

GENETICS OF YIELD AND QUALITY CHARACTERS IN AROMATIC RICE (*Oryza sativa* L.)



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REQUIREMENTS FOR THE DEGREE OF

Doctor of Philosophy
in
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Date :

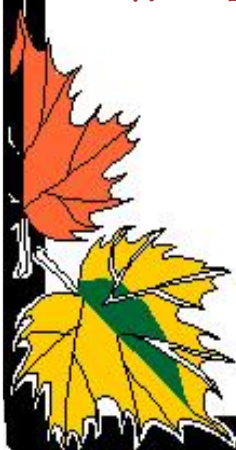
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LIST OF SYMBOLS AND ABBREVIATIONS

%	percentage
°C	Degree centigrade
µg	microgram
µl	microliter
ANOVA	Analysis of Variance
BHU	Banaras Hindu University
bp	Base pair
CD	Critical difference
cm	centimeter
CRBD	Compact Family Randomized Block Design
CTAB	Cetyle trimethyle ammonium bromide
DNA	Deoxyribonucleic acid
dNTP	Deoxynucleoside triphosphate
e.g.	For example
EDTA	Ethylene diaminetetra acetic acid
et al.	Co-authors [et all ii]
etc.	<i>Et cetera</i>
F	Forward
FYM	Farm Yard Manure
g	gram
GA	Genetic advance
GCA and SCA	general and specific combining ability
h²	Heritability
H₂O	Water
ha	hectare
i.e.	that is
MAS	Marker-assisted selection
mg	milligram
MgCl₂	Magnesium chloride
ml	mililiter
mM	milimolar
MSS	Mean sum of squares
N	Nitrogen
ng	nanogram

nm	nanometer
OD	Optical density
PCR	Polymerase chain reaction
pH	Potential of Hydrogen
PIC	Polymorphic Information Content
R	Reverse
rpm	Revolution per minute
SE	Standard error
SSR	Simple Sequence Repeat
TAE	Tris acetate EDTA
Taq	<i>Thermas aquaticus</i>
TE	Tris EDTA
Tris	Tris (hydroxymethyle) aminomethane
UPGMA	Un-weighted Pair Group Method with Arithmetic Mean
USA	United Sates of America
USDA	United States Department of Agriculture
UV	Ultra violet

PREFACE

The present investigation entitled “**Genetics of yield and quality characters in aromatic rice (*Oryza sativa* .L.)**” comprises of two parts. First part deals with the study the nature and magnitude of gene action controlling the inheritance of grain quality, yield and yield contributing characters. Second part assesses the crosses between six parents in terms of combining ability, heterosis and inbreeding depression for various yield and quality traits.

This manuscript is being written for the award of doctoral degree in Genetics and Plant breeding under the supervision of **Dr. H.K. Jaiswal**, Professor, Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, BHU. Chapter wise presentation of the thesis is as follows:

Chapter I provides a general background and an overview of rice in general and quality aspects of rice in particular. This chapter justifies the purpose for choosing this research topic and lastly enlists the objectives of present investigation.

Chapter II attempts to review the available literature on rice with respect to molecular diversity, combining ability, heterosis and inbreeding depression and inheritance of grain quality, yield and yield contributing characters.

Chapter III describes the materials used and methodology followed for carrying the research work. The statistical analysis and molecular evaluation used in the present study has also been mentioned in this chapter.

Chapter IV presents the details of experimental findings with the help of tables and plates.

Chapter V discusses and interprets the results of present investigation in the light of work done by previous workers in India and abroad.

Chapter VI provides brief description of the achievements obtained in present investigation.

Chapter VII conclusion is drawn with the hope that it will provide scope for further research.

Lastly, bibliography includes the list of references in alphabetical order which has been consulted during the course of investigation and cited in the text.



INTRODUCTION

INTRODUCTION

Rice (*Oryza sativa* L.), is supposed to be originated from South East Asia (Vaughan, 1994). The genus *Oryza* includes 24 species of which 22 are wild and two, viz., *Oryza sativa* L. and *Oryza glaberrima* is cultivated. Nine of the wild species are tetraploid and the remaining are diploid. *Oryza glaberrima* is indigenous to the upper valley of the Niger river in Africa and is cultivated only in west tropical Africa. The basic chromosome number (x) of genus *Oryza* is 12. The cultivated varieties of *Oryza sativa* are grouped in to three sub species *indica*, *japonica* and *javanica*. Glaszmann (1987) studied 1688 rice cultivars for allelic variation at 15 isozyme loci and classify them in to six groups. First group contain *indica* and group II had very early maturing and drought tolerant upland rices called *Aus* varieties. Group III and IV had floating rice called *Ashinas* and *Rayadas* respectively. Group V corresponds aromatic rices of Indian subcontinent including basmati. Group VI includes *japonica*.

Rice is the staple food for more than fifty per cent of world's population. It is cultivated in 114 countries across the globe, but 90 percent of world's rice is grown and consumed in Asia. It was cultivated worldwide in 160.9 m. ha with production of 481.73 million tonnes (on milled basis). In India it occupied 44.5 m. ha with production of 106.5 million tons (2015-16). Rice is grown in almost all the states of India, but major rice producing states fall in the regions of middle and lower Ganga plains, as well as the coastal lowlands of peninsular India. The main rice producing states are West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Tamil Nadu, Odisha and Bihar. In India, West Bengal ranks first in area as well as in production.

In early years of 20th century systematic rice breeding was started with the establishment of research stations in erstwhile provinces of Bengal and Madras. Establishment of ICAR in 1929 and CRRI in 1946 further strengthened the research efforts. Rice breeder's initial activities were the purification of existing varieties through pure line selections. Until 1950s varieties developed through hybridization had little impact. Later, mostly hybridization and pedigree method of breeding and to

some extent back cross breeding have been adopted in developing the improved high yielding varieties.

The major production and productivity gains have enabled the country to attain self-sufficiency in rice since mid-1980's. Indian exporters entered into the world rice trade largely through the export of small quantities of highly priced basmati rice which was less than 5% in mid-1980's. Basmati, the unique aromatic quality rice is a nature's gift to Indian sub-continent. Epicureans acclaim its delightful fragrance, taste and texture which makes it the best among the aromatic rices of the world. During 2015-16 India exported 10.34 Mt of rice earning very high foreign exchange to the tune of Rs. 37,847.36 crores. Of this amount 22,718.35 crores was due to basmati (4.04 m.t) and 15,129.01 crores was due to non-basmati rice (6.3 m.t) export. This statistics show the importance of increase in production of aromatic rice.

The exporting of aromatic/ basmati rice will fetch high premium price over non aromatic rice varieties in the international market. So breeding programmes for aromatic rices was gaining more importance in countries which are self-sufficient in their rice production. As per capita income increases consumers prefer quality rice. Consumers base their concept of quality on the appearance, size, shape of the grain, kernel elongation after cooking, tenderness, taste and flavours of cooked rice (Shobha rani *et al.*, 2006). For commercial purposes, the rices are classified according to the kernel length as short grain, medium grain, long grain and long slender grain. The long slender grain type scented rice varieties fetch the maximum premium in the world market.

Length of the grain is more important than the width and thickness or shape and it is more variable. During milling long grains break more than short or medium grains and this effects head rice recovery. Grain length and shape are independently inherited. Some of the grain tissues are maternal in origin and some result from fertilization of genetically diverse gametes. The lemma and palea of the rice hull are maternal tissues. The shape and size of the hull decides the shape and size of seed. Since genetic segregation for shape and size of hulls for spikelets borne on F_1 plants does not occur, all F_2 seeds have similar dimensions even though the parents may be diverse in size and shape (Shobha Rani *et al.*, 2006).

Kernel length is the most important quality trait which decides market price of the rice. So, many studies were done on inheritance pattern of this trait despite variable reports, most studies indicate that kernel length and breadth are due to the action of multiple factors.

Aroma is the second most important feature of basmati and other short grain rices. For development of aroma climatic conditions and genetic factors both are important. Aroma is best developed when aromatic rices are grown in areas where temperature is cooler from flowering to maturity. The biochemical basis of aroma was identified as 2-acetyl-1-pyrroline. In addition to 2-acetyl-1-pyrroline, there are about 100 other volatile compounds (Yajima *et al.*, 1978). Multiple alleles of a single aroma gene, then, could produce slightly different alterations in the same enzyme resulting in rices with different aromatic intensities (Singh *et al.*, 2000). Inheritance of aroma has been reported to vary depending upon the materials used in the study and most studies indicated involvement of a single recessive gene. Several studies have suggested that the presence of 2AP is due to an allele of the betaine aldehyde dehydrogenase 2 (BADH2) gene on chromosome 8 defined by 8 base pair deletion on exon 2 or 7. Several varieties have been identified that accumulate 2AP but do not carry the deletion on exon 2 or 7 of BADH2. Although it is possible that those varieties carry other mutations that could affect the function of BADH2, several varieties with consistently high values of 2AP led to suggest that more than one pathway leads to 2AP in those varieties (Fitzgerald *et al.*, 2009). Shin *et al.*, (2008) reported the discovery of a new badh2 allele and the development of functional markers for the badh2 locus and recently assumption of the existence of a second gene for fragrance in rice was supported by Rai *et al.*, 2015.

Length wise elongation after cooking without increase in grith is considered most desirable in high quality rices. During cooking rice grains absorb water and increase in length, breadth and volume. (Sood *et al.*, 1983) reported penta or hexagonal cells arranged in a honey comb fashion in basmati rices, in contrast to long and rectangular cells radially arranged in columns of 10-12 cells in other varieties. Kernel elongation is also influenced both by genetic factors and climatic conditions during ripening stage. The ambient temperature of about 25 °C during day time, and

21°C during night at ripening has been found to have favorable effect. Maximum elongation was reported in grains matured at these temperatures.

Amylose content is considered the most important predictor of sensor quality in rice. The enzyme granule bound starch synthase I (GBSSI) is required for amylose synthesis, and several alleles are encoded by the *Wx* locus. A single nucleotide polymorphism (SNP) at the splice site of intron 1 differentiates low amylose varieties from intermediate and high varieties and defines the *Wx^a* and *Wx^b* alleles for high and low amylose, respectively. A recent association study shows that an SNP in exon 6 (identified as the *Wxⁱⁿ* allele) results in an amino acid substitution from serine to tyrosine that separates high and intermediate amylose varieties. Using near isogenic lines, it was shown that the SNP on exon 6 decreases the expression of the GBSSI protein, shifting the amylose content of the grain from high to intermediate levels. Varieties with very low amylose (<9%) have an opaque phenotype and show even less activity of GBSSI than low amylose varieties. An SNP in exon 4, resulting in an amino acid substitution from aspartate to glycine, associates with the opaque phenotype and defines the *Wx^{op}* allele. The waxy mutants carry a deletion in the *Wx* gene that is fatal to activity of GBSSI, and consequently they contain no amylose (Fitzgerald *et al.*, 2009).

Our current knowledge of the factors governing quality in different genetic backgrounds is incomplete; this is reflected by the persistence of bench mark varieties for many decades in spite of the yield gains achieved over those same decades. The variety like Sambha Mahsuri and Swarna released decades ago and susceptible to bacterial blight continue to be grown on million hectares in states for which they are not identified because of their excellent grain quality. For overcoming the disease susceptibility of popular varieties techniques like gene pyramiding and marker assisted selection (MAS) were used. Improved Sambha Mahsuri was developed using marker assisted selection and has three major bacterial blight resistance genes *Xa21*, *Xa13* and *Xa5*. Many efforts are made for improving rice grain quality along with yield potential but it is quite challenging. The nature of inheritance and type of gene action governing quality traits are many and complex and when genetically modified to some extent gave a way for the success in quality improvement with the knowledge of conventional breeding methods. Hence a better understanding of the

factors that contribute to the over all grain quality of rice will lay the foundation for developing new breeding and selection strategies for combining high quality with high yield.

Germplasm is an important source for current and future crop improvement programmes. Molecular markers are the powerful tools to detect genetic variation and genetic relationship within and among species. DNA markers are helpful in unmasking new genes for the improvement of crop varieties (Causse *et al.*, 1994). Generally, microsatellite loci are known as simple sequence repeats (SSRs) and these are the most popularly used molecular markers (Litt and Luty, 1989). They are basically PCR dependent markers which are efficient, convenient, cost effective as well as abundant, co-dominant and highly reproducible. In organisms, specific characters are represented by specific sequences and those sequences are easily identified by SSRs (Levinson and Gutman, 1987). That's the reason, why microsatellite markers have been widely applied in rice genome studies as well as allelic diversity analysis (McCouch *et al.*, 1997). Selection of diverse parents is of paramount importance in any breeding programme for getting maximum heterosis and wide range of variability in the segregating generations.

Heterosis refers to the superiority of F_1 hybrids for one or more characters over its parents. Both positive and negative heterosis is useful in crop improvement, depending on the breeding objectives. In general, positive heterosis is desired for yield and negative heterosis for maturity. Heterosis is expressed in three ways, depending on the criteria used to compare the performance of a hybrid. These are mid-parents heterosis (the performance of a hybrid compared with the average performance of its parents), better parent heterosis or heterobeltiosis (the performance of a hybrid compared with that of the best parent in the cross) and standard heterosis (the performance of a hybrid compared with high yielding variety in the region). From a practical point of view, standard heterosis is most important because it is aimed at developing superior hybrids in comparison to the existing high yielding commercial varieties

The combining ability studies of the parents gives the knowledge about selection of better parents for effective breeding strategies and it also provides information on additive and dominance variance. Its role is important in deciding

parents, crosses and appropriate hybrid breeding procedure to be followed to exploit heterosis.

The estimation of heterosis and inbreeding depression together provide information about the type of gene action involved in the expression of various quantitative traits. If high heterosis is followed by inbreeding depression, it indicates the presence of non-additive gene action (dominance and epistasis). If the performance is almost same in F_1 and F_2 , it reveals the presence of additive genes. If the heterosis is negative in F_1 and there is increase in F_2 , it again indicates presence of additive gene action.

Knowledge regarding the nature of gene interactions for different quality traits is important to achieve genetic improvement of the quality characters. Studies on nature of gene interaction controlling the quality traits are limited. Many different procedures are used to predict the gene action using the mean values but the presence of epistasis will effect the true estimates of genetic components leading to biased estimates and their interpretation. The presence or absence of epistasis can be determined by using the scaling tests developed by Mather (1949) and the Joint Scaling Test of Cavalli (1952). To estimate components of genetic variance and epistasis, generation mean analysis has been considered as one of the best method. In this method a set of segregating and non-segregating generations belonging to a common ancestry is subjected to analysis simultaneously for extracting additive, dominance and epistatic components of variance. Every single cross is considered as a unit and analyzed separately and estimates can be obtained. The analysis of the model gives information about six parameters viz., mean (m), additive gene effects (d), dominance effects (h) and three types of non-additive gene interactions like additive x additive (i), additive x dominance (j) and dominance x dominance (l) in presence of epistasis and when epistasis is absent then the three parameter model gives the values of mean (m), additive gene effects (d), dominance effects (h). This information helps in deciding a suitable procedure for improvement of traits under study.

Keeping in view the above mentioned facts the present investigation entitled **“Genetics of yield and quality characters in aromatic rice (*Oryza sativa* L.)”** was undertaken with the following objectives.

1. To study the nature and magnitude of gene action controlling the inheritance of grain quality, yield and yield contributing characters.
2. To estimate the general and specific combining ability effects for grain yield and quality parameters.
3. To study the nature and magnitude of heterosis and inbreeding depression.



REVIEW OF LITERATURE

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Breeding for quality in rice has become the most important objective after yield increase was achieved in mega varieties like Sambha Mahsuri, Pusa Basmati 1121 and Pusa Basmati 1509. A better understanding of the factors that contribute to the overall grain quality of rice will lay the foundation for developing new breeding and selection strategies for combining high quality with high yield. Aromatic rices fetch far higher price in both national and international markets as compared to non-aromatic rices. But many of the aromatic rices are low yielders prone to lodging because of their tall stature and susceptible to pest and diseases. But, due to their excellent quality characters these varieties are still cultivated by the farmers. With the improvement of rural infra structure, economic globalization and changes in acquisitive power, dietary patterns and working conditions, consumers have become more demanding with respect to grain quality and are willing to pay higher price for a given quality and type of rice.

For developing good quality varieties with high yield potential, knowledge about the type of parents which are used for crossing purpose is essential. The extent of variation among the available germplasm gives an idea about the variability for different yield and quality traits. Combining ability analysis will be helpful to decide parents, crosses and appropriate hybrid breeding procedure to be used to exploit heterosis. The estimation of heterosis and inbreeding depression together provides the knowledge about the type of gene action involved in the expression of various quantitative traits. Knowledge regarding the nature of gene interactions for different quality traits is important to achieve genetic improvement of the quality characters. Genetic analyses of various yield components and quality traits were studied by several investigators. The literature pertaining to previous research efforts for yield and quality characters are presented as under.

2.1 Molecular diversity

Genetic diversity in plants was traditionally assessed using morphological or physiological traits. The assessment of phenotype may not be a reliable measure of genetic differences as gene expressions are influenced by environment. But genetic variations based on DNA polymorphism are abundant and independent of environmental factor. DNA markers that differentiate genotype are more reliable and convenient than physiological or morphological traits in the identification and characterization of genetic variation.

Chakravarthi and Naravaneni (2006) reported about genetic diversity of 15 elite rice genotypes using 30 SSR primers on chromosome numbers 7-12 was investigated. The investigation revealed that all the primers showed distinct polymorphism among the cultivars studied indicating the robust nature of microsatellites in revealing polymorphism. Cluster analysis grouped the rice genotypes into 10 classes in which japonica types DH1 (Azucena) and Moroborekan clustered separately from indica types. Principal component analysis was done to visualize genetic relationships among the elite breeding lines. The results were similar to UPGMA results. Based on this study, the larger range of similarity values for related cultivars using microsatellites provides greater confidence for the assessment of genetic diversity and relationships.

Ram *et al.*, (2007) studied genetic diversity among 35 rice accessions, which included 19 landraces, 9 cultivars and 7 wild relatives using microsatellite (SSR) markers distributed across the rice genome. The mean number of alleles per locus was 4.86, showing 95.2% polymorphism and an average PIC value of 0.707. Cluster analysis based on microsatellite allelic diversity clearly demarcated the landraces, cultivars and wild relatives into different groups. The allelic richness computed for the clusters indicated that genetic diversity was the highest among wild relatives (0.436), followed by landraces (0.356), and lowest for cultivars.

Seetharam *et al.*, (2009) studied thirty rice genotypes comprising land races, pure lines, somaclones, breeding lines and varieties specifically adapted to coastal saline environments using SSR markers. Out of 35 primers of SSR markers, 28 were found to be polymorphic. The PIC value ranged from 0.064 (RM 274) to 0.72 (RM

580) with an average of 0.46. The Jaccard's similarity coefficient ranged from 0.42 to 0.90. At the genetic similarity of 56% the genotypes were grouped into five clusters. PCA components explained 41.6% of variation. There was overlapping of tolerant genotypes and susceptible genotypes within the cluster.

Prabakaran *et al.*, (2010) studied the genetic divergence of 12 rice land races using five SSR markers. A total of 11 alleles were detected in 12 land races and the number of alleles per locus ranged from 2 to 3 with an average of 2.2 per locus. Among the primers used RM 481 indentified more number of alleles and average PIC was 0.43. The dendrogram based on SSR marker analysis grouped the 12 rice accession into six clusters, where cluster VI was the largest with three accessions. The similarity coefficient through Jaccard's revealed that Anna samba and Chettivirippu were ascertained to be genetically diverse from the other land races.

Pervaiz (2010) studied genetic diversity using thirty-five microsatellite markers and 75 genotypes. Among the markers used a total of 142 alleles were detected at 32 polymorphic SSR loci. The number of alleles identified by each marker ranged from 2 to 13 with a mean of 4.4. Polymorphism information content ranged from 0.124 to 0.836, with an average of 0.569. A dendrogram based on total microsatellite polymorphism grouped 75 genotypes into four major clusters at 0.40 similarity coefficient.

Sajib *et al.*, (2012) studied a total of 24 SSR markers across 12 elite aromatic rice genotypes. Among these 24 markers nine microsatellite markers showed polymorphism. The number of alleles per locus ranged from two alleles (RM510, RM244, and RM277) to six alleles (RM 163), with an average of 3.33. The PIC values ranged from 0.14 (RM510) to 0.71 (RM163) in all nine loci with an average of 0.48. Cluster analysis grouped these varieties in to five clusters.

Ashfaq and Khan (2012) reported genetic diversity among rice genotypes, including 15 indica basmati advance lines and five basmati improved varieties using 27 SSR markers and one indel marker. The SSRs covered all the 12 chromosomes that distributed across the rice genome. The mean number of alleles per locus was 3.60, showing average number of polymorphism information content using 0.48. A

total of 101 alleles were also identified from the microsatellite marker loci. Pair wise Nei's genetic distance between rice genotypes ranged from 0.07 to 0.95. The dendrogram based cluster analysis using SSR polymorphism grouped the 20 genotypes of rice in to five clusters based on their genetic similarity.

Shahriar *et al.*, (2014) studied the genetic diversity of advanced rice (*Oryza sativa* L.) breeding lines using three SSR markers viz., RM147, RM167 and RM215. Thirty T- aman advanced breeding lines at F9 generation along with 4 check varieties were assessed. All three primers showed polymorphism. A total of 29 alleles were detected among the rice genotypes with an average of 9.67 alleles per locus. Polymorphism information content (PIC) ranged from 0.47 to 0.88 with an average of 0.71. A dendrogram was constructed based on total microsatellite polymorphism and 34 genotypes were grouped into four major clusters at 0.36 similarity co-efficient.

Salgotra *et al.*, (2015) reported that 141 basmati rice genotypes collected from different geographic regions of North Western Himalayas were characterized using 40 traits linked microsatellite markers. Number of alleles detected by the primers were 112 with a maximum and minimum frequency of five and two alleles, respectively. The maximum and minimum polymorphic information content values were found to be 0.63 and 0.17 for the primers RM206 and RM213, respectively. The genetic similarity coefficient for the most number of pairs ranged between of 0.2-0.9 with the average value of 0.60 for all possible combinations, indicating moderate genetic diversity among the chosen genotypes. Clustering method divided these genotypes into five groups (A, B, C, D and E).

Singh *et al.*, (2016) reported a set of 729 Indian rice varieties being genotyped using 36 HvSSR markers to assess the genetic diversity. A total of 112 alleles were amplified with an average of 3.11 alleles per locus with mean Polymorphic Information Content (PIC) value of 0.29. Cluster analysis grouped these varieties into two clusters.

2.2 Combining ability

Combining ability studies are frequently used by the breeders to evaluate the parental lines for their usefulness in crosses and to assess the nature of gene action involved in their inheritance.

Hung and Ro (1995) studied the combining ability of aromatic rice cultivars in combination with some early and high yielding varieties. The results showed that Jasmine 85 possessed good general combining ability. The crosses of Jasmine 85 and IR64, Jasmine 85 and Om 1300-6, and Jasmine 85 and Om987-1 were promising for further selection, because both the parents involved in these crosses had high GCA.

Babu *et al.* (2000) studied 32 rice hybrids obtained from line x tester design. They found that CMS lines IR58025A and IR 62829A, and testers WGL 3962, IET 9762, IET10021 were good general combiners for yield and other yield attributes.

Significant gca effects for all grain quality characters were recorded by Lioa *et al.* (2000) indicating that selecting parents on the basis of combining ability is very important in hybrid rice breeding. Additive effects were predominant for length/breadth ratio, gelatinization temperature and amylose content.

Hasib *et al.* (2001) investigated combining ability for panicle traits in aromatic rice in line x tester analysis. The mutants 88-8-3 and 124-17-4 were good general combiners for grain yield and fertility percentage.

Selvi *et al.* (2001) experimented with 42 rice hybrids and seven parents for the estimation of combining ability of grain yield and physiological characters. They found that CO 43 was best general combiner for flag leaf area and harvest index. Hybrid IR 20 x ACM 44 was best specific combiner for flag leaf area and leaf area index.

Swain *et al.* (2003) found that predominance of non additive gene action was recorded for days to flowering, number of panicles per plant and grain yield per plant, while additive type of gene action was predominant for plant height, panicle length and 1000 grain weight.

Banumathy *et al.* (2003) reported the predominance of non-additive gene action over additive gene action in the inheritance of grain yield and associated traits.

Vanaraj *et al.* (2003) experimented with 28 rice hybrids along with their parents to evaluate the combining ability for yield and 17 yield traits. They found that Vyttila 3 was good general combiner.

Swain and Nagaraju (2004) while studying 21 crosses developed through diallel mating design, observed preponderance of additive gene action in the inheritance of the trait amylose content. Estimates of genetic components showed both additive and non additive gene effects to be important for the trait. High amylose is dominant over intermediate and waxy and intermediate is dominant over waxy amylose content. The parent Sitabhog was considered as the best general combiner and the cross Sitabhog / Ratna and Basmathi 370 / Tulasi Manjari were identified as best cross combinations for this trait.

Singh and Kumar (2004) crossed three CMS lines with nine testers to generate 27 hybrid combinations in line x tester mating design. They found that IR68886A, Gautam, Prabhat and RAU 1411-4 were good combiners for earliness. IR68897A, Dhanalaxmi, Pusa 1107 and Pusa 1040 were better combiners for late flowering; whereas, IR68897A, Dhanlaxmi and Prabhat were better combiners for dwarfness. PSRM-1-16-48-11, Pusa 1107, and RAU 1411-4 were found to be good combiners for high productive tillers.

Panwar (2005) studied the combining ability of parents and crosses in rice and reported the importance of non-additive gene action controlling all the traits studied. The line IET 13846 and the testers Kasturi, Basmati 370, Pusa Basmati-1, Taraori Basmati and IR 64 were good general combiners for grain yield per plant. 14 cross combinations recorded significant *sca* effects for grain per plant.

Bisne and Motiramani (2005) studied combining ability for grain yield and its components in rice in line x tester mating design. They found that lines DRR 2A and PMS 10A, and testers BKP 232, R 827-287, R 1060-1674-1-1 and R 714-2-103 were good combiners for grain yield. Crosses DRR 2A x R 827 and DRR 2A x R 1060-1674-1-1 recorded higher specific combining ability with high standard heterosis for grain yield.

Sharma *et al.* (2005) studied 13 rice genotypes in line x tester mating design. They took 10 lines and three testers to generate 30 F₁ cross combinations. They found that lines Punshi and KD-6-7-1, and testers Neela and Satary were good combiners for grain yield per plant. Neela was found to be best combiner for days to 50% flowering and harvest index.

Bisne and Motiramani (2005) studied 32 F₁ combinations along with 12 parents and reported that kernel length and kernel breadth was under the control of non additive gene action.

Anand Kumar *et al.* (2006) investigated combining ability in line x tester method and found that mean squares due to parent vs. crosses differed significantly for majority of the traits. Among the CMS lines, IR 68886A for earliness and IR 58025A for yield and its component traits were found to be superior general combiners. Four testers viz., Pusa 1040, PSRM-1-16-48-11, RAU 1411-4 and RAU 1414-10 were rated as good general combiners for yield. The crosses IR 68886A / Pusa 1040, IR 58025A / RAU 1411-10 and IR 68886A / PSRM-1-16-48-11 recorded significant heterosis for yield and yield contributing traits.

Hariprasanna *et al.* (2006) evaluated 35 crosses generated in line x tester mating design. They used seven CMS lines and five pollen parents and observed that high x high GCA combination resulted in significant negative SCA for filled grains and productive tillers per plant. They noticed that three crosses that had significant positive SCA for grain yield were obtained from average x average GCA combinations, while average x average and average x low combinations also resulted in hybrids with significant negative SCA.

Jagadeesan and Ganesan (2006) reported predominance of non additive gene actions for all the traits studied. Based on the gca effects of parents, the line IR 58029-99-3-1-3 (L5) and tester BR 4828-2-2-1(T2) recorded negative gca effects for days to 50 per cent flowering and plant height. In addition, the line IR 58108-3-1-1-2 (L6) and tester BR 802-78- 2-1-1 (T3) possessed high gca effects, the cross IR 44962-161-2-4-4-2/AS 37800 and IR 58108 -3-1-1-2/AS 37800 showed highly significant results for days to 50 per cent flowering and grain yield per plant respectively.

Akram *et al.* (2007) studied the inheritance of traits related to seedling vigour and yield and found that tillers per plant was controlled by additive and dominance gene actions with the additive effects playing greater role, as where panicle length was under the control of both additive and non additive gene actions.

Narasimman *et al.* (2007) investigated combining ability and heterosis for grain yield and its component characters in nine rice genotypes. They found that ADT 44 was good general combiner for all the six traits studied. CR 1009 was observed to be a good combiner for all the traits except harvest index. The cross ADT 44 x CR 1009 showed highly significant positive SCA effect for the trait.

Sanjeev Kumar *et al.* (2007) found that preponderance of additive gene action was recorded for the traits *viz.*, plant height, days to 50 per cent flowering and 100 seed weight. While both additive and non-additive gene effects were almost equally important for grain yield per plant, preponderance of non-additive gene action was recorded for panicle length and grain length. Parents HPR 2047, VL 93-3613 and J08 were good general combiners for grain yield and other related characters. The cross combinations HPR 2047 / VL93-3613, HPR 1164 / IR 57893-8, VL 91-1754 / J08, VL 93-3613 / J08 and VL 91-1754 / VL 93-3613 showed significant positive specific effects for grain yield per plant and some associated characters.

Sarma *et al.* (2007) observed that additive genetic variance was higher in magnitude for plant height, panicle length and all other quality parameters. Non-additive gene action on the other hand was predominant for grain yield and its components *viz.*, effective tillers, panicle weight and grain weight.

Singh *et al.*, (2007) observed the GCA and SCA were significant for all the seven characters, indicating the importance of both additive and non-additive genetic components for these traits. The per se performance was observed to be a good indication of GCA effects of the parents and SCA effects of the crosses. Among parents studied, Vaidehi and Rajshree were observed to be good general combiners for grain yield. The superior specific cross combinations Saket 4 x Vaidehi, Rajshree x Kamini, Prabhat x Rajshree and Sita x Vaidehi appeared promising for further exploitation in rice breeding programme.

Venkatesan *et al.*, (2007) observed the combining ability analysis revealed non-additive gene action governing the characters viz., days to first flower, plant height, panicles per plant, grain yield per plant and grain L/B ratio. Predominance of GCA variance was recorded for days to first flower, plant height, grains per panicle and grain yield per plant. Among the parents, the lines AD 95137, AD 95157 and MDU 5 and testers ADT 36, ADT 43 and IR 50 were good combiners for grain yield and most of the component characters studied.

Bagheri *et al.* (2008) studied combining ability and gene action for yield and yield related traits viz., days to maturity, tillers per plant, panicle length and 1000 grain weight. The study indicated that both additive and non additive gene actions play major role in the inheritance of these traits.

Dalvi and Patel (2009) investigated sixty hybrids for combining ability analysis and reported that BR-827-35-3-1, RTN-3, IR-46 were good general combiner for grain yield and most of the component characters. The most promising specific combinations for grain yield per hill were IR 58025A / BR-827-35-3-1, IR-58025A / RTN-3 and IR-68885A / RTN-711.

Karthikeyan *et al.* (2009) studied gene actions among six lines and five testers. The results suggested that the traits panicle length, productive tillers and grain yield per plant were under the control of non additive gene action.

Salgotra *et al.* (2009) crossed five genetically diverse varieties viz., Sanwaal Basmati, Super Basmati, Pusa 2517-2-51-1, P1121-92-8-1-1-3-3 and PAU 2935-16-3-5-2 with three well adapted varieties, Ranbir Basmati, Pusa Basmati 1 and Basmati 370 in a line x tester design. The preponderance of dominant gene action was observed for plant height, effective tillers per plant, panicle length, number of grain per panicle, spikelet sterility, 1000 grain weight and grain yield per plant. Pusa 2517-2-51-1, Sanwaal Basmati, Super Basmati, Ranbir Basmati and Basmati 370 were found to be good general combiners which can be taken up to generate desirable segregates for further selection. High SCA effects were observed in the crosses, Super Basmati x Ranbir Basmati, Pusa 2517-2-51-1 x Pusa Basmati 1, P1121-92-8-1-1-3-3 x Ranbir Basmati and PAU 29-35-16-3-5-2 x Basmati 370.

Lakshmi (2009) reported high non additive gene action for volume expansion ratio, gelatinization temperature, amylose content, iron and zinc contents in 21 crosses developed from 7x7 diallel.

Sanjeev Kumar *et al.* (2009) reported predominance of non additive gene action for plant height and biological yield, while studying combining ability in segregating generations of rice varieties developed in 9x9 diallel design. The parents HPR2047, VL93-3613, JD8, VL93-6052 and HPR1164 were good general combiners for grain yield and its components.

Shivani *et al.* (2009) while studying combining ability analysis in 18 *indica/indica* hybrids reported that the crosses involving IR 58025A with MTU 9992 and KMR-3, IR 62829A with MTU 9992 and IR 29723 and IR 68886A with IR 40750R and IR 21567 showed significant positive specific combining ability (sca) effects. The magnitude of s^2_{gca}/s^2_{sca} revealed the predominance of non-additive genetic variance for most of the quality characters. For gel consistency, IR 62829A among lines and Ajaya R and IR 40750 R among testers registered significant positive gca effects indicating them to be good general combiners for obtaining hybrids with soft gel consistency.

Chaturvedi *et al.*, (2010) observed prevalence of additive as well as non-additive gene action for all the characters studied. Bahadur and Teke were the best general combiners with respect to grain yield per plant. These two parents were good general combiners for at least four other desirable traits also. In the study good x good combiners like Teke x Bahadur and Teke x Ranjit and good x poor combiners like Malong x Bahadur, Mehuru x Ranjit, Mehuru x Bahadur and Teke x Piolee were among the best specific combiners.

Satheesh Kumar *et al.*, (2010) observed dominant type of gene action for all the six traits namely, days to 50 percent flowering, plant height, number of productive tillers per plant, number of grains per panicle, hundred grain weight and grain yield per plant. Parents Jaya and CRAC 2221-67 were good general combiners for grain yield per plant and most of the yield traits. The cross combinations CRAC2221-67 x

Jaya and IR6331-1-B-3R-B-24-3 X Jaya were the best specific combiners for grain yield per plant.

Tyagi *et al.*, (2010) observed that none of parental line was found excellent for all the 11 qualitative characters. Among the nine lines, three lines viz., Pusa-1121(L7), Pusa 1463(L9) and Pusa-1176(L6) showed good general combining ability effect for maximum quality characters. Among all the crosses, P-1463 x P-44 showed high specific combining ability effects as well as high heterosis. P-1173 x Heibao, Shah-Pasand x P-44 and Bas-370 x Heibao were good specific combiner for different characters.

Akter *et al.* (2010) studied twenty hybrids which were produced using five CMS lines (BRR13A, BRR19A, IR73328A, BRR 110A and IR78355A) and four restorers (BRR112R, BRR113R, BRR114R and BRR115R) following line x tester mating design to find out the best combinations in respect of their combining ability effects among parents and hybrids. The ratio of GCA and SCA variances were found less than unity for all the characters except plant height, days to maturity and panicles per square meter. The relative contribution of lines, testers and combinations of line x tester interactions for ten characters were calculated and it was observed that panicle weight contributed the highest (69.53%) followed by thousand grain weight (63.62%), yield per plant (54.76%), panicle per meter square (51.52%) in their hybrids. IR73328A was identified as good general combiner for shorter plant height (-6.09) and panicles per square meter (16.92). BRR110A and IR78355A produced significant positive GCA for yield per plant. Six hybrid combinations were found with significant and positive SCA effect for yield per plant; of these the highest value was obtained from BRR13A x BRR114R (2.46) followed by IR73328A x BRR113R (2.23).

Bagheri and Jelodar (2010) studied combining ability and heterosis in 12 F₁ hybrids along with their seven parental genotypes (three cytoplasmic male sterile lines and four restorer varieties) to know the pattern of inheritance of some morphological traits. Variances of SCA were higher than the GCA variances for all the traits except plant height. The proportional contribution of testers was observed to be higher than that of the interactions of line x tester, which revealed higher estimates of GCA.

Within CMS parents, IR62829A and among male parents, IR50 and Poya were observed to be good general combiners for most of the characters studied. The cross combinations IR62829A x Mosa-tarom, IR68899A x Poya, IR58025A x IR50 and IR58025A x Poya were observed to be good specific cross combinations for grain yield and most of the related traits.

Saidaiah *et al.*, (2011) studied the combining ability analysis which revealed significant differences among the parents for all the characters studied indicating the predominance of dominance gene action in governing yield and related traits. Two CMS lines (APMS 6A and CRMS 32A) and six testers (1096, 612-1, GQ-70, GQ-120, KMR 3 and SG 27-77) were found to be good general combiners for yield and other yield attributes. The hybrids APMS 6A x 612-1, PUSA 5A x KMR-3, CRMS 32A x IR 43 exhibited higher specific combining ability with at least one of the parent possessing positive alleles for grain yield. The interrelationship of gca with sca revealed the predominance of non additive gene action viz., additive x dominance and dominance x dominance type for gene interaction for most of the hybrid combinations.

Tiwari *et al.* (2011) evaluated 60 F₁ hybrids along with their parents (three CMS lines and 20 restorers). They found that male lines IR35454-18-1-1-2R, IET201108 and IR52256-9-2-2-1R were good general combiners for grain yield and almost all its major components. A higher magnitude of SCA than GCA variance was observed for all the characters studied. High SCA effects was observed in the crosses NMS4A x IR633-76-1R, IR58025A x IR19058-107-1R, IR58025A x IR32419-28-3-1-3-3R, NMS4A x IR35455-18-1-1-2R and NMS4A x IR5226-9-2-2-1R.

Mirarab *et al.* (2011) studied heterosis, combining ability and genetic parameters of yield and yield components in rice. Five lines were crossed with two testers in line x tester manner to produce ten F₁ hybrids. The general combining ability (GCA) effect was significant for total number of grains per panicle, number of filled grains and grain yield per plant, and specific combining ability (SCA) effect was significant for yield and all of its studied components except 100 grain weight. Lines IR42 and Pouya showed significant GCA effect for grain yield in opposite direction (20.9 and -13.7, respectively). The two lines also showed highest significant

GCA for number of filled grains (22.7 and 23.3, respectively). For total number of grains per panicle, lines IR8 and IR42, and tester Usen showed highest significant GCA (34.79, 27.97 and 12.56, respectively). Cross combination IR68897 x IR8 showed highest significant SCA for grain yield (9.7 g/plant). For number of filled grains and tiller number, combinations IR68897 x IR8 and Usen x IR36 showed significant positive SCA (18.9 and 2.1, respectively).

Patil *et al.*, (2012) reported the magnitude of mean square due to SCA were smaller than the GCA for most of the traits indicating preponderance of additive gene effects for all the character under study, whereas the ratio of the estimates of variances due to GCA to that of SCA indicated the preponderance of non-additive type of gene effects for most of the characters except for kernel length/breadth ratio and protein content. The best general combiner for grain yield per plant were GR-12, IET-20548 and IET-20536, whereas for other yield attributing characters the best general combiner were NVSR-20 and IET-20528. The top specific cross combinations GR-12 x Safed kada, NVSR-20 x IET-20528, Safed kada x Lal kada, IET-20528 x IET-20533 and IET-20548 x IET-20536 showed the highest SCA effect for grain yield per plant.

Ghara *et al.* (2012) studied general and specific combining ability in 50 F₁ hybrids along with 15 parental rice genotypes (five cytoplasmic male sterile lines and ten restorers) to know the pattern of inheritance for some morphological traits. The experiment was carried out according to line x tester mating design, and analysis of variance indicated significant differences among genotypes, crosses, lines, testers and line x tester interactions for tiller number, plant height, days to 50% flowering, panicle length, number of spikelets per panicle, spikelet fertility and grain yield traits. Within CMS parents, Nemat A and among male parents, Ahlamitarom were observed to be good general combiners for most of the characters studied. The cross combination NematA x IR-9 was observed to have highly significant SCA for grain yield and most of its related traits.

Sanghera and Hussain (2012) studied combining ability in 36 cross combinations by crossing 18 genotypes (Males) with two CMS lines (Females) in line x tester mating design. Analysis of variance revealed significant differences among

genotypes, crosses, lines, testers and line x tester interactions for all the traits studied. Preponderance of non-additive gene effects was realized by higher values of specific combining ability, ratio of SCA to GCA and average degree of dominance. The proportional contribution of testers was observed to be lower than that of line x tester interactions, thus resulting in higher estimates of SCA variances. The estimates of GCA effects indicated that male parent K-08-61-2 was a good general combiner for grain yield per plant and other yield contributing traits. Among female parents SKAU 11A was observed to be a good general combiner.

Chandirakala *et al.*, (2012) observed four lines, GD 98014 and GD 98049 showed good general combining ability effect for maximum main quality characters. Among the testers, IR 72, CO 47 and TKM 12 expressed good gca effects for maximum quality characters. Among the crosses, GD 99017 x CO 47 and GD 98014 x TKM 12 showed high specific combining ability effects. GD 98049 x IR 72 and GD 98049 x CO 43 were good specific combiner for different characters.

Padmavathi *et al.*, (2012) reported predominance of non additive gene action for all the characters studied. Among CMS lines APMS 9A and APMS 10A and among testers viz., MTU II-110-9-1-1-1-1, MTU II -187-6-1-1, MTU II-143-26-2, MTU II-290-42-1 and MTU II-283-7-1-1 were found to be good general combiners for grain yield and yield component traits. The crosses APMS 10A x MTU II-290-42-1, APMS 6A x MTU II-187-6-1-1 and PMS 6A x MTU II-110-9-1-1-1-1 were identified as most promising hybrids for grain yield per plant.

Satheeshkumar and Saravanan (2013) crossed six ovule parents with five pollinator parents in line x tester fashion so as to identify suitable general and specific combiners for breeding program. Dominant types of gene action for all the seven traits namely, days to first flower, plant height, number of productive tillers per plant, panicle length, filled grains per panicle, hundred grain weight and grain yield per plant was observed. Parents TRY 1, ADT 36, AURC 8 and AURC 10 were good general combiners for grain yield per plant and most of the yield traits. The cross combinations AURC 10 x ADT 43, AURC 8 x ADT 43, AURC 8 x ADT 36 and AURC 25 x ADT 36 were good specific combiners for grain yield per plant.

Utharasu and Anandakumar (2013) reported both additive and non additive gene action to control the expression of the traits under study. The magnitude of combining ability revealed non additive genetic variance to be higher than the additive variance for all the studied traits. Parents PMK3, RMD(R)1, ARB6, ARB7, ARB8 and CB-04-801 were found to be good combiners for drought tolerance and yield traits. The crosses RMD(R)1/ARB7, PMK3/ARB8, PMK3/ARB7, ADT43/IR77080-B-34-3 and MDU5/Anjali recorded high sca effects for grain yield.

Hasan *et al.*, (2013) reported the combining ability for grain yield and its components from line $\times$ tester analysis of 70 rice hybrids produced by crossing seven CMS lines and ten testers of local and exotic origin. The analysis revealed higher sca variance than gca variance for all the traits indicating the prevalence of non-additive gene action. Testers played important role towards panicle length, spikelet fertility and grain yield/plant indicating predominance of paternal influence for these traits. The contribution of interactions were found vital for plant height, effective tillers/plant, days to 50% flowering, days to maturity, flag leaf length, panicles/m² and panicle weight. D. Shan A was the only good general combiner among the female parent for earliness and dwarfness. Male parent IR64R was best general combiner for dwarfness. The crosses BRRI9A $\times$ BR168R and D. ShanA $\times$ BR168R were identified as most promising for yield and desired traits based on sca effects, per se performance and gca effects of parents for grain yield and its components in rice which could be exploited beneficially in future rice breeding program by adopting heterosis breeding strategy.

Veerasha *et al.*, (2013) reported eight cross combinations exhibited high SCA effects for grain yield per plant. Among these crosses, specific combining ability revealed the potentiality of IR-68897A $\times$ KMR3, IR-58025A $\times$ IR-10198 and IR-79156A $\times$ IR-72 hybrids for grain yield. These crosses were found to involve at least one parent with high GCA effect and other parent with high or low GCA effect indicating the involvement of additive as well as non-additive gene action.

Rajkumar and Ibrahim (2013) observed predominance of non-additive gene action for days to 50% flowering, number of productive tillers per plant, panicle length, number of grains per panicle, spikelet fertility, 100-grain weight, relative

water content, root length, root dry weight, root: shoot ratio, harvest index and single plant yield, while additive gene action was predominant for plant height, proline content and chlorophyll stability index. Among the parents, IR 58025 A, MAS 946 -1, CB 87 R and BI 33 were found to be general combiners for majority of the traits including drought tolerance and yield characters. The hybrids IR 58025 A x CB 87 R, IR 68897 A x MAS 946 -1, IR 68897 A x IR 65912 R and IR 58025 A x MAS 26 were specific combiners for most of the yield contributing and drought tolerant traits including single plant yield.

Prasad (2014) generated 36 F_1 's by crossing three genotypes with 12 lines in line x tester design. Among the parents, five genotypes (IR551793B113, IR 11T159, Jaya, IR 58025 B and NDRK 50026) exhibited significant GCA effects for grain yield per plant, indicating the involvement of additive gene action for yield and component traits. Among the crosses, five hybrids (Narendra Usar Dhan 2009 x NDRK 50026, Jaya x Narendra Usar Dhan 2008, IR11T164 x Narendra Usar Dhan 2008, CSR 28 x NDRK 50026 and Jaya x Narendra Usar Dhan 3) exhibited significant SCA effects for grain yield per plant, indicating the preponderance of non-additive gene action for yield and component traits. Majority of the desirable heterotic cross combinations possessed at least one of the high general combiner.

Priyanka *et al.* (2014) conducted an experiment to estimate combining ability for yield, yield attributing traits and some grain quality parameters in rice. The crosses were made among three CMS lines *i.e.*, IR58025A, Pusa6A and IR68897A and seven pollen parents *viz.*, Sarjoo-52, Jaya, Sasyashree, Swetha, HUR 5-2, PR-106 and BPT 5204. Twenty one hybrids were generated in line x tester design. Cross combination IR68897A x Jaya and IR68897A x BPT 5204 exhibited good x good parental GCA effects suggesting that there is additive x additive type of gene action. The cross IR68897A x Jaya showed highest positive SCA effect.

Dhivyapriya and Kalaiyarasi (2014) reported that the magnitude of SCA variance was higher than the GCA variance for all yield contributing characters, which indicated the presence of non-additive gene action. Based on the sca effects and heterosis, TS09 22 X T1408.10, TS09 28 X CO 43, TS09 12 X CO 43, TS09 22 X WGL 14 and TS09 22 X CO(R) 50 were identified as potential hybrids.

Mallikarjuna *et al.*, (2014) reported higher SCA variance than GCA variance for all the characters except plant height indicating the prevalence of non-additive gene action. The line KCMS 45A and testers MSN 36 and KMR 3 were good general combiners for yield and major contributing characters. The hybrids KCMS46A x MSN 75, KCMS 44A x KMR 4 and KCMS 45A x KMR 3 were identified as potential hybrids for yield contributing characters based on SCA effects. The contribution of testers towards the total variance was found higher than lines and line x tester interaction.

Dorosti and Monajjem (2014) reported line $\times$ testers showed significant differences for all traits except for number of spikelets per panicle and hundred grain weight. Parents with low $\times$ high general combining ability effects resulted in heterotic hybrid combination. A low $\times$ low GCA gave highly heterotic combination indicating that it will be unwise to discard the low GCA types. Predominance of dominant gene action for all the traits studied except for flag leaf width and number of spikelets per panicle.

Kolom *et al.*, (2014) reported that sca variance and non- additive variance components were higher than genetic variance and additive variance for yield characters under study. The estimates of gca effects indicated that, Koyapvu Tsok, Manchio Tsük among lines and RCM-5 and Teke among testers were good general combiners for grain yield per plant. Out of the 45 crosses, 21 crosses exhibited positive sca effects for grain yield per plant. The best sca effects were observed in the cross, Leikhumo x Teke for plant height, which also showed best sca effects for filled grains per panicle.

Satyapal *et al.*, (2014) reported the predominance of non-additive gene action for all the characters suggesting the possibility of exploiting heterosis in the material. CMS line IR58025A was rated as a good general combiner for grain yield per plant, fertile spikelet per panicle and other component traits. Testers viz. HR-NPT6-3, IR72164- 352-2-5-5, IR72910-177-1-1-3, R1659-3629-1-462-1, Chinikapoor (aromatic short grain), Sawrna selection-2 and Mahsuri (medium slender grain) were identified as good general combiner for grain yield per plant, and other contributing traits. Cross combinations viz. IR58025A X Mancha, IR58025A X IR72164-352-2-5-

5, CRMS 32A X IR72910-177-1-1-3, CRMS 31A X R1557-1317-1-580-1 and CRMS 31A X HR-NPT-6-3 possessed significant and positive SCA effect for grain yield per plant and other component traits.

Savita *et al.*, (2014) reported that cross HPR 2639 x HPR 2143 was good specific combination for grain yield per plant, panicle length, spikelets per panicle, grains per panicle, biological yield per plant, days to 50% flowering and plant height. Another hybrid HPR 2529 x HPR 1156 also showed high heterosis over standard check for grain yield per plant, biological yield per plant, grain fertility and plant height.

Patil and Mehta (2014) reported that male parent lines, PD-19, NAUR-1 and IET-18654 appeared to be good general combiners for grain yield and most of the component characters. The female line IR-58025B was found to be good general combiner for all the traits and average general combiner for plant height and harvest index whereas poor general combiner for test weight. The most promising specific combinations for grain yield per plant were IR-58025A x NAUR-1, IR-68888A x NAUR-1 and IR-58025A x IET-18654.

Adilakshmi and Upendra (2014) reported that the sca variance was greater than gca variance for all the characters under study except for milling percentage and protein content indicating that the traits were under the influence of non-additive gene action. Significant values of mean squares for both gca and sca for all the quality characters indicated considerable influence of both additive and non-additive variances. Non-additive gene action was predominant in governing the protein, iron and zinc contents. The results indicated that there was close relationship between mean performance of the parents and their gca effects in most of the cases studied. Based on gca effects Indra was the best parent among all the seven studied as it recorded positive gca effects for hulling, milling, head rice recovery, L/B ratio and grain yield per plant. The characters viz. L/B ratio, volume expansion ratio, amylose, iron and zinc contents are predominantly governed by non-additive gene action. However the role of additive component of gene action appears to be considerable along with non-additive effect for head rice recovery, L/B ratio and elongation ratio.

Zeinab *et al.*, (2014) reported that variances of SCA were higher than the GCA variances for number of productive tillers per hill, panicle length and 100-grain weight which indicated predominance of non-additive gene action in the inheritance of these traits. P35 tester produced the lowest height among testers, highest number of productive tillers and number of spikelets per panicle among parents and its hybrids produced highest number of productive tillers, longest panicles, highest number of spikelets per panicle and lowest height among hybrids. Also this variety was found to be good general combiner for height and panicle length. Crosses namely Tarom-Jelodar $\times$ Sange-Tarom, Danesh $\times$ Jahesh and Danesh $\times$ P35 had useful and significant heterosis for all traits.

Ashok (2014) observed no heterosis for hulling and milling percentage, kernel length and length breadth ratio. Hybrids were characterized as intermediate between the parents for grain quality and physico-chemical traits. Therefore both the parents need to possess aroma, long slender grains with intermediate gelatinization temperature (GT) to develop aromatic, long grain basmati hybrids. The restorers Basmati 385 was characterized as good general combiner for all grain quality and physico-chemical traits while Karnal Local for grain quality and HKR 241 for physico-chemical attributes. These restorer in combination with basmati CMS lines could be utilized for developing basmati hybrids. Heterotic hybrids for grain yield IR 58025A $\times$ Basmati 385 and IR 58025A $\times$ Karnal Local with significant SCA effects were identified as specific combinations for grain quality and physico-chemical traits, respectively.

Rishika and Suneeta (2014) reported the lines UPRI 99-79-1 and UPRI 99-60-2 and tester Pant Dhan 4 to be the good general combiners for yield contributing characters. There was lack of correspondence between the per se performance and combining ability of parents their investigation. Eight cross combinations exhibited high SCA effects for grain yield per plant involving at least one parent with high GCA status and other with low GCA status indicating the involvement of additive as well as non-additive gene actions operating in these crosses.

Patil and Mehta (2014) observed among the male parental lines, PD-19, NAUR-1 and IET-18654 appeared to be best general combiner for grain yield and

most of the component characters. The female line IR-58025B was found to be good general combiner for all the traits and average general combiner for plant height and harvest index whereas poor general combiner for 1000-grain weight. The most promising specific combinations for grain yield per plant were IR-58025A x NAUR-1, IR-68888A x NAUR-1 and IR-58025A x IET-18654.

Patel *et al.*, (2015) reported the magnitudes of gca variances were higher than sca variances for all the characters which indicated that additive gene action was predominant in the expression of the traits under study. The estimation of gca effects for parents revealed that females, Acharmati, Pusa Sugandha-5 and males IET-1934 7, GR- 4 and GNR-2 were good general combiners for yield and yield contributing characters. The best specific cross combinations obtained through poor x good and poor x average combining parents respectively for grain yield per plant.

2.3 Heterosis and inbreeding depression

Heterosis refers to the superiority of F_1 over its parents for one or more characters like adaptation, yield, quality, disease resistance, maturity and general vigour. Heterosis can best be exploited through hybrid breeding. The hybrid technology in rice has not only made tremendous gains during last 20 years, but it has been conceived that hybrid rice will play a key role in ensuring global food security in the future decades.

Davis and Rutger (1976) studied yield and yield components of F_1 hybrids, and recorded -41.0 to 67.0 per cent heterosis for grain yield over the better parent. Two hybrids significantly out yielded the check variety by 23 per cent and 16 per cent. They also recorded the heterosis over better parent for the characters viz., grains per panicle, 100 seed weight and number of effective tillers per plant with range from 24.0 to 55.0 per cent, -31.0 to 9.0 per cent and -31.0 to 19.0 per cent, respectively.

Amrithadevarathinam (1983) reported heterosis over better parent in 28 hybrids derived from line x tester mating of seven local rice cultivars with four improved strains. Heterosis over the better parent ranged from -14.0 to 101.9 per cent for plant height, -52.2 to 48.6 per cent for productive tillers, -49.4 to 70.1 per cent for grains per panicles and from 66.2 to 95.0 per cent for grain yield per plant. However,

maximum intervarietal heterosis over the better parent was 223.2 per cent for grain yield per plant, 35.5 per cent for number of effective tillers per plant, 21.8 per cent for panicle length, 87.6 per cent for grains per panicle and 25.4 per cent for 100 grain weight.

Patnaik *et al.* (1990) reported significant heterobeltiosis and standard heterosis for grain yield and yield related characters in most of the hybrids. Heterosis for grain yield was mainly due to significant heterosis for spikelets per panicle and 100 seed weight. Hybrids shorter than the shortest parent and earlier than the earliest parent were not observed.

Reddy *et al.* (1991) reported that heterosis for grain length was low, while grain breadth was significantly high in all the F₁s except Prabhavati x Ambemohor Local. Heterosis for L/B ratio was non-significant and none of the hybrids were superior to their better parent for grain fineness. However, high grain yield was found to be negatively associated with grain fineness.

Ram (1992) studied heterosis in rice for five yield related traits and observed that 19 crosses exhibited more than 20 per cent heterobeltiosis for grain yield, while seven show more than 40 per cent heterobeltiosis for the same character. Out of 54, 11 crosses showed significant heterobeltiosis for grains per panicle.

Pandey *et al.* (1995) determined the extent of heterosis for several characters including grain yield per plant. Most of the crosses manifested significant heterosis for grain yield, number of effective tillers per plant, panicle length, grains per panicle and days to maturity. Very few hybrids manifested significant heterosis for plant height. The heterosis for grain yield per plant ranged from -96.7 to 258.2 per cent over the better parent and -96.3 to 301.6 per cent over the standard variety.

