant effect was more important than additive effects at all stages. The importance of additive effects changed more with growth stage than the dominant effect and super dominance was found at some stages. Distinct differences were found in the control of the rate of leaf production on the main stem.

Honarnejad (1995) evaluated 15 F_1 hybrids and 6 parents of rice from a diallel cross for 10 quantitative traits. GCA and SCA values were generally high and indicated additive gene action in the control of days from transplanting to first panicle appearance (DTFPA), plant height and grain length: breadth ratio. Non-additive gene action and low heritability estimates were noted for earliness, panicle length, empty grains per panicle, tiller per plant and 1000-grain weight, Plant height was significantly and negatively correlated with tillers per plant and positively with DIFPA.

He *et al.* (1996) presented a result from tests of hybrids of a diallel set of crosses between 5 varieties of rice. But additive effect were more important for protein content and non-additive effects were more important for protein content and non-additive effects for free amino acid content. Cytoplasmic effects were significant for amino acid content but not for protein. The significant linear regression between GCA for protein and amino acid contents suggested that both could be improved simultaneously by breeding. Jiangxiang 1, Peiai 64, 1R58 and Mcp231-2 had high GCA and could be used as superior parents in breeding.

Honarnejad *et al.* (1999) crossed six Iranian and exotic rice cultivars in a half-diallel crossing and 8 traits were evaluated. Analysis of variance showed that difference due to genotypes and general and specific combining abilities were significant, indicating the presence of additive and non-additive variance. The presence of partial dominance in the genetic control of plant height, with heritability values of 61 to 68%, made selection for dwarf plant height possible. In spite of the presence of over dominance for characteristics such as length to width ratio of brown rice, there is a good chance of successful selection for long grains, due to high heritability estimates of 64 to 94%.

Nguyen *et al.* (1997) analyzed GCA and SCA and their effects for six major characters in a diallel mating system with 6 early maturing sorghum parents by sowing in spring and summer. The GCA and SCA effects were highly significant for all traits studied. Sonic parents were identified having high positive GCA for grain yield, and low or negative GCA for culm length and days to heading which were considered as good combiners. Genotype x sowing time interaction effect was significant for grain yield, culm length and days to heading. Genotype x sowing density interaction effect was significant for grain yield in spring sowing but not in summer sowing.

Jiang *et al.* (1998) analyzed combining ability for grain yield stability in hybrid rice and relationship between grain yield based on data from an incomplete diallel cross grown at 4 sites and its stability was analyzed using the AMMI model. There were interaction effects between sites and both grain yield of combinations and the combining ability of parents. The relationships between grain yields of combinations or combining ability of parents and stability were not significant at 5 or 1% level. The stability of grain yield in hybrid rice was controlled by general combining ability (GCA) and specific combining ability (SCA) of parents and GCA was more important than SCA. Breeding hybrid rice combinations with high stability in grain yield needs at least one parent with higher GCA for stability.

Lee *et al.* (1997) crossed nine varieties differing in salinity tolerance in a partial diallel cross. Twelve-day-old hybrid seedlings were grown in saline solution, initially at an EC of 6 ds/m for 4 days, followed by an EC of 12 ds/m for 20 days. Agronomic characters such as plant height, dry shoot weight and dry root weight were measured in seedlings after 20 days. General combining ability (GCA) and specific combining ability (SCA) effects were highly significant for all tested parameters. However, mean squares of GCA were about 5 times larger than those for SCA, suggesting the preponderance of additive gene action. Among tolerant varieties, Gaori and Namyang 7 were good combiners for improving salinity tolerance at the seedling stage.

Li *et al.* (1998) studied heritability and combining ability for blast *(Magnaporthe grisea)* resistance, amylose content (AC), gelatinization temperature (GT) and 4 yield components in a diallel cross involving 10 rice cultivars. Blast resistance, AC and GT were mainly controlled by additive gene effects. Number of tillers per plant, number of panicles per plant, panicle length and plant height were controlled by both additive and non-additive effects. Waixuan 35 exhibited high blast resistance combined with good combining ability and heritability, an attractive grain shape, but low combining ability and heritability for GT and AC. Erbazhan combined favorable blast resistance and quality traits with high GCA.

Singh *et al.* (1998) conducted an experiment and gave information on combining ability for 10 yield-related traits in 8 rice genotypes and their 28 F_1 hybrids. GCA and SCA variances were significant for all the traits studied. Laloo 14 was a good general combiner for grain yield per plant, earlinessand low sterility percentage and harvest index. Mahsuri was good general combiner for tillers per plant, whereas PWR54 was a good general combiner for panicle length and grains per panicle. Mahsuri and Madhuri both were good general combiners for biological yield per plant. Basmati 370 x Dribraj was best specific combiner for plant height and flag leaf area. The crosses exhibiting higher SCA effects for grain yield per plant were Ismail 370 x Dubraj, RWR54 x Mahsuri and Madhuri x Laloo 14.

Surek and Korkut (1998) crossed 8 rice cultivars (Delta, Baldo, Balilla, Titanio, Rodina, Krasnodarsky-424, H-33, and K-78-13) in all possible combinations (excluding reciprocals) to determine the nature of gene action and inheritance of some quantitative characters in the F_1 and F_2 generations. The additive genetic variance was significant and greater than the non-additive genetic variance for all characters except grain yield per plant in both generations. Additive and dominance estimates were significant for nine characters, whereas only the non-additive component was significant for biological yield per plant, grain yield per plant, and harvest index. The mean degree of dominance was less than unity, indicating partial dominance, for plant height, panicle length, spikelet sterility, 1000-grain weight, and grain length; equal or near unity, suggesting complete dominance, for days to heading; and greater than unity, indicating over dominance, for the number of panicles per plant, number of spikelet per panicle, biological yield per plant, grain yield per plant, harvest index and grain width.

Borgohain *et al.* (1998) conducted an experiment on F_1 populations and parent of deep water rice with 9 yield related traits from an 8×8 diallel cross (including reciprocals) and analyzed combining ability genetic variance. Both GCA and SCA variance were significant for yield and its component characters. The GCA/SCA ratio indicated the preponderance of additive gene action for grain yield per plant, plant height, days to 50% flowering, inter-node length and kneeing ability; non-additive gene action was more important for the rest of the characters studied. The best general combiners for grain yield and most of the components were DWR2, DWR I and DWR5. DWR2 x DWR4 was the best reciprocal combiner for plant height, days to flowering flag leaf area and1000grain weight. DWR7. DWR 1 x DWR2, DWR2 DWR4, DWR3 x DWR6 and DWR5 x DWR6 were the four best specific cross combinations for grain yield and its component characters.

Geetha *et al. (1998)* experimented combining ability derived from 12 yield-related traits in parents and F_1 progeny of a diallel cross involving 6 rice cultivars. Data indicated a predominance of additive gene action for all the characters studied. 1R50 and ADT4l were rated the best parents based on per se performance and GCA effects for all characters. The cross 1R50/ADT39 was recommended for improvement of both grain yield and grain length/breadth ratio by recombination breeding.

Chen *et al.* (1999) analyzed the combining ability of newly selected genetically male-sterile (MS) lines and reported the breeding of two-line hybrids, the MS indica lines SE2ls, SEI 26, SE152, Zhenshan 97A, Longtepu A and Fuyi A and 6 indica restorer lines were crossed in an incomplete 6 x 6 diallel design. Combining ability for 8 agronomic traits was analyzed in the 36 hybrids and the parents. The results showed that both GCA and SCA effects played an important role for all 8 yield-related characters in the F_1 hybrids. MS lines SE152, Longtepu A and SE21s and the restorer lines Minghui 86 and tingliui 63 were good general combiners for grain weight per plant. Grain weight per plant in 5 F_1 hybrids exceeded that of the control, Shanyou 63 by more than 10%.

Dwivedi and Senadhira (1999) Studied combining ability and nature of gene effects in a 7 x 7 diallel (excluding reciprocals) for plant elongation in some deepwater rice cultivars through short duration flooding treatment given at the 3 week old seedling stage. Estimates of genetic parameters and combining ability analysis showed highly significant additive and non-additive effects. Additive gene effects were more prominent than dominance effects. Partial dominance was operating for the trait. Recessive genes were slightly more frequent in diallel combinations. Variance due to general combining ability was greater than specific combining ability confirming the preponderance of the additive nature of gene action. Variety Jalmagna was found to be the best general combiner.

Honarnejad (1999) analyzed that seven Iranian and foreign rice cultivars and their F_2 progenies, produced via a half-diallel mating design. Data were collected on 8 quantitative characteristics. ANOVA showed significant differences among genotypes for means and for general and specific combining ability, for all the traits except number of full and empty grains per panicle. For number of tillers per plant, partial dominance gene effects were observed. Over dominance gene effects were observed for time to panicle emergence, days to grain maturity, plant height, 1000-grain weight, and number of full and empty grains per panicle. Estimated heritability (narrow sense) was 44% for time to panicle emergence, 22% for grain maturity, 21% for plant height, 47% for number of tillers per plant and 23% for 1000-grain weight. Early emergence of panicles and lateness of grain maturity, tallness of plant, higher number of tillers per plant and reduced 1000-grain weight are mostly controlled by dominant genes.

Bansal *et al.* (2000) assessed combining ability effects in diallel cross of 11 parent involving 8 scented (Dawag, Bindli, N750, Basmati 1 A, Basmati 372, Karnal Local, Basmati1 and Basmati 405) and 3 non-scented (Pula 44-33, 1E11585 and TNI) rice (*Oryza sativa*) stocks. The estimates of general combining ability (GCA) and specific combining ability indicate predominance of non-additive gene effects for days to flower, plant height, panicle length, tillers per plant, number of fertile tillers per plant, grain yield per plant, 1000-grain weight and length to breadth (L:B) ratio.

Jin *et al.* (2000) reported that six japonica rice varieties with different chalkiness rate in rice grains were crossed by Griffing's diallel method IV to investigate their combining ability in F_1 and F_2 generations. The results showed that GCA and SCA variations of chalkiness ratio in rice grains were significant at 0.01 level, which suggested that the chalkiness rate of rice grains was controlled by a gene additive effect as well as non-additive effect. The ratio of GCA MS/SCA MS was also significant in F_1 and F_2generations and increased as the generation advanced. It is suggested that the additive effect was principal. The additive variation of the total variation was dominant in F_1 and F_2 generations. The relationship of the combining ability effect between the two generations was significant and there was difference between the chalkiness rate of rice grains of parents and the GCA could be approximately estimated from the mean value of parents.

Roy and Mandal (2001) crossed some rice cultivars Mansarovar, Pokkali, IR72, IR43, Annad, IR50, Tulsari, Pusa Basmati, Tarori Basmati and Karnal local-95 in all possible combinations excluding reciprocals. The mean sum of squares of treatments, general combining ability (GCA) and specific combining ability (SCA) were significant indicating prevalence of genetic diversity among parents and F_1 hybrids. Among the parents, Pokkaliand Armada were good general combiners for all the characters. The F_1s with high GCA effects for grain yield also possessed positive SCA values for other yield component characters. Majority of the promising F_1s had parents with high GCA which suggests that selection could be made based on per SCA performance. The SCA performance of F_1s indicates that either one or both the parents were good general combiners.

Sharma and Mani (2001) analyzed that combining ability for grain yield and some other characters in a 9 x 9 diallel cross (excluding reciprocals) involving seven basmati (Basmati

370, Basmati C 622, Basmati 5853, Kasturi, Pusa Basmati I, Haryana Basmati I, and UPR 85-71-8-1) and two non-basmati (Pant Dhan 11 and TN 1) genotypes following Griffing's approach. Non-additive gene effects appeared to be predominant for days to flowering, plant height, flag leaf area, productive tillers plant^{-1}, panicle length, grains panicle^{-1}, grain weight panicle^{-1}, 100-grain weight, grain yield plant^{-1}, head rice recovery, and amylose content, while both additive and non-additive gene effects were equally important for harvest index and kernel elongation ratio. Basmati 370, Haryana Basmati 1, Kasturi and Pusa Basmati 1 emerged as good general combiners for grain yield and other characters. UPR 85-71-8-1 was a good general combiner for earliness and shorter plant height. Crosses with good specific combining ability were also identified.

Cao *et al.* (2002) investigated combining ability of root activity and its declined properties in indica hybrid rice using a 4 x 4 incomplete diallel cross design with four male sterile lines and four restorer lines. The results exhibited h^2 in root activity and its declined value was more than 85%. The estimated variance for general combining ability (GCA) and specific combining abilities (SCA) were highly significant for 2 traits, indicating that the root activity and declined value existed for both additive and non-additive effects, but the former was mainly affected by the non-additive effect and vice versa. The cultivars Longtefu A and Zhenhui 048 had higher GCA and larger variance of SCA, which implies that they can be utilized as superior parents in rice breeding.

Reddy *et al.* (2002) made diallel crosses (excluding reciprocals) were with 8 lowland rice genotypes, i.e. Gayatri, Sabita, Lunishree, Utkalprabha. Manoharsali. OR1334-8,CN 59 and CN 718-8-21-10. Then they obtained 28 F_1 and 28 F_2 bulks from the crosses under two planting situations i.e. normal and late. Analysis of variance showed significant differences for all the characters studied among the 28 F_1 and 28 F_2 bulks under both normal and late planting situations. Analysis of variance for combining ability revealed that both general and specific variances were significant for both the F_1 and F_2 generations for grain yield and its components, indicating the importance of both additive and non-additive genetic variance in the inheritance of those characters in lowland rice.

Hong *et al.* (2002) studied combining ability of eight agronomic important characters of F_1 derived from different ecological types in japonica rice and their parents by an 8 x 8 diallel design. In the populations consisted of different ecological types of japonica rice, additive and non-additive genetic effects were equally important for the four characters of plant height, spikelet's per panicle, filled grains per panicle and grain yield per plot. For the three characters of heading date, panicle length and effective panicles per plant, additive effects were more important than those of non-additive. And for the character of 1000-grain weight, non-additive effect was more important than that of additive. Xiushui 04 and 3726 were the parents with excellent general combining ability effects and special combining ability variance for grain yield per plot and yield components. Koshillikari × Xitishui 04 was a superior combination with good special combining ability effects and overall characters.

Sha *et al.* (2002) reported combining ability analysis using 10 fine-aromatic rice germplasms in a partial diallel crossing design to estimate General Combining Ability (GCA), Specific Combining Ability (SCA) and nature of gene action to help in breeding fine-aromatic rice cultivars. Considerable variation among parents and crosses (F_1s) for agronomic parameters were observed. The additive variance (δ^2A) estimate was 0.30 and that of dominance variance (δ^2D) was 3.79, thereby indicating low genetic heritability (0.064) and presence of both additive and non-additive gene effects on panicle weight of fine-aromatic rice.

Vanaja *et al.* (2003) studied twenty-eight rice hybrids, produced from diallel crossing including reciprocals among eight parents (Mattatriveni, Hraswa, Mahsuri, Vyttila 3, Kachsiung Sen Yu 338, IR 36, IR60133-184-3-2-2 and PK3355-5-1-4) along with the parents for combining ability for yield and 17 yield components. The study revealed the importance of both additive and non-additive gene effects in governing yield and most of the yield components with preponderance of non-additive gene action for most of the yield components. Additive gene action was found important for 1000-grain weight, second uppermost inter-nodal length and height of plant at harvest. The parent Vyttila 3 was found to be a good general combiner. The hybrid IR36 x Vyttila 3, Hraswa x PK3355-5-1-4 were the reciprocal combiner for days to maturity, panicles per hill, panicle weight. Whereas the hybrid Mattatriveni x IR 36 was the best reciprocal combiner for yield per plant. The hybrids PK3355-5-1-4x Hraswa. Vyttila 3 x IR60133-184-3-2-2, Vyttila 3 x IR36, Vyttila3 x Mattatriveni and IR36 x Mattalxiveni showed significant favorable specific combining ability effect for yield and different yield components.

Verma *et al.* (2003) reported that genetic analysis have been made to uncover the supremacy of gene action and combining ability for certain grain quality related physicochemical traits in seven diverse eco geographical genotypes of indica rice using a 7 x 7 half-diallel cross following Griffing's Model-1, Method-2. Comparative results obtained from 7 parents + 21 F_1s+ 21 F_2s revealed the involvement of both additive (polygenic) and non-additive (epistasis or interallelic) gene action(s) in the governance of grain quality traits.

Iftekharuddaula *et al.* (2004) investigated the specific combining ability for yield and yield components in an eight parent half diallel cross in rice. The parental genotypes used in the study were BRRI dhan29 , BR 4828-54-4-1-4-9, BRRI dhan 28 , IR8, Amo 13, IR65610-38-2-4-2-6-3, Minikit and Zhong Yu7, which were chosen for their genetic differences and diverse origins.

The study of specific combining ability (SCA) effects revealed that in most of the cases, a combination of high x low or even low x low crosses exhibited high SCA effects for most of the characters, rather than high x high cross combinations, indicating the importance of gene interactions. There were highly significant positive correlations among per SCA performance and SCA for almost all the rice characteristics.

Singh and Singh (2004) crossed rice cultivars namely Dihula, Niwari, Rairmunuwa, JR 353, RWR 3-45, Poornima, Vanprabha and Kalinga 3 in all possible combinations. A predominance of additive gene action was observed for all the characters measured. Raimunuwa, JR 353 and RWR 3-45 were good general combiners for grain yield per plant. Dihula, Poornima and RWR 3-45 recorded significant negative general combining ability for number of days to 50% flowering. The cross Raimunuwa x Poornima and Poornima x Vanprabha were the best specific combiners for days to flowering, days to maturity, 1000 grain weight and crop yield and some physiological characters.

Liu *et al.* (2004) crossed 51 japonica rice cultivars from 9 ecotypes in a diallel fashion. The genotypes were classified into heterotic groups based on general combining abilities (GCA) and specific combining abilities (SCA) for 6 traits (number of panicles per plant, number of filled spikelet per panicle, number of spikelet per panicle, seed set, grain weight per plant, and 1000-grain weight). The variance of GCA was higher than that of SCA. The characters were mainly controlled by additive gene effects. The relationship between GCA and hybrids was significant.

Raju *et al.* (2004) analyzed combining ability of some rice cultivars like IR-20, Shiva, Tellahamsa, Lunisree, WGL-NDL-2, Erramallelu and RDR-763 and their 21 F_1s progenies

(Obtained by crossing the parents in a diallel fashion). Analysis of variance revealed significant differences among the parents and hybrids for all the characters studied. Combining ability analysis revealed significant mean squares due to General Combining Ability (GCA) and specific combining abilities (SCA) for all the characters indicating the importance of both additive and non-additive gene actions.

Hosseini *et al.* (2005) crossed 8 Iranian and exotic rice cultivars in a half-diallel crossing system. During the following year, parental lines as well as progenies were sown to evaluate seven quantitative traits. Analysis of variance showed that differences due to genotypes as well as general and specific combining abilities were significant. The presence of additive and non-additive variance was observed in the crosses. The presence of partial dominance in the genetic control of time of 50% heading and plant height was observed with 68 and 61% heritability, respectively. The presence of over dominance for characteristics such as full maturity time, paddy weight per plant, harvest index and period of growing were evident. The non-additive variance effect was higher than the additive variance effect.

Suresh and Anbuselvan (2006) determined the combining ability analysis for yield and yield components of rice in a 6 x 6 diallel cross among genotypes Nanjing 3678, OM 1327-14, RPI 506-2709-688- 1, RPI 674-690-39-14, RP 2095-1-10-9 and RP 825-24-7. Nanjing 3678, RP 2095-1-10-9 and RP 825-24-7 exhibited positive significant GCA effects for grain yield per plant. There was a close relationship between per SCA performance and GCA effects indicating the possible use of per SCA performance as a selection criterion for selection of parents. The majority of the crosses showed significant specific combining ability (SCA) effects, which involved at least one parent having high GCA effects. The best SCA effect and high per SCA performance were observed in the hybrid RPI 674-690-39-14 x RP 825-24-7.

Dhakar *et al.* (2006) studied combining ability between the seven parents viz., Vikas, kanak, Chambal, IR-64, BK-79, Jaya and IR-36 crossed in a diallel fashion (excluding reciprocal). Observation were recorded on grain weight along with other characters viz., days to flowering, days to maturity, tillers per plant, panicle length, grains per panicle, 100-grain weight and yield per plot. Combining ability analysis revealed the preponderance of non-additive gene action for most of the characters. Parents Vikas, Kanak and IR-64 were good general combiners for yield and yield attributing characters like grains per panicle, grain panicle weight and yield per plot. In addition to this parent Vikas was found to be good general combiner for 1000-grain weight.

Kumar *et al.* (2006) analyzed a 9 x 9 diallel mating design of F_1 generation (excluding reciprocals) of rice *(Oryza sativa)* for grain yield; various yield components and some grain quality traits. The magnitude of GCA variance was relatively higher than the SCA variance and thus, the predominance of additive gene action (d) was observed for all the traits except for net assimilation rate ($g/cm^2/day$), biological yield per plant (g), harvest index (%) and protein content (%). Based on GCA effects, the parental cultivars HPR 2047, VL 91-1754 and JD 8 were good general combiners for grain yield and most of its contributing characters.

Kumar *et al.* (2007) analyzed combining ability with variable maturity period of diverse rice genotypes namely ADT 37, IR 50 (short); IR 64, Sasayasree, IR 20 (medium), and ADT 38, ADT 44 and CR 1009, mated in a 9 x 9 diallel fashion. The result showed that the General Combining Ability (GCA) and Specific Combining Ability (SCA) variances and reciprocal effects were significant for all the six characters of interest, namely number of productive tillers per plant, number of filled grains per panicle, 100-grain weight, biomass per plant, grain yield per plant, and harvest index. The parent ADT 44 portrayed significant positive GCA effects for number of panicle per plant, number of filled grains per panicle, 100-grainweight, biomass per plant, grain yield per plant and harvest index.

Kumar *et al.* (2007) studied a nine parent full diallel analysis of rice genotypesViz. ADT 37, Tulsi, IR 50, ADT 38, Sasayasree, IR 64, ADT44, CR 1009 and IR20, revealed the importance of both additive and non-additive gene actions in the expression of all the sixteen traits of interest. The parents ADT 44 and CR 1009 were found to be good general combiners for grain yield per plant.

2.4 Heterosis

Suresh *et al. (1999)* studied on heterosis for yield and yield components in rice. Five testers (TNAUBPHU 831293 (T1), TANU 831521 (T2). W1263 (T3). ARC 6650 (14) and Re 10550 (T5)) and seven lines (IR 50 (L1), Kannagi (L2), TKH 9 (L3), Co 33 (L4), ASD 16 (L5), ADT 36 (L6) and Co 34 (L7)) were crossed in a line x tester mating design. All hybrids showed negative heterosis over mid- and better parent for days to 50% flowering, but only 12 of these hybrids showed negative heterosis over standard parent. L1 x T4 showed the highest positive heterosis for plant height. Nine hybrids showed positive heterosis for productive tillers per plant and 8 hybrids showed positive heterosis for panicle length and L5 x T4 showed the highest positive heterosis for these yield component. L4 x L4, L5 x T 1 and L5 x T4 showed the highest positive heterosis for number of grains per panicle. L4 x T4 alone showed significantly positive heterosis for 100-grain weight. Three cross combinations (Ll x T3, L2 x T3 and L4 x T3) showed high heterosis for over-all grain yields and its components.

Tiwari *et al.* (2001) studied on eleven hybrids, derived from ten high yielding, widely-adapted and local cultivars were evaluated with parental lines and the standard cultivar, Kranti, to determine the nature and extent of heterosis for seven characters including grain yield per plant. The range of heterosis for grain yield per plant was -11.70-150.00% over mid-parent, -28.60-148.50% over better parent and -37.7-158.10% over the standard cultivar. The highest heterotic effects for grain yield was observed from JR 353 x Mahamaya followed by Kranti x Badalphool, Kranti x Mahamaya and JR 353 x Kranti, which was higher, respectively, by 150.00, 107.80. 98.30, and 94.60% over mid-parent. 148.50. 114.80, 129.70, and 95.60% over better parent and 158.10, 124.80, 129.8 and 91.00% over the standard cultivar.

Wei et al. (2001) conducted a study to determine heterosis of japonica hybrid rice. Grain yield per plant and seed-bearing tillers per plant of the F_1s showed considerable positive heterobeltosis and competitiveness while panicle length, 1000-grain weight and seed set demonstrated a negative heterobeltiosis over their male parents. The F_1s of all the 3 CMS lines had significant heterobeltiosis and some standard heterosis in terms of grain yield per plant and 216A showed the highest average yield of F_1 grain, followed by 16A and 552A.

Janardhanam *et al.* (2001) studied on eight parental rice cultivars (Nootripattu, Poongar, Seengani, and Vellaichithiraikar as lines and ADT.36, IR.20, IR.50, and MDU.5 as testers) and 16 hybrids were studied for Heterosis. Relative heterosis was significant for plant height (10 hybrids), panicle length (10 hybrids), number of spikelets (6 hybrids), number of grains per panicle (10 hybrids), and single plant yield (13 hybrids). Heterobeltiosis was significant for plant height (11 hybrids), panicle length (8 hybrids), number of spikelets (3 hybrids), number of grains per panicle (9 hybrids), and single plant yield (12 hybrids). Standard heterosis was significant for plant height (all hybrids), panicle length (6 hybrids), number of grains per panicle (14 hybrids), and single plant yield (15 hybrids). Seengani x ADT.36, Seengani x IR.50, Seengani x MDU.5, Vellaichithiraikar x ADT.36, Poongar x ADT.36, Nootripattu x MDU.5 and Nootripattux ADT 36 showed 80% heterobeltiosis for single plant yield. Seenganix ADT.36, Vellaichithiraikar x ADT.36, and Poongar x ADT.36 exhibited standard heterosis for single plant yield.

Singh *et al.* (2002) found 38-50% of the hybrids exhibited significant and positive heterobeltiosis and standard heterosis for grain yield per plant. Heterosis for grain yield was mainly due to heterosis for EBT per plant, 1000-grain weight and number of fertile grains per panicle, biological yield and harvest index. The superior heterotic combinations exhibiting 60% standard heterosis for yield over the control (Sarjoo-52) were IR 58025 A/NDR 6054 and PMSIA/NDR 2022.

FengYi *et al.* (2002) studied heierosis in vegetative growth in interspecific hybrids between *Oryza sativa* and *O. glaberrima*. The interspecific hybrids of *O. sativa* ssp. *indica* x *O. glaberrima* showed significant heterobeltosis as compared with either parent and significant standard heterosis over the inter-subspecific hybrids *indica* x japonica in dry weight at the tillering stage and in tiller number per plant. The hybrids of *O. sativa* ssp. *Japonica* x *O. glaberrima* had significant heterobeltiosis in dry matter weight at both the tillering and the heading stages, but they showed no significant standard heterosis over the intraspecific hybrids of *O. glaberrima* x *O. glaberrima*. These results suggest that the interspecific hybrids of *O. sativa ssp, indica* x *O. glaberrima* may increase the dry weight of the plants at the tillering stage and tiller number to a greater extent than *indica* x *japonica* hybrids.