Reddy and Nerkar (1995) studied heterosis over better parent in eight crosses of rice. Highly significant and positive heterosis for grain yield over better parent was expressed by four hybrids. Such a high grain yield heterosis was due to additive heterotic effect of one or more component traits. In all the cases, heterosis for number of effective tillers was observed to be major contributor to grain yield.

Yolanda and Das (1995) studied heterosis for amylose content of the grain in 36 F₁ hybrids obtained by crossing three CMS lines with 12 testers. Highest heterosis (28.6%) and heterobeltiosis (9.31%) values for amylose content were observed in V20A x ADT-39.

Ganesh and Rangaswamy (1996) estimated heterosis and heterobeltiosis by crossing five WA CMS lines with eight rice varieties in line x tester fashion. They reported that CMS IR-62829A was most promising followed by MS 37A.

Paramasivam *et al.* (1996) studied heterosis in F₁ hybrids for ten grain characters, viz., grain length, grain breadth, grain thickness, length/breadth ratio, grain length after cooking, grain breadth after cooking, linear elongation ratio, breadth wise elongation ratio, hulling percentage and milling percentage. IR 50 and White ponni possessed significant per se performance for these grain quality characters. The hybrid combinations ADT37 x White ponni, TKM9 x White ponni and ADT39 x ADT40 were recommended for use in commercial heterosis breeding.

Vivekanand and Giridharan (1996) evaluated heterosis in crosses involving Pusa Basmati-1 and five other rice varieties. Heterosis for grain yield was significantly high in all the five hybrids analysed. The grain yield and quality traits were found to be negatively correlated.

Vishwakarma *et al.* (1998) recorded the extent of heterosis for grain yield over better parent (BP) which ranged from -65.1 to 154.9 percent and over a standard variety (Jaya) from -76.7 to 121.1 per cent.

Yogesha and Mahadevappa (1998) observed that hybrids, IR 54752 A x IR 54 and IR 54752 A x IR 27318 recorded standard heterosis of 45.1% and 41.9%, respectively for grain yield per plant.

Cheema *et al.* (1999) observed that the degree of heterosis varied greatly for different characters and different cross combinations in a study on six F₁ hybrids resulting from crosses involving three commercial varieties (Basmati-370, Basmati Pakistan and Super Basmati) with three dwarf mutants.

Sathya *et al.* (1999) assessed the nature and extent of heterosis, heterobeltiosis and standard heterosis for yield and its component traits in a line x tester design. They found cross combinations IR 62829A x IR 50 and IR 62829A x AS 90043 showing significant heterosis for productive tillers per plant and grain yield per plant.

Singh and Haque (1999) reported high positive heterosis over better parent for grain yield per plant (99.6%) and panicle bearing tillers per plant (83.8%). The cultivars Birsa Dhan 202, Rajendra Dhan 202 and Rasi were promising and exhibited high heterosis estimates for most of the yield components studied.

Vishwakarma *et al.* (1999) reported that the cross combination IR 58025 A x NDRK 5042 showed high heterosis for grain yield per plant (108.8% over better parent and 73.33% over standard variety) followed by IR 580258 A x NDR 507 (100% over better parent and 60.50% over standard variety) and IR 58025 A x NDRK 5026 (89.76% over better parent and 65.70% over standard variety). The high heterosis for grain yield was accomplished with high heterosis for effective tillers per plant.

Bansal *et al.* (2000) estimated heterosis in 11 partial diallel crosses involving eight scented and three non-scented rice stocks. Heterosis was significantly high for grain yield and its component characters in most of the hybrids.

Satin *et al.* (2000) evaluated heterosis for six characters in 15 rice hybrids and found significant standard negative heterosis for days to 50% flowering and significant positive heterosis for plant height, number of panicles per plant, number of spikelets per panicle, 1000-grain weight and grain yield.

Singh (2000) reported 23-70 per cent heterosis over the standard variety for grain yield per plant. Besides exhibiting an exploitable level of heterosis for yield, some of the hybrids (V20 A x IR 24 and IR 62829 A x Saket 4) also showed heterosis for earliness and dwarfness. In hybrids, yield was primarily influenced by effective tillers per plant and fertile grains per panicle, whereas in parents it was mainly influenced by panicle length, maturity and effective tillers per plant.

Suresh *et al.* (2000) computed heterosis over better parent and standard check for 35 rice hybrids. All the hybrids showed negative heterosis over better parent for days to 50% flowering. However, 12 of these hybrids showed negative heterosis over standard check. Nine hybrids showed positive heterosis for productive tillers per plant and eight hybrids showed positive heterosis for panicle length.

Durai and Nadarajan (2001) studied the extent and nature of heterosis for yield and component traits in rice. With respect to productive tillers per plant, 13 hybrids showed significant positive heterobeltiosis and none of the hybrids recorded significant positive standard heterosis. Significant positive heterosis for filled grains per panicle was recorded by 15 hybrids over better parent and 12 hybrids over standard variety. Among these, four hybrids viz., PMS 9A x IR 50400-64-1-2-2, PMS 10 A x IR 31406, V 20 A x MDU 3 and IR 62829 A x MDU 3 recorded more than 20 per cent standard heterosis. In case of 100 grain weight, seven hybrids outperformed the better parent and among these six were found to be superior to standard check. However, only one hybrid IR 58025 A x BR 736-20-3-1 showed more than 20 per cent standard heterosis for 100 grain weight. With respect to grain yield per plant, 12 hybrids recorded significant positive heterobeltiosis and nine hybrids showed significant standard heterosis.

Bhav *et al.* (2002) evaluated 32 rice hybrids derived from two CMS lines (IR 58025 A and IR 62829 A) and 16 local restorers (RTN 73, KJT 1, KJT 4, RTN 711, RTN 24, RTN 1, PNL 1, PNL 2, KJT 3, PLG 1, RTN 2, KJT 2, RTN 3, KJT 147, and RTN 68) for heterosis, heterobeltiosis and standard heterosis for grain yield per plant, plant height, number of tillers per plant, days to 50% flowering, days to maturity, panicle length, number of grains per panicle, grain fertility and 100 grain weight. For grain yield per plant heterosis ranged from -65.91 to 162.39 per cent, while heterobeltiosis and standard heterosis ranged from 73.63 to 98.76 per cent and -84.96 to 132.32 per cent, respectively. Heterosis, heterobeltiosis and standard heterosis for productive tillers ranged from -26.10 to 124.32 per cent, -44.79 to 90.80 per cent and 58.50 to 80.43 per cent, respectively. For days to maturity these parameters ranged from -14.74 to 17.08 per cent, -7.50 to 23.95 per cent and -6.96 to 16.25 per cent, respectively; however, for number of grains per panicle these ranged from -46.72 to

68.90 per cent, -57.25 to 54.75 per cent and -67.04 to 19.16 per cent, respectively. Heterobeltiosis and standard heterosis for grain fertility ranged from 0.04 to 90.70 per cent and -45.97 to 5.96 per cent, respectively. Three most promising hybrids (IR 58025 A x RTN 68, IR 8025 A x PNL 1 and IR 62829 A x PNL 2) were identified for grain yield and other yield contributing characters.

Janardhanam *et al.* (2002) reported significant heterobeltiosis and standard heterosis for plant height, panicle length, number of spikelets and yield per plant. Hybrids, Seengani x ADT 36, Poongar x ADT 36, Nootripattu x MDU 5 and Nootripattu x ADT 36 showed 80 per cent heterobeltiosis for yield per plant.

Murayama and Sarker (2002) revealed that F₁ hybrids flowered earlier than their parental cultivars. The average heterosis for number of panicles per plant, number of spikelets per panicle and test weight was positive among yield components.

Singh *et al.* (2002) evaluated 36 rice hybrids produced from crossing between two wild abortive cytoplasmic male sterile lines (PMS 1 A and IR 58025 A) and 18 genotypes in a line x tester design. Approximately 38-50 per cent 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 ear bearing tillers per plant, test weight and number of fertile grains per panicle. The superior heterotic combinations exhibiting 60 per cent standard heterosis for yield over control (Sarjoo-52) were IR 58025 A x NDR 6054 and PMS 1 A x NDR 2022.

Agrawal (2003) evaluated seven rice cultivars (*viz.*, Sasyashree, Chambal, Haya, Vikas, Ratna, Kanak and IR 64) as well as their F₁s for grains per panicle, 100 grain weight and crop yield. Heterosis over better parent was highest for grains per panicle, 100 grain weight and grain yield in Vikas x Ratna and Sasyashree x Kanak.

Kumari *et al.* (2003) conducted an experiment with 42 rice hybrids involving *indica/ japonica* crosses. The results revealed that hybrids Palawan x ASD 18 and BPI 76 (G) x ASD 18 had the highest standard heterosis for number of grains per panicle and yield per plant, respectively.

Patil *et al.* (2003) investigated the magnitude of relative heterosis, heterobeltiosis and standard heterosis in F_1 hybrids among crosses between various genotypes. The crosses TGMS 15 x ADT 36, Pei'ai 64S 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 64S x C 20 recorded high heterosis for tillering ability, panicle length, grains per panicle and grain yield. Relative heterosis in the range of 52.03-72.08 per cent coupled with heterobeltiosis in the range of 56.03-59.59 per cent and standard heterosis in the range of 46.55-70.00 per cent was observed for grain yield per plant.

Satish and Ramaiah (2003) estimated heterosis for yield and yield components, and certain grain quality characters. For grain yield the extent of heterobeltiosis and heterosis ranged from -25.63 to 5.27 per cent and -4.56 to 17.89 per cent, respectively.

Krishnaveni *et al.* (2005) studied five parents and 25 crosses and reported very low heterosis values for quality traits when compared to yield and yield components. The average heterosis and heterobeltiosis ranged from -12.41 to 3.9 and -14.5 to 3.7 for kernel length, -8.42 to 12.69 and -9.0 to 5.6 for kernel breadth, -21.56 to 13.74 and -28.9 to 13.5 for kernel length/breadth ratio; -12.12 to 13.53 and -19.3 to 13.2 for kernel length after cooking, -23.62 to 15.2 and -15.3 to 12.9 for elongation ratio, -9.91 to 80.4 and -19.3 to 63.6 for alkali spreading value and -9.66 to 14.69 and -11.7 to 1.5 for amylose content respectively.

Raju *et al.* (2005) observed mid parent heterosis for most of the crosses and heterobeltiosis was low and negative with 12 crosses exhibiting in undesirable direction and only four crosses in useful direction. For kernel length and length/breadth ratio the percent heterosis and heterobeltiosis values ranged from -3.8 to 8.83 and -12.8 to 8.3 and -13.98 to 3.05 to -26.82 to 0.21 respectively.

Veni *et al.* (2005) studied heterosis over mid parent and better parent in 23 F_1 s, and recorded significant positive heterosis and heterobeltiosis for grain yield per plant in four crosses. The high heterosis for yield was due to additive genetic effect of

one or more component traits. In all the crosses, heterosis for number of tillers per plant was found to be major contributor to grain yield per plant.

Saravanan *et al.* (2006) studied heterosis in 28 different hybrids and found that crosses between high x high and high x low gca parents exhibited high heterosis. The parents CRAC 2221-67 and Jaya were promising parents which showed high heterosis for grain yield per plant and number of grains per panicle. None of the crosses was heterotic for all the traits simultaneously.

Singh *et al.* (2006) studied 36 hybrids for the extent of heterosis and heterobeltiosis in ten characters and IR 580 25A/ NDR 6054; PMS 1A/ NDR 3026; IR 58025A/NDR 3013 and IR58025A/ MDR 2022 were identified as the potential hybrids exhibiting greater than 60 per cent heterosis for grain yield.

Sarial *et al.* (2006) undertook a study to evaluate heterosis for yield and its component traits in F₁ hybrids derived from basmati type fertility restorers and WA type CMS lines. 45 germplasm lines of aromatic rice were test crossed with four CMS lines viz., IR 58025A, IR 62829A, PMS 2A and PMS 3A. 84 hybrids were derived, out of which IR 58025A x Basmati-385 and HKR-241 were found to be heterotic for all yield traits. The most promising were PMS 3A x P 1030-8-5-1, IR 58025A x Basmati-385, IR 62829A x Basmati-385, IR 62829A x HKR 241 and PMS 2A x HKR 241.

Senguttuvel *et al.* (2006) estimated heterosis in 40 rice hybrids, derived from four CMS lines (IR 50A, IR 36A, ASD 16A and ADT 36A) and ten testers. They reported that ASD 16A x CD 98804 and IR 50A x CD 98013 recorded maximum heterosis for days to 50% flowering; however, IR 50A x Tapet observed highest number of productive tillers, panicle length, 100 seed weight, filled grain per plant and single plant yield. Cross combination ASD 16A x CD 98002 recorded high values for all the parameters except 100 seed weight.

Bhanumathy *et al.* (2007) studied the magnitude of relative heterosis, heterobeltiosis and standard heterosis in 100 rice hybrids for grain yield and related traits. The hybrid IR 69616 A x IR 10198-66-2 R registered maximum significant

positive heterosis (205.29%) and heterobeltiosis (187.25%) for grain yield. Top yielding hybrids viz., IR 70364 A x TNAU 80030, IR 70364 A x IR 65515-47-2-1-19 and IR 58025 A x TNAU 94301 exhibited significant standard heterosis over CORH 2 and ADTRH 1, while IR 69616 A x TNAU 841434 and IR 58025 A x IR 6551547-2-1-19 manifested significant standard heterosis over ADTRH 1. Most of the high yielding hybrids manifested positive heterosis for long panicles, filled grains and spikelet fertility. Standard heterosis for productive tillers and 100 grain weight also resulted in increased grain yield in some cross combinations.

Sarvanan *et al.* (2007) developed 28 hybrids derived from seven CMS lines (IR 6331-1-B-3R-B-24-3, IR-71895-17-1-2-13, MTU 1067, KJT-3, AUR-4, CRAC 2221-67 and CR-WITA 12) and four testers (TRY-1, Co-43, Jaya and HUR DBS- 7). The line CRAC 2221-67 and tester Jaya were found to be promising parents which showed high heterosis for grain yield per plant and number of grains per panicle.

Venkatesan *et al.* (2008) observed the lower estimates of heterosis values for physical characters when compared to yield and yield components and positive average heterosis and heterobeltiosis for grain length/breadth ratio. Nine hybrids manifested positive and significant heterosis over midparent, better parent and standard check for grain yield per plant, of which AD 95157 / IR 50, MDU 5 / IR 50, AD 95157 / ADT 43, MDU 5 / ADT 36, AD 95157 / ADT 36 and AD 95137 / ADT 36 were top rankers. On considering both yield and physical traits together the crosses MDU 5 / IR 50, MDU 5 / ADT 36, AD 95157 / ADT 36, AD 95157 / ADT 43, AD 95157 / IR 50 and AD 95137 x ADT 36 could be isolated for possessing desirable average heterosis, midparental heterosis and standard heterosis for yield and grain traits.

20 rice hybrids developed through a line x tester crossing programme involving five high yielding lines and four superior grain quality testers were evaluated for yield and quality characters by Roy *et al.* (2009). They reported that higher magnitude of heterosis for all yield and quality traits were not expressed in a single hybrid combination which varied from cross to cross. The cross combinations IET 5656 / Kalonunia, IET 8002 / Dudheswar, IET 5656 / Dudheswar and IR 62 / Samba Mahsuri were identified for their superior yield and grain quality characters.

Shivani *et al.*, (2009) reported for head rice recovery, IR 68886A x IR 21567 registered significant positive relative heterosis and heterobeltiosis. For kernel length only one cross viz., IR 58025A x IR 21567 possessed positive significant mid parent heterosis. Most of the indica/indica hybrids exhibited significant negative heterosis for water uptake and volume expansion ratio. Significant negative relative heterosis was recorded for gel consistency in all the hybrids except for IR 62829A x IR 29723. The relative heterosis and heterobeltiosis for amylose content were found to be negative indicating that the indica/indica hybrids in the present study had their amylose content less than their mid parent and better parent values.

Rahimi *et al.* (2010) observed heterosis for 11 traits in 15 F₁ hybrids generated by half diallel crosses of six diverse rice cultivars (three Iranian local cultivars viz., Domsefid, Hashemi and Binam, and three improved cultivars viz., Dorfak, Kadous and IR30). Assessment of standard heterosis based on check variety Dorfak showed that there was significant heterosis for all the traits studied in the 15 hybrids. For grain yield, the Dorfak x Domsefid cross recorded highest heterosis. This hybrid has good heterotic values for many traits such as growth period, reproductive period and 1000 grain weight.

Vaithiyalingan and Nadarajan (2010) studied 42 inter and intra sub-specific hybrids utilising seven wide compatible varieties (WCVs) including two *indica* (Dular and ASD 16) and five tropical *japonica* cultivars (WCR 6, IR 65600-32-4-6-1, IR 65601-120-3-5, IR 66158-38-3-2-1 and IR 67323-46-2-1). For most of the characters, the mean heterosis per cent were in the order of *indica* / *japonica* F₁ > tropical *japonica* / *indica* F₁ > *indica* / *indica* F₁ > tropical *japonica* / *japonica* F₁. The combinations with significant standard heterosis over local variety MDU 5 for grain yield and yield components were Dular x IET 16114 (*indica* / *japonica*); IR 65601-120-3-5 x ADT 43, IR 67323-46-2-1 x ADT 43 (tropical *japonica* / *indica*) and IR 66158-38-3-2-1 x Odaebayeo (tropical *japonica* / *japonica*).

Amudha *et al.*, (2010) reported four hybrids viz., IR 68885A / IR 73718-3-1-3-3, IR 67684A / CT-6510-24-1- 2, IR 70369A / IR 73718-3-1-3-3 and IR 70372A/ PSBRC 80 exhibited heterotic vigour for yield and maximum number of yield components and showed better adaptability to aerobic conditions.

Krishna *et al.* (2011) conducted an experiment with 28 hybrids generated by crossing eight parents in diallel fashion. The mean heterosis and heterobeltiosis were estimated for yield and quality characters. High amount of heterosis existed for the yield components viz., panicle weight, 1000 grain weight, and productive tillers per plant; whereas, it was very low for the quality traits viz., kernel length and length/breadth ratio. The promising cross combinations identified were WGL 32100 x White ponni, JGL1881 x White ponni and JGL3844 x MTU 4870.

Soni and Sharma (2011) estimated heterosis and heterobeltiosis for grain yield and its component traits in 27 cross combinations to develop heterotic hybrids. Five hybrids viz., IR58028A x IRFAN-115, IR58025A x SR-6-SW-8, IR58025A x ET 1-13, APMS 6A x ET 1-12 and APMS 6A x NPTR-2 showed significant heterosis for grain yield. Seven hybrids showed significant negative heterosis for earliness; however, only three hybrids recorded significant negative heterosis for plant height.

Singh *et al.*, (2011) observed maximum relative heterosis and heterobeltiosis for grain yield per plant recorded for IR74371-54-1-1/ IR67017-124-2-4. The maximum standard heterosis for grain yield was exhibited by IR 81413-B-B-75-4/ IR 81429-B-31 (179.95 per cent). On the basis of sca effects seven crosses were identified for high grain yield per plant.

Varpe *et al.*, (2011) reported magnitude of heterosis varied from cross to cross for all the characters studied. The significant positive heterosis over better parent for grain yield per plant ranged from - 28.71% to 39.18%. The cross combinations IR 28 x IET 20152 (39.18 %), followed by IR 28 x GR 103 (38.32%) and IR 28 x NVSR 20 (31.37%) exhibited significant positive heterosis over better parent for grain yield per plant. These superior crosses also exhibited significant and positive heterosis for panicles per plant, panicle length, grains per panicle, 1000 grain weight, protein content, amylose content and L/B ratio.

Gulzar and Waseem (2012) observed heterosis based on standard checks (SR-1 and Jhelum) of effectively restored cross combinations showed that there was significant heterosis for all the traits except number of filled grains per panicle and the degree of heterosis varied from trait to trait. All combinations that showed superiority

over standard checks for grain yield per plant (ranged from 25.88% to 55.70%), also showed significant heterosis for majority of other traits. The best cross combination in terms of grain yield was SKAU7A x K-08-61-2 and for early maturity SKAU11A x SR-2 over check SR-1 only. Cross combinations SKAU 7A x K-08-61-2, SKAU 7A x SR-2, SKAU 11A x K-08- 60-2, SKAU 11A x K-08-59-3 and SKAU 11A x SKAU-389 were found to be good specific combinations for grain yield per plant and other desirable traits.

Patil *et al.*, (2012) observed sufficiently high magnitude of heterobeltiosis in desirable direction for grain yield per plant, grains per panicle, panicles per plant, panicle length, days to 50 % flowering, 1000 grain weight and L/B |ratio. As many as 16 crosses showed significant positive heterosis over their respective better parental value for grain yield per plant. Crosses Sathi 34-36 x Lal kada, Sathi 34-36 x GR-6, and GR-5 x GR-6 were found to be most heterotic for grain yield per plant.

Jarwar *et al.* (2012) estimated superior heterosis and presence of variability in various traits under two different environmental conditions. Lines (male parents) viz., Rataria, Sugdasi and LR2; and testers (female parents) viz., Pandan and Basmati 370 had highest values under both the environments. The hybrids Bengalo x Pandan, Sugdasi x Pandan and DR-65 x Vertin recorded highest average heterotic values under lowland and upland conditions. Significant negative heterosis was observed for days to 50% flowering, days to maturity and plant height which is desirable for developing early maturing and medium tall varieties.

Reddy *et al.* (2012) studied the heterosis in aromatic rice for yield and quality characters. Five crosses showed significant negative heterosis over mid parent and six crosses exhibited significant negative heterosis over better parent for days to 50% flowering. For productive tillers per plant, two crosses recorded significant positive heterosis and one showed significant negative heterosis over better parent. Six crosses showed significant positive heterosis for grain yield both over mid parent and better parent. Five crosses registered significant positive heterosis for kernel length over mid parent with highest value of 8.21 per cent (PUSA1121 x BM71). However, none of the crosses was superior over better parental values. For kernel breadth, RNR2354 x MTU1081 showed significant negative heterosis (-4.27%).

Sanghera and Hussain (2012) developed 36 cross combinations by crossing two cytoplasmic male sterile (CMS) lines with 18 testers in line x tester mating design. Analysis of variance revealed significant differences among genotypes, crosses, lines, testers and line x tester interactions for all the traits studied. Based on standard check varieties (SR-1 and Jhelum), assessment of heterosis for effectively restored cross combinations showed significant values for all the traits except number of filled grains per panicle. The degree of heterosis varied from trait to trait. The combinations that recorded superiority over standard checks for grain yield per plant also showed significant heterosis for majority of other traits. The average proportion of restorers, partial restorers, partial maintainers and maintainers were 16:22:33:27, respectively. The best cross combination for grain yield was SKAU7A x K-08-61-2 and for early maturity was SKAU11A x SR-2.

Hussain and Sanghera (2012) observed standard heterosis based on standard checks (SR-1 and Jhelum) of effectively restored cross combinations showed that there was significant heterosis for all the traits except number of filled grains per panicle and the degree of heterosis varied from trait to trait. All the cross combinations that showed superiority over standard checks for grain yield per plant also showed significant heterosis for majority of other traits. The best cross combination in terms of grain yield was SKAU7A x K-08-61-2 and for early maturity SKAU11A x SR-2 over check SR-1 only.

Singh *et al.*, (2013) reported heterobeltiosis for grain yield ranged from -41.07% to 38.20%, standard heterosis 1 (SH1) from -52.61 to 10.03% and standard heterosis (SH2) from 26.20 to 71.38%. The high heterotic effect among yield components was observed for number of effective tillers/ plant followed by number of grains per panicle and panicle length. Top two high yielding crosses were IR68897A x CR2496 and Pusa 6A x CR2496. These two crosses showed negative standard heterosis for days to maturity.

Mallikarjuna *et al.*, (2013) reported heterosis for different yield contributing characters which indicated that out of thirty hybrids studied, KCMS 45A x MSN 91, KCMS 45A x KMR 3, KCMS 46A x Thanu and KCMS 46A x MSN 36 were identified as promising with maximum heterosis for grain yield.

Veeresha *et al.*, (2013) reported the hybrid IR-68897A x KMR 3 showed standard heterosis and heterobeltiosis for panicles per plant, panicle weight, 1000 seed weight and grain yield. Relative heterosis for grain yield per plant ranged between -57.26 to 421.22 coupled with significant heterobeltiosis from -59.89 to 364.41. The standard heterosis ranged from -65.52 to 204.52 for grain yield per plant. Based on *per se* performance and standard heterosis, the hybrids IR-68897A x KMR3, IR-68897A x IR-60199-B-B-2-1R, IR-68888A x KMR 3 and IR-68897A x IR-65912-90-1-6-3-2-3R were identified as the superior hybrids for panicle length, grains per panicle and grain yield.

Latha *et al.* (2013) estimated the nature and magnitude of heterosis in 18 F₁ rice hybrids involving three CMS lines and six testers using line x tester analysis. The magnitude of relative heterosis, heterobeltiosis and standard heterosis was estimated for different characters. A high degree of relative heterosis was observed for grain yield (20.45-82.37%) in hybrids viz., CRMS 32A x Super rice-8, APMS 6A x Super rice-8, APMS 6A x Jitpiti and CRMS 32A x R 1099- 2569-1-1. While, a higher degree of heterobeltiosis (13.60- 68.37%) was observed for grain yield in the hybrids viz., CRMS 32A x Super rice-8, CRMS 32A x R 1099-2569-1-1, APMS 6A x Super rice-8 and APMS 6A x Jitpiti. A high degree of standard heterosis was observed for grain yield in the hybrid CRMS 32A x R 1099-2569-1-1. The hybrid CRMS 32A x R 1099-2569-1-1 recorded a high degree of relative heterosis (62.01%), heterobeltiosis (57.35%) and standard heterosis (15.05 and 25.51%) over hybrid checks Mahamaya and Indira sona.

Sharma *et al.*, (2013) reported the magnitude of heterobeltiosis for grain yield was significantly superior in 28 hybrids ranging from 10.85 to 66.35% and only in two hybrids (IR58025A×Sarju-52; IR58025A×BPT5204) over the standard hybrid (Arize-6444) with the magnitude of 11.87% and 20.60% respectively. These crosses also exhibited significant heterosis for days to maturity, number of spikelets per panicle and number of grains per panicle. Pusa6A×BPT5204, IR68897A×BPT 5204 and Pusa6A×Krishna Hansa expressed more than 40% heterobeltiosis for grain yield alongwith other desirable yield components.

Priyanka *et al.* (2014) crossed three cytoplasmic male sterile (CMS) lines of rice *i.e.*, IR58025A, IR68897A and Pusa 6A with seven pollen parents (Sarjoo-52, Jaya, Sasyashree, Swetha, HUR 5-2, PR-106 and BPT 5204) into line x tester design. In addition to yield traits, mean performance for grain quality characters were recorded in parents and all the 21 hybrids. Based on their yield performance and grain quality features, only two hybrid combinations, IR68897A x Jaya and IR68897A x BPT 5204 were identified to be superior as compared to their parents and the check variety.

Venkanna *et al.*, (2014) reported significant heterosis over mid and better parent in desired direction in many crosses for various traits under study. The crosses IR 64 X NLR 34449 and MTU 1010 X BPT 5204 exhibited highly significant heterosis and heterobeltiosis for yield. The crosses JGL 3844 X JGL 11690, Erramallelu X LGL 11690, BPT 5204 X JGL 11690 and MTU 1001 X JGL 1798 exhibited significant positive heterosis for yield along with one or more grain quality traits. In most of crosses significant inbreeding depression existed for grain yield while five crosses reported inbreeding depression towards negative side. The crosses with significant positive heterosis and heterobeltiosis were also reported to record high inbreeding depression.

Sreenivas *et al.*, (2014) reported that Warangal Samba was best combiner for grain yield among lines and among the testers Ramappa, Jagtial Samba and Kavya were judged as better parents for yield. Crosses *viz.*, Samba Mahsuri x Jagtial Samba, Akshayadhan x JGL-11727, Surekha x Ramappa, Samba Mahsuri x Ramappa, Warangal Samba x Jagtial Samba, Warangal Samba x Ramappa and Akshayadhan x Early Samba having high sca values and per se performance for grain yield per plant, also recorded a high degree of relative heterosis. The maximum expression of (79.21 per cent), heterobeltiosis (70.59 per cent), and standard heterosis (88.76 per cent) for observed in cross Samba Mahsuri x Jagtial Samba.

Sunil *et al.*, (2014) reported that among the 30 hybrids, six hybrids Sarjoo-52/Swarna Sub 1, Sarjoo 52/ NDR 98030135, IR-64/ Swarna Sub1, IR-64/ NDR 98030144, NDR-359/Swarna Sub 1, and NDR-359/NDR-9803011 showed significant heterosis for grain yield and nine hybrids showed significant negative heterosis.

Mistry *et al.*, (2015) reported that highest heterotic effects observed over better parent and mid parents were 29.02% and 23.62% for grain yield per plant for the crosses Krishna Kamod x IET-19389 and Krishna Kamod x GNR-2, respectively. Considerable magnitude of heterosis and heterobeltiosis was observed for grain yield per plant, panicle length, grains per panicle and amylose content. Crosses viz., Krishna Kamod x GNR-2, Krishna Kamod x IET-19389, Acharmati x GR-11, Krishna Kamod x IET-19419 and Acharmati x GR-11 were found to be most heterotic hybrids for grain yield per plant due to simultaneous increase in grains per panicle and panicles per plant.

2.4 Generation Mean Analysis

Huang and Li (1990) studied inheritance of amylose in 6 crosses and reciprocals in F_1 , F_2 and F_3 generations. The results indicated that a single major gene in association with modifier genes governed inheritance of amylose. Gene dosage effects existed in several crosses.

Roy and Panwar (1993) observed additive, dominance and all types of epistasis in the inheritance of kernel length and kernel breadth. Pooni *et al.* (1993) investigated the genetic control of amylose content of 10 rice crosses produced by pair wise crossing of rice varieties. Importance of additive and dominance effects in determining the genetic variability was observed. Epistasis was also observed to contribute significantly to the variability among the generation means of most crosses. Dominance was generally towards the higher score and its effects were enhanced by a complimentary dominance x dominance interaction in several sets of basic generations. Component 'D' was significant and components H_1 and H_2 were non-significant in all the crosses. Non allelic interactions for grain length, breadth and L/B ratio which was of additive x dominance in combination with dominance x dominance type was reported by Verma *et al.* (1994b).

In a study of grain characters Vivekanandan and Giridharan (1995b) crossed TKM 9, ADT 37, ADT 39, IR 50 and improved White Ponni varieties with Pusa Basmati-1 and their corresponding F_1 , F_2 , BC_1 and BC_2 generations were studied for kernel length, L/B ratio, kernel length after cooking and elongation index. Kernel

elongation and elongation index were governed by additive, dominance and epistatic interaction of additive x additive, dominance x dominance and duplicate type, whereas kernel length and L/B ratio were controlled by additive, dominance and all three epistatic interaction.

Kumar and Mani (1995) estimated six genetic parameters mean (m), additive [d], dominant [h], additive x additive [i], additive x dominant [j] and dominant x dominant [l] for different characters in seven inter-varietal crosses. Both additive (d) and dominance (h) effects played an important role in the inheritance of the traits under study. Among non allelic interactions additive x additive [i] component was found to be significantly positive in majority of the crosses, whereas additive x dominance [j] and dominance x dominance [l] type were found to be significant in few cases, mostly negative.

According to Dharendra Singh *et al.* (1996) the scaling tests indicated the presence of non allelic interaction for yield and all the yield contributing characters. The dominance (h) and additive x additive (i) gene effects were important for grain yield in cross HPU 741 / HPU 2216. In case of yield attributes additive x dominance (j) and dominance x dominance (l) were important.

The genetic parameters controlling the expression of tillers per plant, panicle length, 1000 grain weight and grain yield per plant were studied by Dharendra Singh and Katoch (1997) using means of six generations (P_1 , P_2 , F_1 , F_2 , BC_1 and BC_2) in two crosses of rice viz., HPU 741 / Ch 988 and HPU 824 / Ch 988. The estimates of genetic effects revealed that the grain yield per plant in both the crosses exhibited significant contribution of additive x additive and dominance x dominance type of interactions. Number of tillers per plant was mainly influenced by dominance, dominance x dominance and additive x additive type of interactions in cross HPU 824 / Ch 988, where as in cross HPU 741 / Ch 988 there was positive contribution of additive x dominance and dominance x dominance interactions.

Dikshit *et al.* (1998) reported inheritance of amylose content in hybrid rice in two crosses (low x high and intermediate x high). The inheritance of amylose content was found to be under the control of one major gene, suggesting use of bulk

population or back cross breeding for improvement of amylose content in parents.

Kumar and Mani (1998) studied six generations of seven crosses involving eight rice cultures for panicle length and 1000 grain weight. They reported that a simple three parameter model was adequate to account for variability in panicle length in most of the crosses. For 1000 grain weight there was sufficient variability in the parental material. The study showed additive, dominance gene effect as well as additive x additive interactions.

Roy (1998) investigated six generations viz., P_1 , P_2 , F_1 , F_2 , BC_1 and BC_2 generated from two crosses Maibi / IR 64 and Maibi / Culture I. The results revealed that the additive (d), dominance x dominance (l) and additive x additive (i) gene interactions were important for yield and yield attributing characters in both the crosses. Duplicate type of epistasis played an important role in the inheritance of days to heading.

Roy (1999) studied nature of gene action, using means of six generations viz., P_1 , P_2 , F_1 , F_2 , BC_1 and BC_2 of a cross Maibi / CRM 53 to determine the magnitude of gene action governing yield and yield components. The results revealed that both additive and non additive gene action were important in controlling all the characters studied. As far as interaction parameter is concerned the dominance x dominance component was a major component of epistasis for grain yield per plant, days to heading, plant height and panicle length than additive x additive and additive x dominance components.

Honarnejad and Tarang (2001) reported that the traits grain yield, plant height and panicle length were genetically controlled by additive and dominance gene effects, although non-allelic gene interactions were observed in some cases. The degree of dominance in most of the families indicated the predominance of dominant and over dominant gene effects for full or empty grains per panicle.

Hasib *et al.*, (2002) reported that additive and dominance effects had major role in most of the crosses for the expression of plant height, days to flowering, panicle number per plant, panicle length, spikelet fertility per cent, grain length, grain

length/breadth ratio, test weight and grain yield per plant. Among interactions, additive x additive and dominance x dominance effects were almost equally important, while additive x dominance was less important than the other genetic effects for the inheritance of traits. Duplicate type of epistasis was observed in most of the traits studied. In general, both additive and non additive gene action were important for the expression of almost all characters studied.

Faruq *et al.* (2004) made an attempt to know the inheritance pattern of cooked kernel elongation in Mahsuri Mutant crosses. They reported that kernel elongation ratio is controlled by 1 or 2 major genes and those were influenced with few modifier genes. However, it was noted that nature of kernel elongation of Mahsuri Mutant is totally different compared to Basmati type rices. Because only through aging this Mutant produced good kernel elongation ratio.

Swain and Nagaraju (2004) reported additive and non additive gene action for amylose content. Kumar *et al.* (2006) reported additive and non additive gene action for L/B ratio. Nayak (2007) while studying genetics of quality characters in 3 crosses (C1: Pusa Basmati -1 / Kasturi, C2: Kalimochi / Gourav and C3: Muskbudhi / Dubaraj) found that kernel length was controlled by both additive and dominance effects, kernel length/breadth ratio was controlled by additive, dominance and epistatic effects in all crosses except dominance x dominance effect in C2. For alkali spreading value, in C1 and C3 crosses and for water uptake in C1 and C2 additive, dominance and all three interactions were important. Cooked kernel length was controlled by additive ($\hat{d}$) and additive x additive ($\hat{i}$) in C1 and C2 and in C3, additive, dominance ($\hat{h}$) and additive and additive ($\hat{i}$) were significant. Additive, dominance and epistatic gene actions of additive x additive and dominance x dominance and duplicate type of interaction controlled elongation ratio. The volume expansion was influenced by additive gene effect in C1, dominance action in C2 and non additive gene action in C3. Amylose content was under the control of duplicate epistasis.

Banumathy and Thiyagarajan (2005) studied generation mean analysis in four crosses and reported the influence of additive gene action on grain yield per plant, in negative direction in all the four crosses. The influence of dominant gene action and non allelic interactions of additive x additive and dominance x dominance type were

found to be significant and positive in IR 58025A / TNAU 841434. The cross IR 58025A / TNAU 94241 showed complementary type of epistasis due to presence of dominant and interaction components.

Sanjeev Kumar *et al.* (2005) observed additive and non-additive gene effects with predominant additive gene action for plant height, days to 50 per cent flowering, panicle length and 100 grain weight and predominant dominant effect for grain yield.

Murugan and Ganesan (2006) studied six crosses and reported the traits, productive tillers per plant and panicle length were predominantly influenced by additive gene effects and interaction component of $[\hat{j}]$ and $[\hat{l}]$ along with duplicate epistasis, the traits filled grains per panicle and hundred grain weight were controlled by dominant gene action and among interactions, $[\hat{i}]$ and $[\hat{j}]$ effects were influenced these traits along with duplicate gene actions. Grain yield per plant was predominantly under the control of dominance and interaction components $[\hat{i}]$, $[\hat{j}]$ and $[\hat{l}]$ along with duplicate type of gene action.

Patil *et al.* (2006a) reported the mean, additive $[\hat{d}]$ and t^2 test was highly significant and positive in entire cross combination studied and dominance effects $[\hat{h}]$ were positively significant in all the crosses except Pei 64S / C-20 (-11.20) for days to 50 per cent flowering. Productive tillers per plant showed negative significant additive $[\hat{d}]$ genes effect and significant and positive dominance $[\hat{h}]$ gene effect in all crosses except IR-68948-12-3-7 / C-20. The additive $[\hat{d}]$ and dominance $[\hat{h}]$ gene effect was significant and positive in TGMS-18/C-20, IR-68945-4-33-14 / C-20, IR-68949-11-5-31 /C-20 and TGMS-18 / ADT-36 for grains per panicle. In 1000 grain weight, the additive $[\hat{d}]$ and dominance $[\hat{h}]$ effects coupled with significant values of mean and χ^2 test showed significant differences in all the crosses with duplicate gene action. Positive and significant additive $[\hat{d}]$ gene effect was also recorded in grain yield per plant.

Patil *et al.* (2006b) studied generation mean analysis in six generations of six crosses. All the hybrids showed significant differences in epistatic properties of the genes and involvement of digenic model and good fit for complementary and duplicate gene action. The traits productive tillers per plant and 1000 grain weight

showed good fitness for complementary gene action as where the traits grains per panicle and grain yield per plant showed involvement of duplicate gene action. In case of productive tillers, both $[\hat{h}]$ and $[\hat{l}]$ have negative sign and are of lower magnitude, it reflects mainly complementary interaction between dominant decreasing genes. Whereas, 1000 grain weight showed $[\hat{h}]$ and $[\hat{l}]$ components are positive and higher magnitude, it will indicate mainly complementary interaction between increasing genes.

Sinha *et al.* (2006) reported that additive components were important for days to 50 per cent flowering plant height, panicle length and grains per panicle. Non additive component was predominant for grain yield per plant and 1000-grain weight according to Hayman's approach and additive component was predominant for 1000-grain weight besides complementary type of interaction according to Griffing approach when they compared both.

Verma *et al.* (2006) studied six generations of the crosses Jhona 9349 / IET 12944 and Narendra 80 / Lalmati based on six parameter model. Results revealed the predominant role of dominance and epistasis for grain yield, tillers per plant, grains per panicle and 1000 grain weight in both the crosses. Additive and dominance effects were important for plant height and panicle length. Among the digenic interactions, additive x additive and dominance x dominance effects contributed more in majority of the characters. Additive x dominance gene effect was also significant for all the traits in both the crosses. In general, duplicate non-allelic interaction was observed for most of the yield contributing characters.

Six generations viz., P_1 , P_2 , F_1 , F_2 , BC_1 and BC_2 generations of four crosses involving scented and non-scented rice varieties were studied by Nayak *et al.* (2007). A simple three parameter model was adequate for the variability in respect of days to 50 percent flowering, panicle length per plant and grain length. Among the digenic interaction models both five and six parameter models were fitted for almost all the characters. The dominant effects were more important than the additive effects in most of the crosses. The duplicate type of epistasis was present with the exception of panicle length in cross Muskbudhi / Ratna in which the complementary type of

epistasis was evident.

Sing *et al.* (2007) studied the seven generations (P_1 , P_2 , F_1 , F_2 , F_3 , B_1 , B_2) of the three crosses viz., SBIR 66366-7-M-1-1-1-1 / Rajshree, SBIR 66876-11-M-1-1-1-1 / Rajshree and SBIR 67471-8-M-1-1-1-1 / Rajshree employing simple and joint scaling test and six parameter model of generation mean analysis. Simple and joint scaling tests indicated presence of epistatic interaction and fitness of digenic interaction model. Six parameter model of generation mean analysis revealed importance of additive [$\hat{d}$] and dominance [$\hat{h}$] gene effects as well as one or more epistatic gene interaction [$\hat{l}$].

Thirugnana Kumar *et al.* (2007) studied five generations (P_1 , P_2 , F_1 , F_2 and F_3) of six rice crosses for estimating the nature and magnitude of gene effects for grain yield and its component characters. The scaling tests indicated that the scales 'C' and 'D' were significant for all the six characters in all the crosses studied. The results indicated the importance of duplicate dominant epistasis for number of productive tillers, number of filled grains and 1000 weight. For grain yield complementary recessive epistasis was found to be important.

Lakshmi (2009) studied six generations of two crosses viz., Samba Mahsuri / Polasa Prabha and Samba Mahsuri / Nellore Mahsuri and estimated six genetic components. The results revealed that epistatic interactions played major role in the inheritance of days to 50 per cent flowering, plant height, number of tillers, panicle length and 1000 grain weight. For hulling percent and gelatinization temperature both additive ([$\hat{d}$] and [$\hat{i}$]) and dominant type ([$\hat{h}$] and [$\hat{l}$]) components were significant.

Mahalingam and Nadarajan (2010) reported that additive x dominance ($\hat{j}$) type of epistasis effect was recorded for grain yield, hulling percentage, panicle length, milling percentage and duplicate dominant epistasis was observed for productive tillers, 100 seed weight, grain yield, hulling percentage, milling percentage and head rice recovery.

Kiani *et al.*, (2013) reported that the additive $\times$ dominance model was significant for traits in all crosses. The join scaling test indicated that the inheritance of traits related to yield was described by additive $\times$ dominance components, non-

allelic interactions mainly additive $\times$ additive and additive $\times$ dominance and duplicate epistasis. More than one major gene group appeared to be involved for the expression of 1000-grain weight and plant height while the remaining traits showed the presence of at least one major group of genes controlling their inheritance.

Gnanamalar and Vivekanandan (2013) reported that milling percentage and linear elongation ratio were governed by additive, dominance and epistatic interactions of additive $\times$ additive, dominance $\times$ dominance and duplicate epistasis. Hulling percentage was governed by additive, dominance and duplicate type. Head rice recovery was under the control of additive, dominance, dominance $\times$ dominance and duplicate epistasis. Kernel length and kernel breadth were predominantly under the control of additive, dominance, additive $\times$ dominance and duplicate gene interactions. Kernel L/B ratio and kernel length after cooking were influenced by additive, additive $\times$ dominance and duplicate type. Dominance, additive $\times$ additive and duplicate type of gene actions influenced alkali spreading value. Water uptake, volume expansion ratio, amylose content and gel consistency were under the control of non additive gene action.

Saumya and Lal (2014) observed that additive $\times$ additive ($\hat{i}$) type of epistasis was significant for traits spikelet per panicle, test weight and yield per plant as where dominance $\times$ dominance was found to be significant for per cent filled grains. Simple scaling test indicated that the inheritance of traits related to yield was described by non-allelic interactions mainly additive $\times$ additive, dominance $\times$ dominance and duplicate epistasis.

Gopikannan and Ganesh (2014) reported that complex epistatic interactions have major role in controlling sodicity tolerance traits. Duplicate dominant type of epistasis was found to be governing the inheritance of all traits under investigation. The involvement of dominance $\times$ dominance interactions for some traits indicated that it might be useful to postpone selections at later generations.

Divya *et al.*, (2014) reported that epistatic interaction model was found adequate to explain the gene action in most of the traits. The interaction was complementary for number of productive tillers, economic yield, lesion number,

infected leaf area and potential disease incidence but duplicate epistasis was observed for the remaining traits.

Kacharabhai (2015) reported that nature of gene interaction in the inheritance of 12 yield and its components traits was studied deploying generation mean analysis following 5 parameter model for parents, F_1 , F_2 , and F_3 generations of four crosses of rice. The results indicated that gene action differs over crosses. In general, most of the traits are governed by non-additive gene action.

Chinyere and Ignatius (2015) reported that digenic epistatic model was adequate to explain variation in generation means for all the panicle traits for the pooled analysis. Most of the crosses manifested non-allelic interactions for number of spikelet per panicles and fertile spikelet per panicle and is an indication that epistasis is determined to some extent by the genotypes used for the study.

Jhansi rani *et al.*, (2015) studied two rice crosses MTU 1075/ MTU 3626 and MTU 1121/ TN 1 was performed to determine the nature of gene action governing 11 quality traits viz., kernel length, kernel breadth, L/B ratio, hulling percentage, milling percentage, head rice recovery, kernel elongation ratio, volume expansion ratio, alkali spreading value, gel consistency and amylose content. All the traits studied showed non allelic gene interaction indicating presence of epistatic gene action. Nature of gene action varied with the character and both additive and non-additive gene action was involved in expression of the characters having the duplicate type of epistasis. The traits were predominantly governed by dominance and dominance x dominance interaction effects.

2.5 Frequency distribution

Frequency distribution of F_2 would yield information about the trait controlled by single gene, oligogenic or polygenic based on the shape of the curve and it also gives information about selective elimination zygotes with recombinant genotypes.

Khush *et al.*, (1986) reported when parents differed widely in amylose content, the F_2 single grains were clearly classifiable into two, three, or four categories. However, segregation for amylose content did not hurt cooking and eating quality of hybrid grains.

Cho *et al.*, (1994) studied the linkage relationship between the semidwarf gene (sd-1) and the isozyme locus EstI-2 was elucidated using segregating populations derived from crosses between several semidwarf testers and tall rice varieties. Bimodal distributions for culm length were observed in F₂ populations of three cross combinations, including Shiokari/Shiokari (sd-1), Taichung 65 (A,Pn,Pau)/Taichung 65 (sd-1), and Milyang 23/Kasalath. Taking the valley of the distribution curves as the dividing point, two height classes were apparent with a segregation ratio of 3 tall:1 short, demonstrating this character to be under the control of a single recessive gene.

Faruq *et al.*, (2004) reported the inheritance pattern of cooked kernel elongation in Mahsuri Mutant crosses. In all the three Mahsuri Mutant crosses, the frequency distribution of kernel elongation ratio of segregating populations always formed a bimodal curve. However, in crosses of Mahsuri Mutant and Mahsuri (even in the reciprocal cross) the bimodal curve progressed towards lower kernel elongation. So it can be assumed that this character may be governed from 1 or 2 loci. But in cross of Mahsuri Mutant and 9192 a very smaller peak compared to the other was noted, which denotes the predominance of one major gene along with few modifier genes.

Veni and Rani (2008) reported gene action governing the inheritance of kernel length, kernel breadth and length/breadth ratio were studied in three cross combinations viz., IET 13554/Ranga Joh 2, Pusa Basmati 1 / Ranga Joha 2 and IR 64 / Badshabhog. In all the three crosses, kernel breadth was under polygenic control along with few modifier genes. In the former two crosses, which had Ranga Joha 2 as common short bold grain parent, grain length and length ratio also followed the same pattern as that of kernel breadth. Whereas in the IR 64 / Badshabhog cross the inheritance of grain length and shape was under monogenic control with long and slender grain types being dominant. In all the three crosses studied, transgressive segregation was observed particularly towards longer and slender grain size and confirming the role of minor genes in the inheritance of these characters.





MATERIALS AND METHODS

MATERIALS AND METHODS

The present study entitled “**Genetics of Yield and Quality Characters in Aromatic Rice (*O. sativa* L.)**” was carried out over three seasons viz., *kharif*-2013, *kharif*-2014 and *kharif*-2015 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (UP). The grain quality traits were evaluated at Rice Quality Laboratory, whereas the molecular analysis was accomplished at the Molecular Biology Laboratory of the Department of Genetics and Plant Breeding, Institute of Agricultural Sciences. The site of study is situated at 25° 18' N latitude and 83° 03' E longitude at an elevation of 80.71 m above mean sea level. The soil is characterized by a typical soil of Indo-Gangetic alluvial loam. This centre receives an annual rainfall of approximately 1100 mm, a major portion of which is received during the months of July to September.

3.1 Experimental material

The experimental material consisted of six parental genotypes which were selected from 100 genotypes of rice on the basis of yield and quality parameters. Pusa 1121, Pusa Sugandh-2, Type-3 were used as female parents and Kasturi, BPT-5204 and Adamchinni used as male parents in the hybridization programme. Pusa basmati-1 (yield check), Taraori basmai (quality check) and Pusa RH-10 (hybrid check for both yield and quality) were used as checks for comparison of yield and quality attributes of the F₁ hybrids obtained. All the genotypes were obtained from the ‘All India Coordinated Rice Improvement Project (AICRIP), Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. The details of experimental material are given in Table 3.1.

Table 3.1: Experimental material used in present study

FEMALES		
Cultivars	Duration in days	Desirable feature
Pusa 1121	140-145	Extra long uncooked grain with high aroma. Longest cooked kernel length. Grain shape is very long slender Average seed yield is 40 q/ha.
Pusa Sugandh-2	126-130	It has extra-long slender grains with strong aroma; almost twice elongation on cooking, soft texture, good mouth feel and appealing taste. Grain shape is very long slender Average seed yield is 55.0 q/ha
Type-3	145-150	Long grain, good kernel elongation after cooking. Average seed yield is 35 q/ha.
MALES		
Cultivars	Duration in days	Desirable feature
Kasturi	119-123	It is semi dwarf basmati variety It has long, slender, scented grains with awns and moderate field resistance to blast Grain shape is long slender. Average seed yield is 30q/ha.
BPT-5204	141-145	Medium slender white rice, non aromatic, non lodging, high yield with excellent consumer preference panel score Grain shape is medium slender. Average seed yield is 6.5 t/ha.
Adamchinni	153-157	Short grain aromatic white rice with excellent cooking quality. Grain shape is short medium. Average seed yield is 25-30 q/ha.

3.2 Experimental methodology

Selection, hybridization and evaluation of selected genotypes

First year: - (kharif- 2013)

- The selected parental genotypes were seeded in nursery at 3 dates, 15 days apart and transplanted at a spacing of 20 x 15 cm in 5m rows and one meter gap was given after every two rows to facilitate crossing in crossing blocks in the field at 21-25 DAS.
- Three females (testers) were crossed with three males (lines) to produce nine F₁'s (excluding reciprocals) in line x tester fashion.
- Standard agronomic package of practices were followed to raise a good crop.
- F₁ seeds from each of the cross were harvested at maturity sun dried and stored separately for growing in *Kharif* 2014.

Second year :- (kharif 2014)

- The parental genotypes were seeded in nursery at 3 dates, 15 days apart and transplanted at a spacing of 20 x 15 cm in 5m rows and one meter gap was given after every two rows to facilitate crossing in crossing blocks in the field at 21 DAS.
- Fresh F₁'s were prepared for the nine cross combinations.
- The F₁'s were sown along with parents on the second date and transplanted in experimental land.
- The F₁'s were backcrossed with both the parents to produce B₁ and B₂.
- Remaining F₁'s were selfed to produce F₂ seeds.
- Seeds from P₁, P₂, F₁, B₁ and B₂ were harvested separately, crosswise.

Third year :- (kharif-2015)

- All six generations (parents (P₁, P₂), F₁'s, F₂'s and back crosses (B₁, B₂)) of nine crosses along with three checks were sown in three replications in a compact family random block design with three replications.
- Data on yield and yield traits were recorded.

- Seeds from six generations of each of the nine crosses were harvested separately and analyzed for the quality characters in the laboratory.

3.3 Observations recorded:

Ten competitive plants from each of the parents and F_1 s', 20 plants from backcrosses (B_1 and B_2) and 50 plants from each F_2 population from each replication were randomly selected and tagged for recording data on the following traits.

Yield traits

3.3.1. Days to 50 % Flowering:-

The number of days taken from sowing to heading in main panicle of 50 % plants of a plot was recorded.

3.3.2. Days to maturity:-

The number of days taken from sowing to physiological maturity of all the plants of a plot was recorded.

3.3.3. Plant height (cm):-

The height of individual plant was measured in centimeters from the ground level to the tip of terminal spikelet (excluding the awn) of the main shoot.

3.3.4. Effective tillers per plant:-

The number of tillers that have panicles with filled grains per plant was recorded.

3.3.5. Number of grains per panicle:-

The number of grains per panicle was recorded from main tiller after the harvesting of plant.

3.3.6. Hundred grain weight (g):-

One thousand filled grains were taken randomly after sun drying at 12% moisture level and was weighted in gram.

3.3.7. Grain yield per plant (g):-

The weight of filled grains of each plant in grams was recorded.

Quality characters

The grain quality traits were also recorded on randomly selected plants from each replication and the arithmetic means of observations from each replication were used for the statistical analysis. Observations were recorded on the traits given below.

3.3.8 Hulling recovery

The grains were dried to a moisture level ranging between 12-14 per cent before hulling. A sample of 100g was taken for hulling in a rice huller (Indosaw) and the weight of brown rice recorded. Hulling recovery on dry weight basis was calculated as:

$$\text{Hulling recovery} = \frac{\text{Weight of hulled kernel}}{\text{Weight of paddy}} \times 100$$

3.3.9 Milling recovery

The de-hulled kernels recovered after hulling were milled in a rice polisher (Indosaw) for one minute. The milled rice obtained was weighed in grams and milling value was calculated as the ratio of milled rice to initial weight of the paddy sample (100 g) expressed in percentage. Milling recovery on dry weight basis was calculated as:

$$\text{Milling recovery} = \frac{\text{Weight of polished kernel}}{\text{Weight of paddy}} \times 100$$

3.3.10 Head rice recovery

The milled rice obtained after polishing was separated into broken and unbroken (intact) kernels. The head rice recovery was calculated as the ratio of unbroken to the initial weight of paddy sample (100 g) expressed in percentage as:

$$\text{Head rice recovery} = \frac{\text{Weight of whole polished kernel}}{\text{Weight of paddy}} \times 100$$

3.3.11. Grain length (mm):

Length of 10 grains from its base to tip was recorded.

3.3.12. Grain breadth (mm):

Grain breadth was measured at the widest point of the 10 grains.

3.3.13. Brown rice length (mm):

Length of 10 dehulled (before milling) grains from its base to tip was recorded.

3.3.14. Brown rice breadth (mm):

Dehulled grain breadth (before milling) was measured at the widest point of the 10 grains.

3.3.15. Kernel length (mm):

Average length of 10 randomly selected, polished kernels from its base to tip was measured using an electronic grain analyzer.

3.3.16. Kernel breadth (mm):

Average breadth of 10 randomly selected, polished kernels was measured at the widest point using an electronic grain analyzer.

3.3.17. L/B ratio:

Average length and breadth of 10 kernels were recorded in millimeters, and length/breadth ratio was calculated by dividing the average length with the average breadth as:

$$\text{L/B ratio before cooking} = \frac{\text{Length of milled grain}}{\text{Breadth of milled grain}}$$

3.3.18. Kernel length after cooking (mm):

Ten randomly selected kernels from each sample were placed in labeled test tubes and pre-soaked in 10 ml of water for 30 minutes. The test tubes were then placed in a water bath maintained at 100 °C for 8 minutes. After cooking, tubes were taken out and cooled under running water for 2 minutes. Excess water was removed with blotting paper. Average length of cooked kernels was measured with the help of electronic grain analyzer.