YueJin *et al.* (2002) carried out an experiment on heterosis of F_1 hybrids between the candidate indica-compatible japonica lines (ICJLs) and indica lines. The F_1 hybrids between ICJL G3005-4-1 and indica lines had great mid-parent heterosis in the theoretic grain yield but the other indica-compatible weak japonica lines and indica lines had little mid-parent heterosis. The F_1 hybrids with great mid-parent heterosis in the theoretic grain yield between ICJL G3005-4-1 and indica lines had high total grains, filled grains per panicle, normal seed set rate and proper growth duration and plant height. The mid-parent heterosis of F_1 hybrids in the theoretic grain yield was not correlated to the parent average and the parent coefficient identified by simple sequence repeat markers.

Wei *et al.* (2002) evaluated heterosis of main agronomic traits in indica-japonica lines of rice. All F_1's showed significant or highly significant positive heterobeltiosis in plant height, 1000-seed weight and yield. Significant negative heterobeltiosis was found for number of days to heading. Four cross combinations showed significant or highly significant positive heterosis in grain yield/plant in the late season. Most F_1's involving G2417-1 or G3005-4-1 showed marked positive heterosis in grain yield/plant when sown in the late season.

Surek *et al.* (2002) studied on heterosis for grain yield and its components and to compare the hybrid performance of F_1 and F_2 generations for all traits studied under the temperate conditions using eight rice cultivars (Delta, Baldo. Balilla, Titanio, Rodina, Krasnodarsky-424, H-33 and K-78-13) crossed in all possible combinations (excluding reciprocals). The average heterosis and heterobeltiosis observed in F_1 generation for grain yield per plant were 21.2 and 15.2%, respectively, whereas an average of 8.2% heterosis and -0.2% heterobeltiosis were obtained in the F_2 generation for this trait. Heterosis for grain yield per plant in the F_1 generation was due to heterosis the number of panicle per plant, biological yield and harvest index. The correlations between F_1 and F_2 heterosis values and between F_1 and F_2 heterobeltiosis values indicate that the heterotic effects continued in the F_2 generation for days to heading, plant height, panicle length, the number of spikelets per panicle, biological yield, harvest index, 1000-grain weight and grain length.

Verma *et al.* (2002) worked with seven diverse rice ecotypes (IR 24, Sarjoo 52, NDR 359, T 21, Mahsuri, Jai Lahri and NS 19), along with their F_1 and F_2 populations for heterosis for 5 important quantitative traits (days to 50% flowering, number of productive tillers per plant, number of spikelets per panicle, 100-grain weight and grain yield per plant). The majority of the crosses showed significant heterobeltiosis and standard heterosis over standard variety 1 (SV 1; Mahsuri) and standard variety 2 (SV2; Sarjoo 52) for grain yield and number of productive tillers per plant, and 100-grain weight (over SV1 only). Only a few crosses showed heterobeltiosis for days to 50% flowering and spikelets per panicle. The strong heterotic effects for grain yield per plant were observed in the cross combinations NDR 3591/T 21, Mahsuri/IR 24, Sarjoo 52/NDR 359, IR 24/NDR 359 and NDR 359/Jal Lahri.

Verma *et al.* (2002) estimated heterosis and inbreeding depression for yield and certain physiological traits in hybrids involving diverse ecotypes of rice. Superior crosses for most physiological traits involved diverse ecotypes endowed with some inherent and acclimatized gene pools under the two distinct rice ecologies, viz., UIR (upland irrigated) x RFL, (rainfed lowland) or vice-versa (interecotypic crosses) all the crosses manifesting heterosis were found to carry at least one good parent from either of UIR or RFL. Two cross combinations, viz., Mahsuri/Sarjoo 52 and T 21 /NS 19 having exhibited additive gene effects for biological yield and grain yield heterosis were found to be desirable transgressive segregants.

Kumari *et al.* (2003) observed heterosis for yield and its components involving Indica/japonica wide compatible varieties in rice. A trial was conducted with forty-two hybrids involving indica/japonica crosses. The results revealed that the hybrid Palawan/ASD 18 and BPI 76(G)/ASD 18 had the highest standard heterosis for the number of grains per panicle and single plant yield respectively. This shows that these hybrids can be utilized for further yield improvement.

Patil *et al.* (2003) studied on heterosis exploration in 7 thermo sensitive genic male sterile rice lines (TGMS) and 12 non-TGMS lines through 84 crosses. The crosses TGMS 15 x ADT 36, Pei'ai 645 x ADT 36. TGMS 18 x White Ponni, TGMS 18 x ADT 36, IR 68945-4-33-14 x ADT 36 and IR 68948-12-3-7 x C 20 showed high heterosis for early flowering. The hybrids TGMS 18 x C 20 and Pei'ai 645 x C 20 showed heterosis for high tillering ability, panicle length, grains per panicle and yield. Relative heterosis for grain yield per plant was in the range 52.03-72.08% coupled with significant heterobeltiosis in the range 56.03-59.59%. The standard heterosis was in the range 70-46.55% for yield per plant.

Vanaja *et al.* (2004) studied on heterosis for yield and yield components in rice. The parents and crosses were evaluated and heterosis for yield and its principal components was estimated in experiments conducted. Results suggest that yield increase was largely due to significant and favorable heterosis in yield components, i.e. number of spikelets panicle-^{1}, panicle length leaf area plant- ^{1} (at maximum tillering stage) and number of panicles m-^{2}. Five top heterotic crosses over their mid and better parents for each trait were identified.

WenBang *et al.* (2004) evaluated heterosis of the combinations with dual-purpose genic male sterile rice C815S. The performance of rice crosses derived from crossing 6 female parental lines including cv. C8I5S and 6 male parents including cv. 288 was determined. The cross C815/S288 recorded 15.31% higher yield compared to the other crosses. Crosses involving C8155 recorded the highest yield heterosis (33.33%). The yield of crosses involving C815S was positively related to the number of effective panicles, full grain number, seed setting rate and 1000-grain weight, whereas the number of effective panicles were negatively related to plant height. C815S has a good general combining ability.

Sivakumar *et al.* (2005) studied on heterosis in interspecific crosses involving wide compatible gene in *rice (Oryza sativa* L.*)*. A study was conducted to evaluate the performance of 39 interspecific rice hybrids with wide compatible gene as one of the parents. Preponderance of non-additive gene action was observed for all the 8 traits studied. i.e. plant height, days to 50% flowering, number of tillers per plant, panicle length, pollen fertility, grains per panicle. 100-grain weight and grain yield per plant. It was observed that the crosses involving indica with wide compatible cultivar showed better expression for yield and other yield components.

Rosamma *et al.* (2005) studied on heterosis in rice (*Oryza sativa L.*), hybrids developed for Kerala state. Rice cultivars was Annapooma, MattaTriveni, Kanchana,, IR36 and Aiswarya crossed with four stable cytoplasmic male sterile lines (IR 62829A, IR 68890A, IR 68891A and PMS 10A) in a line x tester mating design. IR 62829A x Kanchana, IR 68890A x Kanchari, IR 68890A x Aiswarya and IR 68891A x IR36 expressed significant positive standard heterosis for grain yield indicating that these hybrids have the potential for hybrid rice production. All hybrids expressed high positive values of standard heterosis for number of panicles per plant. IR 68891 A x IR36 recorded significant positive standard heterosis for grains per panicle.

Sahu *et al.* (2005) observed heterosis in yield attributing and physiological traits of rice hybrids involving male sterile lines. The extent of heterosis for physiological traits was high in crosses involving MS lines 97A and 29A, and testers Heera and Lalat. Among the 5 MS lines used for hybrid production, 97A and 29A showed higher heterosis than the others for the yield components. High heterosis (more than 15%) observed in the crosses 29A x Konark, 97A x Gouri, 29A x Lalat and 29A x Heera can be attributed to very high heterosis for relative growth rate and net assimilation rate, and moderate heterosis in leaf area index, specific leaf area, leaf area ratio, relative growth rate. panicle number/plant and panicle length.

Singh (2005) studied heterosis breeding in aromatic rice for yield and quality characters. Forty one hybrids were evaluated for yield and quality characters with Pusa Basmati-1 and Basmoti -370, respectively. Based on quality characters, three hybrids viz., IR 58025 A x PB-6-12-55-5, IR 68888A x PatloonTahni and IR 68888A x Gopal Bhog were identified superior which also exhibited higher yield heterosis. Hybrid, IR 68888A x PatloonTahni was early in maturity and also showed high outcrossing. These hybrids can be exploited successfully in hybrid rice breeding programme.

Kshirsagar *et al.* (2005) studied on 40 rice hybrids utilizing four cytoplasmic genetic male sterile lines and ten testers and studied for the extent of standard heterosis and heterobeltiosis on thirteen quantitative characters. Among quality characters, kernel length was the most heterotic attribute. The highest heterobcitiosis for grain yield per hill was recorded by the cross IR-68886A x IR-56381-139-2-2. The cross IR-68888A x IET-16309 had the highest standard heterosis for grain yield.

Verma *et al.* (2006) worked with forty-five rice hybrids generated from crossing three lines with 15 testers to determine the nature and magnitude of heterosis over better parent (BP) and standard variety (SV) i.e. Sarjoo-52 for days to 50% flowering, plant height, panicle bearing tillers per plant, panicle length, number of spikelets per panicle, number of filled (fertile) grains per panicle. 1000-grain weight, biological yield per plant, grain yield per plant and harvest index. The manifestation of heterosis for yield per plant was obtained over BP from 54.90 to 82.58% and over SV from 68.66 to 40.34%. The hybrids, in general, which showed superiority over BP and SV for grain yield per plant also exhibited significant heterosis for panicle bearing tillers per plant, panicle length and number of spikelets per panicle, number of filled grain per panicle, biological yield per plant and harvest index.

Biju *et al.* (2006) tested heterosis for yield and related characters in rice hybrids. The hybrid IR 80784H recorded maximum significant positive standard heterosis (46.61%) for grain yield two hybrids viz. IR80784H, IR 79172H recorded grain yield of more than 7 tones/ha. In the above hybrids the heterosis ranged from 3.027% to 46.61%. The hybrids manifested significant positive standard heterosis for spikelet fertility, grain yield and significant negative heterosis for plant height and days to 50% flowering. The study suggested that the high yielding hybrids IR 80784H, IR 79172H and IR 80634H could be exploited for increasing yield in southern regions of India.

Munisonruppa *et al.* (2007) studied on heterosis for 5 quantitative traits (panicles per plant, spikelets per panicle, spikelet fertility, thousand grain weight and yield per plant) in 7 newly developed rice hybrids (APRH-2, DRRH-1, PA 6201, Sahyadri, PHB-71, KMRH-4 and KRH-2) and 2 control cultivars (Jaya and IR 30864) . All hybrids showed significant positive heterosis for all traits in at least one environment over the control cultivars. APRH-2 showed significant positive heterosis in a maximum number of environments, followed by KMRH-4, DRRH-1, KRH-2, PA 6201, Sahyadri and PHB-7, DRRH-1 proved to be superior to the other hybrids as it recorded significant positive heterosis for grain yield in most of the environments followed by Sahyadri and K RH-2.

YongMei *et al.* (2007) studied on heterosis (OPH) of 2-line japonica hybrid rice combinations. The number of panicles per plant, 1000-grain weight and theoretical yield were higher and the number of spikelets per panicle and number of grains per panicle were lower in Yuxithanin Kunming. The japonica hybrid rice combinations showed negative OPH in panicle length and 1000-grain weight, positive OPH the other traits in Kunming and also showed negative OPH for plant height, 1000-wain weight and seed setting rate and positive OPH for the other traits in Yuxi.

XianNeng *et al.* (2007) tested 6 maintainer lines and 8 restorer lines as male parents. Dianjingyou 1 and Minghui 63 as female parents to make a 2 x 14 diallel cross to understand the genetic base of rice heterosis and find new ways for rice heterosis research. Based upon the heterosis performance and special combining ability of all the combinations for panicle number, spikelet number per panicle, and yield per plant, 3 crosses were selected to make backcross to recurrent parents to raise heterosis in near isogenic lines for each trait. Our strategy was to dissect complex trait, heterosis, into single Mendel factor to be mapped and operated via recurrent backcross, selection and molecular mapping.

Kumar *et al.* (2008) evaluated F_1 heterosis over better parent, standard variety (NarendraUsar) and standard hybrid (NUSD) in 40 crosses of rice for yield and five other attributing traits under saline-alkali soil. Highly significant and positive heterosis for grain yield plant-^{1} was expressed over better parent, standard variety and standard hybrid in nine crosses IR 58025 A x IR 72048-B-R-2-2-2-1-B. IR58025 A x NDR9830119, NMS 4A x NDRK 5094, NMS 4A x CSR(S) 14-1-4-0, IR 58025 A x Narendra Usar 3, IR 58025 A x IR 71829-3R-73-I-2-B, IR 58025 A x 21-2-5-B-1 -1, IR 58025 A x NDRK 5086 and NMS x IR 64. Moreover IR 58025 A x IR 71829-3R-73-1-2-B exhibited only better parent heterosis (64.45%) for spikelet fertility percentage.

Kumar *et al.* (2008) conducted an experiment on heterosis and residual heterosis in rice for 6 traits (number of filled grains per panicle, 100-grain weight, biomass per plant, grain yield per plant, and harvest index) in 5 generations (P1, P2, Fl, F7 and F3) of 6 rice cross combinations involving 3 cultivars (ADT 37, ADT 36 and ADT 44). P3 x P1 and P1 x P3 exhibited significant positive relative heterosis for grain yield per plant. The residual heterosis for grain yield per plant was negative and significant in all crosses.