3.3.19. Kernel breadth after cooking (mm):

Ten randomly selected kernels were pre-soaked, cooked and cooled as in case of kernel length after cooking. Average breadth of cooked kernels was measured with the help of electronic grain analyzer.

3.3.20. Elongation ratio:

Kernel elongation ratio was calculated by dividing average kernel length (mm) of 10 grains after cooking with average kernel length (mm) of these grains before cooking as:

$$\text{Elongation ratio} = \frac{\text{Length of cooked kernel}}{\text{Length of raw kernel}}$$

3.3.21. Elongation Index:

Elongation index was calculated by dividing L/B ratio of cooked kernel with L/B ratio of raw kernel as:

$$\text{Elongation index} = \frac{\text{L/B ratio of cooked kernel}}{\text{L/B ratio of raw kernel}}$$

3.3.22. Alkali digestion value:

The spread of the 6 milled rice kernels in 1.7 percent KOH solution for a period of 23 hours was rated as per Standard Evaluation System for Rice (IRRI, 1996). Six milled kernels was placed in 10 ml of 1.7 percent KOH solution in Petri dish and arranged in a manner so that they do not touch each other and was allowed to stand for 23 hours at 30 °C to score spreading on 1-7 scale. Scoring was done as given in Table 3.2.

Table 3.2. SCALE FOR ALKALI DIGESTION VALUE

Scale	Features	Alkali Digestion	GT	GT (° C)
1	Not effected but chalky	Low	High	75 – 79
2	Swollen	Low	High	75 – 79
3	Swollen with collar incomplete and narrow	Low or Intermediate	High or Intermediate	70 – 74
4	Swollen with collar incomplete and wide	Intermediate	Intermediate	70 – 74
5	Split or segmented with collar complete and wide	Intermediate	Intermediate	70 – 74
6	Dispersed, merging with collar	High	Low	55 – 69
7	Completely dispersed and clear	High	Low	55 – 69

(Source: standard evaluation system *IRRI 1996*)

3.3.23. Amylose content:

The cooking and eating quality of rice depends on the ratio of two kinds of starches, amylose and amylopectin in the rice grain (Rao *et al.*, 1952). Amylose is linear, whereas amylopectin is branched starch. The formation of a helical complex between amylose and iodine gives rise to the typical deep blue color of starch dispersions stained with iodine and forms the basis for quantitative determination of amylose content. In I₂-KI solutions, polyiodide ions such as I³⁻ and/or I⁵⁻ interact with

amylose forming single left-handed V-type helices. The formation of these complexes is determined by spectrophotometry (Juliano, 1971).

The simplified calorimetric method described by Juliano (1971) was followed for the estimation of amylose content. Fifty grains of milled rice were ground into a powder and 100 mg of rice powder was put into a 100 ml volumetric flask. One ml of 95 per cent ethanol and 9 ml of 1N sodium hydroxide were added to it. The contents were heated on a water bath at 100 °C to gelatinize the starch. After cooling for one hour, distilled water was added and volume made up to 100 ml. The contents were shaken well and five ml of starch solution was put in a 100 ml volumetric flask. One ml of 1N acetic acid and 2 ml of iodine solution (0.2 g iodine and 2 g of potassium iodide in 100 ml distilled water) were added and the volume was made up to 100 ml with distilled water. Contents were shaken well and let undisturbed for 20 minutes in darkness as I-KI disintegrates on exposure to light. The solution was finally examined under a spectrophotometer at a wavelength of 620 nm for absorbance against a blank iodine solution.

For the standard curve, 40 mg of potato amylose were wet with 1 ml ethanol and 9 ml 1N sodium hydroxide. The contents were heated for 5-10 minutes in a boiling water bath, cooled and made up to 100 ml volume with distilled water. 0, 1, 2, 3, 4, 5 ml of the solution were placed with a pipette in separate 100 ml volumetric flasks. The solution was acidified with 1N acetic acid (0.2, 0.4, 0.6, 0.8 and 1.0 ml, respectively) and treated as above. These standards including blank, respectively correspond to 0%, 4%, 8%, 12%, 16% and 20% of amylose. The absorbance values of standard samples were plotted at 620 nm, against the concentration of amylose. Amylose content of the sample to be examined was determined with reference to the standard curve and expressed on percent basis.

Table 3.3: Classification of rice genotypes on the basis of amylose content

Group	Amylose content (%)
Waxy	0-2
Very low	3-9
Low	10-19
Intermediate	20-25
High	25-30
Very high	>30

3.3.24. Gel consistency test:

Varietal differences in gel consistency exist among varieties of similar amylose content (>25%). The gel consistency test is based on the consistency of the rice paste and differentiates among varieties with high amylose content.

Table 3.4. Classification of high-amylose rice genotypes into three categories:

Categories	Length of gel (mm)
Very flaky rices with hard gel consistency	40 or less.
Flaky rices with medium gel consistency	41-60.
Soft rices with soft gel consistency	More than 61.

(Source: standard evaluation system *IRRI 1996*)

Make certain that all the samples are stored in the same room for at least 2 days so that the moisture content is similar. Place 10 whole milled rice grains in the Wig-L-Bug amalgamator and grind for 40 seconds to give a fine flour (100 mesh).

One hundred mg (± 1 mg at 12% moisture) of powder is weighed in duplicate into the culture tubes (13 $\times$ 100 mm). Hard (Pusa 1121), medium (BPT-5204) and soft (Adamchini) gel rice varieties are included as checks. 0.2 ml of 95% ethyl alcohol containing 0.025% thymol blue (alcohol prevents clumping of the powder during alkali gelatinization, while thymol blue imparts color to the alkali paste to make the gel front easier to read) are added. 2.0 ml of 0.2N KOH is added. Contents are mixed using a Vortex Genie mixer with speed set at 6. The test tubes are covered with glass marbles (to prevent steam loss, and to reflux the samples). The samples are cooked in a vigorously boiling water bath for 8 minutes, making sure that the tube contents reach 2/3 the height of the tube. The test tubes are removed from the water bath and let stand at room temperature for 5 minutes. The tubes are cooled in an ice-water bath for 20 minutes and laid horizontally on a laboratory table lined with millimeter graphing paper. The total length of the gel is measured in mm from the bottom of the tube to the gel front.

3.3.25. Aroma:

For testing aroma, one gram of milled rice kernels per genotype per replication were soaked in 10 ml of 1.7% KOH solution in covered petridishes and kept for 10 minutes at 25-30°C. The aroma was scored by the panel of five experts who have rich experience in Basmati rice quality evaluation. Taraori Basmati was used as control. The samples were scored on a 1–4 scale with 1= non-aromatic; 2= slightly aromatic; 3= moderately aromatic; and 4= strongly aromatic. The modal value was taken as final score (Sood and Siddiq, 1978).

3.4 Molecular diversity

A total of 19 simple sequence repeat (SSR) markers, selected from Rice SSR linkage map (McCouch *et al.*, 2002) were used for genetic diversity analysis among 24 rice genotypes. The details of SSR primers used are listed in Table 3.5.

Table 3.5: List of SSR primers used for detecting parental polymorphism.

S.No.	Primer		Sequence 5'----- 3'
1.	RM217	Forward	ATCGCAGCAATGCCTCGT
		Reverse	GGGTGTGAACAAAGACAC
2.	RM276	Forward	CTCAACGTTGACACCTCGTG
		Reverse	TCCTCCATCGAGCAGTATCA
3.	RM218	Forward	TGGTCAAACCAAGGTCCTTC
		Reverse	GACATACATTCTACCCCCGG
4.	RM3	Forward	ACACTGTAGCGGCCACTG
		Reverse	CCTCCACTGCTCCACATCTT
5.	RM 162	Forward	GCCAGCAAAACCAGGGATCCGG
		Reverse	CAAGGTCTTGTGCGGCTTGCGG
6.	RM 251	Forward	GAATGGCAATGGCGCTAG
		Reverse	ATGCGGTTCAAGATTTCGATC
7.	RM 7049	Forward	AACCTAGATCTAATCCGTGG
		Reverse	CATCTCTGAGTTGAGCAAAC
8.	RM 8226	Forward	TTAGGATACGGCTTCTAGGC
		Reverse	CGTAATTGTTGCATATGGTG
9.	RM 204	Forward	GTGACTGACTTGGTCATAGGG
		Reverse	GCTAGCCATGCTCTCGTACC
10.	RM 505	Forward	AGAGTTATGAGCCGGGTGTG
		Reverse	GATTTGGCGATCTTAGCAGC
11.	RM 3395	Forward	ACCTCATGTCCAGGTGGAAG
		Reverse	AGATTAGTGCCATGGCAAGG
12.	RM 5481	Forward	TGTTATGTGAGCCATAATGA
		Reverse	CTTTCTTAATGAAGCTCCAA

13.	RM 7356	Forward	CCAAGGACACATATGCATGC
		Reverse	GCAATTCATGGCGCTGTTC
14.	RM 7556	Forward	ACGCTAATACGGCGCAGTAG
		Reverse	AGGACTGACAGTGAGAGAGTCG
15.	RM 8264	Forward	ACGCTCCTCGCTTTCTAC
		Reverse	GCACCTCACACCAGTAATTC
16	RM 527	Forward	GGCTCGATCTAGAAAATCCG
		Reverse	TTGCACAGGTTGCGATAGAG
17	RM 447	Forward	CCCTTGTGCTGTCTCCTCTC
		Reverse	ACGGGCTTCTTCTCCTTCTC
18	RM 449	Forward	TTGGGAGGTGTTGATAAGGC
		Reverse	ACCACCAGCGTCTCTCTCTC
19	RM 23097	Forward	GCCAACATCGAAACATTCAAGC
		Reverse	CAGATATCGGTACAAGTCCATGATCG

Table 3.6: List of genotypes used for diversity analysis.

1.	Type-3	13.	Basmati-370
2.	Ranbir Basmati	14.	HUBR-10-9
3.	DDN-3-1	15.	Pusa Sugandh-3
4.	DDN-1-4	16.	TBD-2
5.	DDN(awnless)	17.	Pusa Sugandh-2
6.	DDN-1-8	18.	HUBR-16
7.	Kalanamak	19.	HUBR-9-1-2-1
8.	Dhanprasad	20.	HUBR-1-2-25-5
9.	Adamchinni	21.	Tarori Basmati
10.	BPT-5204	22.	Pusa Basmati-1
11.	Kasturi	23.	Pusa 1121
12.	Sanwal Basmati	24.	Pusa 1509

3.4.1 Isolation of DNA

Young leaves were collected from 12 days old rice seedlings and immediately stored at -20°C till further processing. The DNA was extracted following CTAB extraction method according to Doyle and Doyle, (1987) with few modifications in composition of DNA extraction buffer as given in Table 3.7.

Table 3.7: Extraction buffer used for genomic DNA isolation

Chemical	Stock concentration	Final concentration	Volume in 100 ml
Tris (pH 7.5)	1 M	100 mM	10
Na Cl	5 M	1.4 M	28
EDTA (pH 8.0)	0.5 M	20 mM	4
CTAB	10 %	2%	20
β -Mercaptoethanol	0.02M	0.08mM	0.4
Distilled H_2O	-	-	37.6

3.4.2 DNA quality estimation

The DNA quality estimation was done using Biophotometer plus. The ratio ($\text{OD}_{260}/\text{OD}_{280}$ ratio) thus obtained was used to estimate the nucleic acid purity in the different DNA samples. A ratio of 1.8-2.0 denotes that the absorption in the UV range is due to nucleic acids. A ratio lower than 1.8 indicates the presence of proteins and/or other UV absorbers. A ratio higher than 2.0 indicates that the samples may be contaminated with chloroform or phenol. In either case (<1.8 or >2.0) samples were re-precipitated to purify the DNA.

3.4.3 Polymerase chain reaction (PCR)

Polymerase chain reaction was performed to selectively amplify in vitro a specific segment of the total genomic DNA to a billion fold (Mullis *et al.*, 1986). The most essential requirement of PCR is an availability of a pair of short (typically 20-25 nucleotides) primers having sequence complementary to either end of the target DNA segment (called template DNA) supposed be synthesized in large amount. The PCR conditions standardized for the present experiment are presented in the Table 3.8.

Table 3.8: Standardized concentration of the PCR components

PCR component	Stock concentration	Final concentration	Volume for 15 µl
Primer (F + R)	10 pM	0.7 pM	2.0 (1.0 + 1.0)
Taq DNA Polymerase	5U/µl	1U	0.4
MgCl ₂	25 mM	0.3 mM	0.2
Taq Assay Buffer	10x	1x	1.5
dNTPs	10 mM	0.14 mM	0.2
Genomic DNA	50 -100 ng/µl	50 ng /15µl reaction vol.	2.0
HPLC water	-	-	8.7

For adjustment of concentration of various chemicals, amount of MgCl₂ was changed keeping other PCR components as constant. For PCR programming all the steps were kept as such except the annealing temperature. Annealing temperature was determined based on the GC content of the primer as:

$$T_m = [2 \times (A + T) + 4 \times (G + C)] - 4$$

This formula provided the preliminary information but not the exact annealing temperature. Therefore, the correct annealing temperature was determined based on best PCR amplification. All the amplifications were performed in the Eppendorf Thermo-cycler (USA) using the thermal cycler programme as given in Table 3.9. After the completion of the PCR, the products were stored at -20°C until the gel electrophoresis was done.

Table 3.9: Thermal cycler programme for PCR

Cycle	Temperature	Duration	Objective
First cycle	94°C	4 minutes	Initial denaturation
The next 39 cycles	94°C	45 second	Denaturation
All 40 cycles	T _m °C*	30 second	Annealing
All 40 cycles	72°C	30 second	Extension
At the end of the 40 th cycle	72°C	7 minutes	Final extension
Hold	15°C	∞	Hold

*T_m depends on the annealing temperature of the primer used.

3.4.4 Visualization of amplification products

The amplified DNA products generated through SSR primers were resolved through electrophoresis in 2.5 per cent agarose gel prepared in TAE buffer [242 g Tris-base, 57.1 ml glacial acetic acid and 100 ml 0.5 M EDTA (pH 8.0) dissolved in distilled water, and final volume made to 1000 ml]. Ethidium bromide solution at final concentration of 0.03 ng/μl was added to the agarose solution.

For electrophoresis, 15μl of the PCR product was mixed with 2μl of 6X loading dye (bromophenol blue) and loaded in the slot of agarose gel. In order to determine the molecular size of amplified products, the gels were loaded with 1μg of a 50 bp DNA marker (Fermentas, USA). Gel electrophoresis was carried out at a constant voltage of 65 V for about 3.5 hours and the gels were visualized under a UV light source in a gel documentation system (Gel DocTM XR⁺, BIO-RAD, USA). Finally, the images of amplification products were captured and stored in a computer for further analysis and future use.

3.5. Frequency Distribution

Frequency distribution for all the characters in the nine F₂ populations was prepared and presented graphically. Data from 150 individual F₂ plants were used for the frequency distribution.

3.6 Statistical analysis

3.6.1 Analysis of variance for line x tester mating design and estimation of combining ability effects

The general and specific combining ability variances and effects analysis will be estimated using line x tester mating design suggested by Kempthorne (1957).

Table 3.10: ANOVA for line x tester analysis

Source	d.f.	S.S.	M.S.S.	F. ratio
Replication	r- 1	rSS	Mr	Mr/Me
Treatment	n- 1	nSS	Mn	Mn/Me
Parents	p- 1	pSS	Mp	Mp/Me
Parents vs Crosses	1	pcSS	Mpc	Mpc/Me
Crosses	lt- 1	cSS	Mc	Mc/Me
Lines (Male)	l- 1	lSS	M1	$\sigma^2_e + r\sigma^2_{lt} + r\sigma^2_{2l}$
Testers (Female)	t- 1	tSS	M2	$\sigma^2_e + r\sigma^2_{lt} + r\sigma^2_{2t}$
Lines x Testers	(l-1) (t-1)	ltSS	M3	$\sigma^2_e + r\sigma^2_{lt}$
Error	(r-1) (n-1)	eSS	Me	σ^2_e

Where, r = number of replications, n = number of treatments, p = number of parents (l + t), l = number of female lines, t = number of male lines, c = number of crosses (l × t), MSS = mean sum of squares, df = degree of freedom

The test of significance was carried out with various MSS against eMSS using 'F test' at the respective degrees of freedom for all the sources of variations except lines and testers where MSS due to lines x tester was used. With the help of expectation, covariance of full sibs and half sibs were estimated by using the formula given below:

$$\text{Covariance of half sibs} = \frac{(M_1 - M_2) + (M_2 - M_3)}{r(l + t)}$$

$$\text{Covariance of full sibs} = \frac{(M_1 - M_4) + (M_2 - M_4) + (M_3 - M_4)}{3r} + \frac{6r \text{Cov (H.S.)} - r(l + t) \text{Cov (H.S.)}}{3r}$$

3.6.1.1 Estimation of general and specific combining abilities effects

The additive model was used to estimate the general and specific combining ability effects of ijk^{th} observation is given here:

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

Where,

μ = population mean

g_i = gca effect of i^{th} female parent

g_j = gca effect of j^{th} male parent

s_{ij} = sca effect of ij^{th} combination

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

i = number of female parents

j = number of male parents

k = number of replication

The gca effects for both male and female parents and sca effects for each cross combination were calculated with the help of following formula:

$$\mu = \frac{X}{ltr}$$

Where,

$X_{...}$ = Total of all hybrid combination over replication

$$(i) \quad \text{Lines: gca effect of } i^{\text{th}} \text{ lines } (g_i) = \frac{X_{i..}}{tr} - \frac{X_{i..}}{ltr}$$

$$(ii) \quad \text{Testers: gca effect of } j^{\text{th}} \text{ testers } (g_j) = \frac{X_{.j.}}{lr} - \frac{X_{...}}{ltr}$$

$$(iii) \quad \text{Crosses: sca effect of } ij^{\text{th}} \text{ lines } (s_{ij}) = \frac{X_{..j}}{r} - \frac{X_{i..}}{tr} - \frac{X_{.j.}}{lr} - \frac{X_{...}}{ltr}$$

Where,

$X_{i..}$ = Total of i^{th} line over t testers and r replications

$X_{.j.}$ = Total of j^{th} tester over l lines and r replications

X_{ij} = ij^{th} combination over all replication

3.6.1.2 Standard errors for combining ability effects

In order to test the significance of gca/sca effects or that of the difference of any two gca/sca effects, the SE and SE_d were calculated as under:

- (a) SE for gca effects of lines: $SE\ g_i = (Me/r \times t)^{1/2}$
- (b) SE for gca effects of testers: $SE\ g_j = (Me/r \times l)^{1/2}$
- (c) SE for sca effects of testers: $SE_{sij} = (Me/r)^{1/2}$
- (d) SE for difference between two sca effects: $SE\ (Sij-Skl) = (2Me/r)^{1/2}$

The critical difference (CD) values in each case were computed by multiplying their corresponding SE value with the table 't' values at error degrees of freedom at P= 0.05 and 0.01.

3.6.1.3 Proportional contribution of lines, testers and their interactions to total variance

$$\text{Contribution of Lines} = \frac{SS\ (l)}{SS\ (Crosses)} \times 100$$

$$\text{Contribution of Testers} = \frac{SS\ (t)}{SS\ (Crosses)} \times 100$$

$$\text{Contribution of Lines} \times \text{Testers} = \frac{SS\ (l \times t)}{SS\ (Crosses)} \times 100$$

3.6.2 Estimation of heterosis

Heterosis for each trait was estimated by utilizing the overall mean of each hybrid over replications. Better parent heterosis, standard heterosis over inbred check and standard heterosis over hybrid check were estimated for the yield and quality traits. Pusa basmati-1 and Taraori basmati were respectively used as yield and quality inbred checks for the estimation of standard heterosis (over inbred check). Pusa RH-10 was used as hybrid check for the estimation of standard heterosis in both yield and quality traits (over hybrid check).

Heterosis in F_1 s' will be calculated as the difference of F_1 hybrid performance from the better parents (Heterobeltiosis) and standard checks (Standard heterosis) by using the formulae (Kempthorne, 1957).

$$\text{Heterobeltiosis (\%)} = \frac{(\bar{F}_1 - \bar{BP})}{\bar{BP}} \times 100$$

$$\text{Standard heterosis (\%)} = \frac{(\bar{F}_1 - \bar{C})}{\bar{C}} \times 100$$

Where,

$\bar{F}_1$ = mean performance of F_1 .

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

$\bar{BP}$ = mean performance better parent.

$\bar{C}$ = mean performance of check variety.

Test of significance of heterosis

To test the significance of heterosis, the formula proposed by Arunachalam (1976) was used.

$$\text{SE (Diff.) for } (\bar{F}_1 - \bar{BP} \text{ or } \bar{C}) = (2\text{MSe}/3r)^{1/2}$$

CD = SE (Diff.) $\times$ t value at 5 and 1 per cent significance at respective error degree of freedom.

Where,

MSe = Mean sum of squares due to error.

3.6.3 Inbreeding depression (ID):

Inbreeding depression refers to decrease in fitness and vigor due to inbreeding. The degree of inbreeding is measured by the inbreeding coefficient. Inbreeding

depression was estimated when both F_1 and F_2 populations of the same cross were available. It was measured as follows:

$$\text{Inbreeding depression (ID)} = \frac{\overline{F1} - \overline{F2}}{\overline{F1}} \times 100$$

Where, $\overline{F1}$ = Mean of the F_1 , and

$\overline{F2}$ = Mean of the F_2 .

The estimates of standard error for the ID estimates were obtained as follows:

$$\text{S.E. of inbreeding depression} = \sqrt{V\overline{F1} + V\overline{F2}}$$

Where,

$V\overline{F1}$ = variance of F_1 means, and

$V\overline{F2}$ = variance of F_2 means.

Significance of inbreeding depression estimates was tested by 't' test at error degrees of freedom. The values of 't' were estimated by the following formula:

$$t = \frac{\overline{F1} - \overline{F2}}{S.E.(I.D)}.$$

3.5.6 Estimation of generation mean analysis

Generation mean analysis approach will be calculated as per Mather (1949) and Mather & Jinks (1977).

3.5.6.1 Simple scaling test

Adequacy of scale must satisfy two conditions namely, additivity of gene effects and independence of heritable components from non-heritable ones. The test of first condition provides information regarding absence or presence of gene interactions. The test of adequacy of scales is important because in most of the cases the estimation of additive and dominance components of variances are made

assuming the absence of gene interaction. Mather (1949) and Hayman and Mather (1955) gave following four tests for scale effects:

$$A = 2.\bar{B}_1 - \bar{P}_1 - \bar{F}_1 B = 2.\bar{B}_2 - \bar{P}_2 - \bar{F}_1 C = 4.\bar{F}_2 - 2.\bar{F}_1 - \bar{P}_1 - \bar{P}_2$$

When the scale is adequate, the values of A, B and C should be zero within the limit of their respective Standard Errors.

Variances of above scales

$$V_A = 4.V_{\bar{B}_1} + V_{\bar{P}_1} + V_{\bar{F}_1} V_B = 4.V_{\bar{B}_2} + V_{\bar{P}_2} + V_{\bar{F}_1} V_C = 16.V_{\bar{F}_2} + 4.V_{\bar{F}_1} + V_{\bar{P}_1} + V_{\bar{P}_2}$$

Standard errors of above scale:

$$SE_A = V_A SE_B = V_B SE_C = V_C$$

Now, the 't' values are calculated as follows:

$$t_A = \frac{A}{SE_A} t_B = \frac{B}{SE_B} t_C = \frac{C}{SE_C}$$

The calculated value of 't' are to be compared with tabulated value of 't' at 5% level of significance. In each test, the degree of freedom is sum of the degrees of freedom of various generations (total number of observations - total number of replications) involved.

3.5.6.2 Joint scaling test

The main drawback of simple scale tests is that out of six populations only three or four are included in the test at a time. In order to overcome this problem, Cavalli (1952) gave the method 'Joint scaling test' which includes any combination of families at a time. The 'weighted least square method' developed by Hayman (1960) was used to estimate the parameters m, d and h. Here, the weights are defined as the reciprocal of standard error. From these estimates, the expected generation means were calculated and compared with the observed generation mean values using a χ^2 test. A significant χ^2 value indicates that the model is not adequate and the non-allelic interactions are added in the model.

3.5.6.3 Components of generation means

Hayman (1958) and Jinks and Jones (1958) devised the six parameter model for the estimation of various genetic components; these components were estimated according to Hayman (1958) as follows:

$$m = \text{mean} = \bar{F}_2 \quad d = \text{Additive effects} = \bar{B}_1 - \bar{B}_2 \quad h = \text{Dominance effects}$$

$$= \bar{F}_1 - 4.\bar{F}_2 - \frac{1}{2}.\bar{P}_1 - \frac{1}{2}.\bar{P}_2 + 2.\bar{B}_1 + 2.\bar{B}_2$$

$$i = \text{Additive} \times \text{Additive type of gene interaction} = 2.\bar{B}_1 + 2.\bar{B}_2 - 4.\bar{F}_2$$

$$j = \text{Additive} \times \text{Dominance type of gene interaction} = \bar{B}_1 - \frac{1}{2}.\bar{P}_1 - \bar{B}_2 + \frac{1}{2}.\bar{P}_2$$

$$l = \text{Dominance} \times \text{Dominance type of gene interaction}$$

$$= \bar{P}_1 + \bar{P}_2 + 2.\bar{F}_1 + 4.\bar{F}_2 - 4.\bar{B}_1 - 4.\bar{B}_2$$

Variances of above parameters:

$$V_m = V_{\bar{F}_2} \quad V_d = V_{\bar{B}_1} + V_{\bar{B}_2} \quad V_h = V_{\bar{F}_1} + 16.V_{\bar{F}_2} + \frac{1}{4}.V_{\bar{P}_1} + \frac{1}{4}.V_{\bar{P}_2} + 4.V_{\bar{B}_1}$$

$$V_i = 4.V_{\bar{B}_1} + 4.V_{\bar{B}_2} + 16.V_{\bar{F}_2} \quad V_j = V_{\bar{B}_1} + \frac{1}{4}.V_{\bar{P}_1} + V_{\bar{B}_2} + \frac{1}{4}.V_{\bar{P}_2} \quad V_l$$

$$= V_{\bar{P}_1} + V_{\bar{P}_2} + 4.V_{\bar{F}_1} + 16.V_{\bar{F}_2} + 16.V_{\bar{B}_1} + 16.V_{\bar{B}_2}$$

Standard errors of the parameters:

$$SE_m = \sqrt{V_m} \quad SE_d = \sqrt{V_d} \quad SE_h = \sqrt{V_h} \quad SE_i = \sqrt{V_i} \quad SE_j = \sqrt{V_j} \quad SE_l = \sqrt{V_l}$$

Now, the 't' values are calculated as followed:

$$t_m = \frac{m}{SE_m}$$

$$t_d = \frac{d}{SE_d} \quad t_h = \frac{h}{SE_h} \quad t_i = \frac{i}{SE_i}$$

$$t_j = \frac{j}{SE_j}$$

$$t_l = \frac{l}{SE_l}$$

The calculated value of 't' are to be compared with tabulated value of 't' at 5% level of significance. In each test, the degree of freedom is sum of the degrees of freedom of various generations (total number of observations - total number of replications) involved.

In absence of nonallelic interactions, Jinks and Jones (1958) devised the three parameter model for the estimation of various genetic components

$$m = \frac{1}{2} \overline{P1} + \frac{1}{2} \overline{P2} + 4\overline{F2} - 2\overline{B1} - 2\overline{B2}$$

$$d = \frac{1}{2} \overline{P1} - \frac{1}{2} \overline{P2}$$

$$h = 6\overline{B1} + 6\overline{B2} - 8\overline{F2} - \overline{F1} - \frac{3}{2} \overline{P1} - \frac{3}{2} \overline{P2}$$

The variances for these estimates are calculated as follows

$$V_m = \frac{1}{4} V_{\overline{P1}} + \frac{1}{4} V_{\overline{P2}} + 16V_{\overline{F2}} + 4V_{\overline{B1}} + 4V_{\overline{B2}}$$

$$V_d = \frac{1}{4} V_{\overline{P1}} + \frac{1}{4} V_{\overline{P2}}$$

$$V_h = 36 V_{\overline{B1}} + 36V_{\overline{B2}} + 64 V_{\overline{F2}} + V_{\overline{F1}} + \frac{9}{4} V_{\overline{P1}} + \frac{9}{4} V_{\overline{P2}}$$

Standard errors of the parameters:

$$SE_m = \sqrt{V_m} \quad SE_d = \sqrt{V_d} \quad SE_h = \sqrt{V_h}$$

Now, the 't' values are calculated as followed:

$$t_m = \frac{m}{SE_m}$$

$$t_d = \frac{d}{SE_d}$$

$$t_h = \frac{h}{SE_h}$$

The calculated value of 't' are to be compared with tabulated value of 't' at 5% level of significance. In each test, the degree of freedom is sum of the degrees of freedom of various generations (total number of observations - total number of replications) involved.

3.5.6.4. Molecular analyses

SSR markers, generated clear and unambiguous bands of various molecular weight sizes, were scored for the presence (1) and absence (0) of the corresponding band among the 24 genotypes. The marker data was used to generate a data matrix in Microsoft Excel 2007. This data matrix was subjected to further analysis using NTSYS-pc version 2.11. The SIMQUAL program was used to calculate the Jaccard's similarity coefficients. The resulting similarity matrix was used to construct UPGMA

(Unweighted Pair Group Method with Arithmetic Mean) based dendrogram. Polymorphic information content (PIC) for each SSR marker was calculated as per the formula:

$$PIC = 1 - \sum_{i=1}^k P_i^2$$

Where, P_i is the frequency of the i^{th} allele and k is the total number of different alleles at the specific locus. The binary data was subjected to principal component analysis (PCA) using the EIGEN and PROJ modules of NTSYSpC.





EXPERIMENTAL FINDINGS

EXPERIMENTAL FINDINGS

The present investigation was carried out during the *Kharif* seasons of 2013, 2014 and 2015 at the Agriculture Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. Data recorded on various yield, its contributing traits and quality traits were analyzed following standard statistical procedures and statistical software Windostat 10.1. The mean performances of 3 lines, 3 testers, 9 crosses, 18 back crosses for all the traits studied are presented in appendix. The results of present investigation involving different experiments are presented as follows

- 4.1 Molecular diversity analysis for detecting parental polymorphism**
- 4.2 Combining ability analysis for yield and quality traits**
- 4.3 Extent of heterosis and inbreeding depression for yield and quality traits**
- 4.4 Estimates of the gene actions through generation mean analysis**
- 4.5 Frequency Distribution in F_2**

4.1 Molecular diversity analysis for detecting parental polymorphism

Genetic diversity analysis was carried out by using 19 simple sequence repeat (SSR) markers, selected from rice SSR linkage map among 24 selected rice parents. Out of 19 primers 18 produced polymorphic and reproducible banding patterns (Table 4.1). A total of 457 polymorphic bands were yielded by these SSRs. Of the total amplified bands the average polymorphic fragment per primer was 2.15 and number of polymorphic bands per primer ranged from 2-3. The polymorphic information content (PIC) of the 19 SSR primers ranged from 0.07 to 0.54 with an average PIC of 0.36. Typical SSR banding pattern shown in gel images which were generated by the primers RM7049, RM8226 and RM505 are presented in Fig 4.1, Fig 4.2 and Fig 4.3, respectively.

The relationship between the 19 rice genotypes was studied by the un-weighted pair group method arithmetic average (UPGMA) based cluster analysis of data developed by 19 SSR markers. Dendrogram based on UPGMA analysis grouped the 24 genotypes into different clusters. The pair wise similarity was calculated by Jaccard's similarity coefficients, which ranged from 0.18 to 0.94 with an average similarity of 0.51. The genotypes DDN-1-8 and DDN (Awnless) recorded highest similarity coefficient (0.94) and genotypes BPT-5204 and Kalanamak showed lowest similarity coefficient (0.18). A dendrogram was constructed which reveals the genetic distance between the 24 genotypes. The 24 genotypes were clustered into seven groups namely, Cluster I, II, III, IV, V, VI and VII indicating wide genetic diversity. Cluster I was composed of ten genotype viz., Type-3, Ranbir Basmati, DDN(awnless), DDN-1-8-80, Basmati-370, Kasturi, DDN-3-1-72, Tarori Basmati, DDN-1-4-75 and Adamchini whereas cluster II consists of one genotypes i.e., Kalanamak. The cluster III was made up of six genotypes viz., Sonwal Basmati, Pusa Sugandh-3, HUBR-16, HUBR-1-2-25-5, Pusa Sugandh-2 and HUBR-9-1-2-1. Cluster IV composed of four genotypes viz., HUBR-10-9, Pusa Basmati-1, Pusa 1121 and Pusa 1509 whereas Cluster V composed of one genotype i.e. BPT-5204. Cluster VI consists of one genotype i.e, TBD-2 and Cluster VII composed of one genotype i.e., Dhanprasad.

4.2. Combining ability analysis for yield and quality traits

The experimental materials (9 F_1 's along with 3 lines (Adamchini, BPT-5204 and Kasturi) and 3 testers (Type-3, Pusa Sugandh-2 and Pusa 1121) were evaluated for combining ability of various yield and quality traits. The yield attributes studied were days to 50 per cent flowering, days to maturity, plant height, effective tillers per plant, number of grains per panicle, 100 grain weight and grain yield per plant and the quality traits were hulling recovery, milling recovery, head rice recovery, grain length, grain width, brown rice length, brown rice width, kernel length, kernel width, L/B ratio, kernel length after cooking, kernel breadth after cooking, elongation ratio, elongation index, alkali spread value, amylose content, gel consistency and aroma. The quality characters hulling recovery, milling recovery, head rice recovery, L/B ratio, elongation ratio, elongation index, alkali spread value, amylose content and aroma were converted in to arc sine conversion values for applying statistical

methods. The combining ability studies for various traits have been discussed here under various headings.

4.2.1. Analysis of variance (ANOVA) for combining ability of different characters

The data for all the traits were subjected to analysis of variance (ANOVA). Treatment variations showed highly significant differences for all the characters studied indicating sufficient differences for all the traits (Table 4.3). The mean sums of squares for crosses were further partitioned into female, male and female x male components. The mean squares due to female parents were significant for characters, days to 50 per cent flowering, days to maturity, number of grains per panicle and gel consistency. However the variance due to male parents were found to be significant for days to 50 per cent flowering, days to maturity, L/B ratio, kernel length after cooking and aroma. Female x male component of variances were significant for all the traits except head rice recovery, grain length, grain breadth, brown rice length, brown rice breadth, kernel length, kernel width and alkali digestion value.

4.2.2. Combining ability variances for different yield and quality traits

The study of combining ability variances revealed that the magnitude of additive genetic variance (σ^2A) was higher than that of dominance genetic variance (σ^2D) for the characters, days to 50% flowering, days to maturity, plant height, number of grains per panicle, 100 grain weight, hulling recovery, head rice recovery, grain length, grain breadth, brown rice length, brown rice breadth, kernel length, kernel breadth, L/B ratio, kernel length after cooking, alkali digestion value and aroma, suggesting the preponderance of additive gene action for these traits (Table 4.4). However, for rest of the traits studied except milling recovery and kernel breadth after cooking, value of σ^2A was observed to be lower than σ^2D , indicating the predominance of non additive gene action. For the traits milling recovery and kernel breadth after cooking the ratio of σ^2A/σ^2D showed value of near unity indicates importance of both additive and non additive gene action for these traits. Further, the estimates of average degree of dominance showed over dominance for effective tillers per plant (1.107), grain yield per plant (1.542), elongation ratio (1.331), elongation

index (1.777), amylose content (1.567) and gel consistency (1.025) while for traits like milling recovery (0.998) and kernel breadth after cooking (0.982). Whereas partial dominance were observed for days to 50 per cent flowering (0.235), days to maturity (0.227), plant height (0.891), number of grains per panicle (0.846), 100 seed weight (0.678), hulling recovery (0.686), head rice recovery (0.507), grain length (0.177), grain breadth (0.555), brown rice length (0.470), brown rice breadth (0.241), kernel length (0.490), kernel breadth (0.858), L/B ratio (0.492), kernel length after cooking (0.356), alkali digestion value (0.618) and aroma (0.504).

4.2.3. Contribution of females, males and their interaction towards total variance

The proportional contribution of female parents, male parents and their interaction towards the total variance for different traits evaluated has been presented in Table 4.5. It is evident from the table that female parents played an important role towards number of grains per panicle (43.43%), grain breadth (71.71%), brown rice breadth (73.28%), kernel breadth (47.84%) and kernel breadth after cooking (48.54%) indicating predominance of maternal influence for these traits. Male parents were more important for days to 50 per cent flowering (91.01%), days to maturity (91.29%), plant height (38.37%), 100-grain weight (55.54%), hulling recovery (67.35%), head rice recovery (76.48%), grain length (72.47%), brown rice length (77.63%), kernel length (74.94%), L/B ratio (78.87%), kernel length after cooking (74.20%) alkali digestion value (69.31%) and aroma (71.28%), revealing predominant paternal influence for these traits. For rest of the traits studied, the contribution of maternal and paternal interaction (female x male) was observed to be highest in proportion, indicating that the concerned characters were influenced by non-additive gene action.

4.2.4. Combining ability effects for various yield and quality traits

The high positive values of GCA effects indicated that their contribution in transferring these characters to their hybrids is high and vice versa. Deviation in performance of a cross combination from that predicted on the basis of general combining abilities of the parents involved in the cross was shown by SCA. The estimates of general combining ability (gca) effects of six diverse parents (3 lines + 3

testers) and specific combining ability (sca) effects of nine crosses for all the traits are presented in Tables 4.6, 4.7, 4.8 and 4.9. The positive and significant gca and sca effects were considered to be desirable for number of effective tillers per plant, number of grains per panicle, 100 seed weight, grain yield per plant, hulling recovery, milling recovery, head rice recovery, grain length, brown rice length, kernel length, kernel length after cooking and gel consistency. Further, in case of plant height, days to 50% flowering, days to maturity, grain breadth, brown rice breadth, kernel breadth and kernel breadth after cooking the negative and significant gca and sca effects were considered to be desirable. The estimates of general combining ability (gca) effects (Table 4.6 & Table 4.7) of parents and specific combining ability (sca) effects (Table 4.8 & Table 4.9) of crosses in the present study have been particularized trait wise in the following paragraphs.

4.2.4.1. Days to 50% flowering

The significant negative GCA effect for days to 50 per cent flowering among female parents was exhibited by Type-3 (-3.31) followed by Pusa Sugandh-2 (-1.274). Within male parents, the significant negative GCA effect was revealed by Kasturi (-19.08). Hybrid Pusa 1121 x Adamchini (-4.97) showed highest significant negative SCA effect followed by Pusa Sugandh-2 x Kasturi (-3.337) and Type-3 x BPT- 5204 (-2.115).

4.2.4.2. Days to maturity

Among the female parents, Type-3 (-3.307) and Pusa Sugandh-2 (-1.274) showed significant negative GCA effects for days to maturity. Similarly, among male parents Kasturi (-19.219) revealed significant negative gca effects for days to maturity. Hybrid Pusa 1121 x Adamchini (-4.748) showed highest significant negative SCA effect followed by Pusa Sugandh-2 x Kasturi (-3.381) and Type-3 x BPT- 5204 (-2.026).

4.2.4.3. Plant height

The significant negative GCA effect for plant height among female parents was exhibited by Pusa 1121 (-15.29). Among male parents, highest significant

negative GCA effects was exhibited by BPT-5204 (-12.98) followed by Kasturi (-7.23). Hybrid Pusa Sugandh-2 x BPT-5204 (-20.856) showed highest significant negative SCA effect followed by Pusa 1121 x Adamchini (-20.844) and Type-3 x Kasturi (-7.400).

4.2.4.4. Effective tillers per plant

Among the female parents, Pusa 1121 (0.904) recorded significant positive GCA effects for tillers per plant. Similarly among male parents BPT-5204 (1.470) showed significant positive GCA effects for tillers per plant. Hybrid Pusa Sugandh-2 x BPT-5204 (2.396) showed highest significant positive SCA effect for effective tillers per plant followed by Pusa 1121 x Adamchini (1.096).

4.2.4.5. Number of grains per panicle

The significant positive GCA effect for number of grains per panicle among the female parents was recorded in Pusa Sugandh-2 (25.152) followed by Type-3 (5.807) whereas in male parents significant positive GCA effect for number of grains per panicle was observed in Adamchini (15.507) followed by BPT-5204 (8.796). Cross Pusa Sugandh-2 x BPT-5204 (31.381) recorded highest significant positive SCA effect for number of grains per panicle followed by Type-3 x Adamchini (21.115) and Pusa 1121 x Kasturi (21.093).

4.2.4.6. 100 grain weight

The significant desirable value of GCA effects for 100 grain weight among female parents was observed in Pusa 1121 (0.155) followed by Pusa Sugandh-2 (0.094) and within male parents Kasturi (0.273) showed highest significant positive GCA effects for 100 grain weight followed by BPT-5204 (0.129). Hybrid Pusa 1121 x Kasturi (0.251) recorded highest significant desirable SCA effect for 100-grain weight followed by Pusa Sugandh-2 x BPT-5204 (0.047) followed by Pusa 1121 x BPT-5204 (0.036).

4.2.4.7. Grain yield per plant

Among the female parents significant positive GCA effect for grain yield per plant was observed for Pusa Sugandh-2 (1.726) whereas among the male parents BPT-5204 (3.742) recorded highest significant positive GCA effect for grain yield per plant followed by Adamchini (3.034). Crosses Pusa Sugandh-2 x BPT-5204 (9.89) recorded highest desirable significant SCA effect for grain yield per plant followed by Pusa 1121 x Adamchini (8.714).

4.2.4.8. Hulling recovery

For hulling recovery none of the female parents showed significant positive GCA effects for hulling recovery. Among the male parents Adamchini (1.322) showed highest significant positive GCA effect for hulling recovery followed by BPT-5204 (0.999). Hybrid Type-3 x Adamchini (1.282) recorded highest significant positive SCA effect for hulling recovery followed by Pusa 1121 x BPT-5204 (1.266).

4.2.4.9. Milling recovery

Among the female parents Type-3 (1.372) showed significant positive desirable GCA effects for milling recovery whereas among the male parents Adamchini (1.320) showed significant positive desirable GCA effect for milling recovery. The highest significant positive SCA effect for milling recovery was showed by cross Pusa Sugandh-2 x Adamchini (1.842) followed by Pusa 1121 x BPT-5204 (1.130) and Pusa 1121 x Kasturi (1.242).

4.2.4.10. Head rice recovery

For case of head rice recovery, none of the female parents showed significant positive GCA effects. Among the male parents, Adamchini (0.862) showed significant positive GCA effects for head rice recovery followed by BPT-5204 (0.692). Among the crosses only Pusa Sugandh-2 x Adamchini (0.900) showed significant positive SCA effect for head rice recovery.

4.2.4.11. Grain length

Amongst the female parents, a significant positive GCA effect for grain length was recorded for Pusa 1121 (1.186). Among the male parents Kasturi (2.086) showed significant positive GCA effect for grain length. None of the crosses showed significant positive SCA effects for grain length.

4.2.4.12. Grain breadth

For grain breadth, the female parent Type-3 (-0.144) showed significant negative GCA effects whereas among male parents Adamchini (-0.063) showed significant negative GCA effects. None of the crosses showed significant negative SCA effects for grain breadth.

4.2.4.13. Brown rice length

Among the female parents, Pusa 1121 (0.529) showed significant desirable GCA effects for brown rice length. Similarly among the male parents Kasturi (1.479) showed significant positive GCA effects for brown rice length. The highest significant positive SCA effects was recorded for cross Pusa 1121 x Adamchini (0.720) followed by Type-3 x BPT-5204 (0.645) and Pusa Sugandh-2 x Kasturi (0.554) for the trait.

4.2.4.14. Brown rice breadth

Significant negative GCA effect for brown rice breadth among female parents was observed for Pusa Sugandh-2 (-0.046). Among male parents none showed significant negative GCA effects. None of the crosses showed significant negative SCA effects for brown rice breadth.

4.2.4.15. Kernel length

Among the female parents, Pusa 1121 (0.607) recorded significant positive GCA effects for kernel length and within male parents Kasturi (1.464) recorded significant positive GCA effects. The highest significant positive SCA effects for

kernel length was observed for Pusa 1121 x Adamchini (0.850) followed by Type-3 x BPT-5204 (0.701) and Pusa Sugandh-2 x Kasturi (0.517).

4.2.4.16. Kernel breadth

The significant negative GCA effect for kernel breadth among female parents was observed for Pusa Sugandh-2 (-0.022). Among the male parents Kasturi (-0.022) showed significant negative GCA effect for kernel breadth. None of the crosses showed significant negative SCA effects for kernel breadth.

4.2.4.17. L/B ratio

Among the female parents, Pusa 1121 (0.378) showed significant positive GCA effects for L/B ratio and within male parents Kasturi (2.086) showed significant positive GCA effects. Cross Pusa 1121 x Adamchini (0.679) recorded highest significant positive SCA effects for L/B ratio followed by Type-3 x BPT-5204 (0.588) and Pusa Sugandh-2 x Kasturi (0.490).

4.2.4.18. Kernel length after cooking

The significant positive GCA effect for kernel length after cooking among female lines was recorded for Pusa 1121 (0.926). Similarly among male parents Kasturi (1.916) showed significant positive GCA effect for Kernel length after cooking. The highest significant positive SCA effect for kernel length after cooking was observed in Type-3 x BPT-5204 (0.553).

4.2.4.19. Kernel breadth after cooking

The negative significant GCA effects were desirable for kernel breadth after cooking and among female parents Type-3 (-0.076) and Pusa 1121 (-0.133) recorded significant negative GCA effects whereas among male parents Kasturi (-0.08) showed significant negative GCA effects. Cross Pusa Sugandh-2 x Kasturi (-0.210) recorded highest significant desirable SCA effects for kernel breadth after cooking followed by Type-3 x BPT-5204 (-0.164).

4.2.4.20. Elongation ratio

Among the female parents, Pusa Sugandh-2 (0.093) recorded significant positive GCA effects for elongation ratio. Among male parents Adamchini (0.434) showed significant positive GCA effects for elongation ratio. The highest significant positive SCA effects for elongation ratio was recorded for Pusa Sugandh-2 x Adamchini (0.405) followed by Pusa 1121 x BPT-5204 (0.387), Pusa 1121 x Kasturi (0.291) and Type-3 x Adamchini (0.273).

4.2.4.21. Elongation index

The significant positive GCA effects for elongation index among female parents was recorded for Pusa 1121 (0.149) whereas among male parents Adamchini (0.200) showed significant positive GCA effects for elongation index. The highest significant positive SCA effects for elongation index was recorded for Type-3 x Adamchini (0.327) followed by Pusa 1121 x BPT-5204 (0.277), Pusa 1121 x Kasturi (0.250) and Pusa Sugandh-2 x Adamchini (0.200).

4.2.4.22. Alkali digestion value

For alkali digestion value the significant positive GCA effects among female parents was observed for Pusa 1121 (0.338). Among the male parents Kasturi (0.553) and BPT-5204 (0.346) showed significant positive GCA effects for alkali digestion value. Among the crosses the highest positive significant SCA effects for alkali digestion value was observed in Type-3 x BPT-5204 (0.505) followed by Pusa 1121 x Adamchini (0.568).

4.2.4.23. Amylose content

Pusa 1121 (0.696) showed significant positive GCA effects for amylose content among female parents whereas Kasturi (0.607) showed significant desirable GCA effects among male parents. The highest significant positive SCA effects for amylose content was observed in cross Pusa 1121 x Adamchini (2.07) followed by Pusa Sugandh-2 x BPT-5204 (1.326).

4.2.4.24. Gel consistency

The significant positive GCA effects are desirable for gel consistency, among the female parents Pusa 1121 (4.667) and Type-3 (2.389) showed significant positive GCA effects but among males none showed significant positive GCA effects. Within the crosses Pusa Sugandh-2 x Adamchini (9.067) showed highest significant positive SCA effects for gel consistency followed by Pusa 1121 x BPT-5204 (6.078) and Type-3 x BPT-5204 (2.122).

4.2.4.25. Aroma

Among the female parents, Pusa 1121 (0.488) showed significant positive GCA effects for aroma. Similarly among the male parents, Kasturi (0.706) and Adamchini (0.398) showed significant positive GCA effects for aroma. The highest significant positive SCA effects for aroma were observed in Pusa 1121 x BPT-5204 (0.585) followed by Pusa Sugandh-2 x Kasturi (0.523) and Type-3 x Adamchini (0.403).

4.3. Estimation of heterosis and inbreeding depression for yield and quality traits

The magnitude of heterosis in per cent over better parent (heterobeltiosis) and over standard check (standard heterosis) and inbreeding depression in nine F_1 's obtained from line x tester analysis for 25 traits were estimated during *Kharif* 2015 (Table 4.10, Table 4.11). In case of yield traits, Pusa Basmati-1 and Pusa RH-10 were used for the estimation of standard heterosis over pureline check and hybrid check, respectively. For all the quality traits, Taraori Basmati and Pusa RH-10 were used for evaluating the performance of F_1 hybrids over pureline check and hybrid check, respectively. The higher mean of the parent and F_1 was considered better for most of the traits except days to 50% flowering, days to maturity, plant height, grain breadth, brown rice breadth, kernel breadth and kernel breadth after cooking. The magnitude of heterosis was found in both positive and negative directions. In case of better parent heterosis and standard heterosis, only positive values are described for all the traits except, days to 50% flowering, days to maturity, plant height, grain breadth, brown rice breadth, kernel breadth and kernel breadth after cooking for which negative values (desirable ones) have been taken for consideration.

Heterosis and inbreeding depression for yield and quality traits has been described below for individual traits.

4.3.1. Days to 50 percent flowering

For the trait days to 50 percent flowering negative heterosis was desirable so that early flowering hybrids can be obtained. The heterobeltiosis for day to 50 per cent flowering in F_1 s ranged from -5.22 to 25.39 per cent. The range of standard heterosis over Pusa RH-10 was -10.56 to 31.74 and over Pusa Basmati-1 were -21.57 to 14.49. The significant negative heterosis over better parent and Pusa RH-10 was observed in two crosses. Over Pusa Basmati-1, three hybrids showed significant negative desirable heterosis. Cross Pusa Sugandh-2 x Kasturi showed highest significant negative heterosis over better parent and standard checks.

The range of inbreeding depression for days to 50 per cent flowering varied from -16.16 to 12.04. All the crosses showed significant inbreeding depression.

4.3.2. Days to maturity

The negative heterosis was desirable for this trait to obtain early maturing hybrids. The heterobeltiosis ranged from -6.06 to 17.71 and standard heterosis over Pusa RH-10, Pusa Basmati-1 ranged from -9.58 to 22.85 and -22.65 to 5.08 respectively. The magnitude of heterosis was recorded significant negative in two crosses over better parent and Pusa RH-10 and in four crosses over Pusa Basmati-1. The cross, Pusa Sugandh-2 x Kasturi showed highest significant negative heterosis over better parent and standard checks.

The magnitude of inbreeding depression for this trait ranged from -12.23 to 9.78. All the crosses showed significant inbreeding depression.

4.3.3. Plant height

For plant height in rice semi dwarf plants and negative heterosis was desirable. The heterosis over better parent varied from 3.7 to 55.42. The standard heterosis over Pusa RH-10 varied from -2.13 to 73.87, over Pusa Basmati-1 varied from -6.50 to

66.11. None of the crosses showed significant negative heterosis over better parent and Pusa RH-10 and only one cross Pusa Sugandh-2 x BPT-5204 showed significant negative heterosis over Pusa Basmati-1.

The inbreeding depression value for plant height ranged from 1.69 to 20.71. Two crosses showed significant positive inbreeding depression. All the crosses showed significant inbreeding depression except cross Pusa Sugandh-2 x BPT-5204. Cross Pusa Sugandh-2 x Kasturi showed highest significant inbreeding depression.

4.3.4. Effective tillers per plant

The significant positive heterosis was desirable for effective tillers per plant. The range of heterobeltiosis was from 21.16 to 77.19. The range of standard heterosis over Pusa RH-10, Pusa Basmati-1 was 1.64 to 45.00 and 33.44 to 90.31 respectively. All crosses showed significant positive heterosis over better parent and Pusa Basmati-1 and five crosses showed significant positive heterosis over Pusa RH-10. Cross Pusa 1121 x Adamchini showed highest significant positive heterosis over better parent and Pusa Sugandh-2 x BPT-5204 recorded highest significant positive heterosis over both standard checks.

The magnitude of inbreeding depression for effective tillers per plant ranged from 25.87 to 46.73. All the crosses recorded significant inbreeding depression. Pusa Sugandh-2 x BPT-5204 showed highest significant inbreeding depression.

4.3.5. Number of grains per panicle

The positive heterosis for number of grains per panicle was desirable. The heterotic value for number of grains per panicle ranged from -31 to 41.41 per cent over better parent, 41.64 to 148.25 per cent over Pusa RH-10 and 13.31 to 98.60 per cent over Pusa Basmati-1. All crosses showed significant positive heterosis over standard checks and six crosses showed significant positive heterosis over better parent. Hybrid Pusa Sugandh-2 x BPT-5204 showed highest significant positive heterosis over better parent and standard checks.

The inbreeding depression for number of grains per panicle ranged from 18.7 to 33.45. All the crosses recorded significant inbreeding depression. Cross Pusa Sugandh-2 x Kasturi showed significant inbreeding depression.

4.3.6. 100-grain weight

The positive heterosis estimate was desirable for 100 seed weight. The heterobeltiosis ranged from -41.69 to 1.63 per cent, whereas the standard heterosis varied from -29.19 to 23.41 per cent and -23.20 to 33.86 per cent over Pusa RH-10 and Pusa Basmati -1, respectively. None of the crosses showed significant positive heterosis over better parent and four crosses showed significant positive heterosis over standard checks. Hybrid Pusa 1121 x Kasturi showed highest significant positive heterosis over standard checks.

The magnitude of inbreeding depression ranged from -67.47 to 4.13. All the crosses showed significant inbreeding depression. Cross Pusa 1121 x Adamchini showed highest significant inbreeding depression.

4.3.7. Grain yield per plant

The positive significant heterosis was desirable for grain yield per plant as the main objective of any breeding programme is to increase the yield. The range of heterosis over better parent was 49.82 to 145.24 per cent, while the standard heterosis ranged from -6.20 to 49.78 per cent over Pusa RH-10 and 59.44 to 154.63 per cent over Pusa Basmati-1. All crosses exhibited significant positive heterosis over better parent and Pusa Basmati-1 and four crosses exhibited significant positive heterosis over Pusa RH-10. Cross Type-3 x Adamchini recorded highest significant positive heterosis over better parent. However, highest significant positive standard heterosis over the both checks was exhibited by Pusa Sugandh-2 x BPT-5204.

The inbreeding depression for this trait ranged from 13.66 to 25.38. All the crosses observed significant inbreeding depression. Cross Pusa Sugandh-2 x BPT-5204 recorded highest significant inbreeding depression

4.3.8. Hulling recovery

The positive heterosis was desirable for hulling recovery as it is an important factor which decides the marketable produce. The range of heterobeltiosis for hulling recovery was from -6.24 to 3.62 per cent, while the standard heterosis varied from -1.22 to 8.14 per cent over Pusa RH-10 and from 0.98 to 10.55 per cent over Pusa Basmati-1. One hybrid displayed significant positive heterosis over the better parent, five crosses showed significant positive heterosis over Pusa RH-10 and six crosses showed significant positive heterosis over Pusa Basmati-1. The highest value of better parent heterosis was exhibited by Pusa 1121 x BPT-5204, whereas the highest significant positive heterosis over standard check was shown by Type-3 x Adamchini.

The magnitude of inbreeding depression for hulling recovery ranged from 7.35 to 11.88. All the crosses showed significant inbreeding depression.

4.3.9. Milling recovery

The significant positive heterosis was desirable for milling recovery. The perusal of data indicates that heterobeltiosis ranged from -7.59 to 3.21 per cent; standard heterosis ranged from -0.64 to 10.59 over Pusa RH-10 and -0.34 to 10.89 per cent over Taraori Basmati. Two crosses showed significant heterosis over better parent and six crosses recorded significant positive heterosis over standard checks. The highest value of better parent heterosis was exhibited by Pusa 1121 x BPT-5204, whereas the highest significant positive heterosis over standard check was observed for Type-3 x Adanchinni.

The inbreeding depression for milling recovery ranged from 5.97 to 12.19. All the crosses showed significant inbreeding depression.

4.3.10. Head rice recovery

The higher head rice recovery lead to higher marketable produce and hence positive heterotic value was desirable. The magnitude of heterosis for head rice recovery ranged from 1.01 to 4.01 per cent over better parent, 20.03 to 29.47 per cent over Pusa RH-10 and 18.33 to 27.64 per cent over Taraori Basmati. All crosses

showed significant positive heterosis- over standard checks and three crosses recorded significant positive heterosis over better parent. Cross Pusa Sugandh-2 x Adamchini showed highest significant positive heterosis over better parent and standard check.

The magnitude of inbreeding depression for this trait varied from 8.3 to 13.4. All the crosses showed significant inbreeding depression.

4.3.11. Grain length

The higher grain length was a desirable character and hence its heterosis in positive direction was highly desirable. The heterobeltiosis was ranged from -34.32 to 9.07 per cent, while standard heterosis varied from -37.54 to 19.83 per cent over Pusa RH-10 and -42.77 to 9.80 per cent over Taraori Basmati. One hybrid showed significant positive heterosis over better parent and Taraori Basmati and two hybrids showed significant positive heterosis over Pusa RH-10. Cross Pusa 1121 x Kasturi showed significant positive heterosis over better parent and standard check.

The inbreeding depression for this trait ranged from -48.75 to 11.64. Seven out of nine cross showed significant inbreeding depression

4.3.12. Grain breadth

The significant negative heterosis was desirable in grain breadth. The magnitude of heterosis for grain breadth varied from -3.88 to 23.91 per cent over better parents, -16.87 to 4.80 per cent over Pusa RH-10 and -13.43 to 9.14 per cent over Taraori Basmati. None of the crosses showed significant negative heterosis over better parent, whereas seven crosses showed significant negative heterosis over Pusa RH-10 and six crosses showed significant negative heterosis over Taraori Basmati. Cross Type-3 x BPT-5204 recorded highest negative value of heterosis over both the check varieties.

The magnitude of inbreeding depression for grain breadth ranged from -20.93 to 11.88. Six out of nine cross showed significant inbreeding depression.

4.3.13. Brown rice length

The positive significant heterosis was desirable for brown rice length. The heterobeltiosis for brown rice length ranged from -43.50 to 1.54 per cent, whereas standard heterosis ranged from -38.62 to 16.27 per cent and -38.95 to 15.64 per cent over Pusa RH-10 and Taraori Basmati, respectively. None of the crosses showed significant positive heterosis over better parent, two crosses showed significant positive heterosis over standard checks. Hybrid Pusa Sugandh-2 x Kasturi showed highest significant positive heterosis over both standard checks.

The inbreeding depression for this trait varied from -41.23 to 22.45. Five crosses showed significant inbreeding depression

4.3.14. Brown rice breadth

The negative heterosis was desirable for brown rice breadth. The magnitude of heterosis varied from -4.05 to 2.11 per cent over better parent, whereas standard heterosis varied from -1.21 to 6.05 and 0.32 to 7.78 over Pusa RH-10 and Taraori Basmati, respectively. None of the crosses showed significant negative heterosis over better parents and standard checks.

The magnitude of inbreeding depression for this trait ranged from -6.5 to -0.86. Two crosses showed significant inbreeding depression.

4.3.15. Kernel length

The kernel length was the most important trait which decides the quality of rice hence positive significant heterosis was desirable for this trait. The heterobeltiosis for the trait ranged from -42.81 to 3.93 per cent, whereas standard heterosis ranged from -42.86 to 15.64 per cent over Pusa RH-10 and -43.33 to 14.68 per cent over Taraori Basmati. Two crosses showed significant positive heterosis over standard checks and none of the crosses showed significant positive heterosis over better parent. Pusa Sugandh-2 x Kasturi showed highest significant positive heterosis over both standard checks.

The inbreeding depression for kernel length ranged from -48.1 to 1.7. Five out of nine crosses showed significant inbreeding depression

4.3.16. Kernel breadth

The negative significant heterosis was desirable for kernel width. The magnitude of heterosis for kernel width ranged from -4.20 to 3.36 per cent over better parent, 6.29 to 14.73 per cent over Pusa RH-10 and 5.46 to 13.84 per cent over Taraori Basmati. None of the crosses showed significant negative heterosis over better parents and standard checks.

The magnitude of inbreeding depression ranged from -8.9 to 1.98 for kernel breadth. One cross Pusa Sugandh-2 x Adamchini showed significant inbreeding depression

4.3.17. L/B ratio

The magnitude of heterosis for the trait ranged from -23.66 to 1.75 per cent over better parent, -23.85 to 3.95 per cent over Pusa RH-10 and -24.24 to 3.41 per cent over Taraori Basmati. None of the crosses showed significant positive heterosis over better parents and standard checks.

The inbreeding depression for this trait ranged from -12.87 to 13.71. Three crosses showed significant inbreeding depression.

4.3.18. Kernel length after cooking

The positive heterosis was desirable for kernel length after cooking and it was one of the most important grain quality trait. The heterobeltiosis for the trait ranged from -43.74 to 4.24 per cent, whereas the standard heterosis varied from -33.76 to 0.57 per cent and -30.36 to 5.73 over Pusa RH-10 and Taraori Basmati, respectively. One cross Pusa 1121 x Kasturi exhibited significant positive heterosis over Taraori Basmati and none of the crosses exhibited significant positive heterosis over better parent and Pusa RH-10.

The magnitude of inbreeding depression ranged for kernel length after cooking from -30.36 to 18.49. Five out of nine crosses showed significant inbreeding depression. One cross Pusa 1121 x Kasturi showed high significant inbreeding depression.

4.3.19. Kernel breadth after cooking

The negative heterosis was desirable for this trait. The magnitude of heterobeltiosis for this trait ranged from -3.23 to 51.01 per cent and the standard heterosis over Pusa RH-10 and Taraori Basmati ranged from -1.75 to 23.35 and 10.69 to 37.83, respectively. None of the crosses showed significant negative heterosis over better parents and standard checks.

The inbreeding depression for this trait ranged from -19.04 to 15.55. All the crosses showed significant inbreeding depression except cross Type-3 x Kasturi. The positive inbreeding depression value suggests the mean of F_2 is lower than F_1 mean which means the kernel breadth after cooking is reducing in F_2 which was desirable.

4.3.20. Elongation ratio

The significant positive heterosis was desirable for elongation ratio. The heterobeltiosis for this trait ranged from -16.12 to 3.08. The standard heterosis over Pusa RH-10 ranged from -10.46 to 6.21 and over Taraori Basmati ranged from -8.24 to 8.85. One cross showed significant positive heterosis over better parent and two crosses showed significant positive heterosis over standard checks. Pusa Sugandh-2 x Adamchini showed highest significant positive heterosis over better parent and standard checks.

The magnitude of inbreeding depression for elongation ratio was ranged from -6.86 to 10.66. Significant inbreeding depression was recorded for four crosses. One cross Pusa Sugandh-2 x Adamchini showed high significant inbreeding depression

4.3.21. Elongation index

The significant positive heterosis was desirable for elongation index. The magnitude of heterosis ranged from -24.92 to 2.22 per cent over better parent, -13.78

to 2.88 per cent over Pusa RH-10 and -14.89 to 1.55 per cent over Taraori Basmati. One cross Type-3 x Adamchini showed significant positive heterosis over Pusa RH-10 and none of the crosses showed significant positive heterosis over better parent and check Taraori Basmati.

The inbreeding depression for this trait ranged from -15.49 to 11.12. One cross Pusa Sugandh-2 x BPT-5204 showed significant inbreeding depression.

4.3.22. Alkali digestion value

The magnitude of heterosis was ranged from -16.74 to 11.69 per cent over better parent, -14.35 to 2.84 per cent over Pusa RH-10 and -8.23 to 10.18 per cent over Taraori Basmati. Two crosses showed significant positive heterosis over better parent, one cross showed significant positive heterosis over Pusa RH-10 and seven crosses showed significant positive heterosis over Taraori Basmati. Cross Type-3 x BPT-5204 showed highest significant positive heterosis over better parent, cross Pusa 1121 x Kasturi recorded highest significant positive heterosis over standard checks.

The magnitude of inbreeding depression for alkali digestion value varied from -3.87 to 9.48. All crosses showed significant inbreeding depression except Pusa Sugandh-2 x Kasturi.

4.3.23. Amylose content

The magnitude of heterobeltiosis ranged from -11.84 to 16.37; standard heterosis ranged from -3.47 to 15.45 per cent over Pusa RH-10 and -3.47 to 15.45 per cent over Taraori basmati. Three crosses showed significant positive heterosis over better parent and seven crosses showed significant positive heterosis over standard checks. Cross Pusa 1121 x Adamchini showed highest significant positive heterosis over better parent and standard checks.

The inbreeding depression for amylose content ranged from -18.59 to 1.82. Significant inbreeding depression was observed for four crosses.

4.3.24. Gel consistency

The significant positive heterosis was desirable for gel consistency. The magnitude of heterosis varied from -34.25 to 53.82 over better parent, -44.26 to 6.06 over Pusa RH-10 and -65.02 to 33.44 over Taraori Basmati. Four hybrids showed significant positive heterosis over better parent, two crosses showed significant positive heterosis over Pusa RH-10 and none of the crosses showed significant positive heterosis over Taraori Basmati. Hybrid Pusa 1121 x Kasturi showed highest significant positive heterosis over better parent and cross Pusa 1121 x BPT-5204 showed highest significant positive heterosis over Pusa RH-10.

The magnitude of inbreeding depression for this trait varied from -65.06 to 18.26. All the crosses showed significant inbreeding depression.

4.3.25. Aroma

The estimate of heterobeltiosis for this trait ranged from -26.65 to 1.65 per cent, while the standard heterosis ranged from -21.02 to 5.89 per cent over Pusa RH-10 and 30.75 to 7.15 per cent over Taraori Basmati. Two crosses showed significant positive heterosis over Pusa RH-10 but none of the crosses showed significant positive heterosis over better parents and Taraori Basmati. Cross Pusa Sugandh-2 x Kasturi showed highest significant positive heterosis over Pusa RH-10.

The inbreeding depression for aroma ranged from -12.40 to 5.65. Two crosses showed significant inbreeding depression.

4.4 Estimates of the gene actions through generation mean analysis

4.4.1. Scaling tests

The means of parents, F_1 s, F_2 s, B_1 s and B_2 s of nine crosses for 25 characters were subjected to A, B and C scaling tests of Mather (1949) and joint scaling test of Cavalli (1952). The estimates on the scales during *Kharif* 2015 are presented in Table 4.12 and 4.13. The calculated values of A, B and C scaling tests were highly

significant for majority of traits under study, which indicated that the additive dominance model was inadequate to explain the inheritance of the characters.

4.4.1.1. Type-3 / Adamchini :

The calculated values of all the three scaling tests were found significant for most of the characters except days to maturity, effective tillers per plant, 100 grain weight, grain yield per plant, hulling recovery, brown rice breadth, amylose content, gel consistency and aroma. The scales B and C were significant for days to maturity, effective tillers per plant, grain yield per plant and hulling. The scales A and B were significant for amylose content while, scales A and C were significant for kernel breadth. The scale C was significant for 100 grain weight and gel consistency. Joint scaling test revealed significance for all characters except for brown rice breadth, gel consistency and aroma. Brown rice breadth was non-significant for three scaling tests and joint scaling test. For the character gel consistency, joint scaling test revealed non-significant but scale C was significant value and six parameter revealed absence of significant epistatic interaction.

4.4.1.2. Type-3 / BPT-5204:

In this cross, the calculated values of all the scaling tests were found significant for most of the characters except days to 50 per cent flowering, days to maturity, grain yield per plant, hulling recovery, brown rice length, brown rice breadth, kernel length, L/B ratio, kernel length after cooking, elongation ratio and aroma. The scales B and C were significant for days to maturity, grain yield per plant, hulling recovery, brown rice length and kernel length after cooking, while scales A and B was significant for brown rice breadth. Only scale C was significant for days to 50 flowering, L/B ratio and elongation ratio, whereas scale B significant for kernel length. Joint scaling test was significant for all traits except aroma. Character aroma was non-significant for three scales and joint scaling test.

4.4.1.3. Type-3 / Kasturi:

For most of the characters three scaling tests were found significant except plant height, effective tillers per plant, number of grains per panicle, brown rice

length, brown rice breadth, kernel length, kernel breadth, kernel breadth after cooking, gel consistency, amylose content and aroma. The scales A and B were significant for brown rice breadth, kernel breadth and gel consistency, while scales B and C were significant for effective tillers per plant, kernel length and amylose content and scales A and C were significant for plant height. The scale C was significant for number of grains per panicle, brown rice length and kernel breadth after cooking and aroma. The joint scaling test indicates significance for all characters except kernel breadth after cooking. For the trait kernel breadth after cooking, scale C showed significant but joint scaling test showed non-significant and when interallelic interaction were studied by six parameter model it was non-significant for three type of interactions ($\hat{i}, \hat{j}$ and $\hat{l}$).

4.4.1.4. Pusa Sugandh-2 / Adamchini:

In the cross, the calculated values of all the three scaling tests were found significant for most of the characters except plant height, effective tillers per plant, hulling recovery, brown rice length, kernel length, kernel breadth, L/B ratio, elongation index, alkali spread value, amylose content and aroma. Scales B and C were significant for plant height, effective tillers per plant, kernel length, kernel breadth and amylose content. Scales A and B were significant for alkali digestion value, while scales A and C were significant for kernel breadth after cooking. Scale C was significant for hulling recovery and elongation index, whereas scale B was significant for brown rice length and L/B ratio. Joint scaling test was significant for all traits except for aroma. The character aroma was non-significant for three scaling tests and joint scaling test.

4.4.1.5. Pusa Sugandh-2 / BPT-5204

The three scaling test values were found significant for most of the characters except for milling recovery, grain breadth, brown rice length, kernel length, kernel breadth, L/B ratio, alkali digestion value, amylose content and aroma. Scales A and B were significant for brown rice length, kernel length, L/B ratio and aroma, while scales B and C were significant for kernel breadth and alkali digestion value and

scales A and C were significant for amylose content. Scale C was significant for milling, whereas scale B was significant for grain breadth. Joint scaling test was significant for all traits.

4.4.1.6. Pusa Sugandh-2 / Kasturi

In the cross, the three scaling tests were found significant for days to 50 per cent flowering, days to maturity, plant height, number of grains per panicle, head rice recovery, grain length, brown rice breadth, kernel breadth, kernel breadth after cooking and alkali digestion value. Scales A and B were found significant for L/B ratio, kernel length after cooking, elongation ratio and elongation index, while scales B and C were significant for effective tillers per plant, hulling recovery, milling recovery and amylose content. Scale A was significant for 100 grain weight; whereas scale B was significant for grain yield per plant and scale C was significant for grain breadth and aroma. Joint scaling test was significant for all the traits except 100 grain weight and kernel length. Trait kernel length was non-significant for three scales and joint scaling test. The character 100 grain weight was significant for scale A but non-significant for joint scaling test when interaction epistasis were studied it shows significant for $\hat{i}$ and $\hat{j}$ interactions.

4.4.1.7. Pusa 1121 / Adamchini

The three scaling tests were significant for days to maturity, plant height, 100-grain weight, head rice recovery, brown rice breadth, kernel breadth after cooking and elongation index. Scales B and C were significant for days to 50 per cent flowering, grain breadth, alkali digestion value and amylose content, whereas scales A and C were significant for grain yield per plant, milling recovery, kernel length after cooking and gel consistency. Scale C was significant for number of grains per panicle and hulling recovery, while scale A was significant for kernel length and L/B ratio and scale B was significant for kernel breadth. Joint scaling test was significant for all the traits except effective tillers per plant and brown rice length. Traits grain length and aroma were significant only by joint scaling test. Traits effective tillers per plant and brown rice length were non-significant for three scales and joint scaling test.

4.4.1.8. Pusa 1121 / BPT-5204:

In the cross, the three scaling test were significant for effective tillers per plant, hulling recovery, milling recovery, kernel length after cooking, kernel breadth after cooking and gel consistency. Scales B and C were significant for plant height, number of grains per panicle, 100 grain weight, grain length, kernel length, L/B ratio, elongation index, alkali digestion value and aroma. Scales A and C were significant for days to 50 per cent flowering, days to maturity, grain breadth, elongation ratio and amylose content. Scales A and B were significant for brown rice breadth. Scale A was significant for grain yield per plant, while scale B was significant for brown rice length. Trait Kernel breadth was non-significant for three scaling tests and joint scaling test.

4.4.1.9. Pusa 1121 / Kasturi:

The three scaling test values were found significant for most of the characters except for days to 50 per cent flowering, days to maturity, 100 grain weight, grain yield per plant, grain length, grain breadth, brown rice width, kernel breadth, elongation ratio, alkali digestion value, amylose content, gel consistency, aroma. Scales A and B were significant for elongation ratio, alkali digestion value, amylose content and gel consistency, while scales B and C were significant for grain length and grain breadth and scales A and C were significant for days to 50 per cent flowering, brown rice breadth and kernel breadth. Scale C was significant for days to maturity, whereas scale B was significant for grain yield per plant. Joint scaling test was significant for all traits except aroma. For trait 100-grain weight all three scales were non-significant but joint scaling test was significant. For aroma both three scaling tests and joint scaling test were non-significant.

Of 225 tests performed using both scaling tests and joint scaling test the results of joint scaling tests obtained were in agreement for 213 times while the A, B, C scales were in agreement for 210 times. The foregoing clearly indicates that the joint scaling test was more precise in predicting the presence of epistasis than any of the A B or C scales. In all the cases of disagreement the joint scaling test revealed

epistasis while estimates of i , j , l are non-significant. Thus the joint scaling test appears to overestimate epistasis while the A , B and C scales have a tendency of underestimation.

Therefore the joint scaling test and i , j and l estimates have been used as a basis for identification of non interacting crosses where the three parameter model was used for estimation of the gene effects however the six parameter model Hayman (1958) was applied in all the crosses to check and counter check the A , B , C scales and the joint scaling test.

4.4.2. Estimation of gene effects in Noninteracting crosses:

Estimates of m , d and h were obtained from the three parameter model of Jinks and Jones (1958) for the non interacting crosses. The decision for absence of epistasis was based on the significance of i , j and l estimates according to six parameter model.

4.4.2.1. Days to 50 per cent flowering:

Epistasis was absent for the cross Pusa 1121 x Kasturi. The estimate of d was significant for this character indicating that the trait was under the control of additive gene action (table).

4.4.2.2. Days to maturity:

This trait showed lack of interaction in the cross Pusa 1121 x Kasturi. The estimate of d was significant for this character indicating that the trait was under the control of additive gene action (table).

4.4.2.3. Effective tillers per plant:

This trait showed lack of interaction in the cross Pusa 1121 x Adamchini. Estimates of both d and h were significant, the later was more predominant. This indicates a greater role of dominance gene effect in control of this trait (table).

4.4.2.4. Grain breadth:

Epistasis was absent for the cross Pusa Sugandh-2 x BPT-5204 for the trait under study. The estimate of d was significant for this character indicating that the trait was under the control of additive gene action (table).

4.4.2.5. Brown rice breadth:

Epistasis was not detected in the crosses Type-3 x Adamchini and Pusa 1121 x Kasturi. Estimates of d were significant in both the cases while the estimates of h were non-significant, indicating the greater role of additive gene effects for controlling this trait.

4.4.2.6. Kernel length:

Epistasis was absent in the cross Pusa Sugandh-2 x Kasturi. The estimate of d was significant for this trait which indicates greater role of additive gene effects for the control of this trait.

4.4.2.7. Kernel breadth:

Epistasis was not detected for the crosses Type-3 x Adamchini, Pusa Sugandh-2 x BPT-5204 and Pusa 1121 x Kasturi. Estimates of d were significant for all three crosses whereas estimates of h were non-significant indicating the importance of additive gene effects for this trait.

4.4.2.8. Kernel breadth after cooking:

The cross Type-3 x Kasturi was non interacting for this trait. The estimate of d was significant which indicates the greater role of additive gene effects for this trait.

4.4.2.9. Alkali digestion value:

Epistasis was absent in the cross Type-3 x BPT-5204. The estimates of both d and h were significant but later was more predominant. This indicates a greater importance of dominance gene action in control of this trait.

4.4.2.10. Gel consistency:

Epistasis was absent in the crosses Type-3 x Adamchini and Type-3 x BPT-5204. The estimates of d were significant in both crosses while h were non-significant, indicating the importance of additive gene effects for this trait.

4.4.2.11. Aroma:

This trait showed lack of interaction for crosses Pusa Sugandh-2 x Adamchini and Pusa 1121 x Kasturi. The estimates of d were significant in both the cases, while those of h were non-significant, indicating the importance of additive gene effects for this trait.

4.4.3. Genetic components of generation mean

The six genetic components viz., mean ($\hat{m}$), additive ($\hat{d}$), dominance ($\hat{h}$), additive x additive ($\hat{i}$), additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) obtained from analysis of six populations (P_1 , P_2 , F_1 , F_2 , B_1 and B_2) for 7 yield and 18 quality traits of nine crosses viz., Type-3 x Adamchini, Type-3 x BPT-5204, Type-3 x Kasturi, Pusa Sugandh-2 x Adamchini, Pusa Sugandh-2 x BPT-5204, Pusa Sugandh-2 x Kasturi, Pusa 1121 x Adamchini, Pusa 1121 x BPT-5204 and Pusa 1121 x Kasturi are presented in Table 4.14 and 4.15.

4.4.3.1. Days to 50 per cent flowering

For trait days to 50 per cent flowering, complimentary epistasis was shown by two crosses and duplicate epistasis was shown by three crosses. The most diverse cross was Pusa Sugandh-2 x Adamchini which recorded high magnitude of significant dominance x dominance interaction ($\hat{i}$). Additive ($\hat{d}$) gene effects were significant, while dominance ($\hat{h}$) gene effects was non-significant. Interaction effects additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$) were significant. For diverse cross additive gene effects in main effects and dominance x dominance ($\hat{l}$) estimates of interaction were important. The trend of most diverse cross was followed by the cross Pusa Sugandh-2 x Kasturi.

All the crosses showed significant mean ($\hat{m}$) and additive ($\hat{d}$) effects. Seven crosses showed significant dominance effects. Of the interactions additive x additive ($\hat{i}$) was significant in five crosses, while additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) were significant in four and seven crosses respectively. For this trait, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect and dominance x dominance ($\hat{l}$) type of interactions was more important.

4.4.3.2. Days to maturity

Duplicate epistasis was recorded by five crosses and complimentary epistasis was observed for one cross. The most diverse cross for days to maturity was Pusa Sugandh-2 x Adamchini which showed high magnitude of dominance x dominance ($\hat{l}$) interaction. Additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects were significant. Additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$) type of interactions were also significant. For diverse cross additive and dominant gene effects in main effect and dominance x dominance ($\hat{l}$) estimates of interaction were important along with duplicate epistasis. None of the crosses followed the diverse cross inheritance pattern.

All the crosses showed significant mean ($\hat{m}$) and additive effects. Out of nine, eight crosses showed significant dominance effects. Of the interactions additive x additive ($\hat{i}$) was significant in six crosses, while additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) were significant in four and seven crosses respectively. For this trait, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect, additive x additive and dominance x dominance ($\hat{l}$) type of interactions were important.

4.4.3.3. Plant height:

Epistasis of duplicate type was present in four and complimentary type was present in two crosses. The most diverse cross under study was Pusa Sugandh-2 x Adamchini which recorded high magnitude of significant dominance ($\hat{h}$) gene effects. Additive ($\hat{d}$) gene effects were significant. Additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$) type of interactions were also significant. For diverse cross dominant gene effects in main effect and additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$)

types of interaction were important. None of the crosses followed the diverse cross inheritance pattern.

The mean ($\hat{m}$) was significant in all crosses; additive and dominance gene effects were significant in eight crosses. Additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$) types of interaction were significant for seven crosses, while dominance x dominance ($\hat{l}$) interaction was significant for six crosses. For this trait, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect, all type of interactions were important.

4.4.3.4. Effective tillers per plant:

Duplicate type and complimentary type of epistasis were present in two crosses each. For effective tillers per plant, Type-3 x Adamchini was the most diverse cross among studied crosses and high magnitude of dominance ($\hat{h}$) gene effects were recorded. Additive ($\hat{d}$) gene effects were recorded significant. Additive x additive ($\hat{i}$), additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were significant and also showed duplicate epistasis. For diverse cross, dominant gene effects in main effect and additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) types of interaction were important. One cross followed the diverse cross inheritance pattern.

All the crosses showed significant mean ($\hat{m}$), additive and dominance effects. Among the interactions additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$) was significant in six crosses, while dominance x dominance ($\hat{l}$) were significant in four crosses. For this trait, dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$) type of interactions were important.

4.4.3.5 Number of grains per panicle:

Duplicate type of epistasis was recorded for four crosses, while complimentary epistasis was shown by three crosses. Pusa 1121 x Adamchini was the diverse cross for trait number of grains per panicle and it showed high magnitude of additive x additive ($\hat{i}$) type of interaction. Additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects were significant and dominance x dominance ($\hat{l}$) type of interaction was significant. For diverse cross, additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects in main

effect and additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interaction along with duplicate epistasis were important in control of this trait. Out of nine crosses, three crosses followed the inheritance pattern of diverse cross.

For all the crosses mean ($\hat{m}$), additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects were significant. Additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) types of interaction were significant for eight and seven crosses respectively. Additive x dominance ($\hat{j}$) estimates were significant for five crosses. Dominance ($\hat{h}$) gene effects and additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions played a major role in inheritance of this trait.

4.4.3.6. 100-Grain weight:

Complimentary type of epistasis was found in three crosses and duplicate type of epistasis was recorded in two crosses. For the trait 100 grain weight, cross Pusa 1121 x Adamchini was diverse among the crosses and it showed high magnitude of significant dominance ($\hat{h}$) gene effects. Additive ($\hat{d}$) gene effects were also significant. All type of interactions were significant and complementary epistasis was also present. Dominance ($\hat{h}$) gene effects and additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were more important. One cross was followed the inheritance pattern of most diverse cross.

All the crosses showed significant mean ($\hat{m}$) effects. Out of nine crosses, additive ($\hat{d}$) and dominance ($\hat{h}$) were significant in eight and seven crosses respectively. Of the interactions additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were significant in eight and six crosses respectively, while additive x dominance ($\hat{j}$) type of interaction was significant in five crosses. For this trait, additive ($\hat{d}$), and dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) type of interactions were important.

4.4.3.7. Grain yield per plant:

Four crosses recorded duplicate epistasis and two crosses showed complementary epistasis. The most diverse cross was Pusa Sugandh-2 x Adamchini

and recorded high magnitude of significant dominance ($\hat{h}$) gene effects. Additive ($\hat{d}$) gene effects were also significant. Dominance x dominance ($\hat{l}$) type of interactions were significant and duplicate epistasis was present. For diverse cross, dominance ($\hat{h}$) gene effects and dominance x dominance ($\hat{l}$) type of interactions along with duplicate type of epistasis was more important. None of the crosses followed the inheritance pattern of the most diverse cross.

All the crosses showed significant mean ($\hat{m}$), additive ($\hat{d}$) and dominance ($\hat{h}$) effects. Among the interactions additive x additive ($\hat{i}$) type of interactions was significant for three crosses, while additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) were significant in eight and six crosses respectively. For this trait, dominance ($\hat{h}$) gene effects in main effect and among interaction effects additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) types were important.

4.4.3.8. Hulling recovery:

Six crosses showed duplicate type of epistasis. Cross Pusa 1121 x Adamchini was the most diverse cross for this trait. It showed highest magnitude of significant additive x additive ($\hat{i}$) type of interactions. Additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects were also significant. Additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were significant along with duplicate type of epistasis. For diverse cross, dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions along with duplicate type of epistasis was more important. Four out of nine crosses followed the inheritance pattern of the most diverse cross.

All crosses showed significant mean ($\hat{m}$) and dominance ($\hat{h}$) gene effect. Six crosses showed significant additive ($\hat{d}$) effect. All nine crosses recorded significant additive x additive ($\hat{i}$) type of interactions, while additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were significant in three and six crosses respectively. For this trait, dominance ($\hat{h}$) gene effects in main effect and additive x additive ($\hat{i}$) type of interactions were important.

4.4.3.9. Milling recovery:

Duplicate epistasis was recorded for six crosses while complimentary epistasis was observed for two crosses. For trait milling recovery, Pusa 1121 x Adamchini was most diverse cross and it recorded high magnitude of additive x additive ($\hat{i}$) type of interaction. Additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects were significant. Additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were significant along with duplicate type of epistasis. For diverse cross, dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions along with duplicate type of epistasis was more important. None of the crosses followed the inheritance pattern of the most diverse cross.

All crosses showed significant mean ($\hat{m}$) and dominance ($\hat{h}$) effect. Seven crosses showed significant additive ($\hat{d}$) effect. All crosses recorded significant additive x additive ($\hat{i}$) type of interactions, while additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were significant in one and eight crosses respectively. For this trait, dominance ($\hat{h}$) gene effects in main effect and additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important.

4.4.3.10. Head rice recovery:

Three crosses recorded complementary type of epistasis. All crosses showed significant mean ($\hat{m}$) and dominance ($\hat{h}$) effect. Six crosses showed significant additive ($\hat{d}$) effect. Eight crosses recorded significant additive x additive ($\hat{i}$) type of interactions, while additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were significant in two and three crosses respectively. For this trait, dominance ($\hat{h}$) gene effects in main effect and additive x additive ($\hat{i}$) type of interactions were important.

4.4.3.11. Grain length:

Duplicate epistasis was recorded for five crosses while complimentary epistasis was observed for two crosses. For trait grain length, Pusa 1121 x Adamchini was the most diverse cross it showed significant high magnitude of additive ($\hat{d}$) gene

effects. Dominance ($\hat{h}$) gene effects were significant. Additive x additive ($\hat{i}$), additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were significant along with duplicate epistasis. For diverse cross, additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions along with duplicate type of epistasis was more important. Two crosses i.e., Type-3 x Adamchini and Pusa Sugandh-2 x Kasturi followed the most diverse cross inheritance pattern.

All the crosses recorded significant mean ($\hat{m}$) and additive ($\hat{d}$) effects. Seven crosses revealed significant dominance ($\hat{h}$) gene effect. Additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were significant eight crosses while Additive x dominance ($\hat{j}$) type of interactions were significant six crosses. For this trait, additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects in main effect and additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important.

4.4.3.12. Grain breadth:

Duplicate and complementary type of epistasis was observed in three crosses. Cross Pusa 1121 x BPT-5204 was most diverse for this trait which showed high estimates of significant dominance ($\hat{h}$) gene effects. Additive ($\hat{d}$) gene effects were significant. Additive x additive ($\hat{i}$), additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were significant along with duplicate epistasis. For diverse cross, dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions along with duplicate type of epistasis was more important. One cross followed the inheritance pattern of the most diverse cross.

All crosses recorded significant mean ($\hat{m}$), additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects. Additive x additive ($\hat{i}$) type of interactions were significant for eight crosses, while additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were significant in two and six crosses respectively. For this trait, dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important.

4.4.3.13. Brown rice length:

Duplicate type of epistasis was observed in five crosses. For brown rice length, cross Pusa 1121 x Adamchini was most diverse as it showed high estimates of significant additive ($\hat{d}$) gene effects. Additive x dominance ($\hat{j}$) types of interactions were significant. For diverse cross, additive ($\hat{d}$) gene effects in main effect and additive x dominance ($\hat{j}$) type of interactions were more important. One cross followed the inheritance pattern of the most diverse cross.

The mean ($\hat{m}$) was significant in all crosses; additive and dominance gene effects were significant in five crosses. Additive x additive ($\hat{i}$), additive x dominance ($\hat{j}$) and dominance x dominance estimates of interaction were significant for six crosses. For this trait, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect and all type of interactions were equally important.

4.4.3.14. Brown rice breadth:

Duplicate type of epistasis was observed in four crosses. Cross Type-3 x Kasturi was most diverse for this trait and it recorded high magnitude of significant dominance x dominance ($\hat{l}$) type of interaction. Additive ($\hat{d}$) gene effects and additive x additive ($\hat{i}$) type of interactions were significant. For diverse cross, additive ($\hat{d}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were more important. None of the crosses followed the inheritance pattern of the diverse cross.

The mean ($\hat{m}$) was significant in all crosses; additive and dominance gene effects were significant in four crosses. Additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$) estimates of interaction were significant for six and two crosses respectively. Dominance x dominance ($\hat{l}$) estimates of interaction were significant for seven crosses. For this trait, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important.

4.4.3.15. Kernel length:

Duplicate epistasis was observed in five crosses, while one cross showed complementary epistasis. For the trait kernel length, Pusa 1121 x Adamchini, the most diverse cross showed high magnitude of significant additive ($\hat{d}$) gene effects.

Dominance ($\hat{h}$) gene effects were significant. Additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were significant along with duplicate epistasis. For diverse cross, Additive ($\hat{d}$) gene effects in main effect, Additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions along with duplicate epistasis were more important. None of the crosses followed the inheritance pattern of the diverse cross.

All the crosses showed significant mean ($\hat{m}$) effects. Additive ($\hat{d}$) and dominance ($\hat{h}$) were significant in seven and six crosses respectively. Of the interactions additive x additive ($\hat{i}$) was significant in five crosses, while additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) were significant in six and seven crosses respectively. For this trait, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect and all type of interactions were important.

4.4.3.16. Kernel breadth:

Three crosses recorded duplicate type of epistasis. Cross Type-3 x Kasturi was the most diverse for the kernel breadth which recorded high estimates of significant dominance x dominance ($\hat{l}$) type of interactions. For diverse cross, dominance x dominance ($\hat{l}$) type of interactions was more important. None of the crosses followed the inheritance pattern of the diverse cross.

The mean ($\hat{m}$) was significant in all crosses; additive and dominance gene effects were significant in two and four crosses respectively. Additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$) estimates of interaction were significant for four and one crosses respectively. Dominance x dominance ($\hat{l}$) estimates of interaction were significant for five crosses. For this trait, dominance ($\hat{h}$) in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important.

4.4.3.17. L/B ratio:

Duplicate type of epistasis was recorded for four crosses. All the crosses showed significant mean ($\hat{m}$) effects. Additive ($\hat{d}$) and dominance ($\hat{h}$) were shown significant in six and five crosses respectively. Of the interactions additive x additive

($\hat{i}$) was significant in seven crosses, while additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) were significant in six crosses each. For this trait, additive ($\hat{d}$), dominance ($\hat{h}$) gene effects in main effect and all type of interactions were important.

4.4.3.18. Kernel length after cooking:

Seven crosses revealed duplicate type of epistasis. The cross Pusa 1121 x Adamchini was diverse for this trait, and it showed high magnitude of significant additive ($\hat{d}$) gene effects. Dominance ($\hat{h}$) gene effects and additive x dominance ($\hat{j}$) type of interactions were significant. For diverse cross, additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects in main effect and additive x dominance ($\hat{j}$) type of interactions were more important. None of the crosses followed the inheritance pattern of the diverse cross.

The mean ($\hat{m}$) was significant in all crosses; additive and dominance gene effects were significant in eight crosses. Additive x additive ($\hat{i}$), additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) estimates of interaction were significant for eight crosses. For this trait, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect, all type of interactions along with duplicate epistasis were important.

4.4.3.19. Kernel breadth after cooking:

Duplicate epistasis was observed in three crosses, while two crosses showed complementary epistasis. For trait kernel breadth after cooking, the most diverse cross was Pusa 1121 x BPT-5204 showed high estimates of significant additive x additive ($\hat{i}$) type of interactions. The additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects were significant. Dominance x dominance ($\hat{l}$) type of interaction was significant along with duplicate epistasis. For diverse cross, additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects in main effect and additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions along with duplicate epistasis were more important. None of the crosses followed the inheritance pattern of the diverse cross.

All the crosses recorded significant mean ($\hat{m}$) and additive ($\hat{d}$) gene effects. Seven crosses revealed significant dominance ($\hat{h}$) gene effect. Additive x additive ($\hat{i}$) type of interactions were significant in all the crosses, while additive x dominance ($\hat{j}$)

and dominance x dominance ($\hat{l}$) type of interactions were significant in five crosses each. For this trait, additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects in main effect and additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important.

4.4.3.20. Elongation ratio:

Duplicate epistasis was observed in five crosses, while one cross showed complementary epistasis. All the crosses recorded significant mean and additive ($\hat{d}$) effects. Eight crosses revealed significant dominance ($\hat{h}$) gene effect. Additive x additive ($\hat{i}$) type of interactions were significant seven crosses, while additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were significant in five and eight crosses respectively. For this trait, dominance ($\hat{h}$) gene effects in main effect and additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important.

4.4.3.21. Elongation index:

Duplicate epistasis was observed in seven crosses, while one cross showed complementary epistasis. The mean ($\hat{m}$) was significant in all crosses; additive and dominance gene effects were significant in eight crosses. Additive x additive ($\hat{i}$) and dominance x dominance estimates of interaction were significant for all crosses. Additive x dominance ($\hat{j}$) estimates of interaction were significant for seven crosses. For this trait, dominance ($\hat{h}$) gene effects in main effect, all type of interactions along with duplicate epistasis were important.

4.4.3.22. Alkali digestion value:

Seven crosses revealed duplicate type of epistasis. All the crosses recorded significant mean ($\hat{m}$) and additive ($\hat{d}$) effects. Seven crosses revealed significant dominance ($\hat{h}$) gene effect. Additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were significant for all crosses, while additive x dominance ($\hat{j}$) type of interactions were significant in seven crosses. For this trait, dominance ($\hat{h}$) gene effects in main effect and all type of interactions were important.

4.4.3.23. Amylose content:

All the crosses revealed duplicate epistasis. Significant mean ($\hat{m}$), additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects were recorded for all crosses. Additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were significant for all crosses, while additive x dominance ($\hat{j}$) type of interaction were significant for six crosses. For this trait, dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions along with duplicate epistasis were important.

4.4.3.24. Gel consistency:

Six crosses showed duplicate type of interactions. The most diverse cross for the trait gel consistency, was Pusa 1121 x Adamchini. It showed higher estimates of significant dominance x dominance ($\hat{l}$) type of interaction. The additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects were significant. Additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$) type of interactions were significant along with duplicate epistasis. For diverse cross, dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions along with duplicate epistasis were more important. Three crosses followed the inheritance pattern of the diverse cross.

All the crosses showed significant mean ($\hat{m}$), additive ($\hat{d}$) and dominance ($\hat{h}$) effects. Among the interactions additive x additive ($\hat{i}$) was significant for all crosses, while additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) were significant in six crosses each. For this trait, dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions and duplicate epistasis were important.

4.4.3.25. Aroma:

Duplicate epistasis was observed in two crosses for this trait. All the crosses showed significant mean ($\hat{m}$) effects. Additive ($\hat{d}$) and dominance ($\hat{h}$) were shown significant in six and four crosses respectively. Of the interactions additive x additive ($\hat{i}$) was significant in five crosses, while additive x dominance ($\hat{j}$) and dominance x

dominance ($\hat{l}$) were significant in one and four crosses respectively. For this trait, dominance ($\hat{h}$) in main effect and additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important.

4.5. Frequency Distribution in F₂:

4.5.1. Days to 50 per cent flowering:

Eight out of nine crosses observed nearly normal distribution. The cross Pusa Sugandh-2 x Adamchini showed distinct two peaks. A wide range of variation for days to 50 per cent flowering was shown by cross Type-3 x Adamchini. Transgressive segregation in both the directions was observed in five crosses while in crosses Type-3 x Adamchini, Pusa Sugandh-2 x Adamchini, Pusa 1121 x Adamchini and Type-3 x BPT-5204 no plants exceeding the superior parent was observed.

4.5.2. Days to maturity:

All the crosses showed normal distribution for this trait except cross Pusa Sugandh-2 x Adamchini showed two peaks. Transgressive segregation in both the directions was observed in five crosses while in crosses Type-3 x Adamchini, Pusa Sugandh-2 x Adamchini, Pusa 1121 x Adamchini and Type-3 x BPT-5204 transgressive segregants on higher side were not recovered. Maximum variation for this character was shown by cross Type-3 x Adamchini.

4.5.3. Plant height:

Seven out of nine crosses showed near normal distribution, while crosses Type-3 x Adamchini and Pusa 1121 x Adamchini showed bimodal distribution. In most of the crosses transgressive segregants in both directions were recovered but crosses Type-3 x Kasturi and Pusa 1121 x Adamchini transgressive segregants on higher side were not recovered. For plant height maximum variation was observed in the cross Pusa Sugandh-2 x Adamchini.

4.5.4. Effective tillers per plant:

For the character effective tillers per plant all crosses recorded normal distribution. Distribution curve with a marked tendency for skewness towards lower

effective tillers was observed in cross Pusa Sugandh-2 x Kasturi. Transgressive segregants in both directions were recorded in all crosses. Wide range of variation was observed for cross Pusa 1121 x Adamchini.

4.5.5. Grains per panicle

For this trait all crosses showed near normal distribution. Transgressive segregants in both directions were recorded in all crosses. Maximum variation was observed in cross Pusa Sugandh-2 x BPT-5204.

4.5.6. 100 grain weight

All the crosses showed near normal distribution for trait hundred grain weight. Transgressive segregants in both directions were recorded in all crosses except Type-3 x Adamchini and Pusa 1121 x Adamchini. Cross Pusa Sugandh-2 x Adamchini showed wide range of variation and cross Pusa Sugandh-2 x BPT-5204 showed more number of transgressive segregants on higher side which was desirable.

4.5.7. Grain yield per plant:

For the trait grain yield per plant all crosses showed near normal distribution . A marked transgressive segregants in both directions were recorded in all crosses except Type-3 x Adamchini and Type-3 x BPT-5204. Maximum variation for this trait was observed in cross Pusa 1121 x Adamchini. All crosses showed more number of transgressive segregants on higher side which was desirable.

4.5.8. Hulling recovery:

Distribution for this trait was relatively flat and skewed towards lower hulling recovery. Five crosses (Pusa Sugandh-2 x Adamchini, Pusa Sugandh-2 x Kasturi, Pusa 1121 x Adamchini, Pusa 1121 x BPT-5204 and Pusa 1121 x Kasturi) showed bimodal distribution and four crosses (Type-3 x Adamchini, Type-3 x BPT-5204, Type-3 x Kasturi and Pusa Sugandh-2 x BPT-5204) showed near to normal distribution. Transgressive segregants in both directions were recorded in all crosses. Cross Pusa 1121 x Adamchini showed wide range of variation for this trait.

4.5.9. Milling recovery:

All the crosses showed near to normal distribution for the trait milling recovery disregard was observed in three crosses Pusa Sugandh-2 x Adamchini, Pusa 1121 x Adamchini and Pusa 1121 x Kasturi which recorded bimodal distribution. Transgressive segregants in both directions were recorded in all crosses. Maximum variation for this character was shown by cross Pusa 1121 x Adamchini.

4.5.10. Head rice recovery:

All the crosses recored near to normal distribution for the trait head rice recovery except Type-3 x BPT-5204, Pusa Sugandh-2 x Kasturi and Pusa Sugandh-2 x BPT-5204 which observed bimodal distribution. Transgressive segregants in both directions were recorded in all crosses. Cross Pusa Sugandh-2 x Kasturi showed maximum variation for this trait.

4.5.11. Grain length:

For the trait grain length all the crosses showed near to normal distribution. Transgressive segregants in both directions were recorded in all crosses except Type-3 x Adamchini, Pusa Sugandh-2 x Adamchini and Pusa 1121 x Adamchini. Cross Type-3 x Adamchini Showed maximum variation for this trait. Cross Pusa Sugandh-2 x Kasturi showed more number of transgressive segregants on higher side for this trait.

4.5.12. Grain breadth:

Five crosses (Type-3 x Adamchini, Type-3 x BPT-5204, Pusa Sugandh-2 x BPT-5204, Pusa 1121 x Adamchini and Pusa 1121 x BPT-5204) recored near to normal distribution for the trait grain breadth while remaining four crosses (Type-3 x Kasturi, Pusa Sugandh-2 x Adamchini, Pusa Sugandh-2 x Kasturi and Pusa 1121 x Kasturi) observed bimodal distribution. Transgressive segregants in both directions were recorded in all crosses. A wide range of variation was shown by cross Pusa 1121 x Kasturi.

4.5.13. Brown rice length:

Distribution for this trait was skewed towards lower brown rice length. All the crosses recorded near to normal distribution. Transgressive segregants on either direction were recorded for five crosses while four crosses do not show segregants on higher side. Cross Type-3 x BPT-5204 showed maximum variation for this trait.

4.5.14. Brown rice breadth:

Five out of nine crosses recorded multimodal distribution, while remaining four crosses i.e., Type-3 x Adamchini, Type-3 x BPT-5204, Pusa Sugandh-2 x BPT-5204, and Pusa 1121 x BPT-5204 observed near to normal distribution. Transgressive segregants in both directions were recorded in all crosses. Cross Pusa 1121 x Kasturi showed wide variation for this character.

4.5.15. Kernel length:

Distribution for this trait was skewed towards lower kernel length. All the crosses recorded near to normal distribution. Transgressive segregants in both directions were recorded in five crosses (Type-3 x Adamchini, Type-3 x BPT-5204, Type-3 x Kasturi, Pusa Sugandh-2 x Adamchini and Pusa Sugandh-2 x BPT-5204) and not recovered in remaining four crosses. Maximum variation for this trait was shown by cross Type-3 x BPT-5204.

4.5.16. Kernel breadth:

Five out of nine crosses recorded multimodal distribution, while remaining four crosses i.e., Type-3 x Adamchini, Type-3 x BPT-5204, Pusa Sugandh-2 x BPT-5204, and Pusa 1121 x BPT-5204 observed near to normal distribution. Transgressive segregants in both directions were recorded in all crosses. Cross Pusa Sugandh-2 x Kasturi showed maximum variation for this character.

4.5.17. L/B ratio:

Frequency distribution curve for this trait was near to normal with skewness towards lower L/B ratio. All the crosses recorded near to normal distribution.

Transgressive segregants in both directions were recorded in all crosses. Maximum variation for this trait was shown by cross Type-3 x BPT-5204.

4.5.18. Kernel length after cooking:

For the trait kernel length after cooking all the crosses showed near to normal distribution. Transgressive segregants in both directions were observed for only two crosses Type-3 x BPT-5204 and Pusa Sugandh-2 x Kasturi. Cross Type-3 x BPT-5204 observed wide variation for this trait.

4.5.19. Kernel breadth after cooking:

Five out of nine crosses recorded near to normal distribution, while remaining four crosses i.e., Type-3 x Kasturi, Pusa Sugandh-2 x Adamchini, Pusa Sugandh-2 x Kasturi and Pusa 1121 x Kasturi observed multimodal distribution. Transgressive segregants in both directions were observed for all crosses except Type-3 x BPT-5204, Pusa Sugandh-2 x BPT-5204 and Pusa 1121 x BPT-5204. Maximum variation was shown by cross Pusa Sugandh-2 x Adamchini.

4.5.20. Elongation ratio:

Frequency distribution curve for this trait was normal with skewness towards lower elongation ratio. All the crosses recorded near to normal distribution. Transgressive segregants obtained in both directions for all crosses except three crosses (Pusa 1121 x Adamchini, Pusa 1121 x BPT-5204 and Pusa 1121 x Kasturi). The maximum variation was observed for cross Type-3 x BPT-5204.

4.5.21. Elongation index:

For the trait elongation index all crosses recorded near to normal distribution. Transgressive segregants recovered in both directions for four crosses but in remaining crosses transgressive segregants were not recovered on higher side. A wide range of variation was observed for Pusa Sugandh-2 x Adamchini.

4.5.22. Alkali digestion value:

All the crosses showed near to normal distribution for the trait alkali digestion value. Transgressive segregants in both directions were recorded in all crosses.

4.5.23. Amylose content:

For the character amylose content all crosses showed near to normal distribution. Transgressive segregants in both directions were recorded in all crosses except Pusa 1121 x Adamchini. Maximum variation for this trait was shown by cross Type-3 x BPT-5204.

4.5.24. Gel consistency:

Seven out of nine crosses showed near to normal distribution for this trait, while remaining two crosses *i.e.*, Pusa Sugandh-2 x Adamchini and Pusa Sugandh-2 x Kasturi recorded bimodal distribution. Transgressive segregants in both directions were recorded in all crosses. Cross Pusa Sugandh-2 x BPT-5204 showed wide variation for this trait.

4.5.25. Aroma:

For this trait aroma near to normal distribution was observed for cross Pusa 1121 x Kasturi and Pusa Sugandh-2 x Adamchini, while bimodal distribution observed for crosses Type-3 x Adamchini, Type-3 x BPT-5204, Pusa Sugandh-2 x BPT-5204, Pusa Sugandh-2 x Kasturi and Pusa 1121 x Adamchini. Trimodal distribution was observed for crosses Type-3 x BPT-5204 and Pusa 1121 x BPT-5204. Transgressive segregants in both directions were recorded in all crosses.



Table 4.1. Allelic variation and polymorphic information content (PIC) values for SSR markers identified in 24 rice genotypes.