Residual heterosis for number of productive tillers and 100-grain weight were positive and significant.

Bisne *et al.* (2008) studied on CMS lines (IR 68885A, IR 62829A, IRR2A and PMS 10A) and 8 testers (BKP 232, R 827-287, Pusa Basmati, R-1060-1674-1-1, R 714-2103, Culture 1001, Supper rice-2 and R 304-34) were used to study heterosis for 9 characters (number of days to 50% flowering, plant height, panicle length, number of effective tillers per plant, 100-grain weight, harvest index, grain length, grain width and grain yield per plant) of rice. Significant standard heterosis for grain per plant over the control (BKP 232) was estimated for 2 crosses, ie. DRR 2A/R 827-287 and DRR 2A/R 1060-1674-1-1. These hybrids have potential as commercial cultivars.

CHAPTER III

MATERIALS AND METHODS

3.1 Exp erimental site

The study was carried out in Sher-E-Bangla Agricultural University (SAU) research field during Rabi season, 2011.

3.2 Geographical Location

The experimental area was situated at 23°77'N latitude and 90°33'E longitude at an altitude of 8.6 meter above the sea level (Anon., 2004). The experimental field belongs to the Agro-ecological zone of "The Modhupur Tract", AEZ-28 (Anon., 1988a). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hillocks of red soils as 'islands' surrounded by floodplain (Anon., 1988b). The experimental site was shown in the map of AEZ of Bangladesh in (Appendix I).

3.3 Climate

Area has subtropical climate, characterized by high temperature, high relative humidity and heavy rainfall in Kharif season (April-September) and scanty rainfall associated with moderately low temperature during the Rabi season (October-March). Weather information regarding temperature, relative humidity, rainfall and sunshine hours prevailed at the experimental site during the study period is presented in Appendix II.

3.4 Characteristics of soil

Soil of the experimental site belongs to the general soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. Top soils were clay loam in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. Soil pH ranged from 6.0- 6.6 and had organic matter 0.84%. Experimental area was flat having available irrigation and drainage system and above flood level. Soil samples from 0-15 cm depths were collected from experimental field. The analyses were done by Soil Resource and Development Institute (SRDI), Dhaka. Physicochemical properties of the soil are presented in (Appendix III).

3.5 Parent Materials

A set of three Aus cultivars namely BR-21, BR-24 & BR-26 and a set of three Boro cultivars namely BRRI dhan-28, BRRI dhan-29 and BRRI dhan-36 were used as parents for a half diallel cross.

3.6 Cross Combination

All possible combination crosses (excluding reciprocals) were done in a half diallel mating design to produce 15 F_1 seeds. The study was undertaken with the F_2 materials of the crosses to evaluate the performance. The crosses were 36×29; 36×28; 36×26; 36×24; 36×21; 29×28; 29×26; 29×24; 29×21; 28×26; 28×24; 28×21; 26×24; 26×21 and 24×21.

3.7 Experimental Design

The experimental design used was a randomized complete block design (RCBD) with three replications. Each replicate or block contained 21 experimental units or plots (6 parents and 15 F_2 materials). Each plot is consisted 1m width and 4m length.

3.8 Sowing and Transplanting

The seeds of genotypes were sown in nursery beds on December 2^{nd} of 2011.The seedlings were transplanted on January 15^{th} of 2012. Spacing was 25 x 20 cm.

3.9 Intercultural Practices

Routine cultural practices, similar to those used in commercial production of rice, were done as needed.

3.10 Harvesting

Harvesting was started when 80% of seeds in each plant reached at maturity.

3.11 Collection of Data

Data were recorded from 20 randomly selected plants per plot. Among the characters studied days to 50% flowering and plant height were recorded from the field and the remaining characters were recorded in the field laboratory after harvesting.

Data were collected for the following characters:

3.11.1 Plant height

The length of the main culms (cm) from the ground level to the tip of its panicle was measured and average was taken.

3.11.2 Days to 50% flowering

Days to 50% flowering was recorded as days from sowing to flowering when 50% of the plants of each plot were at flowering.

3.11.3 Number of tillers/plant

The total numbers of the tiller were counted from each of the sample plants and the average was taken.

3.11.4 Number of effective tillers/plant

The total number of the panicle bearing tillers were counted from each of the sample plants and the average was taken.

3.11.5 Panicle length

Length of panicle was measured in centimeters from the tip of the panicle to the basal node of the panicle and averaged the values.

3.11.6 Panicle weight

Weight of the total panicle was measured in grams for each genotype per plot.

3.11.7 Number of primary branches/panicle

The total number of primary branches per panicle was counted.

3.11.8 Number of secondary branches/panicle

The total number of secondary branches per panicle was counted.

3.11.9 Number of filled grain of main tiller

Presence of any endosperm in the spikelet was considered as filled grain and total number of filled grain on main tiller and average was counted.

3.11.10 Total number of spikelet/panicle

Numbers of spikelet in panicles were counted and averaged the values.

3.11.11 Days to maturity

Number of days required from sowing to grain maturity of 80% plants of each entry.

3.11.12 Fresh weight of 100 grains

Weight in grams of randomly counted 100 seeds after harvesting was recorded.

3.11.13 Dry weight of 100 grains

Weight in grams of randomly counted 100 seeds after drying was recorded.

3.11.14 Yield/plant

All the seeds by a representative plant was weighed in grams (both fresh and Dry) and considered as yield per plant.

3.12 Statistical Analysis of Data

Statistical analyses were done to calculate the Analysis of variances, mean performance, combining ability analysis and heterosis estimation.

3.12.1 Estimation of LSD

Difference among the mean value evaluated through LSD value.

The formula for the least significant difference is:

$LSD_{A,B} = t_{0.05/2DFW}\sqrt{MSW\,(1/nA + 1/nB)}$

Where:

t = critical value from the t-distribution table

MSW = mean square within, obtained from the results of your ANOVA test

n = number of scores used to calculate the means

3.12.2 Estimation of heterosis:

The amount of heterosis in the F_2's was analyzed using the following formulae:

$$\text{Heterosis over better parent \%} = \frac{\overline{F_2} - \overline{BP}}{\overline{BP}} \times 100$$

Here, $\overline{F_2}$ =Mean of F_2 individuals

$\overline{BP}$ = Mean of the better parent values

$$\text{Heterosis over mid parent \%} = \frac{\overline{F_2} - \overline{MP}}{\overline{MP}} \times 100$$

Here, $\overline{F_2}$ =Mean of F_2individuals

$\overline{MP}$ = Mean of the mid parent values

CD (Critical Difference) values were used for testing significance of heterotic effects.

Critical Differences (CD) = $tx \sqrt{\frac{2\ EMS}{r}}$

Here, EMS= Error Mean Sum of square

r = No. of replication

t = Tabulated t value at error df

CD values were compared with the values come from (F_2-BP) and (F_2-MP) to test significance of respective heterotic effects.

3.12.3 Combining ability in relation to diallel cross

Griffing (1956) proposed four methods of analysis depending on the materials involved. Griffing has also considered Eisenhart's model I (fixed effect) and model II (random effect) situation in the analysis. In the present research work combining ability analysis were done following method 2 (excluding reciprocals) and model-1.

The mathematical model for the analysis was:

$Y_{ij} = m+g_i+g_j+S_{ij}+ 1/bc \sum\sum_{kl} e_{ijkl}$

Where,

$i, j = 1, 2, \ldots\ldots\ldots\ldots, p$

$K = 1, 2, \ldots\ldots\ldots\ldots, b$

$L = 1, 2, \ldots\ldots\ldots\ldots, c$

P = Number of parents

B = Number of blocks or replications

c = Number of observation in each plot

Y_{ij} = The mean of i × jth genotype over K and L

m = The population mean.

g_i = The general combining ability (GCA) effect to ith parent

g_j = The GCA of jth parent

s_{ij} = The SCA effect such that $s_{ij} = s_{ji}$

$1/bc \sum_{kl}\sum e_{ijkl}$ = The mean error effect

The restriction imposed are $\Sigma\, g_i = 0$ and $\Sigma\, S_{ij} + S_{ii} = 0$ (for each i)

The analysis of variance for combining ability was carried out using replication mean of each entry (diallel family) as follows:

Item	df	Sum of Square	MSS	Expected MSS
GCA	P-1	S_g	M_g	$\sigma_e^2 + (P+2)\frac{1}{(P-1)}\Sigma g_i^2$
SCA	P(P-1)/2	S_s	M_s	$\sigma_e^2 + \frac{2}{P(P-1)}\Sigma_i\Sigma_j S_{ij}^2$
Error	(b-1)(e-1)	S_e	M_e'	σ_e^2

Where,

GCA = general combining ability

SCA = specific combining ability

p = Number of parents

b = Number of blocks or replications

e = Number of entry (family)

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

Y_{ii} = Mean value lof the ith parent

Y. = Grand total of the ½ p(p-1) crosses and parental lines

Y_{ij} = Progeny mean values in the diallel table

S_e = Sum of square due to error

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

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

The GCA and SCA effects of each character were calculated as follows;

$$g_i = \frac{1}{(P+2)}\left[\sum_i (Y_{i.} + Y_{ii})^2 - \frac{2}{p} Y_{..}\right]$$

$$s_{ij} = Y_{ij} - \frac{1}{(P+2)} \sum (y_{i.} + y_{ii} + y_{.j} + y_{jj}) + \frac{2}{(p+1)(p+2)} y_{..}$$

The variance of GCA and SCA were,

$$\text{Var}\ (g_i) = \frac{(p-1)}{p(p+2)} \sigma^2 e$$

$$\text{Var}\ (s_{ij}) = \frac{2(p-1)}{(p+1)(p+2)} \sigma^2 e (i \neq j)$$

Standard error (SE) of an estimate was calculated the square root of the variance of concerned estimate eg.

j Var(g;) and jVar(s.)

$\sqrt{\text{Var}(g_i)}$ and $\sqrt{\text{Var}(s_{ij})}$

CHAPTER IV

RESULT AND DISCUSSION

This chapter comprises the presentation and discussion of the findings obtained from the study. The data pertaining to yield and 13 yield contributing characters were computed and statistically analyzed. The results thus obtained are discussed.

4.1 Analysis of variance (ANOVA)

The mean squares due to genotypes for all the traits under present study were highly significant different as showed in the ANOVA. The results indicated significant differences among 21 genotypes of the present diallel study, which was necessary for further analysis (Table 1). Genotypes have been partitioned into parents (P) and crosses (F_2) items. Significant mean squares due to parents and crosses were observed for most of the characters except for panicle length, panicle weight, Number of primary branches per plant, Number of secondary branches per plant, filled grains of main tiller and panicle per plant. Which indicating the presence of adequate genetic variability and the genetic inference could be calculated (Barar and Sukhija, 1977).

4.2 The mean performance of parents and their F_2 generations

The general performances of each parent and each F_2 generations were investigated for each character.

4.2.1 Plant height

Data in (Table 2) showed that the cross (BR21×BR24) had the tallest plant (109.1 cm) followed by BR21×BRRI dhan 26 (105.5 cm), BR24×BRRI dhan 29 (104.9 cm), BR21×BR26 (104.1 cm), BR24 (103.6 cm), BR24×BRRI dhan 28 (101.8 cm), BR21×BRRI dhan 28 (101.4 cm), BR21 (99.93 cm), BRRI dhan 28 (99.67 cm), BR24×BRRI dhan 36 (98.98 cm), BR21×BRRI dhan 29 (98,96 cm), BR24×BR26 (98.88 cm), BR26 (98.30 cm), BRRI dhan 29 (96.57 cm), BR26×BRRI dhan 36 (96.15 cm), BRRI dhan 28×BRRI dhan 29 (95.48 cm), BRRI dhan 28×BRRI dhan 36 (93.78 cm), BR26×BRRI dhan 29 (93.92 cm), BR26×BRRI dhan 28 (90.84 cm) and BRRI dhan 29×BRRI dhan 36 (89.90 cm), while the parental cultivar BRRI dhan 36 had the shortest (81.43 cm) one.

4.2.2 Days to 50% flowering

Concerning days to 50% flowering, the recorded 50% flowering days ranged from 90 (90.67) to 94 (94.33). The cross BR26×BRRI dhan 36 required maximum days to 50% flowering (94.33), while the parental materials required minimum days (90.67) to 50% flowering. The cross BR21×BR24 required minimum days to flowering (91.33) followed by BR21×BRRI dhan 28 (91.66). These crosses are significantly different from each other while the other crosses are statistically similar.

4.2.3 Number of tillers/plant

Regarding number of tillers per plant, the parental material BR26 gave the highest number of tillers per plant (28.77), while the cross BR21×BR24 gave the lowest (16.83) one. The cross combination BRRI dhan 28×BRRI dhan 29 had maximum number of tiller (26.95) followed by BRRI dhan 29×BRRI dhan 36 (26.65), BR26×BRRI dhan 36 (25.27) and BR26×BRRI dhan 29 (25.18). These combination performances are statistically similar while the other crosses had statistically lower number of tiller per plant than the discussed materials.