SSR LOCUS	Sequence 5'----- 3'	Number of alleles	PIC VALUE
RM217	F ATCGCAGCAATGCCTCGT R GGGTGTGAACAAAGACAC	2	0.288194
RM276	F CTCAACGTTGACACCTCGTG R TCCTCCATCGAGCAGTATCA	3	0.204861
RM218	F TGGTCAAACCAAGGTCCTTC R GACATACATTCTACCCCCGG	2	0.414931
RM3	F ACACTGTAGCGGCCACTG R CCTCCACTGCTCCACATCTT	3	0.282986
RM 162	F GCCAGCAAAACCAGGGATCCGG R CAAGGTCTTGTGCGGCTTGCGG	2	0.206597
RM 251	F GAATGGCAATGGCGCTAG R ATGCGGTTCAAGATTGATC	2	0.399306
RM 7049	F AACCTAGATCTAATCCGTGG R CATCTCTGAGTTGAGCAAAC	2	0.074653
RM 8226	F TTAGGATACGGCTTCTAGGC R CGTAATTGTTGCATATGGTG	2	0.449653
RM 204	F GTGACTGACTTGGTCATAGGG R GCTAGCCATGCTCTCGTACC	2	0.444444
RM 505	F AGAGTTATGAGCCGGGTGTG R GATTTGGCGATCTTAGCAGC	2	0.399306
RM 3395	F ACCTCATGTCCAGGTGGAAG R AGATTAGTGCCATGGCAAGG	2	0.262153
RM 5481	F TGTTATGTGAGCCATAATGA R CTTTCTTAATGAAGCTCCAA	2	0.206597
RM 7356	F CCAAGGACACATATGCATGC R GCAATTCATGGCGCTGTTC	2	0.277778
RM 7556	F ACGCTAATACGGCGCAGTAG R AGGACTGACAGTGAGAGAGTCG	2	0.296875
RM 8264	F ACGCTCCTCGCTTTCTAC R GCACCTCACACCAGTAATTC	3	0.4375
RM 527	F GGCTCGATCTAGAAAATCCG R TTGCACAGGTTGCGATAGAG	2	0.548611
RM 447	F CCCTTGTGCTGTCTCCTCTC R ACGGGCTTCTTCTCCTCTC	2	0.0746
RM 449	F TTGGGAGGTGTTGATAAGGC R ACCACCAGCGTCTCTCTCTC	2	0.329861

	Table 4.2: Similarity coefficient among 24 rice genotypes based on molecular analysis.																								
	TYPE-3	RANBIR BA	DDn-3-1-72	DDN-1-4-75	DDN(awnless)	DDN-1-8-80	KALANAMAK	DHANPRASAD	ADAMCHINNI	BPT-5204	KASTURI	SONWALBASMATI	B-370	HUBR-10-9	PS-3	TBD-2	PS-2	HUBR-16	HUBR-9-1-2-1	HUBR-1-2-25-5	TARORIBASMATI	PUSABASMATI-1	PUSA1121	PUSA1509	
TYPE-3	1.00																								
RANBIR BASMATI	0.73	1.00																							
DDn-3-1-72	0.63	0.75	1.00																						
DDN-1-4-75	0.58	0.52	0.66	1.00																					
DDN(awnless)	0.86	0.85	0.72	0.60	1.00																				
DDN-1-8-80	0.86	0.85	0.72	0.60	0.94	1.00																			
KALANAMAK	0.56	0.54	0.48	0.55	0.65	0.65	1.00																		
DHANPRASAD	0.39	0.37	0.39	0.41	0.46	0.46	0.36	1.00																	
ADAMCHINNI	0.56	0.54	0.64	0.70	0.64	0.64	0.41	0.46	1.00																
BPT-5204	0.30	0.28	0.39	0.45	0.27	0.27	0.19	0.31	0.37	1.00															
KASTURI	0.77	0.85	0.72	0.55	0.90	0.90	0.58	0.41	0.58	0.31	1.00														
SONWALBASMATI	0.56	0.54	0.48	0.41	0.52	0.52	0.41	0.31	0.41	0.27	0.58	1.00													
B-370	0.86	0.85	0.72	0.60	0.84	0.64	0.65	0.46	0.64	0.27	0.90	0.52	1.00												
HUBR-10-9	0.50	0.42	0.59	0.45	0.46	0.46	0.27	0.36	0.52	0.46	0.52	0.46	0.46	1.00											
PS-3	0.67	0.52	0.52	0.48	0.56	0.56	0.34	0.22	0.45	0.39	0.63	0.56	0.56	0.50	1.00										
TBD-2	0.34	0.37	0.43	0.37	0.31	0.31	0.31	0.27	0.24	0.41	0.36	0.41	0.31	0.36	0.44	1.00									
PS-2	0.48	0.41	0.47	0.44	0.39	0.39	0.22	0.22	0.50	0.39	0.44	0.50	0.39	0.56	0.60	0.50	1.00								
HUBR-16	0.63	0.54	0.48	0.45	0.58	0.58	0.36	0.31	0.52	0.31	0.65	0.73	0.58	0.52	0.77	0.46	0.70	1.00							
HUBR-9-1-2-1	0.48	0.46	0.52	0.48	0.44	0.44	0.26	0.22	0.50	0.44	0.50	0.50	0.44	0.56	0.60	0.56	0.90	0.70	1.00						
HUBR-1-2-25-5	0.67	0.52	0.47	0.44	0.56	0.56	0.34	0.30	0.50	0.30	0.63	0.70	0.56	0.50	0.82	0.44	0.74	0.89	0.67	1.00					
TARORIBASMATI	0.56	0.61	0.59	0.50	0.65	0.65	0.52	0.31	0.52	0.31	0.73	0.52	0.65	0.46	0.44	0.23	0.39	0.46	0.44	0.44	1.00				
PUSABASMATI-1	0.54	0.41	0.47	0.44	0.44	0.44	0.26	0.26	0.56	0.34	0.50	0.44	0.44	0.63	0.67	0.26	0.60	0.63	0.54	0.67	0.56	1.00			
PUSA1121	0.54	0.41	0.52	0.48	0.44	0.44	0.34	0.26	0.45	0.34	0.50	0.34	0.44	0.63	0.67	0.44	0.60	0.50	0.60	0.54	0.44	0.67	1.00		
PUSA1509	0.54	0.41	0.52	0.48	0.44	0.44	0.34	0.26	0.45	0.34	0.50	0.34	0.44	0.63	0.67	0.44	0.60	0.50	0.60	0.54	0.44	0.67	0.84	1.00	

Table 4.3: Analysis of variance for combining ability of different characters

S.No.	Characters	Mean squares						
		Replications (d.f.= 2)	Crosses (d.f.= 8)	Females (d.f.= 2)	Males (d.f.= 2)	Female x male (d.f.= 4)	Error (d.f.= 28)	Total (d.f.= 44)
1.	Days to 50 percent flowering	2.53	714.57**	150.99*	2601.45**	52.9**	2.51	9583.0108
2.	Days to maturity	2.00	720.53**	150.99*	2631.18**	49.97**	2.42	221.1492
3.	Plant height	1.37	1845.03**	1989.90	2831.55	1279.33**	4.53	594.0298
4.	Effective tillers per plant	0.05	14.61**	5.52	26.50	13.22**	0.80	14.9971
5.	Number of grains per panicle	5.72	4208.94**	7311.68*	4088.36	2717.86**	2.43	1610.4396
6.	Hundred grain weight	0.00	0.51**	0.43	1.13	0.24**	0.00	0.1618
7.	Grain yield per plant	3.34	213.77**	20.86	311.11	261.54**	2.49	108.6555
8.	Hulling recovery	0.69	13.58**	4.05	36.58	6.84**	0.69	4.2066
9.	Milling recovery	0.02	13.13**	14.10	17.24	10.59**	0.57	4.3648
10.	Head rice recovery	0.03	5.36**	1.27	16.38	1.89	0.45	2.7023
11.	Grain length	0.30	10.66**	10.49	30.91	0.63	0.20	3.8205
12.	Grain breadth	0.02	0.08*	0.24	0.03	0.03	0.00	0.0270
13.	Brown rice length	0.27	5.74**	1.90	17.82	1.62	0.20	2.5064
14.	Brown rice breadth	0.03	0.01*	0.02	0.00	0.00	0.00	0.0058
15.	Kernel length	0.10	6.13*	2.54	18.38	1.81	0.15	2.3886

S.No.	Characters	Mean squares						
		Replications (d.f.= 2)	Crosses (d.f.= 8)	Females (d.f.= 2)	Males (d.f.= 2)	Female x male (d.f.= 4)	Error (d.f.= 28)	Total (d.f.= 44)
16.	Kernel breadth	0.02	0.01*	0.01	0.01	0.00	0.01	0.01
17.	L/B ratio	0.06	4.02**	0.96	12.68*	1.22**	0.14	1.81
18.	Kernel length after cooking	0.13	8.59**	5.92	25.48*	1.47**	0.16	7.46
19.	Kernel breadth after cooking	0.02	0.16**	0.30	0.07	0.12**	0.01	0.07
20.	Elongation ratio	0.00	0.73**	0.07	1.27	0.79**	0.01	0.24
21.	Elongation index	0.00	0.41**	0.25	0.27	0.55**	0.01	0.24
22.	Alkali digestion value	0.03	2.00*	0.80	5.55	0.83	0.03	1.47
23.	Amylose content	5.21	6.89**	4.48	6.23	8.42**	0.55	2.97
24.	Gel consistency	0.65	217.36**	347.69*	163.24	179.24**	1.04	104.41
25.	Aroma	0.07	2.96**	1.61	8.45*	0.90**	0.05	1.75

*, ** = Significant at 0.05 and 0.01 levels, respectively

Table 4.4: Estimates of combining ability variances for yield and quality traits

S. No.	Characters	σ^2_{GCA}	σ^2_{SCA}	σ^2_{A}	σ^2_{D}	$\sigma^2_{\text{A}}/\sigma^2_{\text{D}}$	Degree of Dominance $\sqrt{(\sigma^2_{\text{D}} / \sigma^2_{\text{A}})}$
1.	Days to 50 percent flowering	152.634	16.807	305.269	16.807	18.163	0.235
2.	Days to maturity	154.297	15.852	308.593	15.852	19.467	0.227
3.	Plant height	267.355	424.932	534.710	424.932	1.258	0.891
4.	Effective tillers per plant	1.690	4.139	3.380	4.139	0.817	1.107
5.	Number of grains per panicle	633.065	905.142	1266.130	905.142	1.399	0.846
6.	Hundred grain weight	0.087	0.080	0.173	0.080	2.172	0.678
7.	Grain yield per plant	18.166	86.351	36.333	86.351	0.421	1.542
8.	Hulling recovery	2.1812	2.052	4.362	2.052	2.126	0.686
9.	Milling recovery	1.678	3.341	3.356	3.341	1.004	0.998
10.	Head rice recovery	0.930	0.478	1.861	0.478	3.892	0.507
11.	Grain length	2.278	0.142	4.555	0.142	31.991	0.177
12.	Grain breadth	0.014	0.009	0.029	0.009	3.241	0.555
13.	Brown rice length	1.074	0.473	2.147	0.473	4.535	0.470
14.	Brown rice breadth	0.001	0.000	0.001	0.000	-17.193	0.241
15.	Kernel length	1.145	0.551	2.290	0.551	4.158	0.490
16.	Kernel breadth	0.001	-0.001	0.001	-0.001	-1.360	0.858
17.	L/B ratio	0.743	0.360	1.485	0.360	4.127	0.492
18.	Kernel length after cooking	1.727	0.438	3.454	0.438	7.890	0.356
19.	Kernel breadth after cooking	0.020	0.039	0.041	0.039	1.038	0.982
20.	Elongation ratio	0.073	0.260	0.146	0.260	0.564	1.331
21.	Elongation index	0.028	0.179	0.057	0.179	0.317	1.777
22.	Alkali digestion value	0.349	0.267	0.699	0.267	2.618	0.618
23.	Amylose content	0.534	2.621	1.067	2.621	0.407	1.567
24.	Gel consistency	28.270	59.401	56.540	59.401	0.952	1.025
25.	Aroma	0.553	0.281	1.106	0.281	3.933	0.504

Table 4.5: Proportional (per cent) contribution of female parents, male parents and their interaction to total variance

S. No.	Characters	Female parent	Male parent	Female x male interaction
1.	Days to 50 percent flowering	5.282	91.014	3.703
2.	Days to maturity	5.238	91.293	3.4678
3.	Plant height	26.963	38.367	34.669
4.	Effective tillers per plant	9.448	45.330	45.221
5.	Number of grains per panicle	43.429	24.283	32.286
6.	Hundred grain weight	20.935	55.544	23.520
7.	Grain yield per plant	2.440	36.384	61.175
8.	Hulling recovery	7.455	67.349	25.194
9.	Milling recovery	26.844	32.826	40.329
10.	Head rice recovery	5.919	76.478	17.602
11.	Grain length	24.595	72.465	2.939
12.	Grain breadth	71.710	9.264	19.025
13.	Brown rice length	8.282	77.626	14.091

Cont..

S. No.	Characters	Female parent	Male parent	Female x male interaction
14.	Brown rice breadth	73.283	0.702	26.015
15.	Kernel length	10.343	74.937	14.719
16.	Kernel breadth	47.840	38.784	13.375
17.	L/B ratio	6.000	78.870	15.129
18.	Kernel length after cooking	17.226	74.207	8.565
19.	Kernel breadth after cooking	48.543	11.982	39.474
20.	Elongation ratio	2.396	43.511	54.092
21.	Elongation index	15.658	16.921	67.420
22.	Alkali digestion value	9.939	69.308	20.752
23.	Amylose content	16.276	22.614	61.108
24.	Gel consistency	39.991	18.776	41.232
25.	Aroma	13.615	71.275	15.110

Table 4.6: Estimates of general combining ability (GCA) effects of parents for yield and yield traits

Genotypes	Days to 50% flowering	Days to maturity	Plant height	Tillers per plant	Number of grains per panicle	100 grain weight	Yield per plant
Female parents							
Type -3	-3.307**	-3.307**	14.411**	-0.419	5.807**	-0.249**	-1.154*
Pusa Sugandh-2	-1.274*	-1.274*	0.878	-0.485	25.152**	0.094**	1.726**
Pusa 1121	4.581**	4.581**	-15.289**	0.904**	-30.959**	0.155**	-0.571
S.E. ($\pm$)	0.528	0.518	0.709	0.298	0.520	0.009	0.526
Male parents							
Adamchinni	13.526**	13.526**	20.211**	0.415	15.507**	-0.401**	3.034**
BPT-5204	5.559**	5.693**	-12.978**	1.470**	8.796**	0.129**	3.742**
Kasturi	-19.085**	-19.219**	-7.233**	-1.885**	-24.304**	0.273**	-6.777**
S.E. ($\pm$)	0.528	0.518	0.709	0.298	0.520	0.009	0.526

*, ** = Significant at 0.05 and 0.01 levels, respectively

Table 4.7: Estimates of specific combining ability (SCA) effects for yield and yield traits

Cross combinations	Days to 50% flowering	Days to maturity	Plant height	Tillers per plant	Number of grains per panicle	100 grain weight	Yield per plant
Type-3 x Adamchinni	2.685**	2.507*	-1.111	0.985	21.115**	0.324**	1.314
Type-3 x BPT-5204	-2.115*	-2.026*	8.511**	-1.937**	-26.541**	-0.083**	-1.520
Type-3 x Kasturi	-0.570	-0.0481	-7.400**	0.952	5.426**	-0.241**	0.206
Pusa Sugandh-2 x Adamchinni	2.285*	2.241*	21.96**	-2.081**	-4.863**	-0.036*	-10.029**
Pusa Sugandh-2 x BPT-5204	1.052	1.141	-20.856**	2.396**	31.381**	0.047**	9.893**
Pusa Sugandh-2 x Kasturi	-3.337**	-3.381**	-1.100	-0.315	-26.519**	-0.011	0.136
Pusa 1121 x Adamchinni	-4.970**	-4.748**	-20.844**	1.096*	-16.252**	-0.287**	8.714**
Pusa 1121 x BPT-5204	1.063	0.885	12.344**	-0.459	-4.841**	0.036*	-8.373**
Pusa 1121 x Kasturi	3.907**	3.863**	8.500**	-0.637	21.093**	0.251**	-0.341
S.E. ($\pm$)	0.914	0.897	1.23	0.515	0.901	0.015	0.911

*, ** = Significant at 0.05 and 0.01 levels, respectively

Table 4.8: Estimates of general combining ability (GCA) effects of parents for various quality traits

Genotypes	HR	MR	HRR	GL	GB	BRL	BRW	KL	KW	L/B	KLAC	KBAC	ER	EI	ASV	AC	GC	AR
Female parents																		
Type -3	0.413	1.372**	0.419	-0.925**	-0.144**	-0.306	-0.003	-0.376*	-0.021	-0.186	-0.580**	-0.076**	-0.011	0.033	-0.222**	-0.715*	2.389**	-0.215*
Pusa Sugandh-2	0.361	-0.292	-0.114	-0.261	-0.032	-0.223	-0.046*	-0.231	-0.022*	-0.192	-0.346*	0.209**	0.093*	-0.182**	-0.116	0.019	-7.056**	-0.273**
Pusa 1121	-0.774*	-1.080**	-0.305	1.186**	0.177**	0.529**	0.049*	0.607**	0.043	0.378**	0.926**	-0.133**	-0.082*	0.149**	0.338**	0.696*	4.667**	0.488**
S.E. (±)	0.276	0.251	0.224	0.149	0.0235	0.148	0.021	0.130	0.024	0.123	0.132	0.024	0.037	0.031	0.059	0.248	0.340	0.076
Male parents																		
Adamchinni	1.322**	1.320**	0.862**	-1.455**	-0.063*	-1.323**	0.005	-1.391**	-0.017	-1.101**	-1.236**	0.099**	0.434**	0.200**	-0.899**	-0.948**	-4.644**	0.398**
Bpt-5204	0.999**	0.120	0.692**	-0.631**	0.052*	-0.156	-0.001	-0.073	0.039	-0.156	-0.680**	-0.018	-0.219**	-0.081*	0.346**	0.341	-3.722**	-1.104**
Kasturi	-2.321**	-1.440**	-1.555**	2.086**	0.011	1.479**	-0.004	1.464**	-0.022*	1.257**	1.916**	-0.080**	-0.215**	-0.119**	0.553**	0.607*	-0.922*	0.706**
S.E. (±)	0.276	0.251	0.224	0.149	0.0235	0.148	0.021	0.130	0.024	0.123	0.132	0.024	0.037	0.031	0.059	0.248	0.340	0.076

[HR= Hulling recovery (%), MR= Milling recovery (%), HRR= Head rice recovery (%), GL= Grain length (mm), GB= Grain breadth (mm), BRL= Brown rice length(mm), BRW= Brown rice width(mm),KL= Kernel length (mm), KB= Kernel breadth(mm), KLAC= Kernel length after cooking (mm) and KBAC= Kernel breadth after cooking (mm) ER= Elongation ratio, EI= Elongation index, ASV= Alkali digestion value, AC= Amylose content, GC= Gel consistency, AR= Aroma] [*, ** = Significant at 0.05 and 0.01 levels, respectively]

Table 4.9: Estimates of specific combining ability (SCA) effects for various quality traits

Cross combinations	HR	MR	HRR	GL	GB	BRL	BRW	KL	KW	L/B	KLAC	KBAC	ER	EI	ASV	AC	GC	AR
Type-3 x Adamchinni	1.282*	0.530	-0.656	-0.333	0.052	-0.565*	-0.026	-0.646*	0.006	-0.452*	-0.069	-0.081	0.273**	0.327**	-0.445**	-0.752	-2.844**	0.403**
Type-3 x BPT-5204	-1.280*	-0.436	0.063	0.450	-0.070	0.645*	0.004	0.701**	-0.027	0.588*	0.553*	-0.164**	-0.180*	-0.018	0.505**	0.059	2.122**	-0.219
Type-3 x Kasturi	-0.002	-0.094	0.592	-0.117	0.018	-0.080	0.023	-0.055	0.021	-0.136	-0.484	0.245**	-0.093	-0.308**	-0.059	0.693	0.722	-0.184
Pusa Sugandh-2 x Adamchinni	0.542	1.842**	0.900*	-0.133	0.027	-0.225	0.044	-0.204	-0.017	-0.228	0.474	0.078	0.405**	0.200**	-0.122	-1.319**	9.067**	-0.158
Pusa Sugandh-2 x BPT-5204	0.014	-0.694	-0.615	-0.213	-0.066	-0.329	-0.023	-0.313	0.021	-0.263	-0.872**	0.131**	-0.207**	-0.258**	0.050	1.326**	-8.200**	-0.366*
Pusa Sugandh-2 x Kasturi	-0.556	-1.148*	-0.285	0.346	0.039	0.554*	-0.021	0.517*	-0.004	0.490*	0.398	-0.210**	-0.198**	0.059	0.072	-0.007	-0.867	0.523**
Pusa 1121 x Adamchinni	-1.824**	-2.372**	-0.245	0.466	-0.079	0.790**	-0.017	0.850**	0.011	0.679**	-0.405	0.003	-0.678**	-0.526**	0.568**	2.070**	-6.222**	-0.246
Pusa 1121 x BPT-5204	1.266*	1.130*	0.552	-0.237	0.136**	-0.316	0.019	-0.389	0.006	-0.325	0.319	0.033	0.387**	0.277**	-0.555**	-1.385**	6.078**	0.585**
Pusa 1121 x Kasturi	0.558	1.242*	-0.307	-0.229	-0.057	-0.474	-0.002	-0.462	-0.017	-0.354	0.086	-0.035	0.291**	0.250**	-0.013	-0.685	0.144	-0.339*
S.E. (±)	0.478	0.434	0.388	0.258	0.041	0.256	0.036	0.226	0.041	0.213	0.229	0.041	0.063	0.052	0.102	0.429	0.588	0.131

[HR= Hulling recovery (%), MR= Milling recovery (%), HRR= Head rice recovery (%), GL= Grain length (mm), GB= Grain breadth (mm), BRL= Brown rice length(mm), BRW= Brown rice width(mm),KL= Kernel length (mm), KB= Kernel breadth(mm), KLAC= Kernel length after cooking (mm) and KBAC= Kernel breadth after cooking (mm) ER= Elongation ratio, EI= Elongation index, ASV= Alkali digestion value, AC= Amylose content, GC= Gel consistency, AR= Aroma] [* , ** = Significant at 0.05 and 0.01 levels, respectively]

Table 4.10 : Estimates of better parent heterosis, standard heterosis and inbreeding depression for yield traits of rice during *Kharif* - 2015

Traits Crosses	Days to 50% flowering				Days to Maturity				Plant Height				Effective tillers/plant			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	19.93**	29.94**	12.92**	11.47**	13.57**	21.35**	3.81**	9.28**	9.52**	64.33**	57.01**	17.69**	60.14**	27.86**	67.81**	37.65**
Type-3 x BPT-5204	6.89**	15.81**	0.64	12.04**	3.79**	10.90**	-5.13**	9.79**	49.15**	40.77**	34.49**	2.77*	21.16**	14.50*	50.31**	35.68**
Type-3 x Kasturi	-4.36*	-9.75**	-21.57**	-16.16**	-5.30**	-8.85**	-22.02**	-12.24**	21.05**	30.60**	24.78**	14.29**	39.27**	11.21	45.94**	32.89**
Pusa Sugandh-2 x Adamchinni	25.39**	31.74**	14.49**	6.09**	17.71**	22.85**	5.08**	4.98**	55.42**	73.87**	66.11**	14.95**	52.24**	5.50	38.44**	25.87**
Pusa Sugandh-2 x BPT-5204	15.70**	21.57**	5.64**	5.03**	10.47**	15.30**	-1.37	4.23**	3.7	-2.13	-6.50**	1.69	53.40**	45.00**	90.31**	46.73**
Pusa Sugandh-2 x Kasturi	-5.22**	-10.56**	-22.28**	-8.55**	-6.06**	-9.58**	-22.65**	-6.65**	14.35**	23.37**	17.87**	20.71**	46.74**	1.64	33.44**	35.08**
Pusa 1121 x Adamchinni	5.35**	30.20**	13.14**	8.66**	2.85**	21.89**	4.27**	7.23**	4.09*	14.90**	9.78**	3.2*	77.19**	38.07**	81.25**	27.72**
Pusa 1121 x BPT-5204	3.62**	28.06**	11.28**	5.29**	1.28	20.03**	2.67*	4.33**	11.71**	4.9**	0.223	-5.92**	42.32**	34.50**	76.56**	40.96**
Pusa 1121 x Kasturi	10.14**	3.94*	-9.68**	-6.91**	5.44**	1.49	-13.18**	-5.49**	8.26**	16.80**	11.59**	18.95**	40.22**	9.29	43.44**	29.41**
Range of heterosis& I.D	-5.22 to 25.39-	-10.56 to 31.74	-21.57 to 14.49	-16.16to 12.04	-6.06 to 17.71	-9.58 to 22.85	-22.65 to 5.08	-12.23to 9.789	3.7 to 55.42	-2.13 to 73.87	-6.50 to 66.11	1.69 to 20.71	21.16 to 77.19	1.64 to 45	33.44 to 90.31	25.87to 46.73
Number of hybrids with significant positive heterosis& I.D	7	7	5	6	6	6	4	6	8	8	7	8	9	5	9	9
Number of hybrids with significant negative heterosis& I.D	2	2	3	3	2	2	4	3	0	0	1	1	0	0	0	0

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Pusa Basmati-1. Inbreeding depression (I.D)

Cont..

Traits Crosses	No. of grains per panicle				100 grain weight				Grain yield per plant				
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	
Type-3 x Adamchinni	6.98**	123.71**	78.97**	28.63**	-11.72**	-20.23**	-13.48**	-	33.82**	145.24**	37.88**	134.41**	13.66**
Type-3 x BPT-5204	-5.74**	65.46**	32.37**	32.27**	-5.81**	-14.88**	-7.68**	-	24.65**	86.31**	29.30**	119.82**	21.88**
Type-3 x Kasturi	21.90**	64.25**	31.40**	18.7**	-12.52**	-15.46**	-8.31**	-	20.31**	61.99**	-6.20	59.44**	15.33**
Pusa Sugandh-2 x Adamchinni	3.58**	116.61**	73.29**	33.31**	-28.28**	-20.95**	-14.26**	-	20.92**	59.34**	3.71	76.29**	17.24**
Pusa Sugandh-2 x BPT-5204	41.41**	148.25**	98.60**	29.62**	-4.16**	5.64**	14.58**	-	20.97**	115.82**	49.78**	154.63**	25.38**
Pusa Sugandh-2 x Kasturi	5.92**	50.75**	20.60**	33.45**	-0.75	9.39**	18.65**	2.92**	61.55**	5.41	78.74**	19.84**	
Pusa 1121 x Adamchinni	-31.00**	44.29**	15.43**	21.29**	-41.69**	-29.19**	-23.20**	-	67.47**	142.40**	41.70**	140.91**	21.62**
Pusa 1121 x BPT-5204	-14.94**	49.32**	19.46**	19.68**	-11.22**	7.80**	16.93**	-	13.36**	49.82**	3.98	76.77**	22.55**
Pusa 1121 x Kasturi	15.44**	41.64**	13.31**	28.72**	1.63	23.41**	33.86**	4.125**	60.71**	-6.06	59.72**	20.84**	
Range of heterosis & I.D	-31 to 41.41	41.64 to 148.25	13.31 to 98.60	18.7to 33.45	-41.69 to 1.63	-29.19 to 23.41	-23.20 to 33.86	-67.47 to4.13	49.82 to 145.24	-6.20 to 49.78	59.44 to 154.63	13.66to 25.38	
Number of hybrids with significant positive heterosis & I.D	6	9	9	9	0	4	4	2	9	4	9	9	
Number of hybrids with significant negative heterosis & I.D	3	0	0	0	7	5	5	7	0	0	0	0	

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Pusa Basmati-1. Inbreeding depression (I.D)

Table 4.11: Estimates of better parent heterosis, standard heterosis and inbreeding depression for quality traits of rice during *Kharif* - 2015

Traits Crosses	Hulling				Milling				Head rice recovery				Grain length			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	0.48	8.14**	10.55**	10.85**	1.44	10.59**	10.89**	12.19**	1.98	26.94**	25.14**	8.43**	-34.32**	-37.54**	-42.77**	-48.75**
Type-3 x BPT-5204	-1.58	3.28*	5.58**	9.03**	0.86	6.61**	6.91**	9.18**	3.83**	28.30**	26.48**	11.93**	-17.48**	-21.53**	-28.10**	-15.30**
Type-3 x Kasturi	-4.86**	-0.16	2.06	8.16**	-1.26	4.36**	4.66**	9.5**	1.81	24.05**	22.29**	12.53**	-3.41	-0.10	-8.46*	7.98*
Pusa Sugandh-2 x Adamchinni	-0.76	6.81**	9.18**	10.72**	0.85	9.95**	10.25**	8.59**	4.01**	29.47**	27.64**	13.4**	-34.09**	-28.94**	-34.89**	-19.96**
Pusa Sugandh-2 x BPT-5204	2.10	5.37**	7.72**	10.33**	1.25	3.07*	3.37*	8.59**	1.40	25.30**	23.52**	12.55**	-27.22**	-21.53**	-28.10**	-15.01**
Pusa Sugandh-2 x Kasturi	-4.25**	-1.18	1.02	9.36**	-2.39*	-0.64	-0.34	7.14**	1.45	20.55**	18.84**	11.25**	3.07	11.13**	1.83	-6.00
Pusa 1121 x Adamchinni	-6.24**	0.91	3.15*	7.35**	-7.59**	0.74	1.04	5.97**	1.35	26.17**	24.38**	9.26**	-16.75**	-8.54*	-16.19**	-0.99
Pusa 1121 x BPT-5204	3.62**	5.57**	7.92**	11.16**	3.21*	4.98**	5.28**	7.56**	3.36**	27.72**	25.91**	12.49**	-15.66**	-7.34	-15.10**	9.06*
Pusa 1121 x Kasturi	-2.13	-1.22	0.98	11.88**	2.44*	2.31	2.61	11.8**	1.01	20.03**	18.33**	8.3**	9.07*	19.83**	9.80**	11.64**
Range of heterosis	-6.24 to 3.62	-1.22 to 8.14	0.98 to 10.55	7.35to 11.88	-7.59 to 3.21	-0.64 to 10.59	-0.34 to 10.89	5.97to 12.19	1.01 to 4.01	20.03 to 29.47	18.33 to 27.64	8.3 to 13.4	-34.32 to 9.07	-37.54 to 19.83	-42.77 to 9.80	-48.75 to 11.64
Number of hybrids with significant positive heterosis	1	5	6	9	2	6	6	9	3	9	9	9	1	2	1	3
Number of hybrids with significant negative heterosis	3	0	0	0	2	0	0	0	0	0	0	0	6	5	7	4

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Taraori Basmati. Inbreeding depression (I.D)

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Traits Crosses	Grain width				Brown rice length				Brown rice width				Kernel length			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	-1.46	-16.60**	-13.14**	- 11.69* *	-38.18**	-38.62**	-38.95**	- 41.23* *	-4.05	1.25	2.89	-2.43	-42.81**	-42.86**	-43.33**	- 48.1**
Type-3 x BPT-5204	-1.72	-16.87**	-13.43**	- 11.05* *	-5.36	-6.03	-6.55	0.57	-1.32	2.49	4.16	-2.4	-5.32	-5.39	-6.18	1.7
Type-3 x Kasturi	-3.88	-14.95**	-11.43**	- 10.6**	1.54	6.44	5.86	18.68* *	0.52	3.38	5.06	-1.98	3.93	5.57	4.69	17.78* *
Pusa Sugandh-2 x Adamchinni	2.76	-13.03**	-9.43**	- 20.93* *	-43.50**	-32.82**	-33.18**	- 17.46*	-0.17	2.67	4.34	-6.02*	-42.66**	-34.61**	-35.16**	- 19.9**
Pusa Sugandh-2 x BPT-5204	3.96	-12.07**	-8.43**	-2.87	-31.25**	-18.24**	-18.68**	-9.19	-3.98	-1.25	0.36	-6.5*	-27.75**	-17.61**	-18.30**	-5.83
Pusa Sugandh-2 x Kasturi	2.33	-9.47**	-5.71*	- 14.7**	-2.23	16.27**	15.64**	2.93	-3.98	-1.21	0.32	-5.01	1.41	15.64**	14.68**	3.91
Pusa 1121 x Adamchinni	7.78*	-8.78**	-5	1.7	-24.51**	-8.59	-9.09	-0.27	-1.01	4.45	6.15*	-3.03	-20.12**	-8.01	-8.78	3.33
Pusa 1121 x BPT-5204	23.91* *	4.80	9.14**	11.88* *	-23.83**	-7.77	-8.27	11.72* *	2.11	6.05*	7.78*	-0.86	-19.14**	-6.89	-7.66	13.05* *
Pusa 1121 x Kasturi	7.60*	-4.80	-0.86	-4.7	-7.11	12.48*	11.86*	22.45* *	1.90	4.80	6.51*	-2.45	-1.29	13.68**	12.73*	22.64* *
Range of heterosis	-3.88 to 23.91	-16.87 to 4.80	-13.43 to 9.14	-20.93 to 11.88	-43.50 to 1.54	-38.62 to 16.27	-38.95 to 15.64	-41.23 to 22.45	-4.05 to 2.11	-1.21 to 6.05	0.32 to 7.78	-6.5 to -0.86	-42.81 to 3.93	-42.86 to 15.64	-43.33 to 14.68	-48.1 to 1.7
Number of hybrids with significant positive heterosis	3	0	1	5	0	2	2	3	0	1	3	0	0	2	2	3
Number of hybrids with significant negative heterosis	0	7	6	1	5	3	3	2	0	0	0	2	5	3	3	2

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Taraori Basmati. Inbreeding depression (I.D)

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Traits Crosses	Kernel width				L/B ratio				Kernel length after cooking				Kernel breadth after cooking			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	-4.20	7.66*	6.82	-5.01	-18.47**	-23.85**	-24.24**	-12.87*	-25.97**	-33.67**	-30.26**	-8.11*	0.68	5.74*	19.13**	-7.99**
Type-3 x BPT-5204	-3.41	9.04*	8.19*	-0.57	-0.54	-7.11*	-7.59**	1.25	-16.62**	-25.30**	-21.46**	-12.79	23.66**	-1.75	10.69**	-10.08**
Type-3 x Kasturi	0.92	8.25*	7.41*	-2.88	1.69	-1.28	-1.80	10.4*	-4.24	-14.20**	-9.8**	12.41*	9.14**	11.24**	25.32**	0.79
Pusa Sugandh-2 x Adamchinni	-2.75	6.29	5.46	-8.9**	-23.66**	-22.01**	-22.42**	-5.32	-30.64**	-28.14**	-24.45**	4.09	17.03**	22.35**	37.83**	12.73**
Pusa Sugandh-2 x BPT-5204	2.28	11.79**	10.92**	-2.02	-16.15**	-14.34**	-14.78**	-1.84	-36.06**	-33.76**	-30.36**	-16.64*	51.01**	19.98**	35.16**	15.55**
Pusa Sugandh-2 x Kasturi	-0.55	6.68	5.85	-4.82	1.75	3.95	3.41	3.85	-9.52**	-6.26*	-1.45	-3.19	2.89	4.87*	18.14**	-5.04*
Pusa 1121 x Adamchinni	0.71	11.79**	10.92**	-0.72	-11.04**	-9.55**	-10.02**	2.14	-43.74**	-25.34**	-21.51**	-7.15	1.63	6.74**	20.25**	4.65*
Pusa 1121 x BPT-5204	3.36	14.73**	13.84**	1.98	-11.54**	-10.05**	-10.52**	6.10	-36.88**	-16.24**	-11.94**	16.1**	30.26**	3.5	16.60**	-5.62*
Pusa 1121 x Kasturi	2.38	9.82*	8.97*	-3.89	-0.05	1.63	1.10	13.71**	-24.21**	0.57	5.73*	18.49**	-3.23	-1.37	11.11**	-19.04**
Range of heterosis	-4.20 to 3.36	6.29 to 14.73	5.46 to 13.84	-8.9 to 1.98	-23.66 to 1.75	-23.85 to 3.95	-24.24 to 3.41	-12.87 to 13.71	-43.74 to -4.24	-33.76 to 0.57	-30.36 to 5.73	-16.64 to 18.49	-3.23 to 51.01	-1.75 to 22.35	10.69 to 37.83	-19.04 to 15.55
Number of hybrids with significant positive heterosis	0	7	6	0	0	0	0	2	0	0	1	3	5	6	9	3
Number of hybrids with significant negative heterosis	0	0	0	1	5	6	6	1	8	8	7	2	0	0	0	5

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Taraori Basmati. Inbreeding depression (I.D)

Cont..

Traits Crosses	Elongation ratio				Elongation index				Alkali spread value			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	0.24	3.28**	5.85**	9.85**	-2.22	2.88**	1.55	11.12	-5.36**	-14.35**	-8.23**	-3.84*
Type-3 x BPT-5204	-8.12**	-10.46**	-8.24**	-6.86*	-18.82**	-6.78**	-7.98**	-2.58	11.69**	1.09	8.31**	9.48**
Type-3 x Kasturi	-4.76**	-9.33**	-7.07**	-3.41	-8.05**	-11.83**	-12.97**	-8.36	8.92**	-1.43	5.62**	4.14**
Pusa Sugandh-2 x Adamchinni	3.08*	6.21**	8.85**	10.66**	-7.22**	-2.39	-3.64**	6.44	-16.74**	-11.33**	-5.00**	-3.87**
Pusa Sugandh-2 x BPT-5204	-7.15**	-9.52**	-7.26**	-4.97	-24.92**	-13.78**	-14.89**	-15.47*	-7.38**	-1.36	5.68**	8.50**
Pusa Sugandh-2 x Kasturi	-5.37**	-9.34**	-7.08**	-2.67	-6.56**	-9.49**	-10.66**	-3.25	-5.87**	0.25	7.41**	-1.15
Pusa 1121 x Adamchinni	-16.12**	-9.42**	-7.17**	-5.44*	-14.54**	-8.48**	-9.66**	-8.38	-8.85**	-3.29**	3.62**	4.88**
Pusa 1121 x BPT-5204	-11.40**	-4.32**	-1.93	1.79	-13.30**	-0.43	-1.72	5.40	-8.03**	-2.42*	4.55**	2.83*
Pusa 1121 x Kasturi	-12.45**	-5.45**	-3.10*	-2.92	-7.97**	-1.44	-2.72*	4.00	-3.08**	2.84*	10.18**	3.55**
Range of heterosis	-16.12 to 3.08	-10.46 to 6.21	-8.24 to 8.85	-6.86 to 10.66	-24.92 to -2.22	-13.78 to 2.88	-14.89 to 1.55	-15.47 to 11.12	-16.74 to 11.69	-14.35 to 2.84	-8.23 to 10.18	-3.87 to 9.48
Number of hybrids with significant positive heterosis	1	2	2	2	0	1	0	0	2	1	7	6
Number of hybrids with significant negative heterosis	7	7	6	2	8	5	7	1	7	4	2	2

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Taraori Basmati. Inbreeding depression (I.D)

Traits Crosses	Amylose content				Gelconsistency				Aroma			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	-5.22	-3.47	4.31	-2.64	-18.66**	0.58	-36.88**	-7.81**	-7.29**	2.20	-10.39**	3.91
Type-3 x BPT-5204	4.0	5.91*	14.46**	-1.44	1.86	-6.0**	-41.01**	12.50**	-26.51**	-18.99**	-28.97**	-12.40
Type-3 x Kasturi	7.95**	9.94**	18.80**	0.62	4.8*	-3.29	-39.31**	11.35**	-9.82**	-0.59	-12.83**	1.87
Pusa Sugandh-2 x Adamchinni	-11.84**	-2.73	5.12	-18.59**	-14.80**	5.35**	-33.89**	18.19**	-10.81**	-3.97*	-15.79**	-4.15
Pusa Sugandh-2 x BPT-5204	4.09	14.85**	24.11**	-4.54*	-34.25**	-44.26**	-65.02**	-65.06**	-26.65**	-21.02**	-30.75**	-9.40*
Pusa Sugandh-2 x Kasturi	-0.23	10.08**	18.96**	-2.46	8.79**	-24.65**	-52.71**	-21.52**	-1.65	5.89**	-7.15**	5.65*
Pusa 1121 x Adamchinni	16.37**	15.45**	24.76**	-5.00*	-20.38**	-1.55	-38.22**	17.01**	-7.22**	2.73	-9.92**	1.23
Pusa 1121 x BPT-5204	4.16	5.76*	14.29**	-5.84*	25.11**	6.06**	-33.44**	13.55**	-13.28**	-3.97*	-15.79**	-7.73
Pusa 1121 x Kasturi	10.68**	10.08**	18.96**	1.82	53.82**	0.004	-37.25**	18.26**	-5.29**	4.87*	-8.04**	0.50
Range of heterosis	-11.84 to 16.37	-3.47 to 15.45	4.31 to 24.76	-18.59 to 1.82	-34.25 to 53.82	-44.26 to 6.06	-65.02 to -33.44	-65.06 to 18.26	-26.65 to -1.65	-21.02 to 5.89	-30.75 to -7.15	-12.40 to 5.65
Number of hybrids with significant positive heterosis	3	7	7	0	4	2	0	6	0	2	0	1
Number of hybrids with significant negative heterosis	1	0	0	4	4	3	9	3	8	4	9	1

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Taraori Basmati. Inbreeding depression (I.D)

Table 4.12: Significance of the A,B and C scales and of Joint scaling test (JST) for yield and yield traits

Cross combination	A	B	C	JST	i	j	l
	Days to 50% flowering						
Type-3 x Adamchinni	6.97**±3.47	-9.83**±3.02	-44.16**±4.16	133.06**	NS	NS	41.30**±5.53
Type-3 x BPT-5204	NS	NS	-57.93**±3.00	379.88**	53.4**±3.86	1.47**±1.01	-48.87**±6.30
Type-3 x Kasturi	11.1**±1.94	7.43**±1.30	32.42**±2.25	221.16**	-13.89**±2.77	NS	NS
Pusa Sugandh-2 x Adamchinni	-8.07**±2.61	-20.6**±2.32	-12.75**±3.69	95.31**	-15.92**±4.88	6.27**±3.64	44.59**±7.69
Pusa Sugandh-2 x BPT-5204	-6.03**±1.72	-14.30**±1.99	-14.64**±2.54	76.19**	NS	4.13**±1.25	26.03**±5.43
Pusa Sugandh-2 x Kasturi	7.87**±1.77	5.53**±1.33	9.72**±2.00	39.66**	NS	NS	-17.08**±3.97
Pusa 1121 x Adamchinni	NS	-6.13**±1.47	-43.78**±2.75	271.08**	36.75**±3.00	2.62*±0.97	-29.71**±4.54
Pusa 1121 x BPT-5204	-3.03*±1.21	NS	-22.65**±2.57	82.37**	19.41**±2.72	NS	-16.18**±4.00
Pusa 1121 x Kasturi	6.20*±1.98	NS	15.51**±2.39	45.13**	NS	NS	NS
	Days to maturity						
Type-3 x Adamchinni	NS	-11.77**±3.13	-48.18**±4.31	143.35**	41.21**±5.61	8.28**±2.21	-34.25**±9.65
Type-3 x BPT-5204	NS	-6.43*±2.26	-62.99**±3.11	413.09**	53.32**±4.00	NS	-43.65**±6.54
Type-3 x Kasturi	9.03**±4.38	5.07**±1.48	28.07**±2.50	128.33**	-13.97**±4.76	NS	NS
Pusa Sugandh-2 x Adamchinni	-10.43**±2.65	-23.23**±2.42	-17.67**±3.77	115.17**	-16.00**±4.89	6.40**±1.75	49.67**±7.79
Pusa Sugandh-2 x BPT-5204	-8.73**±1.83	-16.73**±2.13	-19.69**±2.64	108.8**	NS	4.00*±1.34	31.24**±5.76
Pusa Sugandh-2 x Kasturi	6.20**±1.90	3.60*±1.44	6.39*±2.22	16.64**	NS	NS	-13.21**±4.58
Pusa 1121 x Adamchinni	-3.60*±1.60	-8.57**±1.58	-48.83**±2.90	297.33**	36.67**±3.11	2.48*±1.03	-24.5**±4.76
Pusa 1121 x BPT-5204	-4.83**±1.32	NS	-26.65**±2.66	103.22**	19.55**±2.80	NS	-12.45**±4.20
Pusa 1121 x Kasturi	NS	NS	10.64**±2.51	18.28**	NS	NS	NS
	Plant Height						
Type-3 x Adamchinni	-28.90**±4.17	-21.23**±4.27	-93.14**±7.57	163.58**	43.00**±7.78	NS	NS
Type-3 x BPT-5204	-49.60**±2.74	-50.2**±3.35	18.60**±5.56	628.18**	-118.40**±5.85	NS	218.20**±8.93

Type-3 x Kasturi	-22.23**±3.24	NS	-69.23**±4.71	277.10**	47.87**±4.31	-11.55**±2.09	-26.50**±8.33
Pusa Sugandh-2 x Adamchinni	NS	-17.8**±4.09	-29.23**±7.83	39.93**	20.13**±7.59	13.25**±2.57	NS
Pusa Sugandh-2 x BPT-5204	-6.03**±1.72	-14.3**±1.99	-14.64**±2.54	76.19**	NS	4.13**±1.25	26.03**±5.43
Pusa Sugandh-2 x Kasturi	7.87**±1.77	5.53**±1.33	9.72**±4.86	39.66**	NS	NS	-17.08**±4.31
Pusa 1121 x Adamchinni	59.43**±3.78	21.80**±3.92	-57.87**±6.28	452.31**	139.11**±7.19	18.82**±2.58	-220.34**±11.38
Pusa 1121 x BPT-5204	NS	-13.63**±3.18	12.49**±4.28	43.15**	-27.83**±4.53	5.97**±1.94	43.16**±8.07
Pusa 1121 x Kasturi	-23.28**±3.15	-34.93**±3.39	-74.60**±4.20	328.25**	16.40**±4.60	5.83**±2.13	41.80**±8.61
	Effective tillers/plant						
Type-3 x Adamchinni	NS	-2.60**±0.54	-10.66**±1.42	73.50**	8.86**±1.40	1.70**±0.43	-7.06**±2.11
Type-3 x BPT-5204	-2.60**±0.65	-2.77**±0.72	-15.45**±1.28	161.78**	10.08**±1.03	NS	-4.71**±1.76
Type-3 x Kasturi	NS	-3.53**±0.82	-9.65**±1.47	61.58**	6.15**±1.25	1.78**±0.46	NS
Pusa Sugandh-2 x Adamchinni	NS	-1.70**±0.50	-3.38*±1.35	17.85**	NS	0.98**±0.31	NS
Pusa Sugandh-2 x BPT-5204	-3.40**±0.83	-10.07**±0.80	-20.55**±1.50	246.23**	7.08**±1.35	3.33**±0.47	6.39**±2.22
Pusa Sugandh-2 x Kasturi	NS	-2.93**±0.61	-8.87**±1.17	67.74**	5.21**±1.05	1.10**±0.34	NS
Pusa 1121 x Adamchinni	NS	NS	NS	NS	NS	NS	NS
Pusa 1121 x BPT-5204	-4.17**±0.65	-3.90**±0.71	-17.42**±1.22	202.82**	9.35**±1.17	NS	NS
Pusa 1121 x Kasturi	-1.73*±0.74	-3.77**±0.72	-6.43**±1.43	33.79**	NS	1.02*±0.43	4.57*±2.03

Cross combination	A	B	C	JST	i	j	l
	No. of grains per panicle						
Type-3 x Adamchinni	-30.10**±4.11	-68.03**±4.47	-145.78**±13.24	301.06**	47.65**±13.21	18.97**±2.65	50.48**±16.27
Type-3 x BPT-5204	-24.20**±3.68	-31.00**±4.48	-178.8**±12.99	216.34**	123.60**±12.78	NS	-68.4**±15.52
Type-3 x Kasturi	NS	NS	-47.97**±8.75	37.03**	52.20**±8.97	NS	-56.43**±12.80
Pusa Sugandh-2 x Adamchinni	-53.37**±3.96	-85.40**±4.47	-193.62**±10.22	599.91**	54.85**±10.04	16.02**±2.60	83.91**±13.63
Pusa Sugandh-2 x BPT-5204	-92.57**±4.69	-42.90**±6.02	-111.36**±14.12	391.51**	NS	-24.83**±3.09	159.57**±17.99
Pusa Sugandh-2 x Kasturi	-22.93**±3.66	-23.20**±3.67	-150.43**±8.67	309.92**	104.30**±8.81	NS	-58.16**±12.00
Pusa 1121 x Adamchinni	NS	NS	-118.26**±11.02	116.00**	105.63**±11.15	NS	-92.99**±14.33
Pusa 1121 x BPT-5204	NS	-32.70**±3.72	-64.06**±10.82	101.83**	32.36**±11.34	16.85**±2.63	NS
Pusa 1121 x Kasturi	-8.20*±3.42	-32.43**±3.71	-75.16**±8.72	121.37**	34.53**±8.76	12.11**±2.22	NS
	100 grain weight						
Type-3 x Adamchinni	NS	NS	2.57**±0.13	449.72**	-2.47**±0.13	NS	2.36**±0.20
Type-3 x BPT-5204	0.73**±0.08	0.70**±0.08	1.84**±0.15	218.27**	-0.41*±0.17	NS	-1.02**±0.25
Type-3 x Kasturi	0.23**±0.08	0.18*±0.09	1.16**±0.17	47.37**	-0.74**±0.19	NS	NS
Pusa Sugandh-2 x Adamchinni	0.48**±0.09	1.12**±0.09	1.04**±0.15	196.12**	0.55**±0.17	-0.32**±0.06	-2.15**±0.27
Pusa Sugandh-2 x BPT-5204	0.68**±0.10	0.94**±0.08	2.53**±0.20	259.06**	-0.91**±0.21	-0.13*±0.06	-0.71*±0.30
Pusa Sugandh-2 x Kasturi	0.19*±0.09	NS	NS	NS	0.26*±0.13	NS	-0.46*±0.22
Pusa 1121 x Adamchinni	0.91**±0.10	1.16**±0.09	3.35**±0.15	599.12**	-1.28**±0.18	-0.12*±0.06	-0.79**±0.28
Pusa 1121 x BPT-5204	NS	0.83**±0.08	1.64**±0.14	195.21**	-0.68**±0.15	-0.35**±0.06	NS
Pusa 1121 x Kasturi	NS	NS	NS	11.32*	NS	-0.15*±0.05	NS
	Grain yield per plant						
Type-3 x Adamchinni	NS	-4.59**±1.17	24.24**±3.60	74.05**	-29.40**±3.63	2.02**±0.72	34.56**±4.49
Type-3 x BPT-5204	-11.29**±1.39	-6.82**±1.03	6.43*±2.84	118.84**	-24.53**±2.93	-2.23**±0.78	42.64**±4.04
Type-3 x Kasturi	5.58**±0.91	3.13**±0.95	4.99*±2.16	43.13**	NS	1.23*±0.60	-12.42**±3.07
Pusa Sugandh-2 x Adamchinni	4.36**±1.22	4.25**±1.07	4.56*±2.31	23.99**	NS	NS	-12.66**±3.54
Pusa Sugandh-2 x BPT-5204	-5.5** ± 1.089	4.06** ± 1.13	11.83** ± 3.85	95.08**	-13.28**±3.75	-4.77**±0.62	14.71**±4.49
Pusa Sugandh-2 x Kasturi	NS	-3.28**±0.97	NS	16.72**	NS	2.13**±0.64	6.67*±3.20
Pusa 1121 x Adamchinni	7.90**±0.99	NS	16.67**±4.27	132.75**	NS	3.39**±0.58	NS
Pusa 1121 x BPT-5204	-4.22**±0.93	NS	NS	21.08**	NS	-1.75**±0.59	NS
Pusa 1121 x Kasturi	NS	-2.57**±0.86	NS	10.39*	NS	1.48*±0.58	NS

Table 4.13: Significance of the A, B and C scales and of Joint scaling test (JST) for quality traits.

Cross combination	A	B	C	JST	i	j	l
	Hulling %						
Type-3 x Adamchinni	NS	-4.00*±1.55	-32.44**±2.52	171.21**	26.17**±2.73	NS	-19.91**±4.34
Type-3 x BPT-5204	NS	-4.63*±1.92	-27.89**±2.48	151.74**	23.92**±2.76	2.65*±1.12	-19.95**±4.75
Type-3 x Kasturi	-6.33**±1.45	-8.27**±1.58	-27.00**±2.36	132.37**	12.40**±2.41	NS	NS
Pusa Sugandh-2 x Adamchinni	NS	NS	-31.56**±2.91	138.21**	29.99**±2.80	NS	-28.43**±4.08
Pusa Sugandh-2 x BPT-5204	-5.73**±1.56	-8.30**±1.95	-27.10**±2.64	112.11**	13.07**±3.09	NS	NS
Pusa Sugandh-2 x Kasturi	NS	-7.63**±1.53	-31.14**±2.59	150.30**	21.01**±2.75	2.57*±1.00	-10.87*±4.28
Pusa 1121 x Adamchinni	NS	NS	-27.93**±2.74	111.05**	26.36**±2.89	NS	-24.79**±4.18
Pusa 1121 x BPT-5204	-8.23**±1.60	-7.07**±1.69	-28.43**±2.68	129.56**	13.13**±3.13	NS	NS
Pusa 1121 x Kasturi	-3.67*±1.40	-9.33**±1.43	-35.97**±2.19	273.77**	22.97**±9.32	2.83**±0.95	-9.97*±4.00
	Milling %						
Type-3 x Adamchinni	-5.12**±0.88	-3.39**±0.83	-25.62**±1.48	306.22**	17.10**±1.59	NS	-8.59**±2.50
Type-3 x BPT-5204	-4.79**±0.91	-6.21**±1.21	-18.01**±1.57	139.24**	7.01**±1.80	NS	NS
Type-3 x Kasturi	-7.43**±0.89	-5.81**±0.99	-20.11**±1.47	206.68**	6.86**±1.49	NS	6.39*±2.52
Pusa Sugandh-2 x Adamchinni	-3.46**±0.72	3.35**±0.62	-18.42**±1.45	226.28**	11.60**±1.45	NS	-4.78*±4.02
Pusa Sugandh-2 x BPT-5204	-3.69**±1.00	NS	-17.76**±1.66	117.38**	12.19**±1.87	NS	-6.62*±3.18
Pusa Sugandh-2 x Kasturi	NS	-3.47**±0.96	-17.18**±1.61	115.40**	11.90**±1.69	NS	-6.62*±2.71
Pusa 1121 x Adamchinni	-2.64**±0.83	NS	-17.04**±1.72	110.07**	14.88**±1.78	-1.56**±0.56	-12.71**±2.64
Pusa 1121 x BPT-5204	-3.85**±0.99	-2.30*±1.09	-12.24**±1.69	59.84**	6.09**±2.00	NS	0.06**±3.14
Pusa 1121 x Kasturi	-4.70**±0.86	-3.72**±0.89	-23.40**±1.40	288.72**	14.98**±1.51	NS	-6.57**±2.46
	Head Rice Recovery						
Type-3 x Adamchinni	-5.42**±0.86	-6.00**±0.77	-14.25**±1.45	135.50**	NS	NS	8.60**±2.40
Type-3 x BPT-5204	-7.00**±0.96	-5.36**±1.23	-20.50**±1.67	168.94**	8.14**±1.92	NS	NS

Type-3 x Kasturi	-7.18**±0.93	-6.87**±1.02	-22.54**±1.52	234.69**	8.48**±1.60	NS	5.57*±2.66
Pusa Sugandh-2 x Adamchinni	-4.80**±0.95	-5.25**±0.88	-20.56**±1.80	139.00**	10.51**±1.79	NS	NS
Pusa Sugandh-2 x BPT-5204	-6.02**±1.05	-6.14**±1.28	-21.09**±1.74	151.59**	8.94**±1.91	NS	NS
Pusa Sugandh-2 x Kasturi	-6.24**±0.98	-4.11**±1.04	-19.51**±1.70	140.17**	9.16**±1.75	NS	NS
Pusa 1121 x Adamchinni	-4.86**±0.91	-5.32**±0.94	-14.75**±1.81	87.23**	4.57*±1.87	NS	5.62*±2.78
Pusa 1121 x BPT-5204	-7.36**±1.05	-4.17**±1.19	-20.46**±1.75	161.72**	8.93**±2.09	-1.60*±0.76	NS
Pusa 1121 x Kasturi	-5.28**±0.94	-2.59**±0.93	-15.14**±1.52	111.29**	7.27**±1.61	-1.35*±0.61	NS
	Grain length						
Type-3 x Adamchinni	1.68**±0.17	4.08**±0.14	9.84**±0.46	1179.67**	-4.07**±0.45	-1.20**±0.10	-1.69**±0.54
Type-3 x BPT-5204	0.92**±0.23	2.51**±0.24	3.76**±0.59	115.92**	NS	-0.80**±0.11	-3.09**±0.64
Type-3 x Kasturi	NS	2.50**±0.35	-3.1**±0.38	195.43**	5.60**±0.42	-1.24**±0.19	-8.11**±0.79
Pusa Sugandh-2 x Adamchinni	1.07*±0.52	4.28**±0.44	3.92**±0.61	101.42**	1.43*±0.66	-1.61**±0.30	-6.77**±1.28
Pusa Sugandh-2 x BPT-5204	4.80**±0.37	5.02**±0.37	2.58**±0.52	323.78**	7.24**±0.51	NS	NS
Pusa Sugandh-2 x Kasturi	NS	NS	3.34**±0.57	70.25**	-3.04**±0.43	NS	2.74**±0.90
Pusa 1121 x Adamchinni	NS	NS	NS	36.31**	-2.17**±0.51	NS	2.35*±0.96
Pusa 1121 x BPT-5204	NS	2.04**±0.41	-3.43**±0.57	134.30**	5.80**±0.54	-0.86**±0.25	-8.17**±1.05
Pusa 1121 x Kasturi	NS	-1.25**±0.43	-2.34**±0.53	30.33**	1.21*±0.52	0.69*±0.27	NS

Cross combination	A	B	C	JST	i	j	l
	Grain breadth						
Type-3 x Adamchinni	0.22**±0.04	0.23**±0.04	0.78**±0.06	161.47**	-0.33**±0.06	NS	NS
Type-3 x BPT-5204	0.25**±0.03	0.28**±0.03	0.69**±0.05	203.80**	-0.16**±0.05	NS	-0.38**±0.09
Type-3 x Kasturi	0.31**±0.04	0.16**±0.04	0.65**±0.09	89.33**	-0.19*±0.09	0.07**±0.03	-0.28*±0.13
Pusa Sugandh-2 x Adamchinni	0.16**±0.05	0.21**±0.05	1.58**±0.10	298.99**	-1.21**±0.09	NS	0.85**±0.14
Pusa Sugandh-2 x BPT-5204	NS	0.14**±0.05	NS	10.79*	NS	NS	NS
Pusa Sugandh-2 x Kasturi	NS	NS	1.19**±0.09	198.14**	-1.13**±0.09	NS	1.08**±0.14
Pusa 1121 x Adamchinni	NS	0.23**±0.04	-0.21**±0.05	93.55**	0.51**±0.06	-0.08**±0.03	-0.80**±0.12
Pusa 1121 x BPT-5204	-0.13**±0.05	NS	-0.61**±0.06	136.90**	0.43**±0.06	NS	-0.25*±0.12
Pusa 1121 x Kasturi	NS	0.12*±0.05	0.49**±0.09	32.62**	-0.34**±0.09	NS	NS
	Brown rice length						
Type-3 x Adamchinni	1.96**±0.17	5.05**±0.14	5.12**±0.45	1281.24**	1.88**±0.44	-1.55**±0.11	-8.89**±0.54
Type-3 x BPT-5204	NS	0.62*±0.24	1.14*±0.58	10.68*	NS	-0.30*±0.11	NS
Type-3 x Kasturi	NS	NS	-5.17**±0.37	266.94**	4.88**±0.43	NS	-4.59**±0.79
Pusa Sugandh-2 x Adamchinni	NS	1.63**±0.44	NS	18.88**	NS	-1.13**±0.29	NS
Pusa Sugandh-2 x BPT-5204	1.12**±0.37	3.36**±0.37	NS	105.64**	4.24**±0.51	-1.12**±0.23	-8.72**±0.96
Pusa Sugandh-2 x Kasturi	-1.24**±0.37	NS	NS	19.22**	-1.57**±0.42	NS	3.38**±0.87
Pusa 1121 x Adamchinni	NS	NS	NS	NS	NS	0.56*±0.24	NS
Pusa 1121 x BPT-5204	NS	1.82**±0.39	NS	126.28**	5.15**±0.53	-1.09**±0.25	-6.62**±1.04
Pusa 1121 x Kasturi	-1.43**±0.42	-0.98*±0.39	-7.42**±0.50	271.22**	5.01**±0.52	NS	-2.61*±1.04
	Brown rice width						
Type-3 x Adamchinni	NS	NS	NS	NS	NS	NS	NS
Type-3 x BPT-5204	0.20**±0.04	0.20**±0.03	NS	69.38**	0.35**±0.05	NS	-0.75**±0.09
Type-3 x Kasturi	0.16**±0.04	0.12**±0.04	NS	19.54**	0.19*±0.09	NS	-0.48**±0.13