Table 1: The analysis of variance of the half diallel mating design for various traits in rice

Source of variance	df	Plant Height (cm)	Days to 50% Flowering	Total no of tiller/Plant	No. of effective tiller/plant	Panicle length (cm)	Panicle weight (gm)	No. of primary branch/panicle	No. of secondary branch/panicle
Replication	2	51.013	10.619	16.57	18.165	6.111	0.187	0.017	3.508
Genotype	20	116.213 **	3.267	30.01	24.76 **	2.565	0.064	0.223	4.301
GCA	5	296.625 **	8.933 **	73.079 **	72.503 **	1.511	0.076	0.088	7.802
SCA	14	56.076 *	1.378	15.654	8.847	2.917	0.061	0.268	3.133
Error	40	26.672	2.286	13.968	7.846	2.267	0.073	0.217	4.554

Source of variance	df	Filled grain of main tiller	Total no. of spikelet/panicle	Fresh weight of 100 grain(gm)	Dry weight of 100 grain(gm)	Yield/plant (fresh weight in gm)	Yield/plant (dry weight in gm)	Days to maturity.
Replication	2	257.954	289.011	0.001	8.956	105.725	23.111 *	140.182
Genotype	20	146.701	166.365	0.002 **	0.002 **	199.811 **	100.144 **	252.531 **
GCA	5	249.479	298.68	7.665	7.44	535.944 **	328.311 **	658.903 **
SCA	14	112.441	122.259	0.003 **	0.002 **	87.766	24.089 **	117.074 *
Error	40	153.238	136.33	4.49	6.036	46.482	4.761	58.101

**** indicates significant at the 0.01 level; * indicates significant at the 0.05 level**

Table 2: Mean performance of parents and their F_2 generations

Variety	PH(cm)	DSF	TTP	ETP	PL (cm)	PW (gm)	PBP	SBP
F2 generation								
21×24	109.13	91.333	16.833	15.017	23.507	3.117	10.4	28.467
21×26	104.12	92	18.967	16.9	23.247	3.067	10.383	28.567
21×28	101.43	91.667	22.75	20.85	23.283	3.293	10.283	28.933
21×29	98.96	92	23.817	21.983	23.677	3.053	10.617	27.05
21×36	105.48	92	21.433	19.75	23.567	3.127	10.333	29.067
24×26	98.88	91.667	17.717	15.987	23.27	3.21	10.967	29.8
24×28	101.78	92.667	20.583	18.767	23.47	2.97	10.267	27.833
24×29	104.93	93.667	22.25	20.117	23.287	3.073	10.15	28.317
24×36	98.98	92	23.876	22.533	22.493	3.05	10.533	28.133
26×28	90.84	91.333	22.167	20.7	22.793	3.09	9.967	26.733
26×29	93.20	92.667	25.183	23.333	23.46	2.847	10.35	26.05
26×36	96.15	94.333	25.267	23.15	23.907	3.433	10.733	29.583
28×29	95.48	92.333	26.95	24.683	24.003	3.297	10.3	28.617
28×36	93.78	92.667	22.433	20.533	27.067	3.31	10.483	28.1
29×36	89.90	93.667	26.65	24.8	23.393	3.07	9.817	26.583
Parents								
21	99.93	90.667	21.033	19	23.083	2.863	10.7	26.767
24	103.57	93	17.8	15.8	23.137	3.003	10.7	28
26	98.30	91.333	28.767	19.867	23.14	3.017	10.567	27.6
28	99.67	90.667	20.267	23.933	23.117	3.107	10.733	28.167
29	96.57	93.667	23.8	21.967	22.32	2.96	10.667	24.933
36	81.43	93.667	23.867	21.833	22.943	3.173	10.433	28.767
LSD Value	8.69	2.699	6.186	4.758	2.579	0.4602	0.7515	3.497

PH= Plant Height, D5F= Days to 50% Flowering, TTP= Total Tiller/ Plant, ETP= Effective Tiller/Plant, PL= Panicle Length, PW= Panicle Weight, PBP= Primary Branches/panicle, SBP= Secondary Branches/Panicle

Table 2: Continued

Variety	GMT	SP	FW of 100 Grain(gm)	DW of 100 Grain(gm)	Yield /Plant(FW in gm)	Yield /Plant (DW in gm)	DM
F2 generation							
21×24	151.35	159.333	2.223	2.077	33.587	32.603	143.667
21×26	151.7	160.55	2.23	2.087	40.73	37.243	142
21×28	164.217	173.433	2.26	2.113	49.107	45.217	143.333
21×29	145.717	156.567	2.213	2.057	57.193	52.673	146
21×36	154.75	163.9	2.277	2.133	51.563	46.897	141
24×26	156.367	166.917	2.253	2.12	42.92	39.713	147.667
24×28	146.85	153.983	2.233	2.107	47.647	43.283	143
24×29	147.667	155.333	2.243	2.107	57.167	52.39	149.667
24×36	150.167	158.85	2.257	2.113	59.173	54.067	144
26×28	152.567	159.9	2.267	2.127	48.597	44.67	141.667
26×29	142.757	150.067	2.257	2.117	68.11	62.837	158
26×36	170.6	179.117	2.253	2.093	62.647	57.437	145.667
28×29	161.433	169.5	2.26	2.123	68.097	62.507	152.333
28×36	160.733	170.517	2.233	2.107	52.333	48.28	146.667
29×36	152.433	161.617	2.243	2.103	61.53	56.58	149.333
Parents							
21	145.167	153.867	2.203	2.083	44.837	41.507	141
24	152.167	160.4	2.183	2.073	58.58	51.953	144.667
26	156.967	164.7	2.21	2.093	51.86	47.253	143.333
28	160.1	167.7	2.21	2.077	55.347	50.497	142.333
29	151.773	153.067	2.227	2.097	64.207	58.403	164
36	160.433	168.133	2.163	2.043	62.637	57.107	148.333
LSD Value	**20.73**	**19.75**	**0.05211**	**0.05211**	**12.98**	**11.57**	**3.911**

GMT= No of filled grain of main tiller, SP= Total number of spikelet/panicle, FW= Fresh weight, DW= Dry weight, DM= Days to maturity

4.2.4 Number of effective tillers/plant

Regarding the number of effective tillers per plant, the cross BRRI dhan 29×BRRI dhan 36 gave highest number of effective tillers per plant (24.80) followed by BRRI dhan 28×BRRI dhan 29 (24.68), BR26×BRRI dhan 29 (23.33) and BR26×BRRI dhan 36 (23.15) which are statistically similar in performance for number of effective tiller per plant. The cross BR21×BR24 gave the lowest (15.02) number of effective tiller per plant.

4.2.5 Panicle length

Data regarding panicle length show that the cross BRRI dhan 28×BRRI dhan 36 had tallest panicle (27.07 cm), while the parental material BRRI dhan 29 had the shortest (22.32 cm) one. All the other parental materials and crosses along with the shortest one had panicle length statistically similar to each other and differing from the tallest one (Table 2).

4.2.6 Panicle weight

Data regarding panicle weight show that the cross BR26×BRRI dhan 36 had maximum panicle weight (3.433 g), while the cross BR26×BRRI dhan 29 had the minimum (2.847 g) one. These two crosses are solely different statistically.

4.2.7 Number of primary branches/panicle

Regarding the number of primary branches per panicle, the cross BR24×BR26 gave highest number of primary branches per panicle (10.97), while the cross BRRI dhan 29×BRRI dhan 36 gave the lowest number (9.817) of primary branches per panicle.

4.2.8 Number of secondary branches/panicle

Regarding the number of secondary branches per panicle, the cross BR24×BR26 gave highest number of primary branches per panicle (29.80) followed by BR26×BRRI dhan 36 (29.58), BR21×BRRI dhan 36 (29.07), BR21×BRRI dhan 28 (28.93), BRRI dhan 36 (28.77), BRRI dhan 28×BRRI dhan 29 (28.93), BR21×BR26 (28.57), BR21×BR24 (28.47), BR24×BRRI dhan 29 (28.32), BRRI dhan 28 (28.17), BR24×BRRI dhan 36 (28.13), BRRI dhan 28×BRRI dhan 36 (28.10), BR24 (28.00), BR24×BRRI dhan 28 (27.83), BR26 (27.60), BR21×BRRI dhan 29 (27.05), BR21 (26.77), BRRI dhan 26×BRRI dhan 28 (26.73), BRRI dhan 29×BRRI dhan 36 (26.58) and BRRI dhan 26×BRRI dhan 29 (26.05), while the parental material BRRI dhan 29 gave the lowest (24.93) one. BR26×BRRI dhan 36 (29.58) and BR24×BR26 (29.80) gave statistically similar number of secondary branches per panicle.

4.2.9 Number of filled grain of main tiller

Regarding the number of filled grain of main tiller, the cross BR26×BRRI dhan 36 gave highest number of filled grain (170.6), while the cross BR26×BRRI dhan 29 gave the lowest (142.8) one. These two crosses had truly difference by LSD test.

4.2.10 Total number of spikelet/panicle

Regarding total number of spikelet per panicle, the cross BR26×BRRI dhan 36 gave highest number of spikelet per panicle (179.1), while the cross BR26×BRRI dhan 29 gave the lowest (150.1) one. These two crosses had truly difference by LSD test.

4.2.11 Days to maturity

Concerning days to maturity, the recorded days ranged from about 141 to 164. The parental material BRRI dhan 29 required maximum days (164), while the other parental material BR21 required minimum days (141) to maturity. Cross combination BR21×BRRI dhan 36 required minimum days to maturity (141) followed by BR26×BRRI dhan-28 (141.7) which is statistically similar.

4.2.12 Fresh weight and dry weight of 100 grains

Fresh weight of 100 grains was recorded maximum in cross BR21×BRRI dhan 36 (2.133 g), while the parental material BRRI dhan 36 gave minimum (2.043 g) fresh weight of 100 grains. The dry weight also recorded similar to the fresh weight in terms of maximum and minimum value (Table 2).

4.2.13 Yield/plant

Concerning yield in fresh weight and dry weight, the fresh weight yield ranged from 33.59 g/plant to 68.11 g/plant and the dry weight ranged from 32.60 g/plant to 62.84 g/plant. The cross BR26×BRRI dhan 29 had the highest yield both in fresh and dry basis, while the cross BR21×BR24 had the lowest one in both cases.

4.3 General and specific combining ability

The half diallel mating design used in this study makes it possible to obtain estimates for the different genetic parameters required for judging further breeding programs, general and specific combining ability effects are of these parameters. Combining ability can play a better role in identifying the precious genotypes; having specific cross combinations, having high usable heterosis and for further selection in segregating generations. The results of analysis of variance and mean squares of the half diallel mating design for all studied traits are shown in table 1. Significant mean squares for GCA and SCA confirm the presence of combining ability.

4.3.1 Plant height

Results presented in Table 1 showed that GCA variation was highly significant, while SCA was significant for plant height. BR24 had the highest positive GCA effects with 4.17 followed by BR21 with 3.94 (Table 3) whereas BRRI dhan-36 had the highest negative GCA effect (-5.04) followed by BRRI dhan-29 (-1.49), BR26 (-0.96) and BRRI dhan-28 (-0.61). As higher negative significant GCA effect is expected for this trait, BRRI dhan-36 was the best general combiner followed by BRRI dhan-29, BR26 and BRRI dhan28. Sharma and Mani (2001) reported UPR 85-71-8-1 as a good general combiner for shorter plant height.

The cross BR26xBRRI dhan28 showed highest negative SCA effect (-5.80) followed by BR26xBRRI dhan29 (-2.56), BR24×BR26 (-2.53), BRRI dhan29×BRRI dhan36 (-1.78) and BR21×BRRI dhan29 (-1.70) (Table 4). Therefore, the cross BR26xBRRI dhan28 was observed to be the best specific combiner for plant height. Singh *et al.* (1998) observed Basmati370×Dubraj as best specific combiner for plant height in their study.

Table 3: Estimates of parental general combining ability effects for various traits

Parents	Plant height (cm)	Days to 50% flowering	Total no of tiller/Plant	N. of effective tiller/plant	Panicle length (cm)	Panicle weight (gm)	No. of primary branch /panicle	No. of secondary branch /panicle	No. of filled grain of main tiller	Total no. of spikelet /panicle	Fresh weight of 100 grain (gm)	Dry weight of 100 grain (gm)	Yield/plant (fresh weight in gm)	Yield/plant (dry weight in gm)	Days to maturity
BR21	3.94**	-0.75**	-1.45**	-1.42**	-0.08*	-0.04**	0.04**	0.03**	-2.57**	-1.79**	-0.003**	-0.006**	-6.26**	-3.49**	-7.18**
BR24	4.17**	0.13**	-2.58**	-2.48**	-0.22**	-0.04**	0.07**	0.40**	-2.74**	-2.58**	-0.007**	0.002**	-2.72**	-1.07**	-2.70**
BR26	-0.96**	-0.21**	1.17**	-0.50**	-0.14**	0.01**	0.05**	0.07**	1.16**	1.27**	0.006**	0.006**	-1.41**	-0.53**	-1.57**
BRRI dhan 28	-0.61**	-0.54**	-0.26**	1.20**	0.35**	0.06**	-0.05**	0.15**	3.42**	3.36**	0.005**	0.006**	-0.34*	-1.78**	-0.35
BRRI dhan 29	-1.49**	0.67**	1.87**	1.88**	-0.20**	-0.06**	-0.07**	-1.11**	-3.14**	-4.58**	0.004**	0.002**	7.01**	7.18**	7.65**
BRRI dhan 36	-5.04**	0.71**	1.24**	1.32**	0.28**	0.08**	-0.05**	0.46**	3.87**	4.31**	-0.006**	-0.006**	3.72**	-0.32**	4.15**
SE (gi)	0.96	0.28	0.70	0.52	0.28	0.05	0.09	0.40	2.31	2.18	0.004	0.005	1.27	0.41	1.42
SE (gi-gj)	1.49	0.44	1.08	0.81	0.43	0.08	0.13	0.62	3.57	3.37	0.006	0.007	1.97	0.63	2.20

** indicates significant at the 0.01 level; * indicates significant at the 0.05 level

Table 4: Estimates of parental specific combining ability effects for various traits

Crosses	Plant height (cm)	Days to 50% flowering	Total no of tillers / Plant	No. of effective tillers / Plant	Panicle length (cm)	Panicle weight (gm)	No. of primary branches / panicle	No. of secondary branches / Panicle
BR21xBR24	2.82**	-0.38**	-1.63**	-1.64**	0.36**	0.09**	-0.16**	0.13
BR21xBR26	2.93**	0.63**	-3.25**	-1.73**	0.02	0.01	-0.15**	0.55**
BR21xBRRI Dhan28	-0.11	0.63**	1.96**	0.52**	-0.43**	0.18**	-0.15**	0.84**
BR21xBRRI Dhan29	-1.70**	-0.25**	0.90**	0.98**	0.51**	0.05**	0.20**	0.22
BR21xBRRI Dhan36	8.38**	-0.29**	-0.85**	-0.71**	-0.08	-0.01	-0.10**	0.67**
BR24xBR26	-2.53**	-0.58**	-3.37**	-1.58**	0.19	0.15**	0.40**	1.42**
BR24xBRRI Dhan28	0.01	0.75**	0.92**	-0.50**	-0.10	-0.16**	-0.21**	-0.62**
BR24xBRRI Dhan29	4.04**	0.54**	0.46	0.17	0.27**	0.06**	-0.30**	1.12**
BR24xBRRI Dhan36	1.64**	-1.17**	2.71**	3.14**	-1.01**	-0.09**	0.06**	-0.63**
BR26xBRRI Dhan28	-5.80**	-0.25**	-1.24**	-0.54**	-0.86**	-0.07**	-0.49**	-1.40**
BR26xBRRI Dhan29	-2.56**	-0.13**	-0.36	1.41**	0.36**	-0.19**	-0.08**	-0.82**
BR26xBRRI Dhan36	3.94**	1.50**	0.36	1.78**	0.33**	0.26**	0.28**	1.15**
BRRI28xBRRI Dhan29	-0.64	-0.13**	2.84**	1.06**	0.42**	0.19**	-0.03	1.67**
BRRI28xBRRI Dhan36	1.22**	0.17**	-1.05**	-2.54**	3.00**	0.07**	0.13**	-0.41**
BRRI29xBRRI Dhan36	-1.78**	-0.04**	1.04**	1.05**	-0.13	-0.05**	-0.51**	-0.67**
se[s(i,j)]	2.64	-0.08	1.91	1.43	0.77	0.14	0.24	1.09

**** indicates significant at the 0.01 level; * indicates significant at the 0.05 level**

Table 4: Continued

Crosses	No. of filled grain of main tiller	Total no. of spikelet/ panicle	Fresh weight of 100 grain (gm)	Dry weight of 100 grain (gm)	Yield /plant (fresh weight in gm)	Yield /plant (dry weight in gm)	Days to maturity
BR21xBR24	2.57**	1.44	-0.002	-0.015**	-8.10**	1.67**	-10.72**
BR21xBR26	-0.98	-1.19	-0.005**	-0.011**	-4.76**	-0.54**	-4.71**
BR21xBRRI Dhan28	9.28**	9.60**	0.024**	0.016**	2.15**	2.04**	2.45**
BR21xBRRI Dhan29	-2.66**	0.67	-0.023**	-0.037**	2.25**	-4.25**	2.54**
BR21xBRRI Dhan36	-0.63	-0.88	0.052**	0.047**	-0.24	-1.75**	0.41
BR24xBR26	3.85**	5.97**	0.022**	0.017**	-5.83**	2.71**	-6.99**
BR24xBRRI Dhan28	-7.92**	-9.07**	0.002	0.004*	-3.33**	-0.71**	-3.48**
BR24xBRRI Dhan29	-0.54	0.22	0.012**	0.009**	-1.58**	-3.00**	-1.97**
BR24xBRRI Dhan36	-5.05**	-5.14**	0.037**	0.023**	3.39**	-1.17**	3.54**
BR26xBRRI Dhan28	-6.11**	-6.99**	0.021**	0.016**	-3.25**	-2.58**	-3.67**
BR26xBRRI Dhan29	-9.34**	-8.88**	0.013**	0.011**	7.56**	4.79**	7.84**
BR26xBRRI Dhan36	11.48**	11.28**	0.018**	-0.005**	5.46**	-0.04	5.88**
BRRI28xBR RI Dhan29	7.07**	8.45**	0.016**	0.018**	6.17**	0.38**	6.61**
BRRI28xBR RI Dhan36	-0.64**	0.59	0.01	0.008**	-4.77**	2.21**	-5.65**
BRRI29xBR RI Dhan36	-2.38**	-0.37	0.008**	0.007**	-3.83**	-4.08**	-4.46**
se[s(i,j)]	6.34	5.98	0.011	0.013	3.49	1.12	3.90

**** indicates Significant at the 0.01 level; * indicates Significant at the 0.05 level**

4.3.2 Days to 50% flowering

A higher negative significant GCA value is expected for this trait. The highest significant and negative GCA effects for days to 50% flowering were found in the parent BR21 (-0.75) followed by BRRI dhan28 (-0.54) and BR26 (-0.21) (Table 3). Rest of the parents showed positive significant GCA effect which is undesirable for this trait.

A higher negative significant SCA value is expected for this trait. The highest negative SCA effect was observed in the cross BR24×BRRI dhan36 with value -1.17 (Table 4). Therefore, the cross BR24xBRRI dhan36 was observed to be the best specific combiner for days to 50% flowering. The crosses Raimunuwa×Poornima and Poornima×Vanprabha were reported best specific combiner for this trait by Singh and Singh (2004).

4.3.3 Number of tillers/plant

Regarding number of tillers per plant, it was found that GCA was highly significant (Table 1).BRRI dhan29 had the highest positive GCA effect (1.87) followed by BRRI dhan36 (1.24) and BR26 (1.17), while other plants had negative GCA effects for number of tillers per plant (Table 3). As higher positive significant GCA effect is expected for this trait, BRRI dhan29 was the best general combiner for tillers per plant. Mahsuri was reported good general combiner for this trait by Singh *et al.* (1998).

The estimates of SCA effects for crosses showed that the cross BRRI dhan28xBRRI Dhan29 had highest positive significant SCA effect (2.84) followed by BR24xBRRI Dhan36 (2.71), BR21xBRRI Dhan28 (1.96), BRRI dhan29xBRRI Dhan36 (1.04), BR24xBRRI Dhan28 (0.92) and BR21xBRRI Dhan29 (0.90), while the other crosses had negative or non-significant values (Table 4). As the higher positive significant SCA effect is desired for this character, BRRI dhan28xBRRI Dhan29 was identified as the best specific combiner.

4.3.4 Number of effective tillers/plant

Regarding number of effective tillers per plant, it was found that GCA was highly significant (Table 1). BRRI dhan29 had the highest positive GCA effect (1.88) followed by BRRI dhan36 (1.32) and BRRI28 (1.20), while other plants had negative GCA effects for number of effective tillers per plant (Table 3). As higher positive significant GCA effect is expected for this trait, BRRI dhan29 was the best general combiner for tillers per plant.

The estimates of SCA effects for crosses showed that the cross BR24xBRRI Dhan36 had highest positive significant SCA effect (3.14) followed by BR26×BRRI dhan29 (1.41), BRRI dhan28xBRRI Dhan29 (1.06), BRRI dhan29xBRRI Dhan36 (1.05), BR21xBRRI Dhan29 (0.98) and BR21xBRRI Dhan28 (1.96), while the other crosses had negative or non-significant values (Table 4). As the higher positive significant SCA effect is desired for this character, BR24xBRRI Dhan36 was identified as the best specific combiner.

4.3.5 Panicle length

The parent BRRI dhan28 (0.35) showed highest positive and significant GCA effect followed by BRRI dhan36 (0.08). Rest of the parents showed significant negative GCA effects which are undesirable for panicle length. Therefore, BRRI dhan28 and BRRI dhan36 is good general combiner for obtaining long panicle. The parent

PWR54 was a good general combiner for panicle length reported by Singh *et al.* (1998).

The highest significant positive SCA effect was provided by BRRI dhan28×BRRI dhan36 (3.00) followed by BR21×BRRI dhan29 (0.51), BRRI dhan28×BRRI dhan29 (0.42), BR26×BRRI dhan29 (0.36), BR21×BR24 (0.36), BR26×BRRI dhan36 (0.33) and BR24×BRRI dhan29 (0.27) for this trait. These crosses may be considered as the good specific combiner for panicle length.

4.3.6 Panicle weight

The highest significant positive effect was obtained from the parent BRRI dhan36 (0.08) followed by BRRI dhan28 (0.06) and BR26 (0.01) for panicle weight. Rest of the parents showed significant negative GCA effects which are undesirable for panicle weight. As the positive significant GCA value is expected for this trait, BRRI dhan36, BRRI dhan28 and BR26 were identified as good general combiner for higher panicle weight. Dhakar *et al.* (2006) observed the parents Vikas, Kanak and IR-64 were good general combiner for panicle weight.

The highest significant positive SCA effect for panicle weight was observed in the cross BR26×BRRI dhan36 (0.26). Cross combinations BR21×BR24 (0.09), BR21×BRRI dhan28 (0.18), BR21×BRRI dhan29 (0.05), BR24×BR26 (0.15), BR24×BRRI dhan29 (0.06), BRRI dhan28×BRRI dhan29 (0.19) and BRRI dhan28×BRRI dhan36 (0.07) showed positive significant SCA effects. These crosses therefore may be selected to improve the panicle weight of rice.

4.3.7 Number of primary branches/panicle

The parent BR24 (0.07) possessed the highest positive significant GCA effect for primary branches per panicle followed by BR26 (0.05) and BR21 (0.04). The other parents showed negative significant GCA effects which is undesirable for this trait. Hence BR24 was identified as good general combiner for more primary branches per panicle followed by BR26 and BR21.

The highest significant positive SCA effect was found in the cross BR24×BR26 (0.40) for this character followed by BR26×BRRI dhan36 (0.28), BR21×BRRI dhan29 (0.20), BRRI dhan28×BRRI dhan36 (0.13) and BR24×BRRI dhan36 (0.06), while the other crosses had significant negative or non-significant SCA effects. As significant positive SCA effect is desirable for this trait, the cited above crosses were identified as good specific combiners to increase primary branches per panicle.

4.3.8 Number of secondary branches/panicle

The highest positive GCA effect was observed in the parent BRRI dhan36 (0.46) for secondary branches per panicle followed by BR24 (0.40), BRRI dhan28 (0.15), BR26 (0.07) and BR21 (0.03). Therefore, BRRI dhan36 was considered as the best general combiner for obtaining more secondary branches per panicle.

The cross BRRI dhan28×BRRI dhan29 (1.67) exhibited the highest positive significant SCA effect followed by BR24×BR26 (1.42), BR26×BRRI dhan36 (1.15), BR24×BRRI dhan29 (1.12), BR21×BRRI dhan28 (0.84), BR21×BRRI dhan36 (0.67) and BR21×BR26 (0.55). These crosses were found to be good for improving number of secondary branches per panicle. Rest of the crosses showed significant negative or non-significant SCA effects which is undesirable for this trait.

4.3.9 Number of filled grain of main tiller

A higher and positive significant GCA value is expected for this trait. The highest positive significant GCA effect for this character was found in parent BRRI dhan36 (3.87) followed by BRRI dhan28 (3.42) and BR26 (1.16). Rest of the three parents showed negative significant GCA effects which is undesirable for this trait. Therefore, BRRI dhan36 was considered as the best general combiner followed by BRRI dhan28 and BR26 for filled grain of main tiller. Ali *et al*. (1994) reported Basmati370 as the best general combiner for percentage of filled grains.

A higher, positive and significant SCA value is expected for this trait. The highest significant positive SCA effect was found in the cross BR26×BRRI dhan36 (11.48) for filled grains of main tiller followed by BR21×BRRI dhan28 (9.28), BRRI dhan28×BRRI dhan29 (7.07) and BR21×BR24 (2.57). These crosses were found to be good specific combiner for more filled grains on main tiller. Basmati 370×Basmati 385 was reported as best specific combiner for this trait by Ali *et al*. (1994).

4.3.10 Total number of spikelet/panicle

A higher and positive significant GCA value is expected for this trait. The highest positive significant GCA effect for this character was found in parent BRRI dhan36 (4.31) followed by BRRI dhan28 (3.36) and BR26 (1.27). Rest of the three parents showed negative significant GCA effects which is undesirable for this trait. Therefore, BRRI dhan36 was considered as the best general combiner followed by BRRI dhan28 and BR26 for number of spikelet per panicle.

A higher, positive and significant SCA value is expected for this trait. The highest significant positive SCA effect was found in the cross BR26×BRRI dhan36 (11.28) for filled grains of main tiller followed by BR21×BRRI dhan28 (9.60), BRRI dhan28×BRRI dhan29 (8.45) and BR24×BR26 (5.97). These crosses were found to be good specific combiner for more number of spikelet per panicle. Rest of the crosses showed negative significant or non-significant SCA effects which is undesirable for this trait.

4.3.11 Days to maturity

A higher and negative significant GCA value is expected for this trait. The highest negative GCA effect was exhibited by the parent BR21 (-7.18) for days to maturity followed by BR24 (2.70) and BR26 (1.57). The other parents had negative significant or non-significant SCA effects which is undesirable for this trait. Therefore, BR21 was considered as the best general combiner followed by BR24 and BR26 for days to maturity. Sharma and Mani (2001) observed UPR 85-71-8-1 as a good combiner for earliness.