Pusa Sugandh-2 x Adamchinni	0.23**±0.05	0.41**±0.05	0.41**±0.09	70.69**	0.23*±0.08	-0.09**±0.03	-0.86**±0.14
Pusa Sugandh-2 x BPT-5204	0.20**±0.06	0.30**±0.05	0.44**±0.06	57.48**	NS	NS	-0.55**±0.14
Pusa Sugandh-2 x Kasturi	0.33**±0.05	0.30**±0.05	0.22**±0.08	69.67**	0.41**±0.08	NS	-1.03**±0.14
Pusa 1121 x Adamchinni	0.09*±0.05	0.23**±0.04	0.19**±0.05	31.00**	0.14*±0.06	-0.07*±0.03	-0.46**±0.12
Pusa 1121 x BPT-5204	0.11*±0.05	0.15**±0.05	NS	14.20**	0.15*±0.06	NS	-0.41**±0.12
Pusa 1121 x Kasturi	0.11*±0.05	NS	0.21*±0.09	8.61*	NS	NS	NS
	Kernel length						
Type-3 x Adamchinni	1.19**±0.18	2.42**±0.14	5.3**±0.44	398.02**	-1.68**±0.42	-0.62**±0.10	-1.93**±0.53
Type-3 x BPT-5204	NS	0.64**±0.24	NS	11.16*	NS	-0.34**±0.11	NS
Type-3 x Kasturi	NS	-0.86*±0.33	-4.66**±0.37	195.55**	3.58**±0.43	NS	-2.50**±0.79
Pusa Sugandh-2 x Adamchinni	NS	2.13**±0.40	1.25*±0.49	30.10**	NS	-1.08**±0.29	-2.96*±0.29
Pusa Sugandh-2 x BPT-5204	1.74**±0.36	3.32**±0.37	NS	124.43**	5.00**±0.51	-0.79**±0.23	-10.05**±0.96
Pusa Sugandh-2 x Kasturi	NS	NS	NS	NS	NS	NS	NS
Pusa 1121 x Adamchinni	1.23**±0.33	NS	NS	15.53**	NS	0.71**±0.21	-1.76*±0.87
Pusa 1121 x BPT-5204	NS	1.71**±0.39	-3.28**±0.55	122.05**	5.33**±0.53	-0.69**±0.24	-7.37**±1.02
Pusa 1121 x Kasturi	-0.92**±0.27	-1.02**±0.27	-6.62**±0.34	388.10**	4.68**±0.42	NS	-2.74**±0.75

Cross combination	A	B	C	JST	i	j	l
	Kernel breadth						
Type-3 x Adamchinni	0.10*±0.04	NS	0.18**±0.06	10.1**	NS	NS	NS
Type-3 x BPT-5204	0.15**±0.04	0.12**±0.04	-0.12*±0.05	55.43**	0.38**±0.05	NS	-0.65**±0.09
Type-3 x Kasturi	0.12**±0.04	0.12*±0.05	NS	12.40*	NS	NS	-0.35**±0.13
Pusa Sugandh-2 x Adamchinni	NS	0.27**±0.05	0.49**±0.09	43.41**	NS	-0.10**±0.03	NS
Pusa Sugandh-2 x BPT-5204	NS	0.11*±0.05	0.17**±0.07	11.52*	NS	NS	NS
Pusa Sugandh-2 x Kasturi	0.23**±0.05	0.25**±0.05	0.30**±0.08	42.46**	0.18*±0.08	NS	-0.66**±0.14
Pusa 1121 x Adamchinni	NS	0.16**±0.04	NS	16.07**	0.15*±0.06	NS	-0.36**±0.12
Pusa 1121 x BPT-5204	NS	NS	NS	NS	0.15*±0.06	NS	-0.25*±0.12
Pusa 1121 x Kasturi	0.11*±0.05	NS	0.31**±0.09	14.35**	NS	NS	NS
	L/B ratio						
Type-3 x Adamchinni	0.56**±0.17	1.97**±0.17	3.77**±0.43	169.10**	-1.25**±0.41	-0.70**±0.11	-1.28*±0.54
Type-3 x BPT-5204	NS	NS	1.07*±0.46	19.18**	-1.17**±0.34	-0.35**±0.11	1.26*±0.54
Type-3 x Kasturi	-0.53*±0.23	-1.08**±0.33	-4.06**±0.42	98.64**	2.45**±0.47	NS	NS
Pusa Sugandh-2 x Adamchinni	NS	1.41**±0.42	NS	12.32**	NS	-0.79**±0.27	NS
Pusa Sugandh-2 x BPT-5204	1.21**±0.32	2.48**±0.32	NS	109.50**	4.04**±0.43	-0.64**±0.19	-7.73**±0.82
Pusa Sugandh-2 x Kasturi	-1.22**±0.31	-0.87**±0.26	NS	22.36**	-1.22**±0.41	NS	3.30**±0.75
Pusa 1121 x Adamchinni	0.82**±0.30	NS	NS	11.22*	NS	0.60**±0.21	NS
Pusa 1121 x BPT-5204	NS	1.27**±0.35	-2.60**±0.53	99.50**	4.02**±0.44	-0.56**±0.19	-5.44**±0.86
Pusa 1121 x Kasturi	-1.03**±0.27	-0.97**±0.29	-6.11**±0.36	294.06**	4.12**±0.45	NS	-2.12*±0.79
	Kernel length after cooking						
Type-3 x Adamchinni	-1.52**±0.19	1.30**±0.14	1.72**±0.47	196.31**	-1.93**±0.46	-1.41**±0.11	2.15**±0.57
Type-3 x BPT-5204	NS	1.38**±0.24	4.55**±0.59	122.94**	-3.51**±0.45	-0.85**±0.12	2.45**±0.64
Type-3 x Kasturi	1.19**±0.24	0.86*±0.34	-6.81**±0.38	620.99**	8.86**±0.43	NS	-10.91**±0.80

Pusa Sugandh-2 x Adamchinni	-2.24**±0.47	2.92**±0.40	-3.51**±0.50	160.50**	4.19**±0.65	-2.58**±0.29	-4.87**±1.21
Pusa Sugandh-2 x BPT-5204	0.73*±0.36	3.11**±0.37	1.09*±0.51	73.15**	2.75**±0.52	-1.19**±0.23	-6.58**±0.97
Pusa Sugandh-2 x Kasturi	0.83*±0.37	1.93**±0.33	NS	37.60**	1.73**±0.43	-0.55**±0.20	-4.49**±0.89
Pusa 1121 x Adamchinni	-2.04**±0.37	NS	-2.07**±0.40	47.31**	NS	-1.22**±0.23	NS
Pusa 1121 x BPT-5204	-1.76**±0.39	3.20**±0.39	-11.81**±0.55	958.73**	13.26**±0.53	-2.48**±0.24	-14.70**±1.02
Pusa 1121 x Kasturi	-4.02**±0.27	1.27**±0.27	-13.34**±0.35	1677.60**	10.59**±0.42	-2.64**±0.18	-7.84**±0.75
	Kernel breadth after cooking						
Type-3 x Adamchinni	0.45**±0.04	0.15**±0.04	0.82**±0.06	207.93**	-0.23**±0.06	0.15**±0.03	-0.36**±0.11
Type-3 x BPT-5204	0.55**±0.04	1.07**±0.03	1.25**±0.05	1109.58**	0.37**±0.05	-0.26**±0.02	-1.98**±0.09
Type-3 x Kasturi	NS	NS	0.21*±0.09	NS	NS	NS	NS
Pusa Sugandh-2 x Adamchinni	-0.34**±0.06	NS	-0.73**±0.09	91.20**	0.45**±0.09	-0.19**±0.03	NS
Pusa Sugandh-2 x BPT-5204	0.31**±0.06	0.35**±0.05	-0.50**±0.06	330.25**	1.16**±0.06	NS	-1.82**±0.14
Pusa Sugandh-2 x Kasturi	0.26**±0.05	0.19**±0.05	0.64**±0.08	67.33**	-0.19*±0.08	NS	NS
Pusa 1121 x Adamchinni	-0.27**±0.05	-0.83**±0.04	-0.57**±0.05	371.74**	-0.52**±0.06	0.28**±0.03	1.62**±0.12
Pusa 1121 x BPT-5204	0.14**±0.05	0.25**±0.05	1.10**±0.06	401.55**	-0.71**±0.06	NS	0.32*±0.13
Pusa 1121 x Kasturi	0.46**±0.05	0.30**±0.05	1.62**±0.09	352.56**	-0.86**±0.09	0.08**±0.03	NS

Cross combination	A	B	C	JST	i	j	l
	Elongation ratio						
Type-3 x Adamchinni	-1.20**±0.05	-1.20**±0.06	-2.60**±0.13	931.05**	0.21±0.12	NS	2.17**±0.16
Type-3 x BPT-5204	NS	NS	0.90**±0.15	78.23**	-1.01**±0.12	NS	1.13**±0.16
Type-3 x Kasturi	0.47**±0.05	0.78**±0.08	0.41**±0.09	152.36**	0.85**±0.11	-0.15**±0.05	-2.10**±0.20
Pusa Sugandh-2 x Adamchinni	-0.79**±0.15	-0.45*±0.17	-2.59**±0.20	184.68**	1.34**±0.22	NS	NS
Pusa Sugandh-2 x BPT-5204	-0.57**±0.07	-0.87**±0.09	0.42**±0.14	315.88**	-1.85**±0.11	0.15**±0.05	3.29**±0.20
Pusa Sugandh-2 x Kasturi	0.55**±0.08	0.63**±0.07	NS	150.19**	1.08**±0.10	NS	-2.26**±0.19
Pusa 1121 x Adamchinni	-0.92**±0.07	NS	-0.72**±0.10	187.29**	NS	-0.55**±0.07	0.76**±0.26
Pusa 1121 x BPT-5204	-0.50**±0.11	NS	-1.74**±0.16	161.98**	1.26**±0.15	-0.26**±0.07	-0.78**±0.29
Pusa 1121 x Kasturi	-0.52**±0.07	0.97**±0.08	NS	224.90**	0.57**±0.12	-0.74**±0.05	-1.02**±0.02
	Elongation index						
Type-3 x Adamchinni	-1.25**±0.04	-1.08**±0.05	-2.67**±0.11	1040.90**	0.34**±0.10	-0.08**±0.03	2.00**±0.14
Type-3 x BPT-5204	-0.42**±0.05	-1.22**±0.06	-0.94**±0.11	470.74**	-0.69**±0.09	0.40**±0.03	2.33**±0.13
Type-3 x Kasturi	0.88**±0.16	1.17**±0.17	1.02**±0.27	117.92**	1.02**±0.11	NS	-3.06**±0.31
Pusa Sugandh-2 x Adamchinni	NS	NS	-2.09**±0.16	209.26**	2.00**±0.20	NS	-1.90**±0.36
Pusa Sugandh-2 x BPT-5204	-0.65**±0.06	-1.20**±0.07	0.89**±0.12	911.65**	-2.74**±0.10	0.28**±0.04	4.60**±0.17
Pusa Sugandh-2 x Kasturi	0.54**±0.07	0.71**±0.06	NS	230.33**	1.21**±0.10	-0.08*±0.04	-2.47**±0.17
Pusa 1121 x Adamchinni	-0.36**±0.07	1.50**±0.11	0.17*±0.09	225.33**	0.96**±0.13	-0.93**±0.06	-2.10**±0.25
Pusa 1121 x BPT-5204	-0.52**±0.09	-0.29**±0.11	-2.92**±0.14	558.35**	2.11**±0.12	-0.12*±0.06	-1.30**±0.24
Pusa 1121 x Kasturi	-0.72**±0.09	0.54**±0.07	-1.34**±0.09	329.18**	1.16**±0.13	-0.63**±0.06	-0.97**±0.24
	Alkali spread value						
Type-3 x Adamchinni	1.00**±0.15	1.89**±0.14	2.15**±0.37	204.14**	0.73*±0.37	-0.45**±0.10	-3.60**±0.50
Type-3 x BPT-5204	-0.28*±0.13	-0.52**±0.14	-1.23**±0.42	20.58**	NS	NS	NS
Type-3 x Kasturi	2.47**±0.12	1.52**±0.12	0.70**±0.26	548.80**	3.29**±0.24	0.47**±0.07	-7.27**±0.35

Pusa Sugandh-2 x Adamchinni	1.21**±0.09	2.89**±0.12	NS	694.57**	3.34**±0.40	-0.84**±0.07	-7.44**±0.47
Pusa Sugandh-2 x BPT-5204	NS	1.46**±0.11	-3.62**±0.34	379.98**	4.88**±0.34	-0.83**±0.07	-6.14**±0.41
Pusa Sugandh-2 x Kasturi	-0.47**±0.09	1.80**±0.11	1.87**±0.22	373.96**	-0.55*±0.22	-1.14**±0.06	-0.78*±0.31
Pusa 1121 x Adamchinni	NS	3.00**±0.13	-1.53**±0.44	608.44**	4.67**±0.45	-1.40**±0.08	-7.81**±0.52
Pusa 1121 x BPT-5204	NS	0.57**±0.17	-0.77*±0.34	24.26**	1.58**±0.35	NS	-2.40**±0.49
Pusa 1121 x Kasturi	-0.29*±0.13	0.85**±0.15	NS	52.72**	0.77**±0.25	-0.57**±0.09	-1.34**±0.40
	Amylose content						
Type-3 x Adamchinni	-2.23**±0.81	-2.27**±0.74	NS	36.97**	-6.52**±1.10	NS	11.02**±1.99
Type-3 x BPT-5204	-4.47**±0.74	-2.80**±0.83	3.30**±1.18	86.64**	-10.57**±1.24	NS	17.83**±2.15
Type-3 x Kasturi	NS	-2.73**±0.82	3.80**±1.37	26.00**	-6.66**±1.45	1.30**±0.48	9.52**±2.22
Pusa Sugandh-2 x Adamchinni	NS	-1.67*±0.81	14.92**±1.46	183.04**	-15.69**±1.30	1.28*±0.51	16.45**±2.26
Pusa Sugandh-2 x BPT-5204	2.07**±0.66	NS	8.71**±1.31	55.29**	-7.37**±1.29	1.40**±0.46	6.04**±2.03
Pusa Sugandh-2 x Kasturi	NS	-3.80**±0.87	4.69**±1.12	57.26**	-9.53**±1.33	1.38*±0.55	14.36**±2.40
Pusa 1121 x Adamchinni	-5.97**±0.73	-7.33**±0.76	14.04**±1.24	492.53**	-27.34**±1.23	NS	40.64**±2.06
Pusa 1121 x BPT-5204	-2.60**±0.72	NS	8.26**±1.48	66.62**	-11.56**±1.48	-0.95*±0.47	14.86**±2.24
Pusa 1121 x Kasturi	-1.80*±0.76	-4.87**±0.81	NS	57.81**	-8.71**±1.33	1.53**±0.50	15.38**±2.19

Cross combination	A	B	C	JST	i	j	l
	Gel consistency						
Type-3 x Adamchinni	NS	NS	8.84*±3.5	NS	NS	NS	NS
Type-3 x BPT-5204	-4.57*±2.05	-6.43**±2.07	-18.86**±4.82	19.35**	NS	NS	NS
Type-3 x Kasturi	-14.93**±2.18	-21.63**±1.67	NS	206.24**	-32.67**±3.95	3.35**±1.16	69.24**±5.81
Pusa Sugandh-2 x Adamchinni	13.30**±2.42	NS	-30.37**±4.75	98.68**	46.37**±5.02	5.30**±1.59	-62.37**±7.54
Pusa Sugandh-2 x BPT-5204	3.90*±1.49	9.10**±1.93	53.06**±4.79	133.73**	-40.06**±4.93	-2.60*±1.14	27.06**±6.26
Pusa Sugandh-2 x Kasturi	12.73**±2.07	7.13**±2.09	41.59**±4.14	111.57**	-21.72**±4.18	2.80*±1.28	NS
Pusa 1121 x Adamchinni	28.77**±2.36	NS	-24.91**±4.14	243.45**	54.45**±4.22	14.00**±1.54	-83.98**±6.83
Pusa 1121 x BPT-5204	-18.87**±1.58	-6.77**±2.18	8.49*±3.98	180.79**	-34.13**±4.08	-6.05**±1.17	59.76**±5.96
Pusa 1121 x Kasturi	-15.67**±1.60	-12.83**±1.84	NS	147.94**	-32.97**±3.77	NS	61.47**±5.36
	Aroma						
Type-3 x Adamchinni	NS	NS	-2.45**±0.67	29.67**	3.09**±0.59	NS	-3.74**±1.05
Type-3 x BPT-5204	NS	NS	NS	10.68*	-2.76**±1.05	NS	NS
Type-3 x Kasturi	NS	NS	-1.82*±0.71	21.86**	2.92**±0.65	NS	-4.01**±1.20
Pusa Sugandh-2 x Adamchinni	NS	NS	NS	NS	NS	NS	NS
Pusa Sugandh-2 x BPT-5204	1.14*±0.49	2.43**±0.74	NS	13.68**	NS	NS	-5.63**±1.82
Pusa Sugandh-2 x Kasturi	NS	NS	-1.85**±0.59	16.69**	1.64**±0.47	NS	NS
Pusa 1121 x Adamchinni	NS	NS	NS	10.18*	1.38**±0.53	NS	NS
Pusa 1121 x BPT-5204	NS	4.64**±0.60	4.13**±1.10	88.20**	NS	-2.11**±0.25	-5.99**±1.42
Pusa 1121 x Kasturi	NS	NS	NS	NS	NS	NS	NS

Table 4.14: Estimation of m, d and h by three parameter model for non-interacting characters in nine crosses.

Cross combination	m	d	h
Days to 50% flowering			
Pusa 1121 x Kasturi	103.00**±2.88	13.433**±0.371	-1.247±7.76
Days to maturity			
Pusa 1121 x Kasturi	131.67**±2.896	13.43**±0.424	-8.347±7.747
Effective tillers per plant			
Pusa 1121 x Adamchinni	7.893**±1.42	1.433**±0.192	12.88**±3.35
Grain breadth			
Pusa Sugandh-2 x BPT-5204	2.154**±0.067	0.146**±0.015	0.191±0.984
Brown rice width			
Type-3 x Adamchinni	2.004**±0.056	0.018*±0.014	-0.136±0.148
Pusa 1121 x Kasturi	1.99**±0.09	0.026*±0.010	0.085±0.218
Kernel length			
Pusa Sugandh-2 x Kasturi	8.337**±0.428	0.455**±0.081	-1.60±1.198
Kernel breadth			
Type-3 x Adamchinni	1.974**± 0.06	0.013*±0.014	-0.076±0.151
Pusa Sugandh-2 x BPT-5204	1.87**±0.068	-0.035*±0.016	0.231±0.197
Pusa 1121 x Kasturi	1.995**±0.089	0.031**±0.010	-0.108±0.216
Kernel breadth after cooking			
Type-3 x Kasturi	2.923**±0.091	0.101**±0.010	0.048±0.215
Alkali digestion value			
Type-3 x BPT-5204	11.84**±0.421	0.611**±0.045	2.168*±0.916
Gel consistency			
Type-3 x Adamchinni	59.74**±4.07	-7.97**±0.620	-7.08±10.18
Type-3 x BPT-5204	37.99**±4.632	2.083**±0.568	7.437±10.55
Aroma			
Pusa Sugandh-2 x Adamchinni	10.05**±0.642	0.485*±0.137	0.104±1.74
Pusa 1121 x Kasturi	10.317**±0.514	0.563**±0.140	0.181±1.462

Table 4.15: Estimates of Gene effects (six-parameter model) for yield and yield traits.

Cross combination	m	d	h	i	j	l	Type of interaction
Days to 50% flowering							
Type-3 x Adamchinni	103.96**±0.88	-6.93*±2.14	46.16**±5.63	41.30±5.53	8.4±2.18	41.30**±5.53	C
Type-3 x BPT-5204	92.08**±0.67	-7.63**±1.38	49.63**±3.92	53.4**±3.86	1.47**±1.01	-48.87**±6.30	D
Type-3 x Kasturi	94.75**±0.46	7.31**±1.03	-24.04**±2.84	-13.89**±2.77	1.83±1.13	-4.65±4.69	--
Pusa Sugandh-2 x Adamchinni	111.81**±0.88	-10.73**±1.69	-7.79±4.91	-15.92**±4.88	6.27**±3.64	44.59**±7.69	--
Pusa Sugandh-2 x BPT-5204	104.34**±0.54	-6.77**±1.20	-1.96±3.29	-5.70±3.22	4.13**±1.25	26.03**±5.43	--
Pusa Sugandh-2 x Kasturi	87.75**±0.36	7.07**±0.95	-5.29*±2.48	3.68±2.38	1.17±1.03	-17.08**±3.97	C
Pusa 1121 x Adamchinni	107.48**±0.60	-5.93**±0.90	35.23**±3.08	36.75**±3.00	2.62*±0.97	-29.71**±4.54	D
Pusa 1121 x BPT-5204	109.61**±0.56	-4.40**±0.77	20.33**±2.79	19.41**±2.72	-1.42±0.88	-16.18**±4.00	D
Days to maturity							
Type-3 x Adamchinni	130.28**±0.90	-6.80**±2.16	43.76**±5.74	41.21**±5.61	8.28**±2.21	-34.25**±9.65	D
Type-3 x BPT-5204	118.39**±0.69	-7.50**±1.44	47.52**±4.06	53.32**±4.00	1.6±1.51	-43.65**±6.54	D
Type-3 x Kasturi	121.07**±0.49	7.18**±1.09	-26.33**±8.69	-13.97**±4.76	1.98±2.93	-0.13±5.01	--
Pusa Sugandh-2 x Adamchinni	138.13**±0.88	-10.60**±1.70	-10.37*±4.94	-16.00**±4.89	6.40**±1.75	49.67**±7.79	D
Pusa Sugandh-2 x BPT-5204	130.66**±0.56	-6.90**±1.28	-4.07±3.46	-5.77±3.39	4.00*±1.34	31.24**±5.76	--
Pusa Sugandh-2 x Kasturi	114.11**±0.39	7.20**±1.00	-7.62*±2.66	3.41±2.54	1.30±1.10	-13.21**±4.58	C
Pusa 1121 x Adamchinni	133.80**±0.62	-6.07**±0.95	33.12**±3.20	36.67**±3.11	2.48*±1.03	-24.5**±4.76	D
Pusa 1121 x BPT-5204	135.88**±0.57	-4.27**±0.81	18.53**±2.88	19.55**±2.80	-1.28±0.95	-12.45**±4.20	D
Plant Height							
Type-3 x Adamchinni	135.25**±1.54	-7.83**±2.37	54.60**±8.08	43.00**±7.78	-3.83±2.71	7.13±12.14	--
Type-3 x BPT-5204	136.87**±1.17	29.32**±1.75	-101.31**±6.04	-118.40**±5.85	0.30±0.15	218.20**±8.93	D

Type-3 x Kasturi	111.93**±0.65	9.30**±1.72	50.58**±4.74	47.87**±4.31	-11.55**±2.09	-26.50**±8.33	D
Pusa Sugandh-2 x Adamchinni	147.87**±1.48	-13.40**±2.37	57.52**±8.01	20.13**±7.59	13.25**±2.57	-11.03±12.29	--
Pusa Sugandh-2 x BPT-5204	104.34**±0.54	-6.77**±1.20	-1.96±3.29	-5.69±3.22	4.13**±1.25	26.03**±5.43	--
Pusa Sugandh-2 x Kasturi	87.75**±0.36	7.07**±0.95	-5.29*±2.48	3.68±2.38	1.17±1.03	-17.08**±4.31	C
Pusa 1121 x Adamchinni	111.22**±1.35	-7.83±2.37	117.52**±7.36	139.11**±7.19	18.82**±2.58	-220.34**±11.38	D
Pusa 1121 x BPT-5204	111.50**±0.74	13.93**±1.71	-14.79**±4.79	-27.83**±4.53	5.97**±1.94	43.16**±8.07	D
Pusa 1121 x Kasturi	94.67**±0.66	7.50**±1.88	23.37**±4.88	16.40**±4.60	5.83**±2.13	41.80**±8.61	C
Effective tillers/plant							
Type-3 x Adamchinni	11.16**±0.29	3.08**±0.39	17.01**±1.45	8.86**±1.40	1.70**±0.43	-7.06**±2.11	D
Type-3 x BPT-5204	10.31**±0.21	-0.83**±0.30	13.78**±1.14	10.08**±1.03	0.08±0.37	-4.71**±1.76	D
Type-3 x Kasturi	10.45**±0.24	2.63**±0.41	11.56**±1.37	6.15**±1.25	1.78**±0.46	-2.65±2.21	--
Pusa Sugandh-2 x Adamchinni	10.94**±0.30	1.97**±0.26	7.90**±1.35	1.95±1.31	0.98**±0.31	-0.51±1.71	--
Pusa Sugandh-2 x BPT-5204	10.81**±0.27	1.77**±0.41	15.78**±1.44	7.08**±1.35	3.33**±0.47	6.39**±2.22	C
Pusa Sugandh-2 x Kasturi	9.24**±0.22	1.68**±0.28	10.76**±1.12	5.21**±1.05	1.10**±0.34	-1.54±1.64	--
Pusa 1121 x BPT-5204	11.12**±0.23	-1.32**±0.36	16.07**±1.23	9.35**±1.17	-0.13±0.42	-1.29±1.88	--
Pusa 1121 x Kasturi	10.80**±0.27	1.90**±0.36	6.72**±1.39	0.93±1.31	1.02*±0.43	4.57*±2.03	C

Cross combination	m	d	h	i	j	l	Type of interaction
No. of grains per panicle							
Type-3 x Adamchinni	149.02**±3.08	-14.93**±2.36	94.32**±13.42	47.65**±13.21	18.97**±2.65	50.48**±16.27	C
Type-3 x BPT-5204	104.60**±3.02	-17.23**±2.13	133.87**±13.01	123.60**±12.78	3.4±2.54	-68.4**±15.52	D
Type-3 x Kasturi	124.63**±1.91	7.60**±2.34	85.55**±9.22	52.20**±8.97	2.05±2.53	-56.43**±12.80	D
Pusa Sugandh-2 x Adamchinni	134.82**±2.24	-11.83**±2.25	92.73**±10.33	54.85**±10.04	16.02**±2.60	83.91**±13.63	C
Pusa Sugandh-2 x BPT-5204	163.06**±3.08	-42.90**±2.79	57.49**±13.96	-24.11±13.54	-24.83**±3.09	159.57**±17.99	C
Pusa Sugandh-2 x Kasturi	93.63**±1.94	8.38**±2.07	123.21**±9.01	104.30**±8.81	0.133±0.057	-58.16**±12.00	D
Pusa 1121 x Adamchinni	105.99**±2.54	-60.57**±2.29	103.84**±11.36	105.63**±11.15	0.35±2.62	-92.99**±14.33	D
Pusa 1121 x BPT-5204	111.93**±2.57	-25.20**±2.40	55.21**±11.47	32.36**±11.34	16.85**±2.63	-0.66±14.47	--
Pusa 1121 x Kasturi	94.23**±1.95	-9.68**±2.00	72.89**±8.98	34.53**±8.76	12.11**±2.22	6.11±11.84	--
100 grain weight							
Type-3 x Adamchinni	2.47**±0.03	0.24**±0.04	-2.43**±0.14	-2.47**±0.13	-0.005±0.04	2.36**±0.20	D
Type-3 x BPT-5204	2.45**±0.03	0.11*±0.05	-0.46**±0.17	-0.41*±0.17	0.017±0.05	-1.02**±0.25	C
Type-3 x Kasturi	2.35**±0.04	-0.056±0.053	-0.96**±0.19	-0.74**±0.19	0.023±0.06	0.33±0.27	--
Pusa Sugandh-2 x Adamchinni	2.20**±0.03	0.16**±0.06	0.31±0.17	0.55**±0.17	-0.32**±0.06	-2.15**±0.27	--
Pusa Sugandh-2 x BPT-5204	2.94**±0.05	0.20**±0.05	-0.67**±0.22	-0.91**±0.21	-0.13*±0.06	-0.71*±0.30	C
Pusa Sugandh-2 x Kasturi	2.45**±0.02	0.24**±0.04	0.38**±0.14	0.26*±0.13	0.08±0.05	-0.46*±0.22	D
Pusa 1121 x Adamchinni	2.74**±0.03	0.50**±0.06	-1.81**±0.18	-1.28**±0.18	-0.12*±0.06	-0.79**±0.28	C
Pusa 1121 x BPT-5204	2.82**±0.03	0.13*±0.05	-0.53**±0.16	-0.68**±0.15	-0.35**±0.06	-0.28±0.25	--
Pusa 1121 x Kasturi	2.73**±0.03	0.16**±0.05	0.14±0.15	-0.21±0.14	-0.15*±0.05	0.19±0.24	--
Grain yield per plant							
Type-3 x Adamchinni	29.49**±0.84	3.25**±0.67	-7.94*±3.68	-29.40**±3.63	2.02**±0.72	34.56**±4.49	D
Type-3 x BPT-5204	25.02**±0.64	-3.52**±0.72	-7.30*±3.00	-24.53**±2.93	-2.23**±0.78	42.64**±4.04	D
Type-3 x Kasturi	19.67**±0.49	1.96**±0.55	13.34**±2.28	3.72±2.24	1.23*±0.60	-12.42**±3.07	D
Pusa Sugandh-2 x Adamchinni	21.26**±0.50	2.48**±0.67	15.20**±2.47	4.05±2.40	0.057±0.72	-12.66**±3.54	D
Pusa Sugandh-2 x BPT-5204	29.63**±0.8934	-5.12**±0.577	7.68**±3.82	-13.28**±3.75	-4.77**±0.62	14.71**±4.49	C
Pusa Sugandh-2 x Kasturi	20.87**±0.48	3.58**±0.59	7.00**±2.30	-4.37±2.24	2.13**±0.64	6.67*±3.20	C
Pusa 1121 x Adamchinni	28.47**±1.024	4.71**±0.540	14.09**±4.28	-7.64±4.23	3.39**±0.58	-1.38±4.78	--
Pusa 1121 x BPT-5204	19.95**±0.54	-2.68**±0.53	8.80**±2.48	-0.69±2.41	-1.75**±0.59	5.64±3.23	--
Pusa 1121 x Kasturi	18.42**±0.49	2.15**±0.52	7.79**±2.26	-1.66±2.20	1.48*±0.58	3.82±3.02	--

Table 4.16: Estimates of Gene effects (six-parameter model) for quality traits

Cross combination	m	d	h	i	j	l	Type of interaction
Hulling %							
Type-3 x Adamchinni	72.24**±0.52	-0.37±0.88	27.54**±2.82	26.17**±2.73	0.87±1.00	-19.91**±4.34	D
Type-3 x BPT-5204	69.99**±0.47	4.03**±1.01	23.87**±2.87	23.92**±2.76	2.65*±1.12	-19.95**±4.75	D
Type-3 x Kasturi	67.83**±0.44	3.93**±0.83	10.97**±2.54	12.40**±2.41	0.97±0.99	2.20±4.08	--
Pusa Sugandh-2 x Adamchinni	71.36**±0.60	-2.05**±0.72	31.36**±2.92	29.99**±2.80	-0.35±0.90	-28.43**±4.08	D
Pusa Sugandh-2 x BPT-5204	70.60**±0.55	1.83±1.08	15.78**±3.17	13.07**±3.09	1.28±1.19	0.97±5.07	--
Pusa Sugandh-2 x Kasturi	66.10**±0.54	4.85**±0.85	19.09**±2.84	21.01**±2.75	2.57*±1.00	-10.87*±4.28	D
Pusa 1121 x Adamchinni	69.32**±0.60	-3.97**±0.79	23.41**±2.96	26.36**±2.89	-1.12±0.88	-24.79**±4.18	D
Pusa 1121 x BPT-5204	70.09**±0.59	-1.12±1.03	16.53**±3.20	13.13**±3.13	-0.58±1.11	2.17±4.93	--
Pusa 1121 x Kasturi	64.23**±0.45	3.95**±0.84	22.32**±2.54	22.97**±9.32	2.83**±0.95	-9.97*±4.00	D
Milling %							
Type-3 x Adamchinni	52.80**±0.31	-1.81**±0.50	18.95**±1.64	17.10**±1.59	-0.87±0.55	-8.59**±2.50	D
Type-3 x BPT-5204	52.64**±0.31	1.59*±0.65	8.66**±1.86	7.01**±1.80	0.71±0.70	3.98±3.04	--
Type-3 x Kasturi	51.35**±0.27	1.02*±0.51	7.58**±1.57	6.86**±1.49	-0.81±0.62	6.39*±2.52	C
Pusa Sugandh-2 x Adamchinni	50.68**±0.30	-1.50**±0.69	13.51**±1.46	11.60**±1.45	-0.12±0.84	-4.78*±4.02	D
Pusa Sugandh-2 x BPT-5204	51.22**±0.32	-0.97±0.68	12.94**±1.95	12.19**±1.87	-0.90±0.75	-6.62*±3.18	D
Pusa Sugandh-2 x Kasturi	50.16**±0.32	1.31*±0.55	11.02**±1.76	11.90**±1.69	0.83±0.63	-6.62*±2.71	D
Pusa 1121 x Adamchinni	51.49**±0.37	-4.29**±0.50	12.90**±1.84	14.88**±1.78	-1.56**±0.56	-12.71**±2.64	D
Pusa 1121 x BPT-5204	52.75**±0.37	-1.30*±0.66	8.60**±2.03	6.09**±2.00	-0.77±0.70	0.06**±3.14	C
Pusa 1121 x Kasturi	49.05**±0.28	-0.63±0.51	16.41**±1.57	14.98**±1.51	-0.49±0.58	-6.57**±2.46	D

Head Rice Recovery							
Type-3 x Adamchinni	46.97**±0.31	-0.59±0.48	4.34**±1.60	2.83±1.55	0.29±0.55	8.60**±2.40	C
Type-3 x BPT-5204	45.66**±0.34	-1.16±0.68	10.26**±1.98	8.14**±1.92	-0.82±0.72	4.22±3.18	--
Type-3 x Kasturi	43.84**±0.29	0.40±0.54	9.77**±1.67	8.48**±1.60	-0.15±0.64	5.57*±2.66	C
Pusa Sugandh-2 x Adamchinni	45.31**±0.37	-1.16*±0.50	14.25**±1.86	10.51**±1.79	0.22±0.58	-0.46±2.68	--
Pusa Sugandh-2 x BPT-5204	44.28**±0.33	-1.46*±0.68	11.10**±1.99	8.94**±1.91	0.06±0.76	3.22±3.25	--
Pusa Sugandh-2 x Kasturi	43.23**±0.33	-1.48*±0.56	10.36**±1.83	9.16**±1.75	-1.07±0.66	1.19±2.83	--
Pusa 1121 x Adamchinni	46.26**±0.38	-1.14*±0.53	6.63**±1.93	4.57*±1.87	0.23±0.59	5.62*±2.78	C
Pusa 1121 x BPT-5204	45.16**±0.38	-2.39**±0.71	11.59**±2.13	8.93**±2.09	-1.60*±0.76	2.61±3.34	--
Pusa 1121 x Kasturi	44.46**±0.30	-1.19*±0.54	7.76**±1.68	7.27**±1.61	-1.35*±0.61	0.61±2.64	--
Grain length							
Type-3 x Adamchinni	9.32**±0.11	0.89**±0.07	-5.26**±0.46	-4.07**±0.45	-1.20**±0.10	-1.69**±0.54	C
Type-3 x BPT-5204	9.08**±0.11	0.37**±0.06	-0.87±0.49	-0.34±0.45	-0.80**±0.11	-3.09**±0.64	C
Type-3 x Kasturi	9.22**±0.06	-1.70**±0.17	5.65**±0.45	5.60**±0.42	-1.24**±0.19	-8.11**±0.79	D
Pusa Sugandh-2 x Adamchinni	8.55**±0.08	1.03**±0.28	0.54±0.71	1.43*±0.66	-1.61**±0.30	-6.77**±1.28	--
Pusa Sugandh-2 x BPT-5204	9.06**±0.08	1.60**±0.20	6.17**±0.55	7.24**±0.51	-0.11±0.23	-17.10**±0.96	D
Pusa Sugandh-2 x Kasturi	11.82**±0.06	0.58**±0.18	-2.71**±0.50	-3.04**±0.43	0.27±0.22	2.74**±0.90	D
Pusa 1121 x Adamchinni	9.26**±0.06	2.82**±0.22	-1.36*±0.53	-2.17**±0.51	-0.21±0.24	2.35*±0.96	D
Pusa 1121 x BPT-5204	8.46**±0.08	0.91**±0.22	5.77**±0.59	5.80**±0.54	-0.86**±0.25	-8.17**±1.05	D
Pusa 1121 x Kasturi	10.62**±0.06	0.88**±3.83	2.84**±0.57	1.21*±0.52	0.69*±0.27	-0.07±1.06	--

Cross combination	m	d	h	i	j	l	Type of interaction
Grain breadth							
Type-3 x Adamchinni	2.26**±0.01	0.08**±0.02	-0.41**±0.06	-0.33**±0.06	-0.006±0.024	-0.13±0.10	--
Type-3 x BPT-5204	2.24**±0.01	0.07**±0.02	-0.26**±0.05	-0.16**±0.05	-0.015±0.021	-0.38**±0.09	C
Type-3 x Kasturi	2.28**±0.02	0.10**±0.02	-0.30**±0.09	-0.19*±0.09	0.07**±0.03	-0.28*±0.13	C
Pusa Sugandh-2 x Adamchinni	2.55**±0.02	0.12**±0.03	-1.31**±0.09	-1.21**±0.09	-0.02±0.03	0.85**±0.14	C
Pusa Sugandh-2 x Kasturi	2.53**±0.02	0.10**±0.03	-1.19**±0.10	-1.13**±0.09	-0.001±0.031	1.08**±0.14	D
Pusa 1121 x Adamchinni	2.18**±0.01	0.09**±0.03	0.48**±0.06	0.51**±0.06	-0.08**±0.03	-0.80**±0.12	D
Pusa 1121 x BPT-5204	2.24**±0.01	0.13**±0.03	0.73**±0.07	0.43**±0.06	-0.04±0.03	-0.25*±0.12	D
Pusa 1121 x Kasturi	2.42**±0.02	0.09**±0.03	-0.31**±0.09	-0.34**±0.09	-0.05±0.03	0.19±0.14	--
Brown rice length							
Type-3 x Adamchinni	6.32**±0.10	0.09±0.07	0.75±0.45	1.88**±0.44	-1.55**±0.11	-8.89**±0.54	--
Type-3 x BPT-5204	6.82**±0.11	0.76**±0.06	0.14±0.48	-0.50±0.44	-0.30*±0.11	-0.13±0.63	--
Type-3 x Kasturi	6.31**±0.06	-0.14±0.17	5.20**±0.45	4.88**±0.43	0.09±0.18	-4.59**±0.79	D
Pusa Sugandh-2 x Adamchinni	5.75**±0.08	1.24**±0.28	-0.97±0.69	0.48±0.65	-1.13**±0.29	-1.48±1.27	--
Pusa Sugandh-2 x BPT-5204	6.51**±0.07	0.67**±0.20	3.26**±0.55	4.24**±0.51	-1.12**±0.23	-8.72**±0.96	D
Pusa Sugandh-2 x Kasturi	8.23**±0.06	0.13±0.18	-1.19*±0.48	-1.57**±0.42	-0.33±0.19	3.38**±0.87	D
Pusa 1121 x Adamchinni	6.69**±0.06	3.00**±0.22	-0.03±0.52	-0.32±0.50	0.56*±0.24	-0.01±0.96	--
Pusa 1121 x BPT-5204	5.94**±0.08	0.75**±0.22	4.89**±0.22	5.15**±0.53	-1.09**±0.25	-6.62**±1.04	D
Pusa 1121 x Kasturi	6.36**±0.06	0.40±0.23	4.99**±0.56	5.01**±0.52	-0.22±0.26	-2.61*±1.04	D
Brown rice width							
Type-3 x BPT-5204	1.96**±0.01	0.03±0.02	0.28**±0.05	0.35**±0.05	0.00±0.02	-0.75**±0.09	D
Type-3 x Kasturi	1.97**±0.02	0.07**±0.02	0.16±0.09	0.19*±0.09	0.02±0.03	-0.48**±0.13	--

Pusa Sugandh-2 x Adamchinni	2.04**±0.02	-0.11**±0.03	0.20*±0.09	0.23*±0.08	-0.09**±0.03	-0.86**±0.14	D
Pusa Sugandh-2 x BPT-5204	2.03**±0.01	-0.06*±0.03	0.03±0.07	0.06±0.07	-0.05±0.03	-0.55**±0.14	--
Pusa Sugandh-2 x Kasturi	1.94**±0.02	0.01±0.03	0.33**±0.09	0.41**±0.08	0.01±0.03	-1.03**±0.14	D
Pusa 1121 x Adamchinni	2.02**±0.01	-0.06*±0.03	0.11±0.06	0.14*±0.06	-0.07*±0.03	-0.46**±0.12	--
Pusa 1121 x BPT-5204	2.00**±0.01	-0.01±0.03	0.17*±0.07	0.15*±0.06	-0.02±0.03	-0.41**±0.12	D
Kernel length							
Type-3 x Adamchinni	6.02**±0.10	1.15**±0.08	-2.95**±0.43	-1.68**±0.42	-0.62**±0.10	-1.93**±0.53	C
Type-3 x BPT-5204	6.62**±0.09	0.71**±0.06	0.40±0.44	-0.26±0.39	-0.34**±0.11	-0.34±0.60	--
Type-3 x Kasturi	6.17**±0.06	0.27±0.17	3.92**±0.45	3.58**±0.43	0.32±0.18	-2.50**±0.79	D
Pusa Sugandh-2 x Adamchinni	5.58**±0.08	1.27**±0.28	-0.37±0.67	0.85±0.65	-1.08**±0.29	-2.96*±0.29	--
Pusa Sugandh-2 x BPT-5204	6.21**±0.08	0.70**±0.21	4.34**±0.55	5.00**±0.51	-0.79**±0.23	-10.05**±0.96	D
Pusa 1121 x Adamchinni	6.33**±0.06	3.07**±0.20	1.32**±0.49	0.72±0.47	0.71**±0.21	-1.76*±0.87	D
Pusa 1121 x BPT-5204	5.77**±0.08	0.83**±0.22	5.41**±0.58	5.33**±0.53	-0.69**±0.24	-7.37**±1.02	D
Pusa 1121 x Kasturi	6.25**±0.06	0.52**±0.17	5.03**±0.43	4.68**±0.42	0.05±0.18	-2.74**±0.75	D

Cross combination	m	d	h	i	j	l	Type of interaction
Kernel breadth							
Type-3 x BPT-5204	1.86**±0.01	0.02±0.02	0.30**±5.43	0.38**±0.05	0.02±0.02	-0.65**±0.09	D
Type-3 x Kasturi	1.89**±0.02	0.06±0.03	0.07±0.09	0.11±0.09	0.002±0.03	-0.35**±0.13	--
Pusa Sugandh-2 x Adamchinni	1.96**±0.02	-0.12**±0.03	-0.21*±0.09	-0.14±0.09	-0.10**±0.03	-0.21±0.14	--
Pusa Sugandh-2 x Kasturi	1.90**±0.02	0.01±0.03	0.16±0.09	0.18*±0.08	-0.01±0.03	-0.66**±0.14	--
Pusa 1121 x Adamchinni	1.91**±0.01	-0.06*±0.03	0.15*±0.06	0.15*±0.06	-0.05±0.03	-0.36**±0.12	D
Pusa 1121 x BPT-5204	1.91**±0.01	-0.04±0.03	0.20**±0.07	0.15*±0.06	-0.03±0.03	-0.25*±0.12	D
L/B ratio							
Type-3 x Adamchinni	10.18**±0.09	0.90**±0.08	-1.68**±0.42	-1.25**±0.41	-0.70**±0.11	-1.28*±0.54	D
Type-3 x BPT-5204	10.85**±0.08	0.53**±0.07	-0.36±0.38	-1.17**±0.34	-0.35**±0.11	1.26*±0.54	--
Type-3 x Kasturi	10.47**±0.08	0.06±0.17	2.85**±0.49	2.45**±0.47	0.27±0.18	-0.85±0.80	--
Pusa Sugandh-2 x Adamchinni	9.71**±0.08	1.39**±0.26	0.07±0.64	0.86±0.62	-0.79**±0.27	-2.11±1.15	--
Pusa Sugandh-2 x BPT-5204	10.30**±0.07	0.72**±0.17	3.49**±0.47	4.04**±0.43	-0.64**±0.19	-7.73**±0.82	D
Pusa Sugandh-2 x Kasturi	11.82**±0.07	0.12±0.15	-0.71±0.45	-1.22**±0.41	-0.18±0.17	3.30**±0.75	--
Pusa 1121 x Adamchinni	10.48**±0.06	2.72**±0.20	0.65±0.47	-0.06±0.46	0.60**±0.21	-0.39±0.87	--
Pusa 1121 x BPT-5204	9.98**±0.07	0.75**±0.17	4.02**±0.49	4.02**±0.44	-0.56**±0.19	-5.44**±0.86	D
Pusa 1121 x Kasturi	10.39**±0.07	0.24±0.18	4.36**±0.47	4.12**±0.45	-0.03±0.18	-2.12*±0.79	D
Kernel length after cooking							
Type-3 x Adamchinni	10.08**±0.11	1.22**±0.08	-2.59**±0.46	-1.93**±0.46	-1.41**±0.11	2.15**±0.57	D
Type-3 x BPT-5204	11.84**±0.11	0.86**±0.07	-3.91**±0.49	-3.51**±0.45	-0.85**±0.12	2.45**±0.64	D
Type-3 x Kasturi	10.56**±0.06	0.26±0.18	8.45**±0.46	8.86**±0.43	0.16±0.19	-10.91**±0.80	D
Pusa Sugandh-2 x Adamchinni	9.69**±0.09	1.07**±0.28	3.26**±0.66	4.19**±0.65	-2.58**±0.29	-4.87**±1.21	D

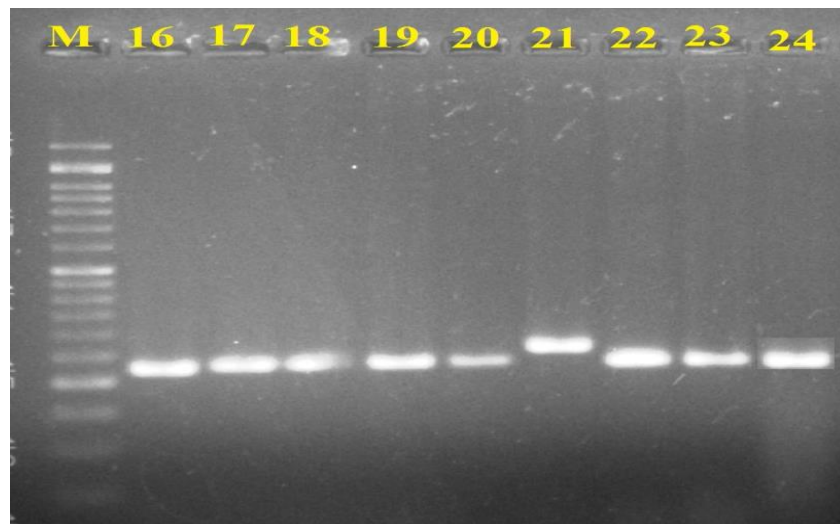
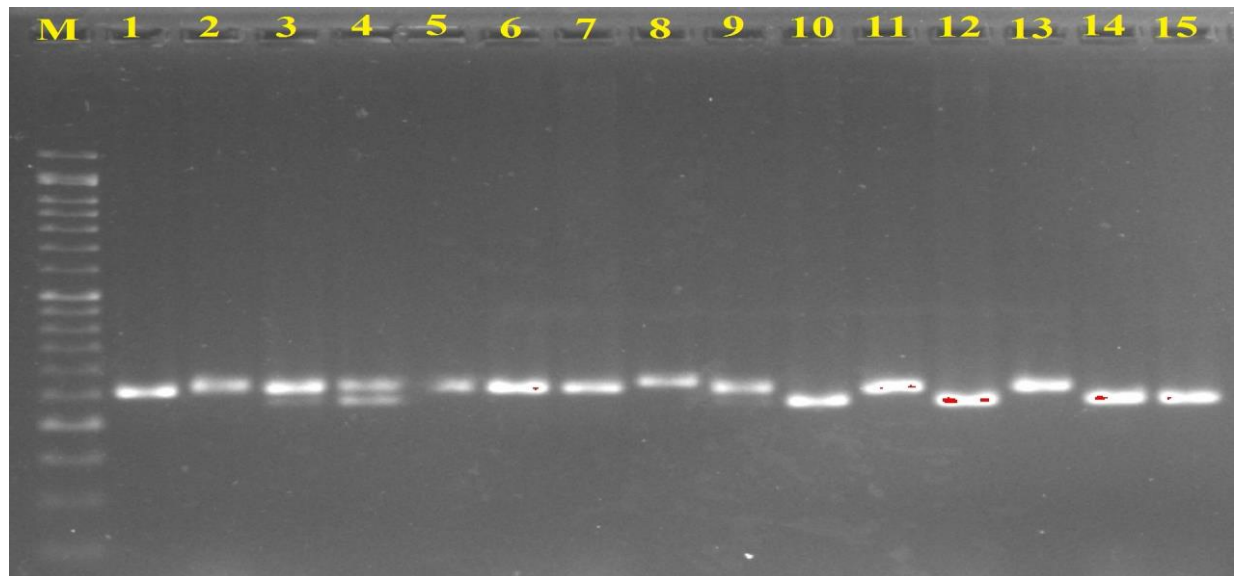
Pusa Sugandh-2 x BPT-5204	10.87**±0.07	1.40**±6.76	0.19±0.34	2.75**±0.52	-1.19**±0.23	-6.58**±0.97	--
Pusa Sugandh-2 x Kasturi	13.60**±0.06	0.50**±0.18	1.41**±0.49	1.73**±0.43	-0.55**±0.20	-4.49**±0.89	D
Pusa 1121 x Adamchinni	11.25**±0.06	4.47**±0.20	-2.10**±0.50	0.43±0.47	-1.22**±0.23	1.21±0.89	--
Pusa 1121 x BPT-5204	9.88**±0.08	2.14**±0.22	11.14**±0.57	13.26**±0.53	-2.48**±0.24	-14.70**±1.02	D
Pusa 1121 x Kasturi	11.52**±0.06	0.52**±0.17	9.15**±0.44	10.59**±0.42	-2.64**±0.18	-7.84**±0.75	D
Kernel breadth after cooking							
Type-3 x Adamchinni	3.05**±0.01	0.21**±0.02	-0.27**±0.06	-0.23**±0.06	0.15**±0.03	-0.36**±0.11	C
Type-3 x BPT-5204	2.89**±0.01	0.14**±0.02	0.46**±0.06	0.37**±0.05	-0.26**±0.02	-1.98**±0.09	D
Pusa Sugandh-2 x Adamchinni	2.85**±0.02	-0.20**±0.03	0.92**±0.09	0.45**±0.09	-0.19**±0.03	-0.16±0.14	--
Pusa Sugandh-2 x BPT-5204	2.70**±0.01	0.31**±0.03	1.90**±0.07	1.16**±0.06	-0.02±0.03	-1.82**±0.14	C
Pusa Sugandh-2 x Kasturi	2.94**±0.02	0.07*±0.03	-0.16±0.09	-0.19*±0.08	0.04±0.03	-0.26±0.14	--
Pusa 1121 x Adamchinni	2.72**±0.01	0.35**±0.03	-0.55**±0.06	-0.52**±0.06	0.28**±0.03	1.62**±0.12	D
Pusa 1121 x BPT-5204	2.92**±0.01	0.36**±0.03	-0.47**±0.07	-0.71**±0.06	-0.05±0.03	0.32*±0.13	D
Pusa 1121 x Kasturi	3.13**±0.02	0.19**±0.03	-1.06**±0.09	-0.86**±0.09	0.08**±0.03	0.11±0.14	--

Cross combination	m	d	h	i	j	l	Type of interaction
Elongation ratio							
Type-3 x Adamchinni	7.49**±0.03	-0.31**±0.02	0.55**±0.13	0.21±0.12	0.00±0.03	2.17**±0.16	C
Type-3 x BPT-5204	7.69**±0.03	-0.11**±0.02	-1.55**±0.13	-1.01**±0.12	-0.04±0.03	1.13**±0.16	D
Type-3 x Kasturi	7.54**±0.02	-0.09*±0.05	0.55**±0.12	0.85**±0.11	-0.15**±0.05	-2.10**±0.20	D
Pusa Sugandh-2 x Adamchinni	7.63**±0.03	-0.50**±0.10	1.87**±0.24	1.34**±0.22	-0.17±0.10	-0.10±0.43	--
Pusa Sugandh-2 x BPT-5204	7.64**±0.02	0.10**±0.04	-2.37**±0.12	-1.85**±0.11	0.15**±0.05	3.29**±0.20	D
Pusa Sugandh-2 x Kasturi	7.49**±0.01	0.04±0.04	0.74**±0.11	1.08**±0.10	-0.04±0.04	-2.26**±0.19	D
Pusa 1121 x Adamchinni	7.68**±0.02	-0.36**±0.06	-1.17**±0.14	-0.02±0.14	-0.55**±0.07	0.76**±0.26	D
Pusa 1121 x BPT-5204	7.56**±0.02	0.17**±0.06	0.67**±0.17	1.26**±0.15	-0.26**±0.07	-0.78**±0.29	D
Pusa 1121 x Kasturi	7.83**±0.02	-0.147**±0.05	0.07±0.13	0.57**±0.12	-0.74**±0.05	-1.02**±0.02	--
Elongation index							
Type-3 x Adamchinni	5.93**±0.02	-0.38**±0.02	0.49**±0.10	0.34**±0.10	-0.08**±0.03	2.00**±0.14	C
Type-3 x BPT-5204	6.19**±0.02	-0.20**±0.01	-1.48**±0.10	-0.69**±0.09	0.40**±0.03	2.33**±0.13	D
Type-3 x Kasturi	6.02**±0.02	-0.11**±0.04	0.61**±0.17	1.02**±0.11	-0.15±0.09	-3.06**±0.31	D
Pusa Sugandh-2 x Adamchinni	5.92**±0.03	-0.39**±0.08	1.77**±0.20	2.00**±0.20	-0.09±0.09	-1.90**±0.36	D
Pusa Sugandh-2 x BPT-5204	6.45**±0.02	-0.30**±0.03	-4.03**±0.11	-2.74**±0.10	0.28**±0.04	4.60**±0.17	D
Pusa Sugandh-2 x Kasturi	6.05**±0.02	-0.03±0.04	0.85**±0.11	1.21**±0.10	-0.08*±0.04	-2.47**±0.17	D
Pusa 1121 x Adamchinni	6.43**±0.01	-0.87**±0.06	0.05±0.13	0.96**±0.13	-0.93**±0.06	-2.10**±0.25	--
Pusa 1121 x BPT-5204	6.11**±0.02	-0.36**±0.05	1.35**±0.14	2.11**±0.12	-0.12*±0.06	-1.30**±0.24	D
Pusa 1121 x Kasturi	6.13**±0.02	-0.22**±0.06	1.00**±0.14	1.16**±0.13	-0.63**±0.06	-0.97**±0.24	D
Alkali spread value							
Type-3 x Adamchinni	12.65**±0.08	0.39**±0.08	0.86*±0.38	0.73*±0.37	-0.45**±0.10	-3.60**±0.50	D

Type-3 x Kasturi	13.44**±0.05	0.80**±0.06	4.80**±0.25	3.29**±0.24	0.47**±0.07	-7.27**±0.35	D
Pusa Sugandh-2 x Adamchinni	13.10**±0.10	1.12**±0.06	2.74**±0.41	3.34**±0.40	-0.84**±0.07	-7.44**±0.47	D
Pusa Sugandh-2 x BPT-5204	12.84**±0.08	0.85**±0.06	5.46**±0.34	4.88**±0.34	-0.83**±0.07	-6.14**±0.41	D
Pusa Sugandh-2 x Kasturi	14.43**±0.05	0.36**±0.06	0.06±0.22	-0.55*±0.22	-1.14**±0.06	-0.78*±0.31	--
Pusa 1121 x Adamchinni	13.08**±0.11	0.48**±0.07	5.25**±0.45	4.67**±0.45	-1.40**±0.08	-7.81**±0.52	D
Pusa 1121 x BPT-5204	13.49**±0.08	1.48**±0.09	1.98**±0.36	1.58**±0.35	-0.16±0.09	-2.40**±0.49	D
Pusa 1121 x Kasturi	14.11**±0.05	0.86**±0.08	1.71**±0.26	0.77**±0.25	-0.57**±0.09	-1.34**±0.40	D
Amylose content							
Type-3 x Adamchinni	22.17**±0.19	1.05*±0.40	-6.65**±1.19	-6.52**±1.10	0.02±0.48	11.02**±1.99	D
Type-3 x BPT-5204	24.04**±0.21	-0.90*±0.45	-9.60**±1.31	-10.57**±1.24	-0.83±0.50	17.83**±2.15	D
Type-3 x Kasturi	24.45**±0.29	1.83**±0.44	-4.46**±1.50	-6.66**±1.45	1.30**±0.48	9.52**±2.22	D
Pusa Sugandh-2 x Adamchinni	25.81**±0.24	3.58**±0.43	-16.32**±1.41	-15.69**±1.30	1.28*±0.51	16.45**±2.26	D
Pusa Sugandh-2 x BPT-5204	26.87**±0.26	2.35**±0.39	-5.36**±1.35	-7.37**±1.29	1.40**±0.46	6.04**±2.03	D
Pusa Sugandh-2 x Kasturi	25.24**±0.21	2.62**±0.52	-8.39**±1.39	-9.53**±1.33	1.38*±0.55	14.36**±2.40	D
Pusa 1121 x Adamchinni	27.12**±0.23	1.12**±0.41	-22.91**±1.30	-27.34**±1.23	0.68±0.46	40.64**±2.06	D
Pusa 1121 x BPT-5204	25.04**±0.31	-1.28**±0.42	-10.19**±1.54	-11.56**±1.48	-0.95*±0.47	14.86**±2.24	D
Pusa 1121 x Kasturi	24.19**±0.25	1.62**±0.45	-6.79**±1.39	-8.71**±1.33	1.53**±0.50	15.38**±2.19	D