The highest negative SCA effect was observed in the cross BR21×BR24 (-10.72) for earliness followed by BR24×BR26 (-6.99), BRRI dhan28×BRRI dhan36 (-5.65), BR21×BR26 (-4.71), BRRI dhan29×BRRI dhan36 (-4.46), BR26×BRRI dhan28 (-3.67), BR24×BRRI dhan28 (-3.48) and BR24×BRRI dhan29 (-1.97). Rest of the crosses had positive significant SCA effects. Thus, BR21×BR24 was the best combiner for earliness followed by BR24×BR26, BRRI dhan28×BRRI dhan36 BR21×BR26, BRRI dhan29×BRRI dhan36, BR26×BRRI dhan28, BR24×BRRI dhan28 and BR24×BRRI dhan29.

4.3.12 Fresh weight and dry weight of 100 grains

A higher significant positive GCA value was expected for these traits. The highest significant GCA effect was observed in the parent BR26 (0.006) for fresh weight of 100 grains followed by BRRI dhan28 (0.005) and BRRI dhan29 (0.004). The other parents showed negative significant GCA effects which is undesirable for this trait. The highest significant GCA effects were observed in the parent BR26 and BRRI dhan28 (0.006) followed by BRRI dhan29 (0.002) and the other parents showed negative significant effects for dry weight of 100 grains. Therefore, the parent BR26 was the best general combiner for both dry and fresh weight of 100 grains.

A higher significant positive SCA value was expected for fresh and dry weight of 100 grains. The highest significant SCA effect was observed in the cross BR21×BRRI dhan36 (0.052) followed by BR24×BRRI dhan36 (0.037), BR21×BRRI dhan28 (0.024), BR24×BR26 (0.022), BR26×BRRI dhan28 (0.021), BR26×BRRI dhan36 (0.018), BRRI dhan28×BRRI dhan29 (0.016), BR26×BRRI dhan29 (0.013) and BR24×BRRI dhan29 (0.012) and the other crosses showed negative significant or non-significant SCA effects for the trait, fresh weight of 100 grains. The highest significant SCA effect was obtained from the cross BR21×BRRI dhan36 (0.047) followed by BR24×BRRI dhan36 (0.023), BRRI dhan28×BRRI dhan29 (0.018), BR24×BR26 (0.017), BRBR26×BRRI dhan28 (0.016), BR21×BRRI dhan28 (0.016), BR26×BRRI dhan29 (0.011), BR24×BRRI dhan29 (0.009), BRRI dhan28×BRRI dhan36 (0.008), BRRI dhan29×BRRI dhan36 (0.007), BR26×BRRI dhan36 (0.005) and BR24×BRRI dhan28 (0.004) for dry weight of 100 grain. Therefore, the cross BR21×BRRI dhan36 was the best specific combiner for both dry and fresh weight of 100 grains.

4.3.13 Yield/plant

The highest significant and positive GCA effect was found in the parent BRRI dhan29 (7.01) followed by BRRI dhan36 (3.72) for yield per plant in fresh weight. The other parents were showed negative significant GCA effects which is undesirable for this trait. On the other hand, the highest significant positive GCA effect was provided by the parent BRRI dhan29 (7.18) for dry weight yield per plant, while the other parents possessed negative significant GCA effects which is undesirable. Therefore, BRRI dhan29 was the best combiner for yield per plant for both dry and fresh weight. Borgohain *et al.* (1998) observed DWR2, DWR1, DWR5 were the best general combiners for grain yield. The parent Raimunuwa, JR 353 and RWR 3-45 were good general combiners for grain yield per plant found by Singh and Singh (2004).

A higher and positive significant SCA value was expected for these characters. The highest significant positive SCA effects was observed by the cross BR26×BRRI dhan29 (7.56) followed by BRRI dhan28×BRRI dhan29 (6.17), BR26×BRRI dhan36 (5.46), BR24×BRRI dhan36 (3.39), BR21×BRRI dhan29 (2.25) and BR21×BRRI dhan28 (2.15) for fresh weight of yield per plant. The other crosses had negative significant or non-significant SCA effects for this trait. The highest significant positive SCA effects was observed by the cross BR26×BRRI dhan29 (4.79) followed by BR24×BR26 (2.71), BRRI dhan28×BRRI dhan36 (2.21), BR21×BRRI dhan28 (2.04), BR21×BR24 (1.67) and BRRI dhan28×BRRI dhan29 (0.38) for dry weight of yield per plant. The other crosses had negative significant or non-significant SCA effects for this trait. Therefore, the crosses BR26×BRRI dhan29 was considered the best combiner for yield per plant both in fresh and dry weight. The cross combinations DWR1×DWR2, DWR2×DWR4, DWR3×DWR6 and DWR5×DWR6 was the four best specific combiner for developing variety with higher yield reported by Borgohain *et al.* (1998). Singh and Singh (2004) observed the crosses Raimunuwa×Poornima and Poornima×Vanparabha were the best specific combiners for crop yield.

Plate1. Photograph showing parent material and their F_2 for panicle

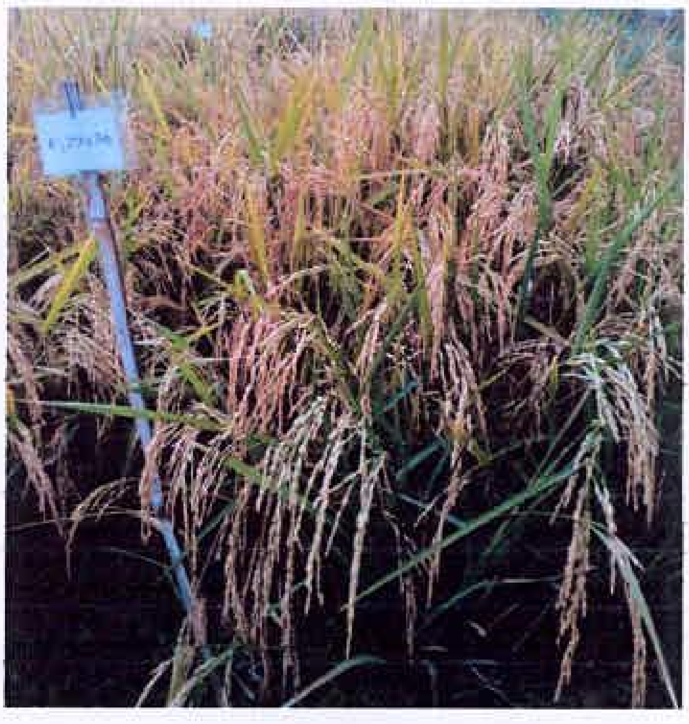

Plate2. Photograph showing maturity stage of F_2 materials

Plate3. Photograph showing different maturity of materials

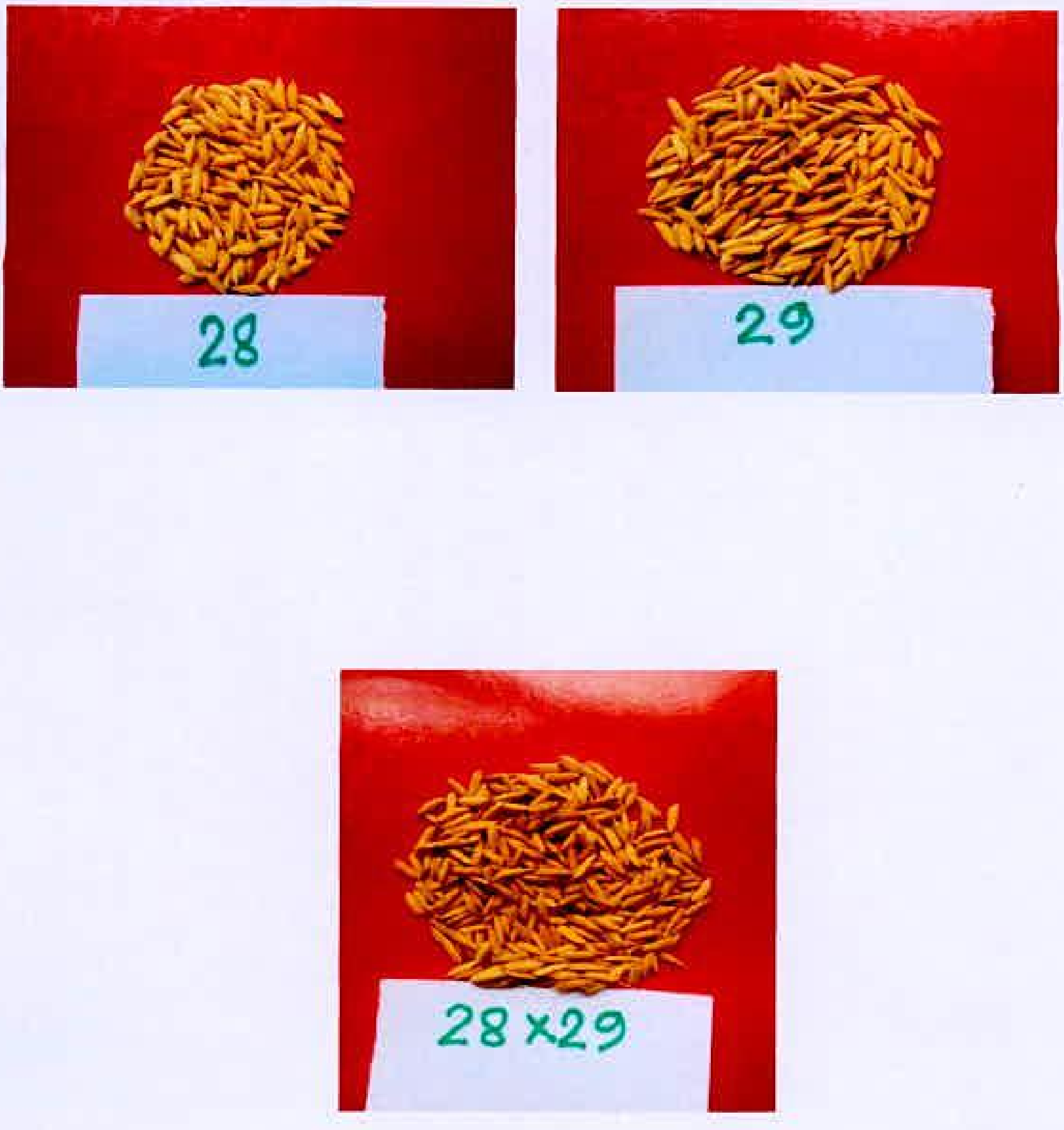

Plate4. Photograph showing grain of parent and F_2 materials

4.4 Heterosis

The amount of heterosis value could be expressed as the percentage deviation of F_2 generation versus the average of mid parent (MP) or the mean of the standard check parent (SP).

4.4.1 Plant height

Heterosis value was obtained from the MP and SP for plant height is presented in (table 5). The results showed that significant heterosis over standard parents for plant height in three crosses from 15 crosses.

4.4.2 Days to 50% flowering

Concerning days to 50% flowering, three crosses out of 15 crosses showed significant with positive values over standard parent.

4.4.3 Number of tillers/plant

Regarding number of tillers per plant, only 4 crosses had significant or highly significant values of heterosis over mid parent, while 14 crosses had significant or highly significant values of heterosis over standard parent.

4.4.4 Number of effective tillers/plant

Regarding number of effective tillers per plant, only 7 crosses had significant or highly significant values of heterosis over mid parent, while all the crosses except one had significant or highly significant values of heterosis over standard parents.

Table 5: F_2 Heterosis (%) over mid parent and check variety in different characters in rice

Variety	PH (cm)		D5F		TTP		ETP		PL (cm)		PW (gm)	
	MPH	SH	MPH	SH	MPH	SH	MPH	SH	MPH	SH	MPH	SH
21*24	7.26	9.50*	-0.55	0.73	-13.31	-16.94*	-13.70*	-37.25*	1.72	1.69	6.27*	0.32
21*26	5.05	4.46	1.10	1.47	-23.83*	-6.41*	-13.04*	-29.39*	0.59	0.56	4.32*	-1.29*
21*28	1.64	1.77	1.10	1.10	10.17	12.25*	-2.87	-12.88*	0.79	0.72	10.32*	5.99*
21*29	0.72	-0.71	-0.18	1.47	6.25	17.52*	7.32	-8.15*	4.30	2.42**	4.86*	-1.74*
21*36	16.32	5.84	-0.18	1.47	-4.53	5.75*	-3.26	-17.48*	2.41	1.95	3.61*	0.64*
24*26	-2.03	-0.79	-0.54	1.10	-23.91*	-12.58*	-10.35**	-33.20*	0.57	0.66	6.64*	3.32*
24*28	0.16	2.12	0.91	2.21	8.14	1.56*	-5.53	-21.59*	1.48	1.53	-2.78*	-4.41*
24*29	4.86	5.28	0.36	3.31*	6.97	9.78*	6.53	-15.94*	2.46	0.74	3.07*	-1.09*
24*36	7.01	-0.69	-1.43	1.47	14.60**	17.81*	19.75*	-5.85*	-2.37	-2.70*	-1.23*	-1.83*
26*28	-8.22	-8.85*	0.37	0.73	-9.59	9.37*	-5.48	-13.51*	-1.45	-1.40	0.91	-0.55*
26*29	-4.35	-6.49	0.18	2.21	-4.19	24.26*	11.55**	-2.51	3.21	1.48	-4.73*	-8.37*
26*36	6.99	-3.53	1.98	4.04*	-3.99	24.67*	11.03**	-3.27	3.76	3.42*	10.92*	10.49*
28*29	-2.68	-4.20	0.18	1.84	22.31*	32.97*	7.55	3.13	5.65**	3.83*	8.69*	6.12*
28*36	3.57	-5.90	0.54	2.21	1.66	10.69*	-10.27	-14.21*	17.53*	17.09*	5.41*	6.53*
29*36	1.01	-9.80*	0.00	3.31*	11.82	31.49*	13.24*	3.62	3.36	1.19	0.11	-1.19*