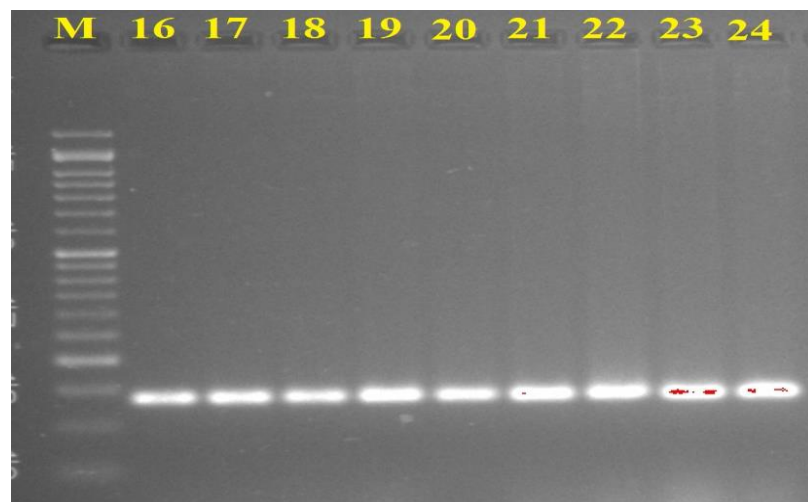
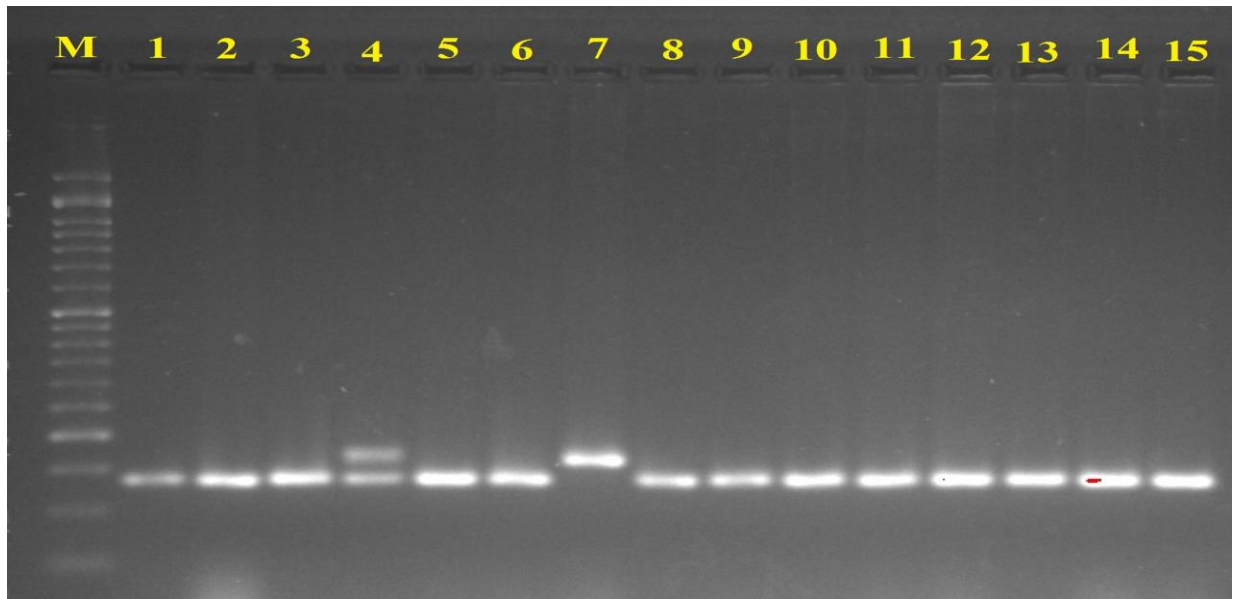
Cross combination	m	d	h	i	j	l	Type of interaction
Gel consistency							
Type-3 x Kasturi	44.29**±0.84	10.18**±1.03	-23.27**±4.11	-32.67**±3.95	3.35**±1.16	69.24**±5.81	D
Pusa Sugandh-2 x Adamchinni	44.53**±1.02	-8.82**±1.46	50.98**±5.17	46.37**±5.02	5.30**±1.59	-62.37**±7.54	D
Pusa Sugandh-2 x BPT-5204	47.54**±1.13	-6.75**±1.01	-51.01**±5.00	-40.06**±4.93	-2.60*±1.14	27.06**±6.26	D
Pusa Sugandh-2 x Kasturi	47.31**±0.87	3.97**±1.17	-17.69**±4.34	-21.72**±4.18	2.80*±1.28	1.85±6.27	--
Pusa 1121 x Adamchinni	42.21**±0.81	-4.08**±1.36	59.30**±4.42	54.45**±4.22	14.00**±1.54	-83.98**±6.83	D
Pusa 1121 x BPT-5204	47.37**±0.86	-14.08**±1.11	-15.03**±4.21	-34.13**±4.08	-6.05**±1.17	59.76**±5.96	D
Pusa 1121 x Kasturi	42.23**±0.83	-4.15**±0.90	-11.87**±3.93	-32.97**±3.77	-1.42±0.99	61.47**±5.36	D
Aroma							
Type-3 x Adamchinni	9.78**±0.10	0.59**±0.20	2.67**±0.64	3.09**±0.59	0.08±0.23	-3.74**±1.05	D
Type-3 x BPT-5204	8.62**±0.16	1.83**±0.41	-3.60**±1.17	-2.76**±1.05	-0.63±0.42	3.40±2.05	--
Type-3 x Kasturi	9.71**±0.11	0.73**±0.24	2.38**±0.71	2.92**±0.65	0.15±0.28	-4.01**±1.20	D
Pusa Sugandh-2 x BPT-5204	8.50**±0.21	1.69**±0.37	1.35±1.16	2.06±1.12	-0.64±0.39	-5.63**±1.82	--
Pusa Sugandh-2 x Kasturi	9.97**±0.08	0.53**±0.16	1.91**±0.53	1.64**±0.47	0.08±0.21	-1.42±0.89	--
Pusa 1121 x Adamchinni	10.12**±0.08	0.61**±0.20	1.12±0.59	1.38**±0.53	-0.06±0.24	-1.73±1.02	--
Pusa 1121 x BPT-5204	10.03**±0.13	0.28±0.23	1.56±0.84	0.93±0.69	-2.11**±0.25	-5.99**±1.42	--

Fig 4.1: Agarose gel electrophoresis images showing SSR banding pattern of 24 rice genotypes generated by the primer RM 8226



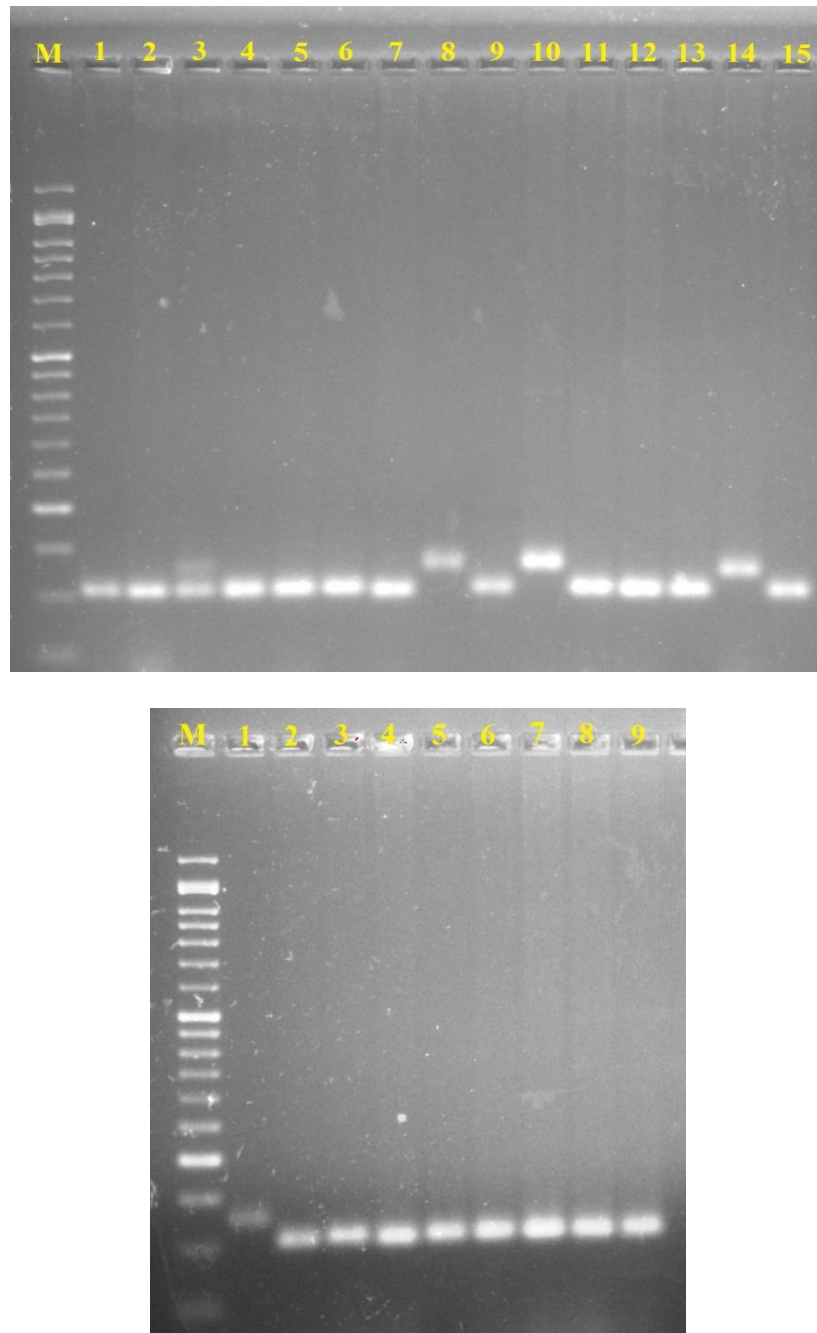
M = Marker (50bp), 1= Type-3; 2= Ranbir Basmati, 3= DDN-3-1, 4= DDN-1-4, 5= DDN(awnless), 6= DDN-1-8, 7= Kalanamak, 8= Dhanprasad, 9= Adamchinni, 10= BPT-5204, 11= Kasturi, 12= Sanwal Basmati, 13= Basmati-370, 14= HUBR-10-9, 15= Pusa Sugandh-3, 16= TBD-2, 17= Pusa Sugandh-2, 18= HUBR-16, 19= HUBR-9-1-2-1, 20= HUBR-1-2-25-5, 21= Tarori Basmati, 22= Pusa Basmati-1, 23= Pusa 1121, 24= Pusa 1509.

Fig 4.2: Agarose gel electrophoresis images showing SSR banding pattern of 24 rice genotypes generated by the primer RM 7049



M = Marker (50bp), 1= Type-3; 2= Ranbir Basmati, 3= DDN-3-1, 4= DDN-1-4, 5= DDN(awnless), 6= DDN-1-8, 7= Kalanamak, 8= Dhanprasad, 9= Adamchinni, 10= BPT-5204, 11= Kasturi, 12= Sanwal Basmati, 13= Basmati-370, 14= HUBR-10-9, 15= Pusa Sugandh-3, 16= TBD-2, 17= Pusa Sugandh-2, 18= HUBR-16, 19= HUBR-9-1-2-1, 20= HUBR-1-2-25-5, 21= Tarori Basmati, 22= Pusa Basmati-1, 23= Pusa 1121, 24= Pusa 1509.

Fig 4.3: Agarose gel electrophoresis images showing SSR banding pattern of 24 rice genotypes generated by the primer RM 3395



M = Marker (50bp), 1= Type-3; 2= Ranbir Basmati, 3= DDN-3-1, 4= DDN-1-4, 5= DDN(awnless), 6= DDN-1-8, 7= Kalanamak, 8= Dhanprasad, 9= Adamchinni, 10= BPT-5204, 11= Kasturi, 12= Sanwal Basmati, 13= Basmati-370, 14= HUBR-10-9, 15= Pusa Sugandh-3, 16= TBD-2, 17= Pusa Sugandh-2, 18= HUBR-16, 19= HUBR-9-1-2-1, 20= HUBR-1-2-25-5, 21= Tarori Basmati, 22= Pusa Basmati-1, 23= Pusa 1121, 24= Pusa 1509.

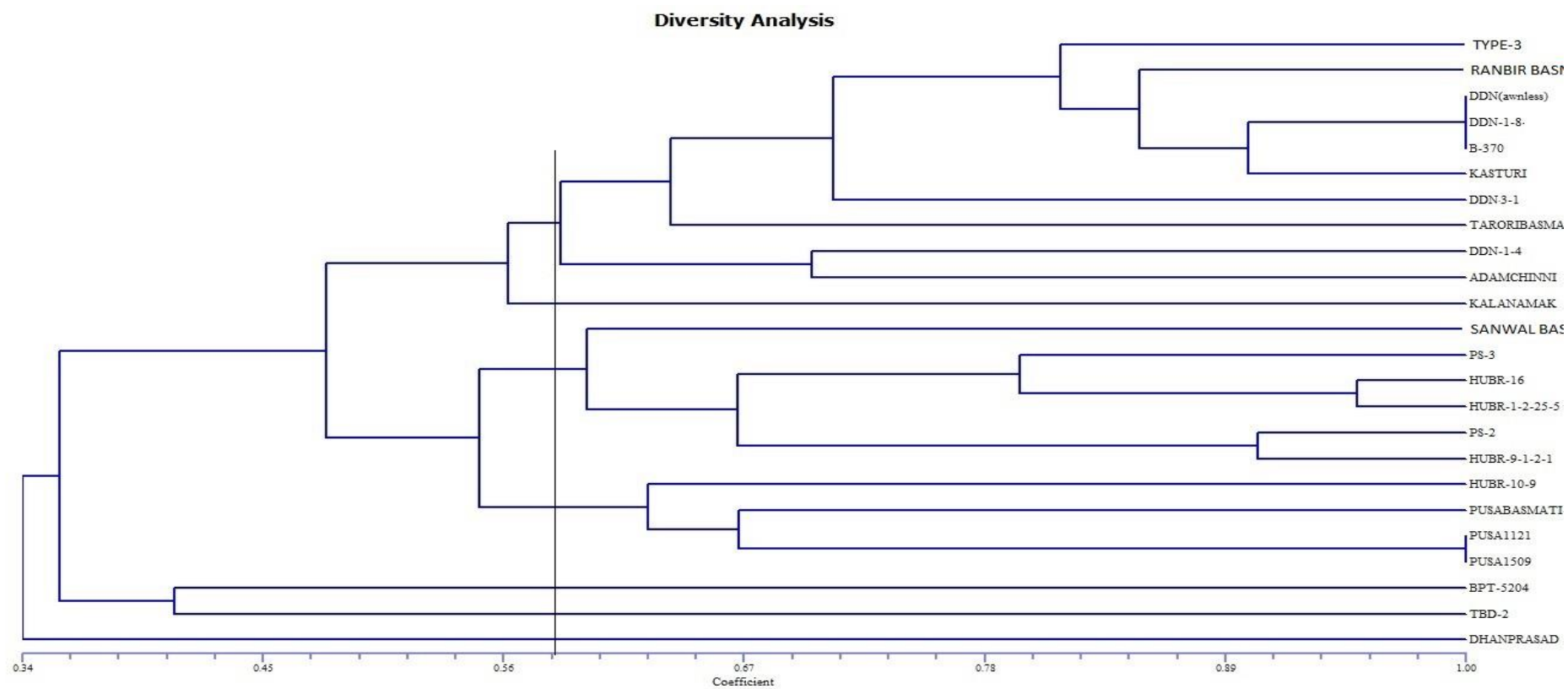


Fig 4.4: Dendrogram resulting from an UPGMA cluster analysis of 24 rice accessions based on data of 19 SSR primer pairs.