**** indicates significant at the 0.01 level; * indicates significant at the 0.05 level**

Table 5: Continued

Variety	PBP		SPP		GMT		SP		FW of 100 grain (gm)		DW of 100 grain (gm)	
	MPH	SH	MPH	SH	MPH	SH	MPH	SH	MPH	SH	MPH	SH
21×24	-2.80*	-3.10*	3.96	1.07	1.80	-5.47	1.40	-4.99	1.37*	0.59*	-0.05	0.00
21×26	-2.36*	-3.26*	5.09	1.42	0.42	-5.25	0.80	-4.26	1.07*	0.90*	-0.05	0.48*
21×28	-4.05*	-4.19*	5.34	2.72	7.59	2.57	7.87	3.42	2.42*	2.26*	1.59*	1.73*
21×29	-0.62	-1.08*	4.64	-3.97*	-1.85	-8.98	2.02	-6.64	-0.09	0.14*	-1.58*	-0.96*
21×36	-2.21*	-3.73*	4.68	3.20*	1.28	-3.34	1.80	-2.27	4.31*	3.03*	3.39*	2.70*
24×26	3.14*	2.18*	7.19	5.80*	1.16	-2.33	2.69	-0.47	2.57*	1.95*	1.78*	2.07*
24×28	-4.19*	-4.34*	-0.89	-1.19	-5.95	-8.28	-6.14	-8.18	1.66*	1.04*	1.54*	1.44*
24×29	-4.99*	-5.43*	6.99	0.53	-2.83	-7.77	-0.89	-7.37	1.72*	1.49*	1.06*	1.44*
24×36	-0.32	-1.86*	-0.88	-0.12	-3.92	-6.20	-3.30	-5.28	3.87*	2.13*	2.67*	1.73*
26×28	-6.41*	-7.14*	-4.13	-5.09*	-3.76	-4.71	-3.79	-4.65	2.58*	2.58*	2.01*	2.41*
26×29	-2.51*	-3.57*	-0.82	-7.52*	-7.52	-10.83	-5.55	-10.51	1.74*	2.13*	1.05*	1.93*
26×36	2.22*	0.00	4.97	5.03*	7.50	6.56	7.63	6.81	3.04*	1.95*	1.21*	0.77*
28×29	-3.74*	-4.03*	7.79	1.60	3.52	0.83	5.68	1.07	1.87*	2.26*	1.72*	2.21*
28×36	-0.94	-2.33*	-1.29	-0.24	0.29	0.40	1.55	1.68	2.13*	1.04*	2.28*	1.44*
29×36	-6.95*	-8.53*	-0.99	-5.62*	-2.35	-4.79	0.63	-3.63	2.19*	1.49*	1.59*	1.25*

**** indicates significant at the 0.01 level; * indicates significant at the 0.05 level**

Table 5: Continued

Variety	Yield/plant (Fresh weight in gm)		Yield/ Plant (Dry weight in gm)		Days to maturity	
	MPH	SH	MPH	SH	MPH	SH
21×24	-35.05**	-39.32*	-30.23*	-35.44*	0.58	0.94
21×26	-15.76	-26.41*	-16.08	-26.25*	-0.12	-0.23
21×28	-1.97	-11.27**	-1.71	-10.46**	1.18	0.70
21×29	4.90	3.34	5.44	4.31	-4.26	2.58
21×36	-4.05	-6.84	-4.89	-7.13	-2.53	-0.94
24×26	-22.27	-22.45*	-19.94	-21.36*	2.55	3.75**
24×28	-16.36	-13.91*	-15.50	-14.29*	-0.35	0.47
24×29	-6.88	3.29	-5.05	3.75	-3.02	5.15*
24×36	-2.37	6.91	-0.85	7.07	-1.71	1.17
26×28	-9.34	-12.20**	-8.60	-11.54**	-0.82	-0.47
26×29	17.36	23.06*	18.95	24.44*	2.82	11.01*
26×36	9.43	13.19*	10.07	13.74*	-0.11	2.34
28×29	13.92	23.04*	14.80	23.78*	-0.54	7.03*
28×36	-11.29	-5.45	-10.26	-4.39	0.92	3.04
29×36	-2.98	11.17**	-2.03	12.05*	-4.38	4.92*

**** indicates significant at the 0.01 level ; * indicates significant at the 0.05 level**

MPH= Mid Parent Heterosis

SH= Standard Heterosis

4.4.5 Panicle length

Heterosis value was obtained from the MP and SP for panicle length is presented in table 5 The results showed that significant or highly significant with positive values of heterosis over mid parents for panicle length in two crosses from 15 crosses, while significant values of heterosis over standard parents in only four crosses out of 15.

4.4.6 Panicle weight

Concerning panicle weight, 13 crosses showed significant values of heterosis over mid parent, while 14 crosses showed significant values of heterosis over standard parent.

4.4.7 Number of primary branches/panicle

Regarding number of primary branches per panicle, 12 crosses had significant values of heterosis over mid parents, while all the crosses except one had significant values of heterosis over standard parent.

4.4.8 Number of secondary branches/panicle

Regarding number of secondary branches per panicle, only seven crosses had significant or highly significant values of heterosis over standard parent.

4.4.9 Number of filled grain of main tiller

Regarding number of filled grain of main tiller, no crosses showed significant values of heterosis over mid parents and standard parent also.

4.4.10 Total number of spikelet/panicle

Concerning total number of spikelet per panicle, no crosses showed significant values of heterosis over mid parents and standard parent also.

4.4.11 Days to maturity

Regarding days to maturity, only five crosses had significant or highly significant positive values of heterosis based on standard parent.

4.4.12 Fresh weight and dry weight of 100 grains

Regarding the weight of 100 grains, 14 crosses and all the crosses had significant positive values of heterosis over mid parents and standard parent, respectively in case of fresh weight. On the other hand, 13 and 14 crosses had significant values of heterosis over mid parents and standard parents, respectively for dry weight.

4.4.13 Yield/plant

Regarding yield in fresh weight, only the cross BR21×BR24 had highly significant negative values over mid parent, while ten crosses had significant or highly significant values over standard parent. Similar scenario had observed in case of yield in dry weight.

CHAPTER V

SUMMARY AND CONCLUSION

This research work was carried out to study the F_2 population of Aus and Boro crosses developing short duration high yielding Boro rice. In the experiment six parents viz. BR21, BR24, BR26, BRRI dhan28, BRRI dhan29, BRRI dhan36 and their 15 F_2 generations were evaluated to study the combining ability and heterosis using 6×6 half diallel fashion. The experiment was conducted at the Sher-E-Bangla Agricultural University (SAU) research field, Sher-E-Bangla Nagar, Dhaka in RCBD design with three replications during Rabi season, 2011. The results of the investigation are summarized and concluded as follows-

Mean squares of the parents and F_2 generations were found significant for almost all the characters indicating the variation among the items.

Combining ability analysis revealed significant general and specific combining ability for most of the traits studied indicating involvement of both additive and non-additive gene action in the inheritance of these characters.

The significant and desirable GCA effect was observed in BR21 for earliness and found to be the best general combiner parent for short duration. BR24 and BR26 possessed significant and desirable GCA effects also for earliness. Therefore, they are considered as good general combiner parent. The significant and desirable GCA effect was observed in BRRI dhan29 for yield and yield contributing character, tiller and effective tiller per plant. Therefore, BRRI dhan29 is considered as the best general combiner parent for yield and yield contributing character, tiller and effective tiller per plant.

The parent BR24 was the best general combiner for primary branch per panicle. On the other hand, for days to 50% flowering, fresh and dry weight of 100 grains, BR26; for plant height, panicle length and dry weight of 100 grains, BRRI dhan28; for panicle weight, filled grain of main tiller, secondary branch and spikelet per panicle, BRRI dhan36 considered as the best general combiner.

Significant, desirable and highest SCA effect was observed for days to maturity in cross combination BR24 x BR26 which might be selected as the best specific combiner for earliness. Highest, significant desirable SCA effects was observed for yield and most of the yield contributing characters in cross combination BR26 x BRRI Dhan29 which might be selected as best specific cross combination followed by BRRI28 x BRRI Dhan29, BR26 x BRRI Dhan36 and BR24 x BR26. These cross combinations also showed heterosis over parents. Therefore, the studied crosses might be used for the respective trait improvement.

From the mean performances, the cross combination BR21xBRRI dhan 36 required minimum days to maturity (141 days) where parent BRRI dhan 36 takes 148.33 days to maturity. Also this cross combination showed higher yield for both fresh and dry condition (51.563 gm/plant and 46.897 gm/plant respectively) which was better than Aus parent BR 21 (44.837 gm/plant and 41.507 gm/plant respectively) followed by BR24xBRRI dhan 36. Therefore, these two cross combination could be selected for short duration and high yielding variety development.

CHAPTER VI

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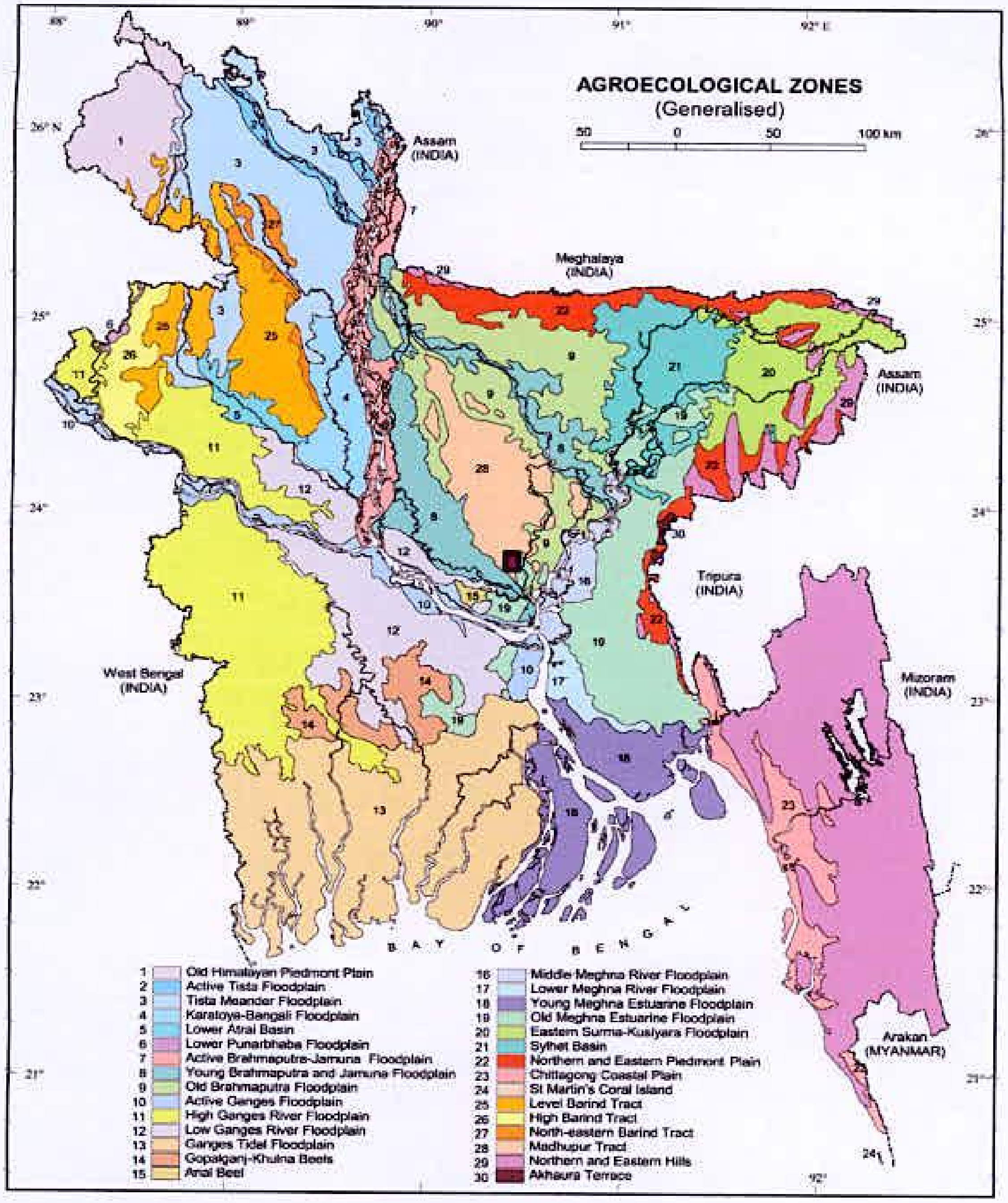
APPENDICES

Appendix I. Map showing the experimental site under the study



The experimental site under study

Appendix II. Monthly average Temperature, Relative Humidity and Total Rainfall and sunshine of the experimental site during the period from October, 2011 to March, 2012

Month	Air temperature (ºc)		Relative humidity (%)	Rainfall (mm) (total)	Sunshine (hr)
	Maximum	Minimum			
October, 2011	34.8	18.0	77	227	5.8
November, 2011	32.3	16.3	69	0	7.9
December, 2011	29.0	13.0	79	0	3.9
January, 2012	28.1	11.1	72	1	5.7
February, 2012	33.9	12.2	55	1	8.7
March, 2012	34.6	16.5	67	45	7.3

Source: Bangladesh Meteorological Department (Climate & Weather Division),

Agargoan, Dhaka - 1212

Appendix III. Physical characteristics and chemical composition of soil of the experimental plot

Soil characteristics	Analytical results
Agrological Zone	Madhupur Tract
P^H	6.00 – 6.63
Organic matter	0.84
Total N (%)	0.46
Available phosphorous	21 ppm
Exchangeable K	0.41 meq / 100 g soil

Source: Soil Resource and Development Institute (SRDI)