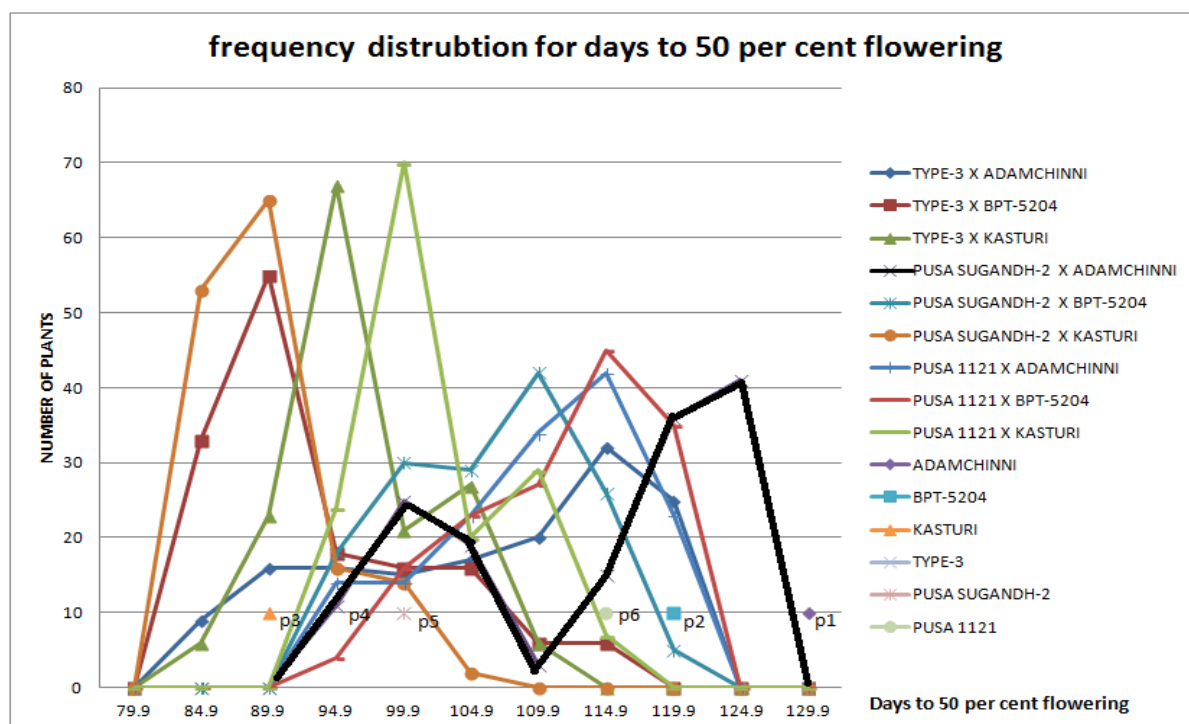


Fig 4.5: Frequency distribution for days to 50 per cent flowering

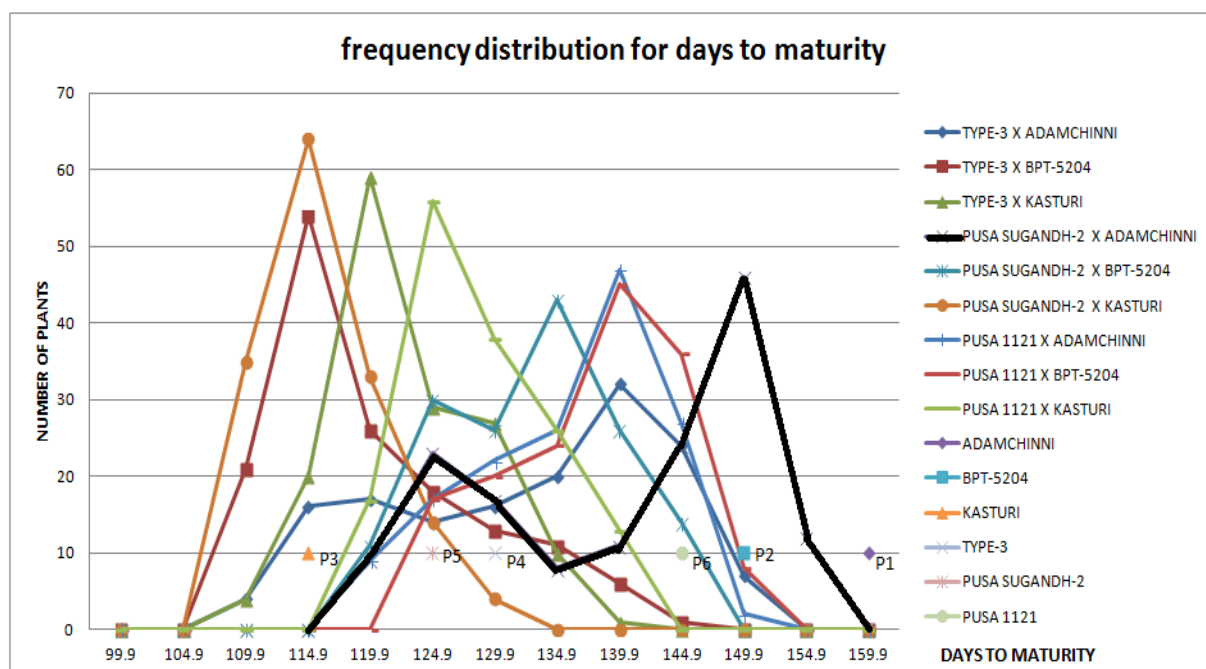


Fig 4.6: Frequency distribution for days to maturity

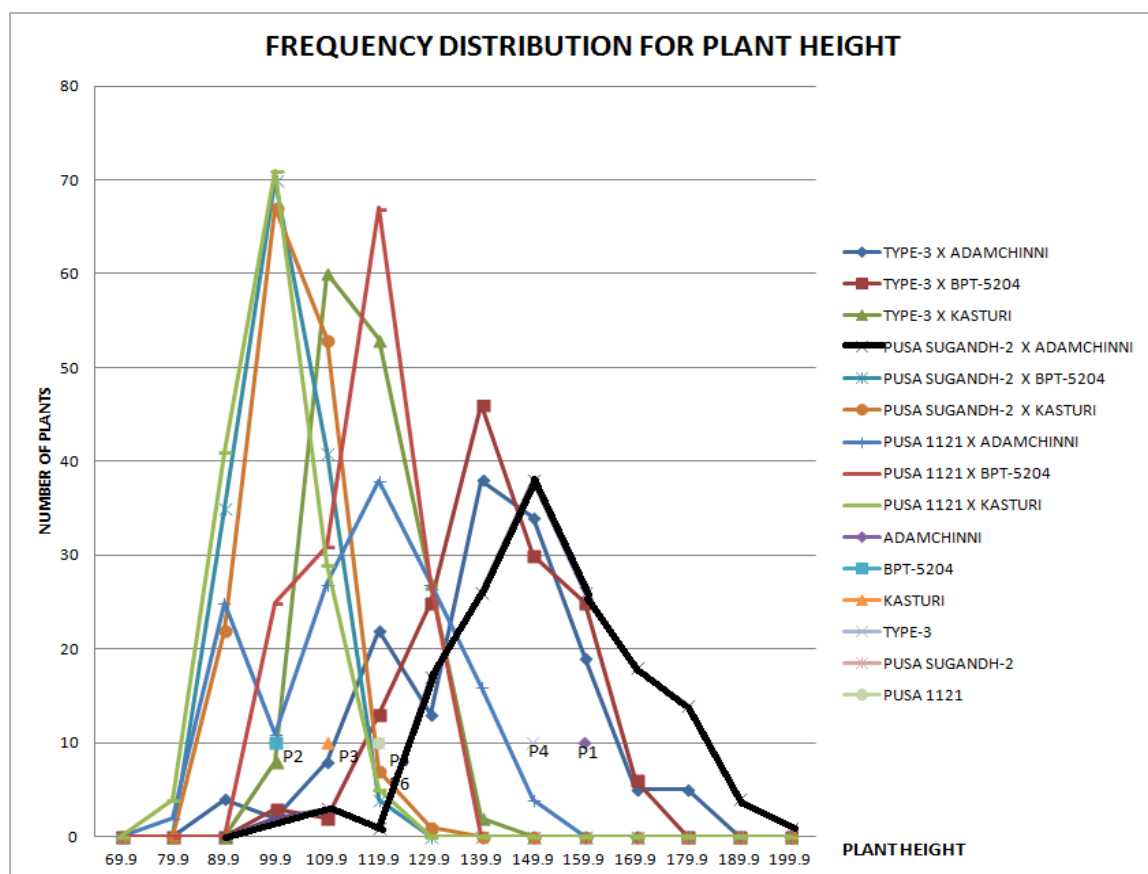


Fig 4.7. Frequency distribution for plant height

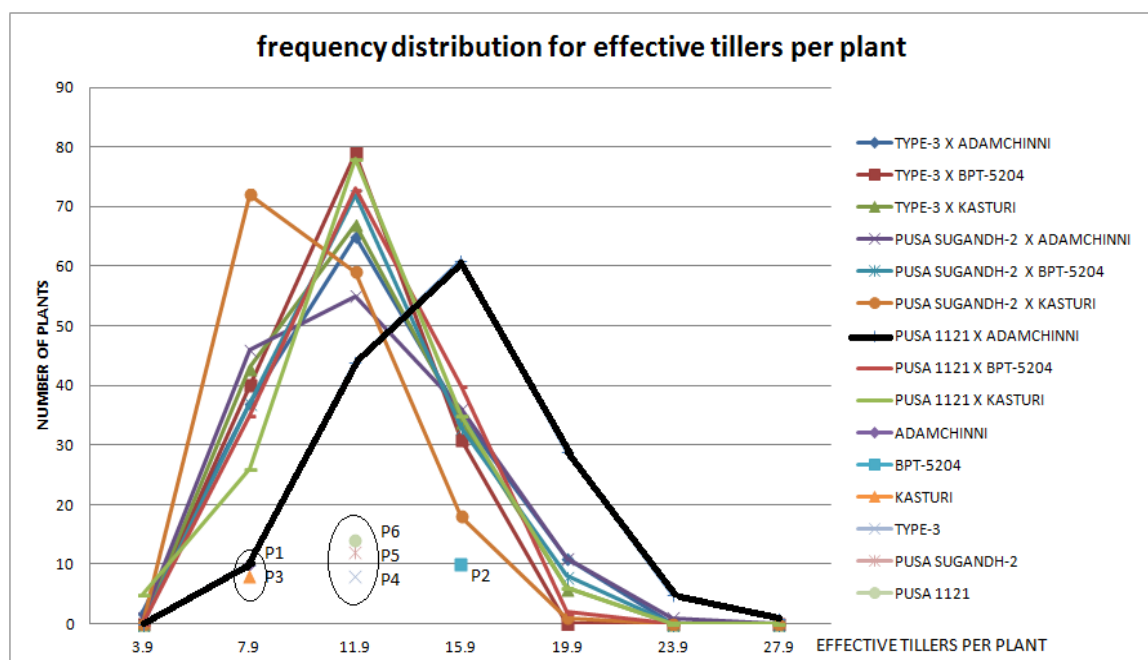


Fig 4.8. Frequency distribution for effective tillers per plant

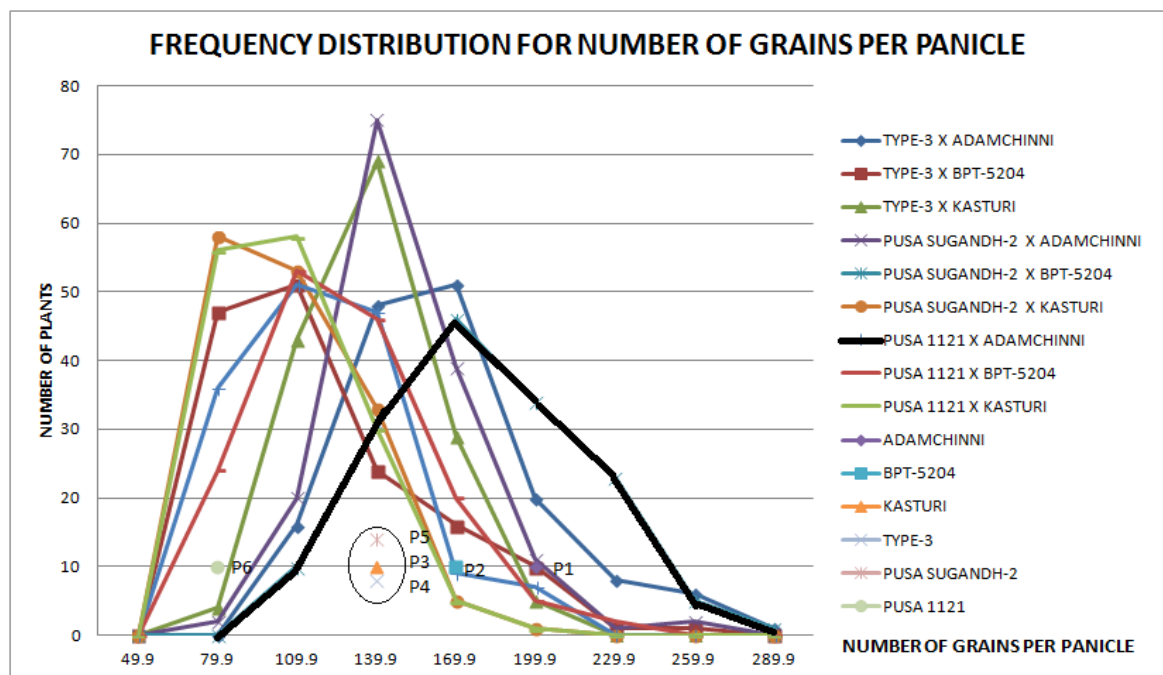


Fig 4.9. Frequency distribution for number of grains per panicle

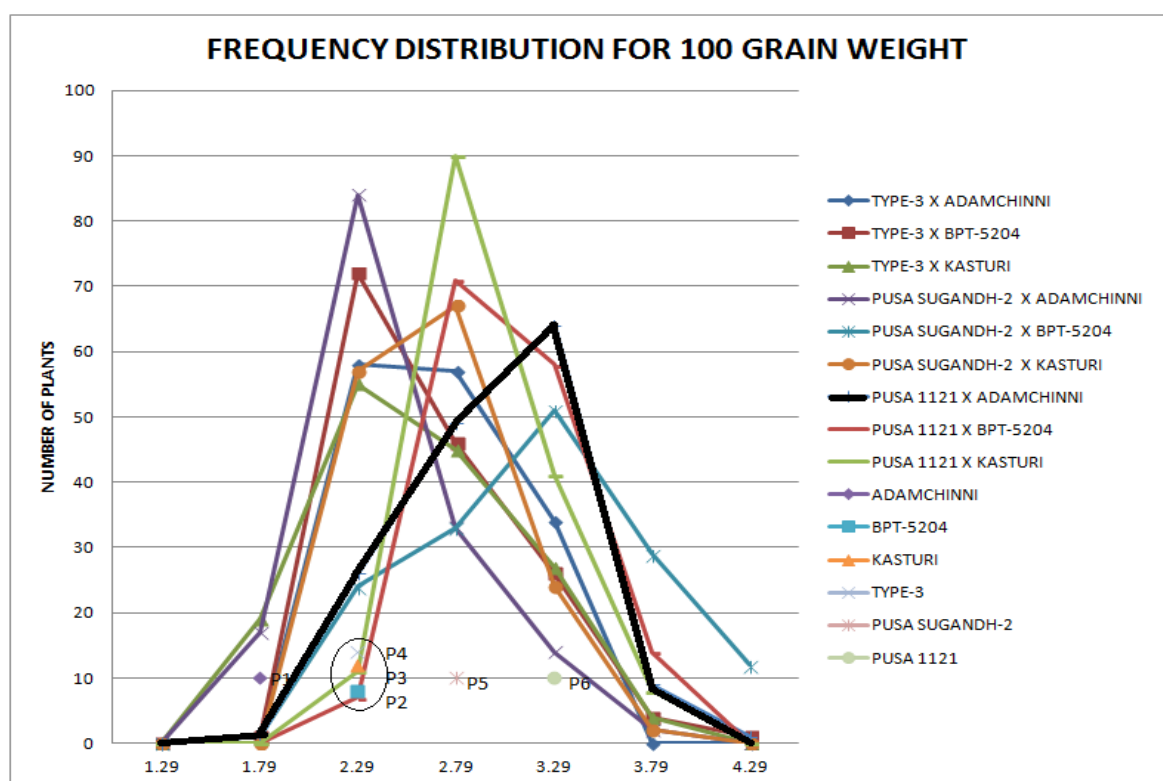


Fig 4.10. Frequency distribution for hundred grain weight

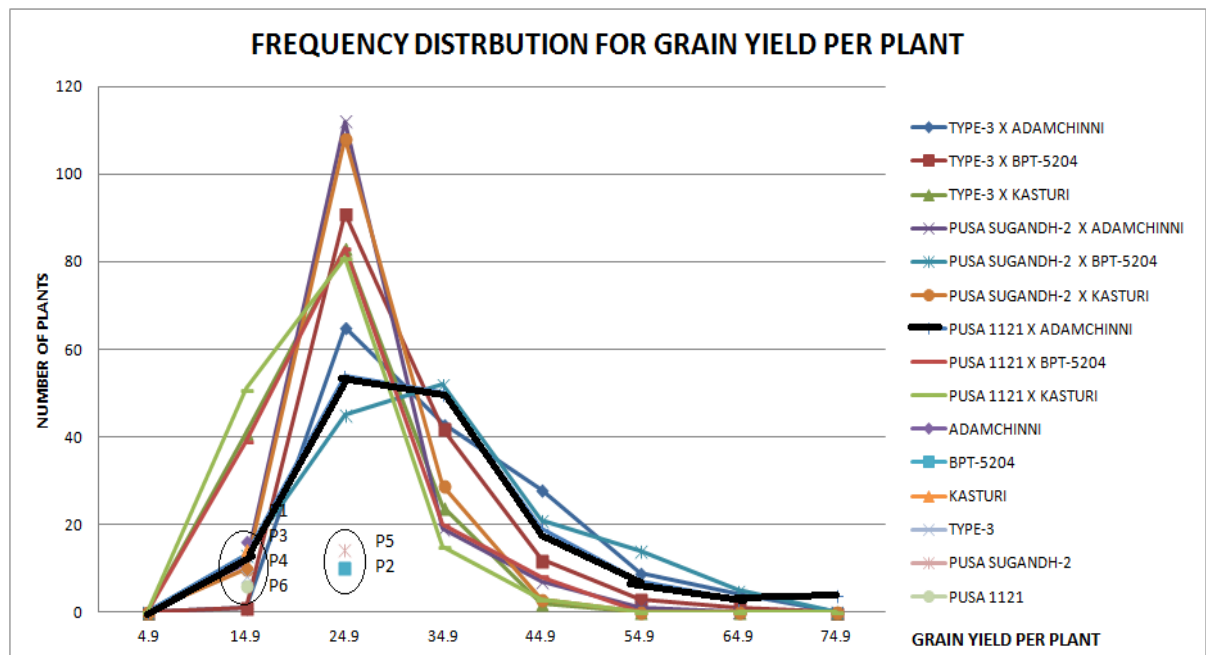


Fig 4.11. Frequency distribution for grain yield per plant

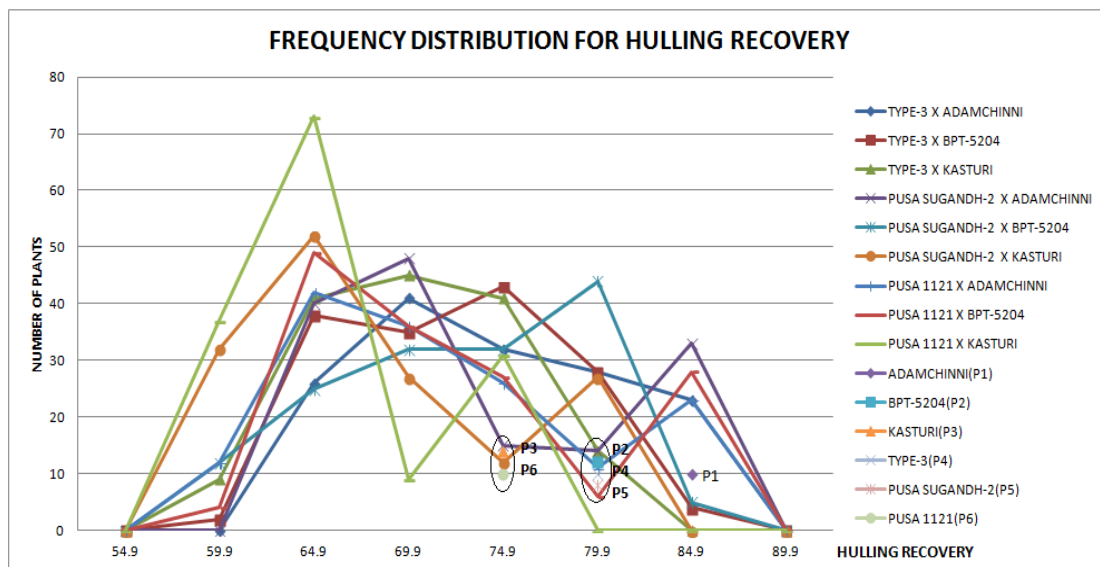


Fig 4.12. Frequency distribution for hulling recovery

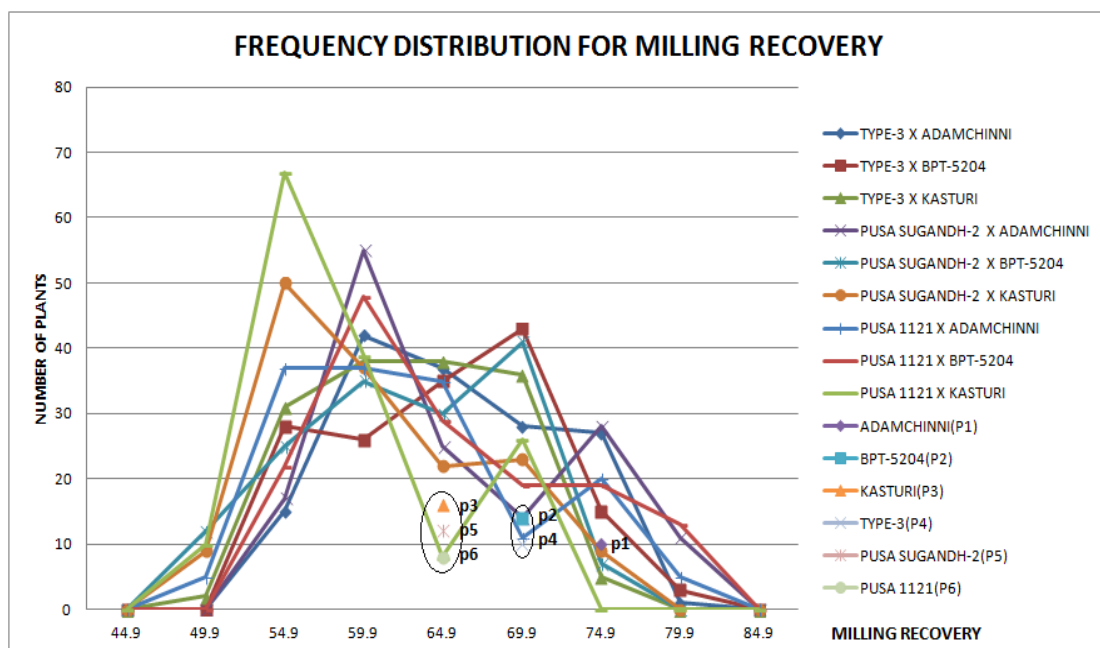


Fig 4.13. Frequency distribution for milling recovery

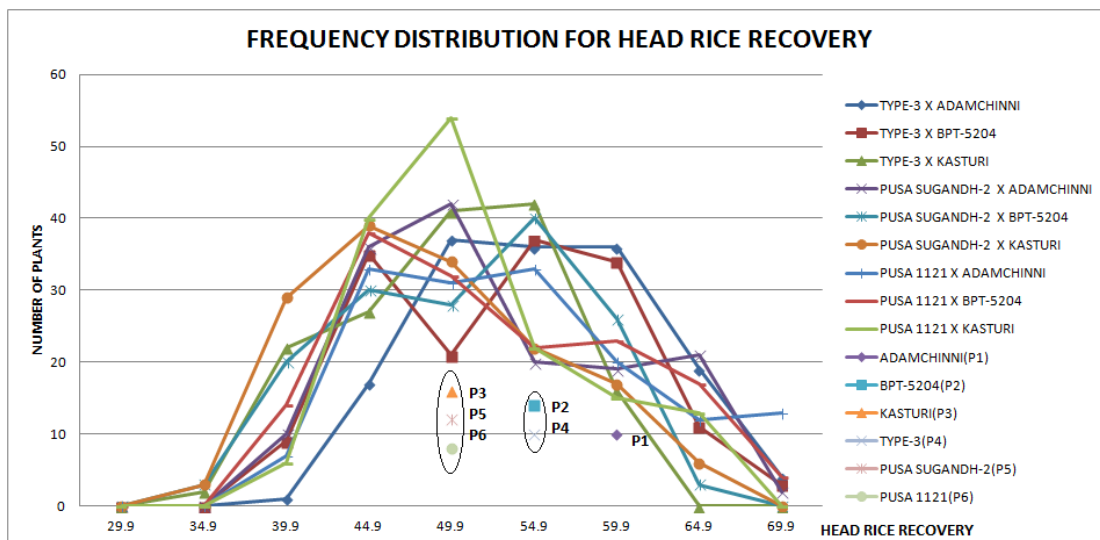


Fig 4.14. Frequency distribution for head rice recovery

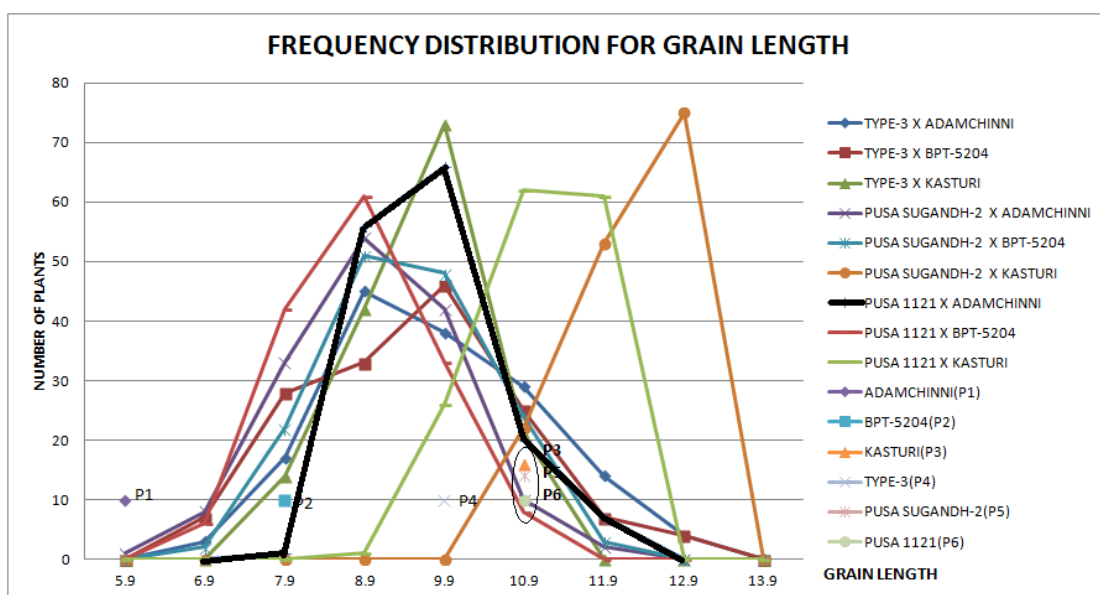


Fig 4.15. Frequency distribution for grain length

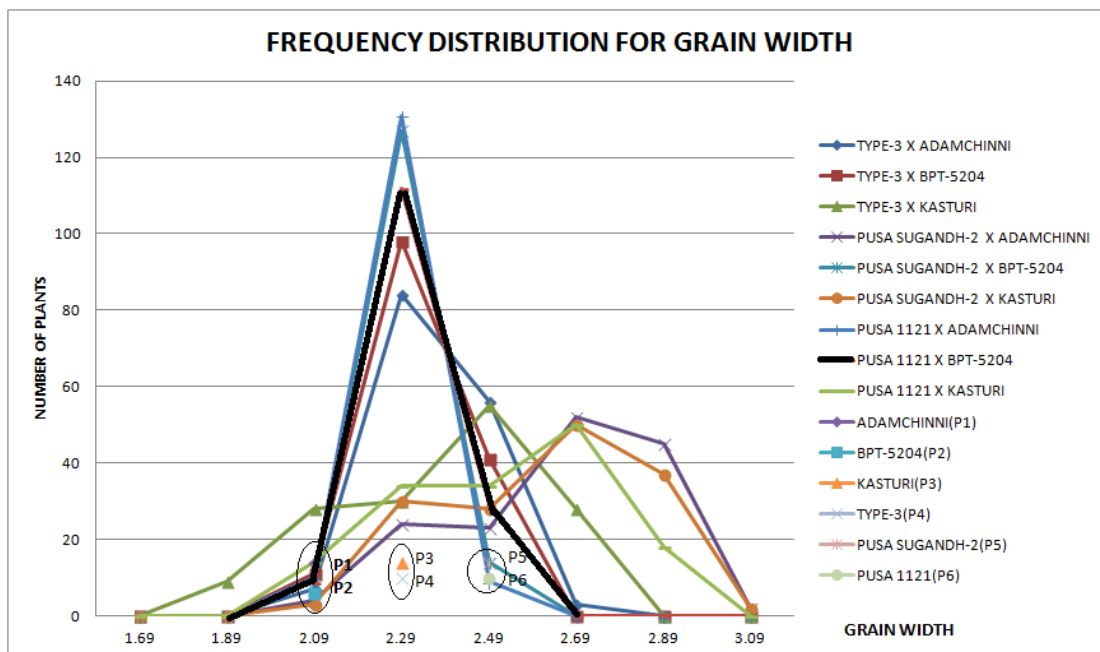


Fig 4.16. Frequency distribution for grain width

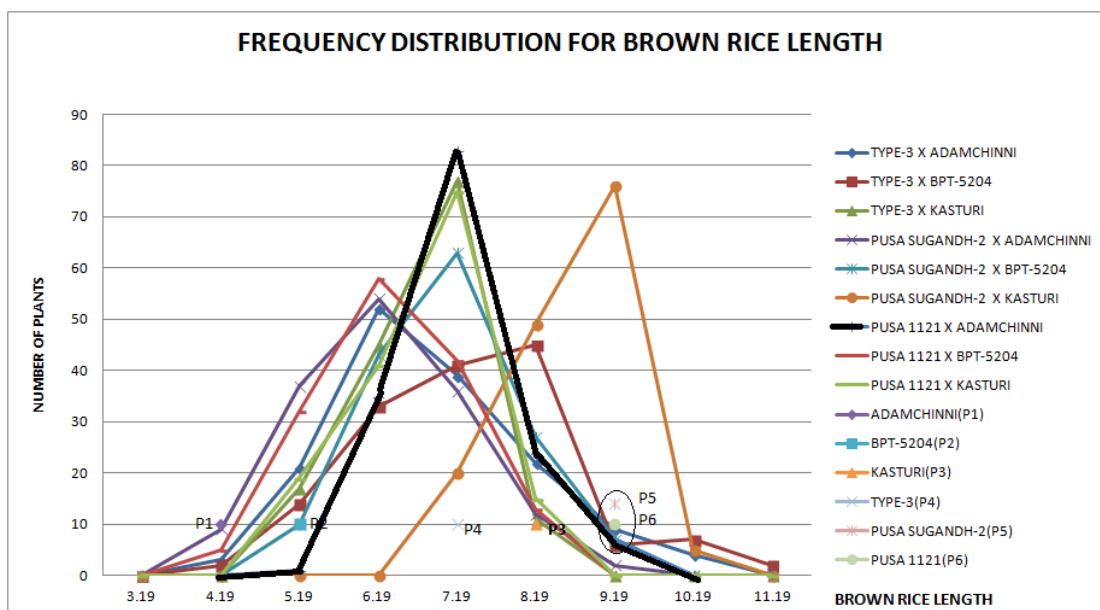


Fig 4.17. Frequency distribution for brown rice length

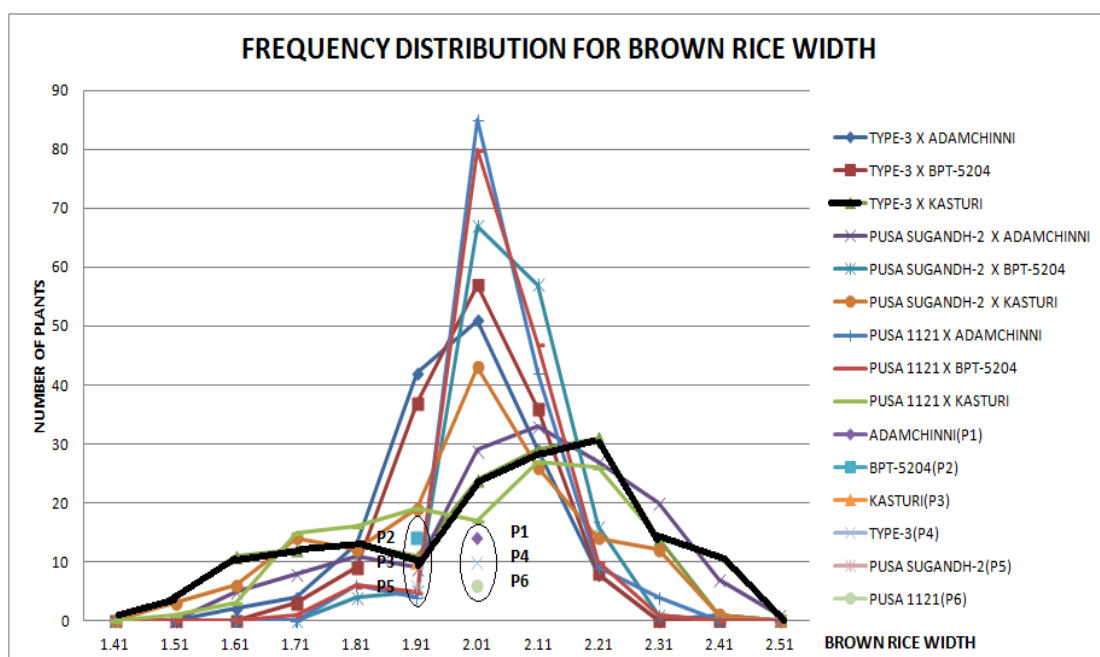


Fig 4.18.Frequency distribution for brown rice width

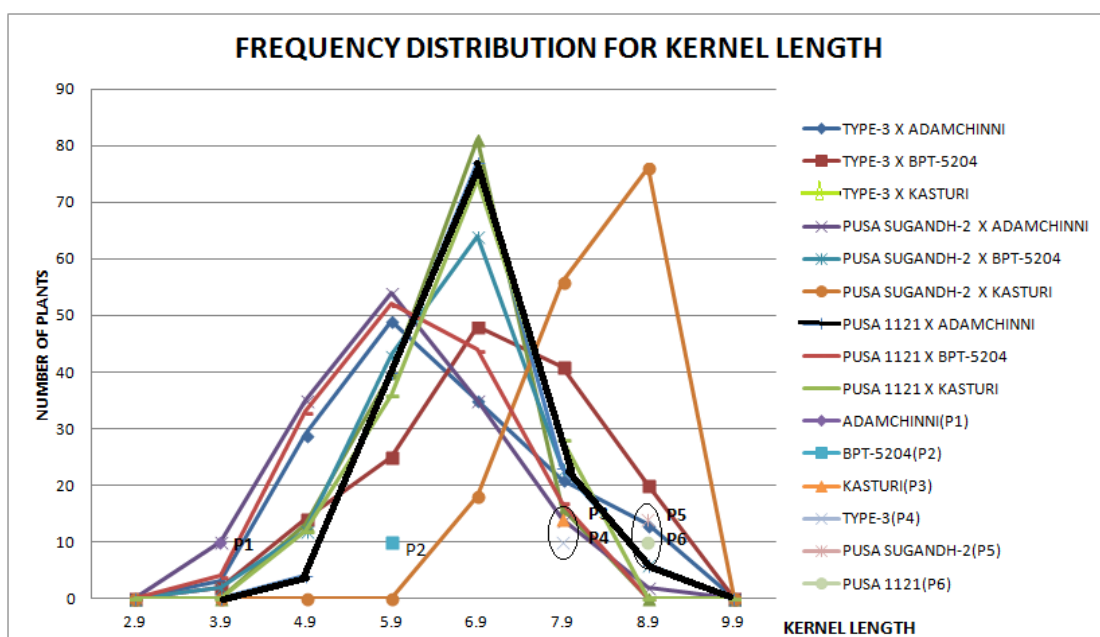


Fig 4.19.Frequency distribution for kernel length

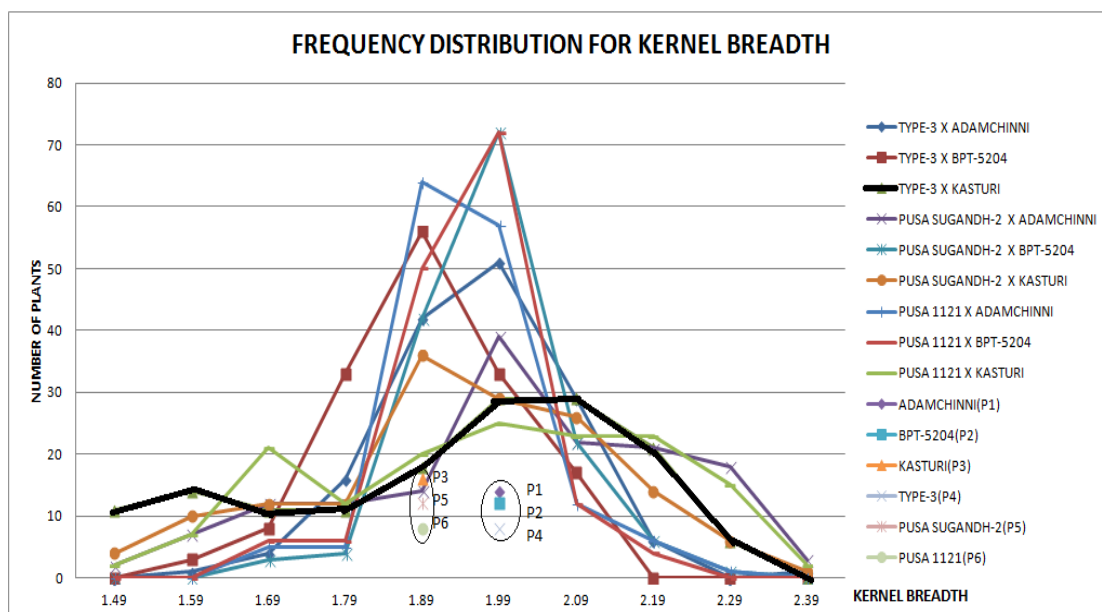


Fig 4.20. Frequency distribution for kernel breadth

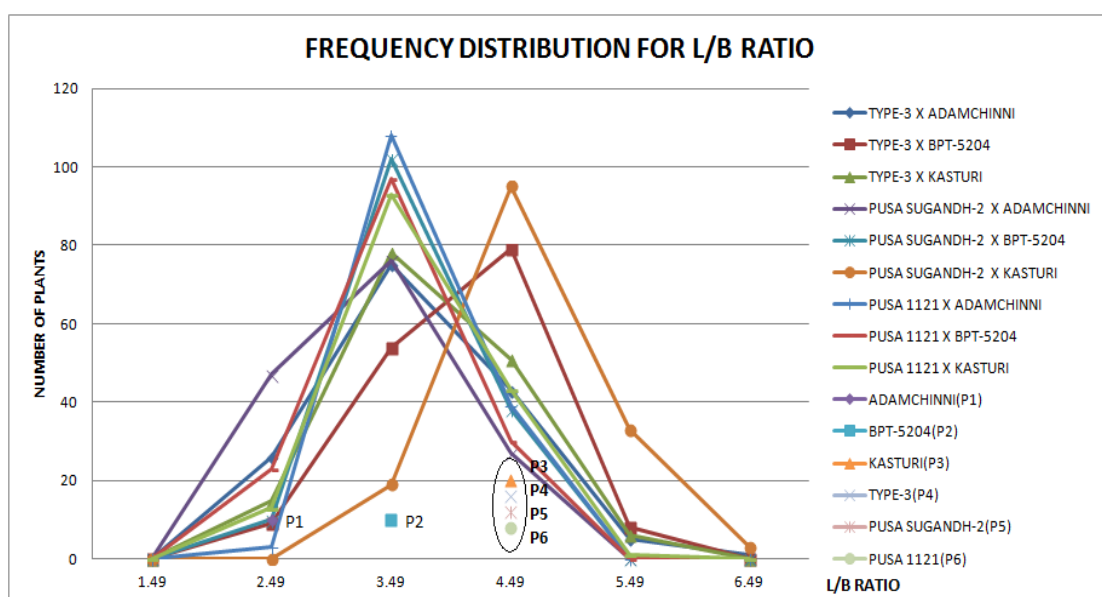


Fig 4.21. Frequency distribution for L/B ratio

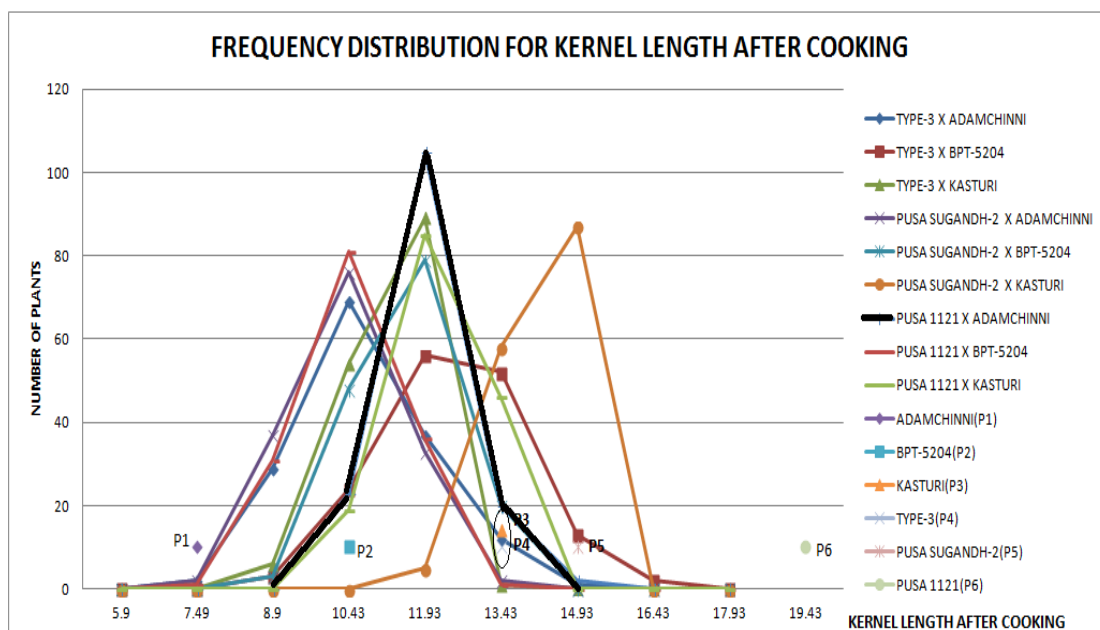


Fig 4.22. Frequency distribution for kernel length after cooking

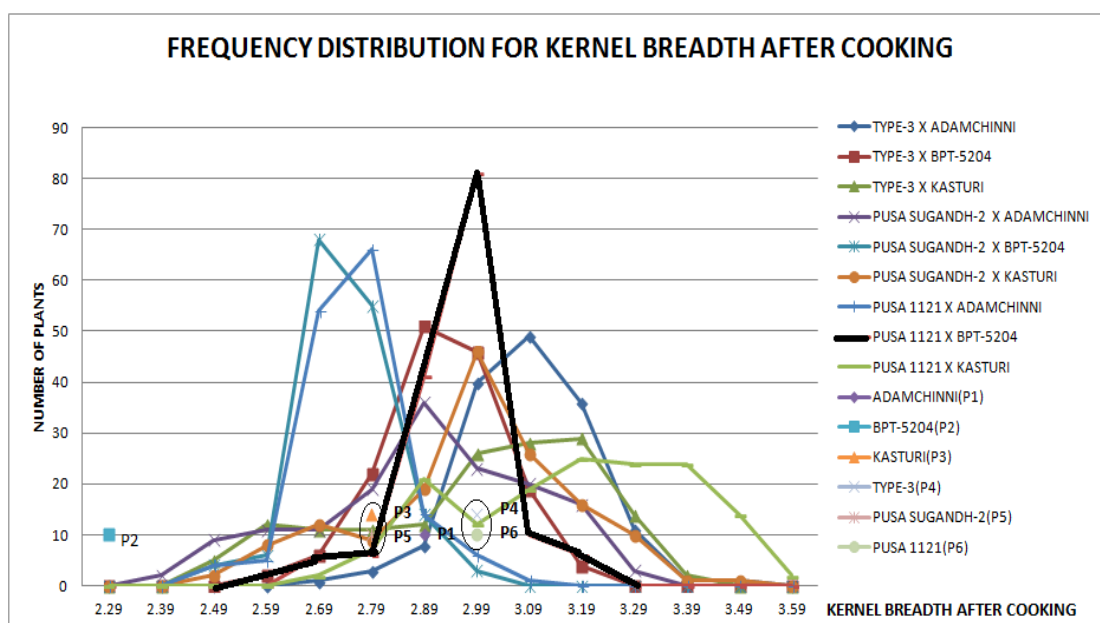


Fig 4.23. Frequency distribution for kernel breadth after cooking

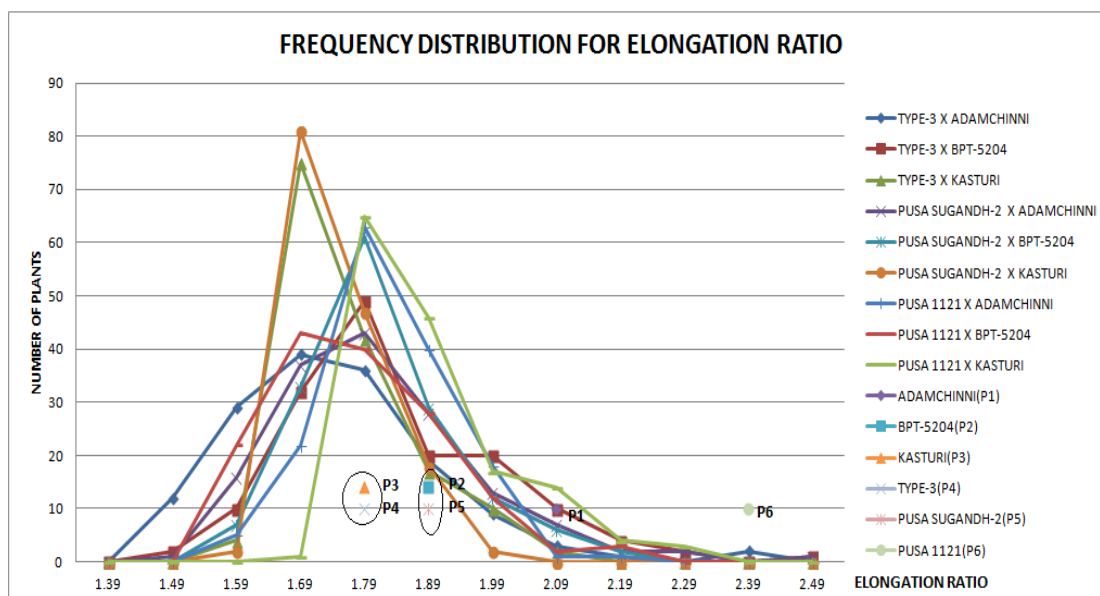


Fig 4.24. Frequency distribution for elongation ratio

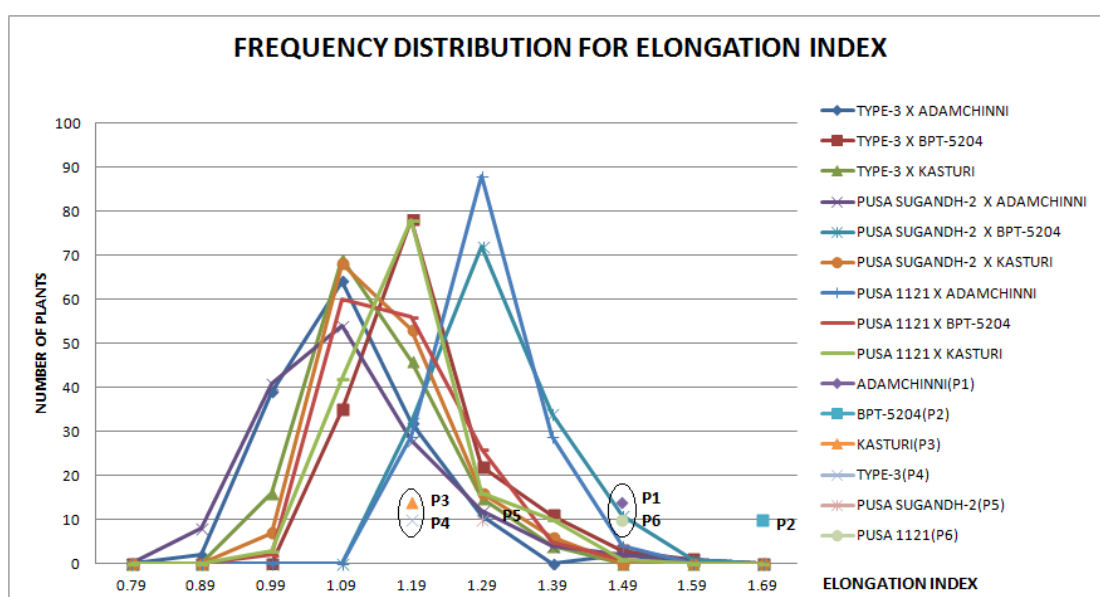


Fig 4.25. Frequency distribution for elongation index

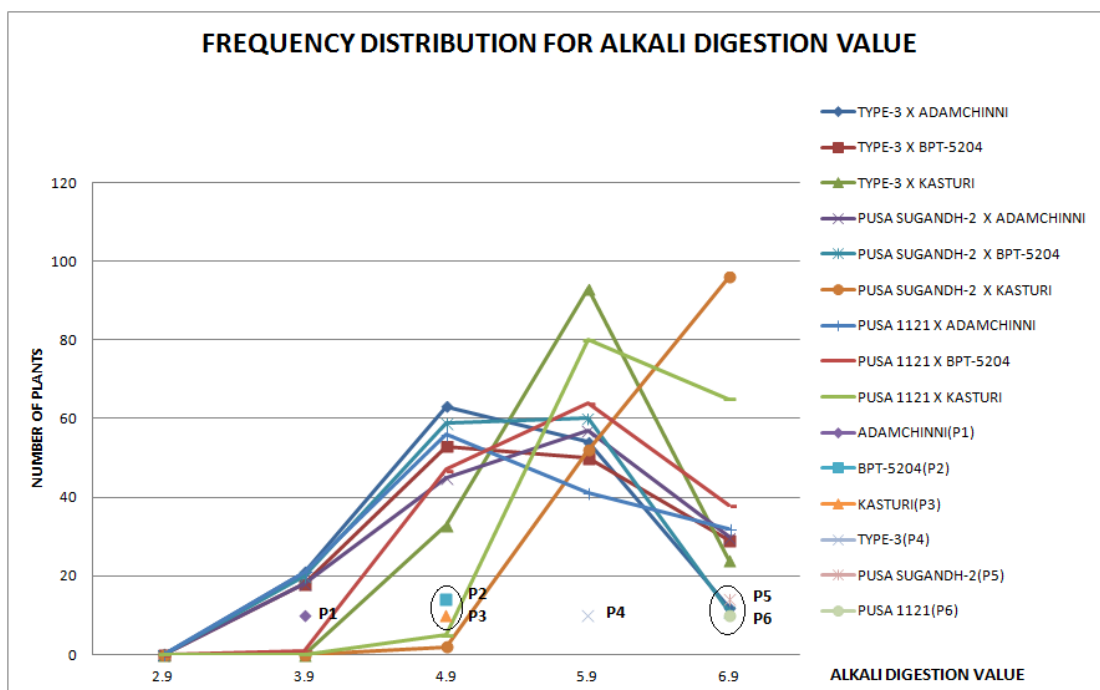


Fig 4.26. Frequency distribution for alkali digestion value

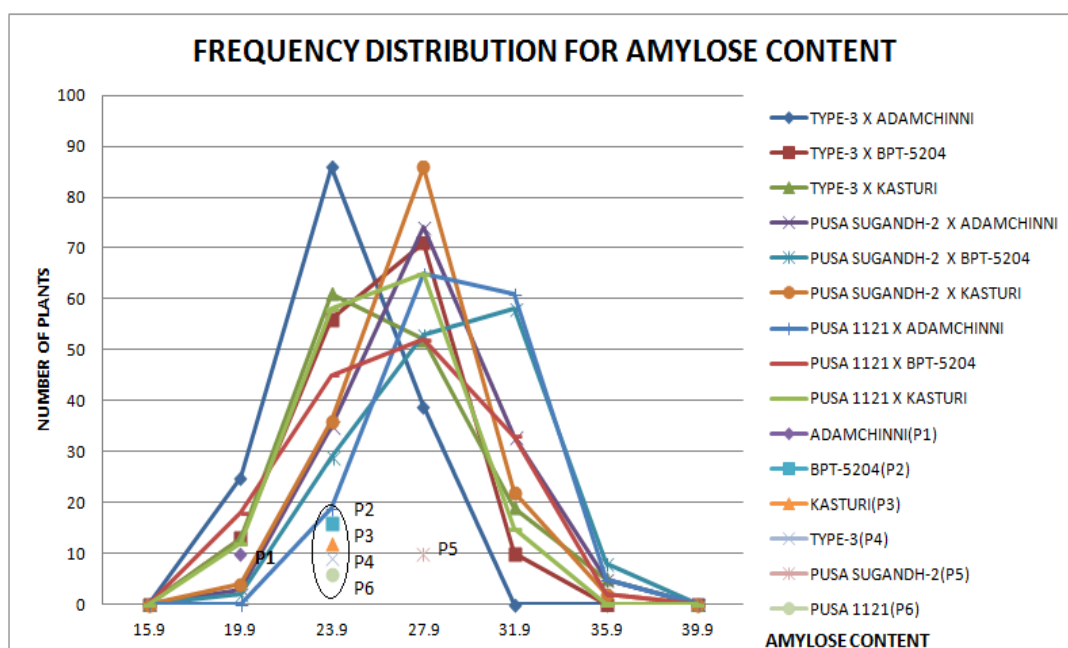


Fig 4.27. Frequency distribution for amylose content

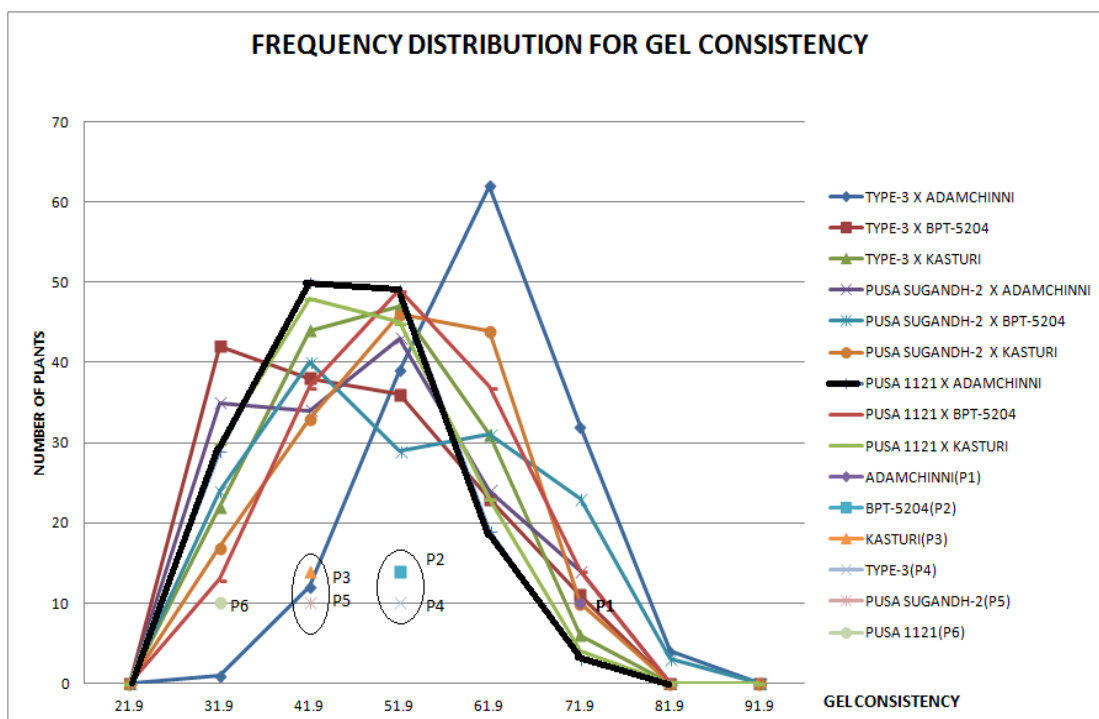


Fig 4.28. Frequency distribution for gel consistency

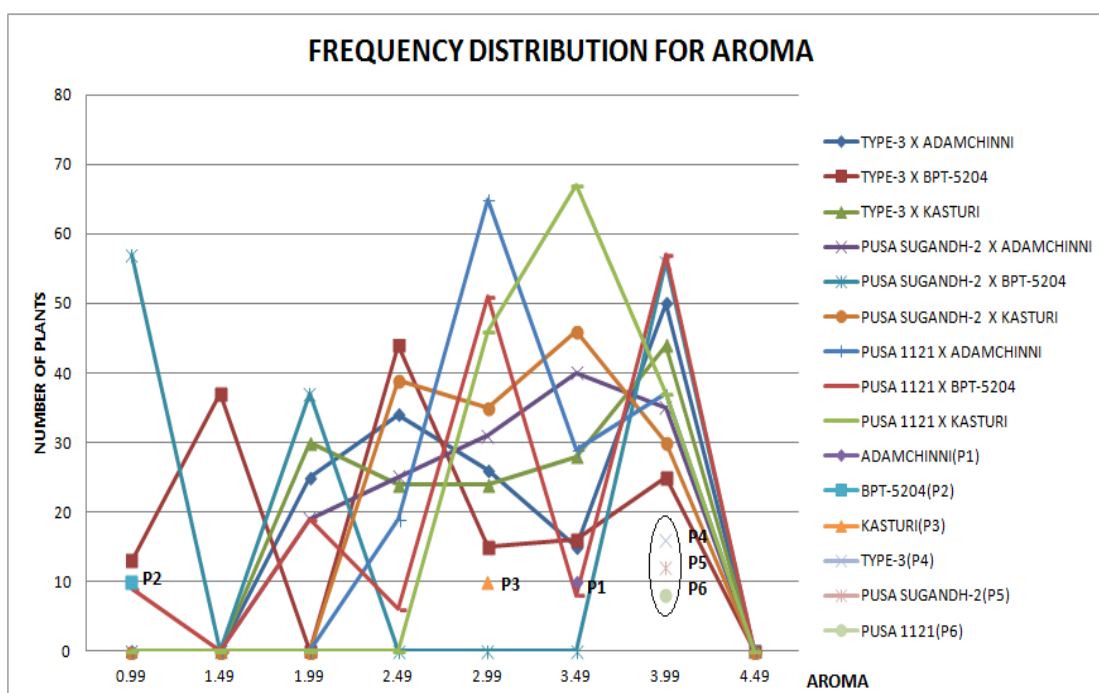


Fig 4.29. Frequency distribution for aroma

Plate-1: Crossing blocks

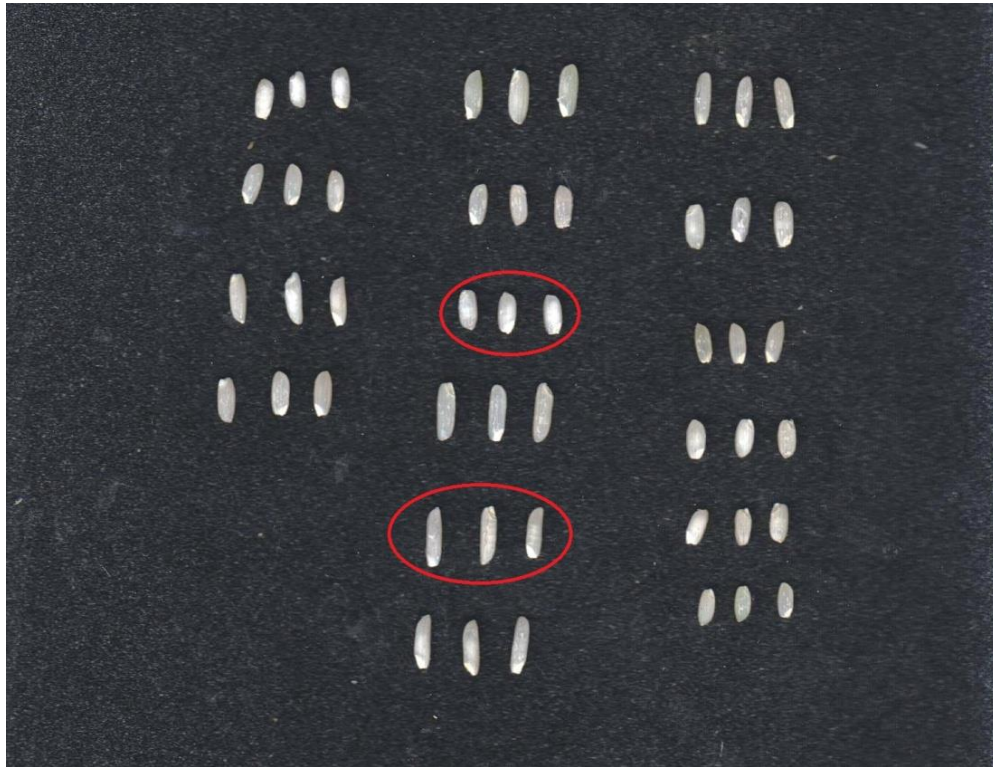


a) Bagged panicles after crossing

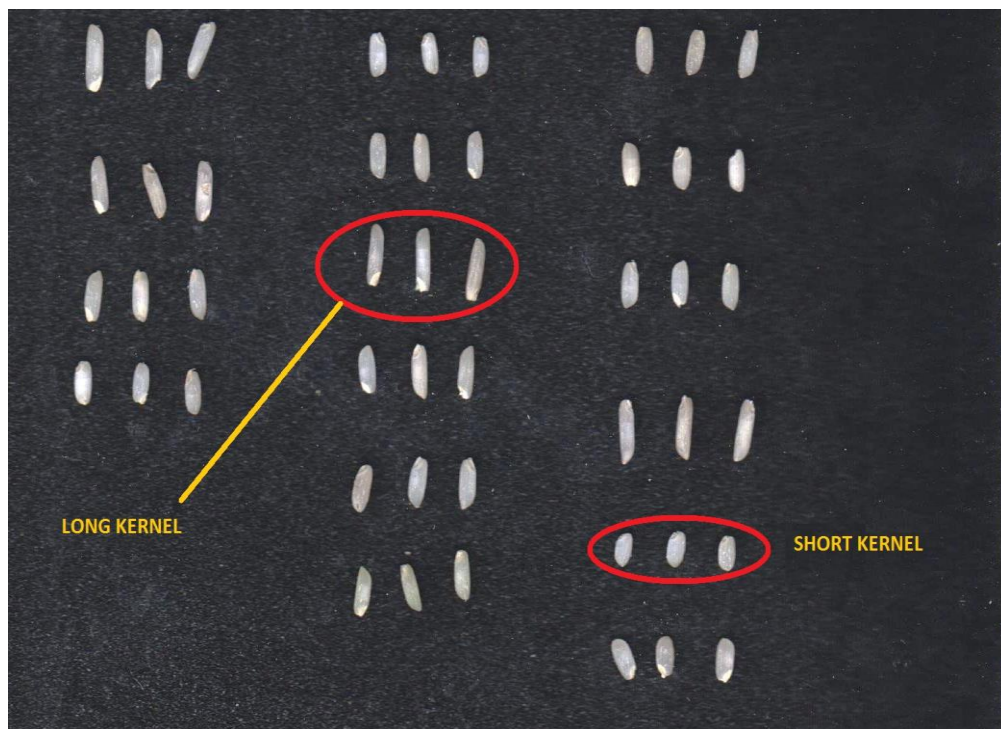


b) Seed setting in panicle

Plate-2: Variation of F₂

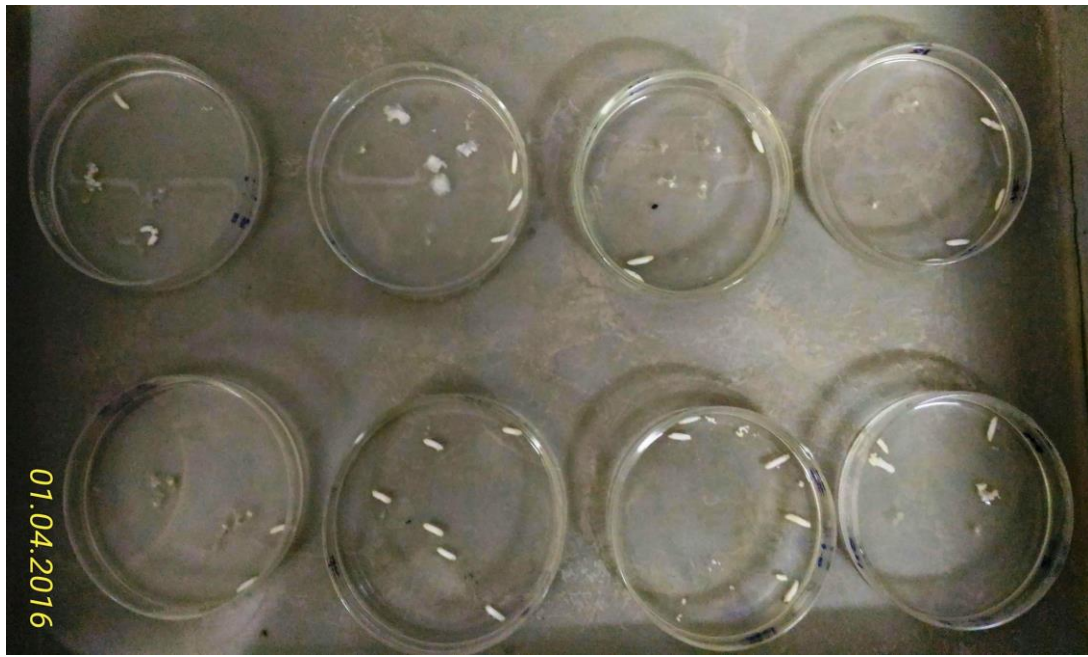


a) Variation of F₂ for brown rice length in diverse cross Pusa Sugandh-2 x Adamchini

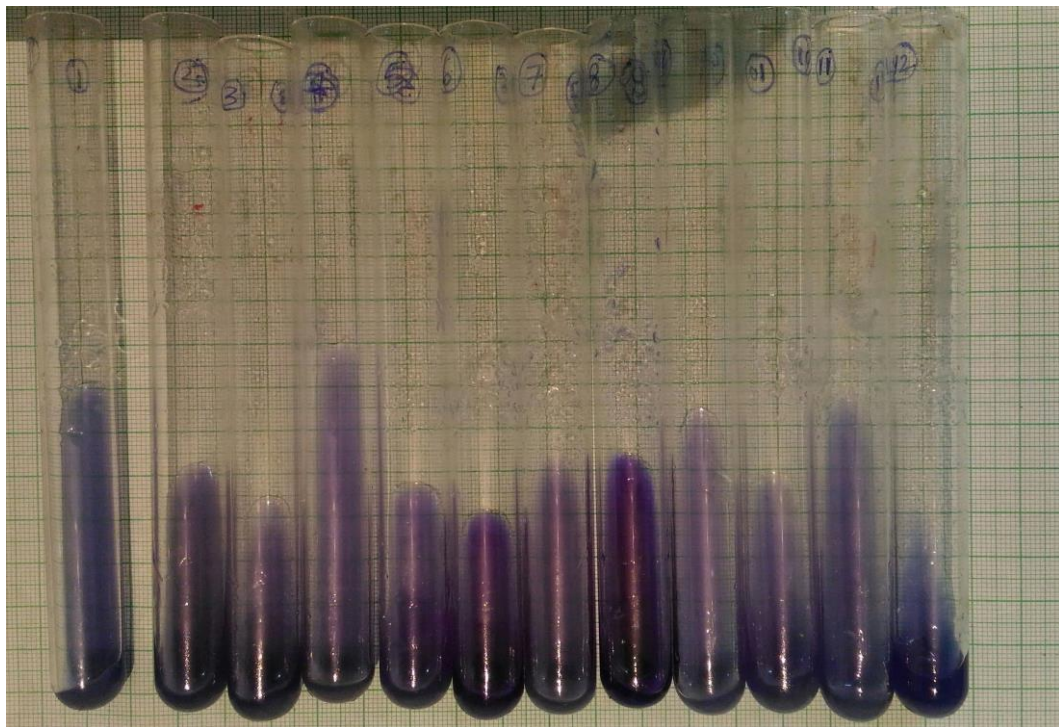


b) Variation of F₂ for Kernel length in diverse cross Pusa Sugandh-2 x Adamchini

Plate-2: Variation of F₂



c) Variation of F₂ for Alkali Digestion value in diverse cross Type-3 x BPT-5204



d) Variation of F₂ for gel consistency in diverse cross Pusa 1121 x Adamchini.



DISCUSSION

DISCUSSION

In rice, quality parameters are now becoming a major breeding objective after yield because many high yielding breeding lines are not adopted by farmers due to lack of quality characteristics in them. The price of the rice and the acceptance of the variety by the consumers is mainly dependant on the quality traits. Many studies have indicated the nature of gene actions governing the quality traits are limited. But most of the quality traits are quantitatively inherited and need continuous efforts to combine (Mahalingam and Nadarajan, 2010). Quality characters can be classified as physical, cooking and chemical traits. Physical properties like grain dimensions (kernel length, kernel breadth and L/B ratio) and milling traits (hulling %, milling % and head rice recovery) are primary components defining market value. The characters that employ major effects on the eating and cooking qualities are related to the chemical properties of rice grains such as amylose content, alkali spreading value and gel consistency and cooking characteristics volume expansion ratio and kernel elongation ratio. Hence there is an imperative need for a shift in emphasis towards development of high quality rice besides yield (Rani *et al.*, 2015).

The complex genetic nature coupled with poor combining ability of parents for quality traits was responsible for the slow success in breeding for good quality grain varieties. Therefore; information about the nature of gene action of complex quality traits will be helpful in breeding high yielding cultivars with good quality. Keeping in view the above mentioned facts, the present investigation entitled **“Genetics of yield and quality characters in aromatic rice (*Oryza sativa* .L)”** was undertaken and the results obtained are discussed here in under.

5.1 Molecular diversity analysis

A total of 19 SSR markers, selected from rice SSR linkage map were used for genetic diversity analysis among 24 selected rice genotypes. The variation of genetic

diversity and allele distribution were greatly dependent on the loci that were analyzed. The genetic distance among the 24 rice accessions based on SSR data obtained in this study showed that these accessions have wide genetic diversity since the 24 genotypes were clustered into seven groups namely, Cluster I, II, III, IV, V, VI and VII. Cluster I was composed of ten genotype viz., Type-3, Ranbir Basmati, DDN(awnless), DDN-1-8-80, Basmati-370, Kasturi, DDN-3-1-72, Tarori Basmati, DDN-1-4-75 and Adamchini whereas cluster II consisted only one genotype Kalanamak. The cluster III was had six genotypes viz., Sanwal Basmati, Pusa Sugandh-3, HUBR-16, HUBR-1-2-25-5, Pusa Sugandh-2 and HUBR-9-1-2-1. Cluster IV was composed of four genotypes viz., HUBR-10-9, Pusa Basmati-1, Pusa 1121 and Pusa 1509 whereas Cluster V had one genotype BPT-5204. Cluster VI consists of one genotype TBD-2 and Cluster VII composed of one genotype Dhanprasad.

The SSRs yielded a total of 457 polymorphic bands of which number of polymorphic bands per primer ranged from 2 to 3 with an average of 2.15. The polymorphic information content (PIC) of the 19 SSR primers ranged from 0.07 to 0.54 with an average PIC of 0.36 showing a high level of polymorphism. The Jaccard's Similarity Index was used to produce a dendrogram to obtain the clustering of 24 rice genotypes. The pair wise similarity calculated by Jaccard's similarity coefficients revealed high diversity among genotypes, as coefficients ranged from 0.19 to 0.94 with an average similarity of 0.51. The highest similarity coefficient (0.94) was observed between genotypes DDN-1-8 and DDN (Awnless), whereas lowest similarity coefficient (0.19) was observed between genotypes BPT-5204 and Kalanamak.

5.2 Combining ability analysis for yield and quality traits

The combining ability analysis of the parents provides the information for selecting better parents for best breeding strategies and it also provides knowledge about additive and dominance variances. Role of combining ability studies is important to take decision about parents, crosses and appropriate Cross breeding procedures to be carried out to exploit heterosis. Keeping the above in view, the present investigation was carried out to study the combining ability in order to identify good combiners and superior Cross combinations. Nine F₁ Hybrids obtained

from three female parents (Type-3, Pusa Sugandh-2 and Pusa 1121) and three male parents (Adamchini, BPT-5204 and Kasturi) were evaluated to study the combining ability for various yield and quality traits. Analysis of variance revealed that the treatment variations showed highly significant differences for all the characters studied indicating sufficient differences for all the traits and variance due to crosses differed significantly for most of the characters. The mean squares due to female parents were significant for characters, days to 50 per cent flowering, days to maturity, number of grains per panicle and gel consistency. The variance due to male parents were significant for days to 50 per cent flowering, days to maturity, L/B ratio, kernel length after cooking and aroma. Female x male component of variances were significant for all the traits except head rice recovery, grain length, grain breadth, brown rice length, brown rice breadth, kernel length, kernel width and alkali digestion value. These results were in confirmation with the findings of Sarker *et al.* (2002), Akter *et al.* (2010), and Bagheri and Jelodar (2010).

In present study, combining ability variances revealed that the estimates of additive genetic variance (σ^2A) was higher than dominance genetic variance (σ^2D) for the characters, days to 50% flowering, days to maturity, plant height, number of grains per panicle, 100 grain weight, hulling recovery, head rice recovery, grain length, grain breadth, brown rice length, brown rice breadth, kernel length, kernel breadth, L/B ratio, kernel length before cooking, alkali digestion value and aroma, suggesting the preponderance of additive gene action for these traits. However, for rest of the traits studied except milling recovery and kernel breadth after cooking, value of σ^2A was observed to be lower than σ^2D , indicating the predominance of non additive gene action. For the traits milling recovery and kernel breadth after cooking the ratio of σ^2A / σ^2D showed value of near unity indicates importance of both additive and non additive gene action for these traits. The existence of both additive and non additive type of gene action for various yield traits has also been reported by Montazeri *et al.* (2014). However, Saravanan *et al.* (2006), Kumar *et al.* (2004) and Thakare *et al.* (2013) reported lower value of σ^2A than σ^2D for all the characters studied indicating the predominance of non additive gene action. Predominance of non additive gene action for grain yield and its components has been reported by Satyanarayana *et al.* (2000), Rita and Motiramani (2005), Singh *et al.* (2005),

Venkatesan *et al.* (2007), Dalvi and Patel (2009), Saidaiah *et al.* (2010), and Hasan *et al.* (2013).

In this study, the proportional contribution of female parents, male parents and their interaction towards total variance was also calculated. Female parents played a major role towards number of grains per panicle, grain breadth, brown rice breadth, kernel breadth and kernel breadth after cooking indicating predominance maternal influence for these traits. Male parents were more important for days to 50 per cent flowering, days to maturity, plant height, 100 grain weight, hulling recovery, head rice recovery, grain length, brown rice length, kernel length, L/B ratio, kernel length after cooking, alkali digestion value and aroma, revealing the predominant paternal influence for these traits. For rest of the traits studied, the contribution of maternal and paternal interaction (female x male) was observed to be highest in proportion, indicating that the concerned characters were influenced by non-additive gene action. High contribution of maternal and paternal interaction for most of the traits studied has been reported by Raju *et al.* (2014). However, low contribution of maternal and paternal interaction towards the total variance was reported by Sarker *et al.* (2002), Zhang *et al.* (2002), Rashid *et al.* (2007) and Montazeri *et al.* (2014) for various traits studied.

5.2.1 Combining ability effects for various yield and quality traits

For the characters days to 50% flowering, days to maturity, plant height, grain breadth, brown rice breadth, kernel breadth and kernel breadth after cooking negative combining ability effects are generally considered to be desirable and for the remaining traits positive combining ability is desirable.

The significant negative GCA effect for days to 50 per cent flowering among female parents was exhibited by Type-3 followed by Pusa Sugandh-2. Within male parents, the significant negative GCA effect was revealed by Kasturi. Cross Pusa 1121 x Adamchini showed highest significant negative SCA effect followed by Pusa Sugandh-2 x Kasturi and Type-3 x BPT- 5204. For days to 50 per cent flowering predominance of additive gene action was indicated by the ratio of σ^2A/σ^2D was more than unity which was in accordance with Shanthi *et al.* (2004), Verma *et al.* (2006),

Sanjeev Kumar *et al.* (2007) and Singh *et al.*, (2014) while Raju *et al.* (2006), Sharma and Mani (2008), Shukla and Pandey (2008) and Mallikarjuna (2014) reported non additive gene action in the inheritance of this trait. Significant negative GCA and SCA effects for days to 50 per cent flowering were also reported by Tiwari *et al.* (2011) and Latha *et al.* (2013).

Among the female parents, Type-3 (-3.307), Pusa Sugandh-2 (-1.274) showed significant negative GCA effects for days to maturity. Similarly, among male parents Kasturi (-19.219) revealed negative significant gca effects for days to maturity. Cross Pusa 1121 x Adamchini (-4.748) showed highest significant negative SCA effect followed by Pusa Sugandh-2 x Kasturi (-3.381) and Type-3 x Bpt- 5204 (-2.026). For this trait additive gene action played a greater role as the ratio of σ^2A/σ^2D was more than unity.

The significant negative GCA effect for plant height among female parents was exhibited by Pusa 1121. Among male parents, highest significant negative GCA effects was exhibited by BPT-5204 followed by Kasturi. Cross Pusa Sugandh-2 x BPT-5204 showed highest significant negative SCA effect followed by Pusa 1121 x Adamchini and Type-3 x Kasturi. Additive gene action was predominant for this trait as ratio of σ^2A/σ^2D was more than unity. Similar results were reported Raju *et al.* (2006), Sanjeev Kumar *et al.* (2007) and Deepa Sankar *et al.* (2008) for this trait. Non additive gene action was observed by Yadav *et al.* (2007), Vijaya Lakshmi *et al.* (2008), Karthikeyan *et al.* (2010), Singh *et al.*, (2014) and Mallikarjuna *et al.*, (2014).

Among the female parents, Pusa 1121 recorded significant positive GCA effects for tillers per plant. Similarly among male parents BPT-5204 showed significant positive GCA effects for tillers per plant. Cross Pusa Sugandh-2 x BPT-5204 showed highest significant positive SCA effect for effective tillers per plant followed by Pusa 1121 x Adamchini. For this trait nonadditive gene action played a major role as the ratio of σ^2A/σ^2D was less than unity. Anand Kumar *et al.* (2006), Raju *et al.* (2006), Deepa Sankar *et al.* (2008), Karthikeyan *et al.* (2010), Singh *et al.*, (2014), Mallikarjuna *et al.*, (2014) also recorded non additive gene action for this trait. However, additive type of gene action was reported by Muhammad Akram *et al.* (2007) and Gnana Sekaran *et al.* (2006) in their studies.

The significant positive GCA effect for number of grains per panicle among the female parents was recorded in Pusa Sugandh-2 followed by Type-3 whereas among male parents significant positive GCA effect for number of grains per panicle was observed in Adamchini followed by BPT-5204. Cross Pusa Sugandh-2 x BPT-5204 recorded highest significant positive SCA effect for number of grains per panicle followed by Type-3 x Adamchini and Pusa 1121 x Kasturi. For this trait, presence of additive gene action was reported as the ratio of σ^2A/σ^2D was more than unity. Mallikarjuna *et al.*, (2014), Singh *et al.*, (2014) reported non additive gene action for this trait.

The significant desirable value of GCA effects for 100 grain weight among female parents was observed for Pusa 1121 followed by Pusa Sugandh-2 and within male parents, Kasturi showed highest significant positive GCA effects for 100 grain weight followed by BPT-5204. Cross Pusa 1121 x Kasturi recorded highest significant desirable SCA effect for 100 grain weight followed by Pusa Sugandh-2 x BPT-5204 and Pusa 1121 x BPT-5204. Additive gene action was indicated for this trait as the ratio of σ^2A/σ^2D was more than unity. Similar results were reported by Shanthi *et al.* 2004; Raju *et al.* 2006. However, Verma *et al.*, 2006 and Sanjeev Kumar *et al.* 2007. Mallikarjuna *et al.*, (2014), Singh *et al.*, (2014) reported non additive gene action for this trait.

Among the female parents significant positive GCA effect for grain yield per plant was observed for Pusa Sugandh-2 whereas among the male parents BPT-5204 recorded highest significant positive GCA effect for grain yield per plant followed by Adamchini. Cross Pusa Sugandh-2 x BPT-5204 recorded highest desirable significant SCA effect for grain yield per plant followed by Pusa 1121 x Adamchini. For this trait non additive gene action was playing major role which was revealed by ratio of σ^2A/σ^2D was less than unity. Similar results were reported by Raju *et.al.* (2006), Yadav *et al.* (2007) and Shukla and Pandey (2008), Mallikarjuna *et al.*, (2014), Singh *et al.*, (2014). Additive gene action was reported by Verma *et al.* (2006), whereas both additive and non additive gene action was reported by Sanjeev Kumar *et al.* (2007) and Vijaya Lakshmi *et al.* (2008). This may be due to the differences in the material under study.

For hulling recovery none of the female parents showed significant positive GCA effects for hulling recovery. Among the male parents Adamchini showed highest significant positive GCA effect for hulling recovery followed by BPT-5204 as the two genotypes possess small and medium grains respectively and hulling recovery is better for small and medium grain types. Cross Type-3 x Adamchini recorded highest significant positive SCA effect for hulling recovery followed by Pusa 1121 x BPT-5204. Trait hulling recovery was under the control of additive gene action, which was evidenced by ratio of σ^2A/σ^2D was more than unity. Thakare *et al.* (2013) reported both positive and negative SCA effects for hulling recovery in a study on rice by hybrids.

Among the female parents Type-3 showed significant desirable GCA effects for milling recovery whereas among the male parents Adamchini showed significant desirable GCA effect for milling recovery. The highest significant positive SCA effect for milling recovery was showed by cross Pusa Sugandh-2 x Adamchini followed by Pusa 1121 x BPT-5204 and Pusa 1121 x Kasturi. For this trait both additive and non additive gene action were equally important as revealed by the ratio of σ^2A/σ^2D which was equal to unity. Thakare *et al.* (2013) reported both positive and negative significant GCA effects for milling recovery. Adilakshmi and Upendra (2014) reported Sambha Mahsuri to be a good general combiner for milling recovery.

In case of head rice recovery, none of the female parents showed significant positive GCA effects. Among the male parents Adamchini showed significant positive GCA effects for head rice recovery followed by BPT-5204. Among the crosses only Pusa Sugandh-2 x Adamchini showed significant positive SCA effect for head rice recovery. Additive gene action was indicated for this trait as the ratio of σ^2A/σ^2D was more than unity. Adilakshmi and Upendra (2014) reported Sambha Mahsuri a good general combiner for head rice recovery and observed both additive and non additive gene action was equally important.

Amongst the female parents, a significant positive GCA effect for grain length was recorded for Pusa 1121. Among the male parents Kasturi showed significant positive GCA effect for grain length. None of the crosses showed significant positive

SCA effects for grain length. For this trait additive gene action was playing a major role as revealed by ratio of σ^2A/σ^2D being more than unity.

For grain breadth, the female parent Type-3 showed significant negative GCA effects whereas among male parents Adamchini showed significant negative GCA effects. None of the crosses showed significant negative SCA effects for grain breadth. For this trait presence of additive gene action was recorded as the ratio of σ^2A/σ^2D was more than unity.

Among the female parents, Pusa 1121 showed significant desirable GCA effects for brown rice length. Similarly, among the male parents Kasturi showed significant positive GCA effects for brown rice length. The highest significant positive SCA effects was recorded for cross Pusa 1121 x Adamchini followed by Type-3 x BPT-5204 and Pusa Sugandh-2 x Kasturi. Additive gene action was predominant for this trait as the ratio of σ^2A/σ^2D was more than unity.

Significant negative GCA effect for brown rice breadth among female parents was observed for Pusa Sugandh-2. Among male parents none showed significant negative GCA effects. None of the crosses showed significant negative SCA effects for brown rice breadth. Trait brown rice width was under the control of additive gene action, which was evidenced by ratio of σ^2A/σ^2D which was more than unity.

Among the female parents, Pusa 1121 recorded significant positive GCA effects for kernel length and within male parents Kasturi showed significant positive GCA effects. The highest significant positive SCA effects for kernel length was observed for Pusa 1121 x Adamchini followed by Type-3 x BPT-5204 and Pusa Sugandh-2 x Kasturi. Additive gene action was indicated for this trait as the ratio of σ^2A/σ^2D was more than unity. Similar results were reported by Sharma *et al.* (2006) while non additive gene action was reported by Saravanan *et al.* (2006a) and Sanjeev Kumar *et al.* (2007). Both desirable and undesirable SCA effects for kernel length in various cross combinations were reported by Thakare *et al.* (2013) in their studies.

The significant negative GCA effect for kernel breadth among female parents was observed for Pusa Sugandh-2. Among the male parents Kasturi showed

significant negative GCA effect for kernel breadth. None of the crosses showed significant negative SCA effects for kernel breadth. The ratio of σ^2A/σ^2D was more than unity which indicates predominance of additive gene action. Similar results of non-additive gene action was observed by Saravanan *et al.* (2006a), Venkatesan *et al.* (2007) and Sanjeev Kumar *et al.* (2008).

Among the female parents, Pusa 1121 showed significant positive GCA effects for L/B ratio and within male parents Kasturi showed significant positive GCA effects. Cross Pusa 1121 x Adamchini recorded highest significant positive SCA effects for L/B ratio followed by Type-3 x BPT-5204 and Pusa Sugandh-2 x Kasturi. For this trait presence of additive gene action was shown by the ratio of σ^2A/σ^2D was more than unity. These findings were in accordance with the reports of Sharma *et al.* (2006) and Sanjeev Kumar *et al.* (2007). Venkatesan *et al.* (2007), Vijaya Lakshmi *et al.* (2008), Mallikarjuna *et al.*, (2014). Adilakshmi and Upendra (2014) reported both additive and non additive gene action to be equally important for the trait.

The significant positive GCA effect for kernel length after cooking among female lines was recorded for Pusa 1121. Among male parents Kasturi showed significant positive GCA effect for kernel length after cooking. The highest significant positive SCA effect for kernel length after cooking was observed in Type-3 x BPT-5204. Additive gene action was indicated for this trait as the ratio of σ^2A/σ^2D was more than unity.

The negative significant GCA effects were desirable for kernel breadth after cooking. Among female parents Type-3 and Pusa 1121 recorded significant negative GCA effects whereas among male parents Kasturi showed significant negative GCA effects. Cross Pusa Sugandh-2 x Kasturi recorded highest significant desirable SCA effects for Kernel breadth after cooking followed by Type-3 x BPT-5204. For this trait both additive and non additive gene action played a major role which was revealed by ratio of σ^2A/σ^2D was equal to unity.

Among the female parents, Pusa Sugandh-2 recorded significant positive GCA effects for elongation ratio. Among male parents Adamchini showed significant

positive GCA effects for the trait. The highest significant positive SCA effects for elongation ratio was recorded for Pusa sugandh-2 x Adamchini followed by Pusa 1121 x BPT-5204 and Pusa 1121 x Kasturi. The ratio of σ^2A/σ^2D was less than unity which indicates predominance of non additive gene action. Adilakshmi and Upendra (2014) reported importance of both additive and non additive gene action.

The significant positive GCA effects for elongation index among female parents were recorded for Pusa 1121 whereas among male parents Adamchini showed significant positive GCA effects for elongation index. The highest significant positive SCA effects for elongation index was recorded for Type-3 x Adamchini followed by Pusa 1121 x BPT-5204 and Pusa 1121 x Kasturi. Non additive gene action was indicated for this trait as the ratio of σ^2A/σ^2D was less than unity.

For alkali digestion value the significant positive GCA effects among female parents was observed for Pusa 1121. Among male parents Kasturi and BPT-5204 showed significant positive GCA effects for alkali digestion value. Among the crosses high positive significant SCA effects for the trait was recorded for Type-3 x BPT-5204 followed by Pusa 1121 x Adamchini. For this trait presence of additive gene action was indicated by the ratio of σ^2A/σ^2D which was more than unity.

Pusa 1121 showed significant positive GCA effects for Amylose content among female parents whereas Kasturi showed significant desirable GCA effects among male parents. The highest significant positive SCA effects for amylose content was observed in cross Pusa 1121 x Adamchini followed by Pusa Sugandh-2 x BPT-5204. Non additive gene action was indicated for this trait as the ratio of σ^2A/σ^2D was less than unity.

Significant positive GCA effects are desirable for gel consistency. Among female parents Pusa 1121 and Type-3 showed significant positive GCA effects and among males none of the parents showed significant positive GCA effects. Cross Pusa Sugandh-2 x Adamchini showed highest significant positive SCA effects for gel consistency followed by Pusa 1121 x BPT-5204 and Type-3 x BPT-5204. Non additive gene action was involved in the inheritance for this trait as the ratio of σ^2A/σ^2D was less than unity.

Among the female parents, Pusa 1121 showed significant positive GCA effects for aroma. Among the male parents, Kasturi and Adamchini showed significant positive GCA effects for aroma. High significant positive SCA effects for aroma were observed in Pusa 1121 x BPT-5204 followed by Pusa Sugandh-2 x Kasturi and Type-3 x Adamchini. For this trait presence of additive gene action was shown by the ratio of σ^2A/σ^2D was more than unity.

5.3 Estimation of heterosis and inbreeding depression for yield and yield traits

In the present study, heterosis for various yield traits over better parents, standard inbred check (Pusa Basmati-1) and standard Cross check (Pusa RH-10) were calculated for all the nine cross combinations. The characters viz., days to 50% flowering, days to maturity and plant height negative heterotic value were considered to be desirable, while for others positive heterotic estimates are usually preferable.

For days to flowering significant negative heterosis was desirable so that early flowering hybrids could be obtained. As compared to better parent and Pusa RH-10, significant early flowering was observed in two crosses and over Pusa Basmati-1, three Hybrids showed significant negative desirable heterosis. Cross Pusa Sugandh-2 x Kasturi showed highest significant negative heterosis over better parent and standard checks. A wide range of standard heterosis from negative to positive values have been reported by Rahimi *et al.* (2010), Latha *et al.* (2013), Rani *et al.*, (2015), Balakrishna and Satyanarayana (2015) and Nayak *et al.*, (2015) for the trait days to 50 per cent flowering. Only negative values of standard heterosis for days to 50 per cent flowering were reported by Purohit (1972), Young and Virmani (1990), Patil *et al.* (2003) and Tiwari *et al.* (2011). However, Patel *et al.* (1994), Pandey *et al.* (1995), Lingaraju *et al.* (1999) and Sen and Singh (2011) reported positive heterotic values for days to 50 per cent flowering in their studies. All the crosses showed significant inbreeding depression.

The negative value of heterosis for days to maturity was desirable. In present study four crosses were early maturing than Pusa Basmati-1 and two crosses were early maturing than better parent and Pusa RH-10. The cross, Pusa Sugandh-2 x Kasturi showed high significant negative heterosis over better parent and standard

checks. Significant desirable standard heterosis for earliness has been reported by Leenakumari *et al.* (1998), Tang *et al.* (2002), Bhandarkar *et al.* (2005), Gawas *et al.* (2007), Jayasudha and Sharma (2009) and Rahimi *et al.* (2010). However, Sen and Singh (2011), and Soni and Sharma (2011) reported significantly early maturity in only some of the crosses studied. Significant inbreeding depression was recorded for all crosses.

Semi dwarf plant phenotype is desirable for recording high yield in rice as partitioning of biomass is affected and it also reduces lodging. For plant height, all the F_1 s were taller than their respective better parents and standard check Pusa RH-10. Only one cross was negatively significant over Pusa Basmati-1. Sarawgi *et al.* (2000), Vaithiyalingam and Nadarajan (2010), Tiwary *et al.* (2011), and Sanghera and Hussain (2012) observed significant positive estimates of heterobeltiosis and standard heterosis for tallness which support the findings of the present investigation. Negative heterotic values for plant height were observed by Ghosh (2002), Tang *et al.* (2002), Khoyumthem *et al.* (2005) and Gawas *et al.* (2007), Sunil *et al.*, (2014), Balakrishna and Satyanarayana (2015) and Rani *et al.*, (2015). Careful selection of the parents for plant height, to be involved in crosses, would effectively reduce the height in the F_1 's. Eight out of nine crosses recorded significant inbreeding depression for trait plant height.

For effective tillers per plant, positive heterosis was desirable as it increases the more number of panicle bearing tillers and which directly increase grain yield per plant. In the present study, all crosses showed significant positive heterosis over better parent and Pusa Basmati-1 and five crosses showed significant positive heterosis over Pusa RH-10. Cross Pusa 1121 x Adamchini showed highest significant positive heterosis over better parent and Pusa Sugandh-2 x BPT-5204 recorded highest significant positive heterosis over both standard checks. For number of effective tillers significantly positive heterosis was earlier observed by Sarawgi *et al.* (2000), Vaithiyalingam and Nadarajan (2010), Latha *et al.* (2013), Sunil *et al.*, (2014), Rani *et al.*, (2015), Balakrishna and Satyanarayana (2015) and Nayak *et al.*, (2015). All the crosses recorded significant inbreeding depression.

The magnitude of inbreeding depression for effective tillers per plant ranged from 25.87 to 46.73. Two crosses showed significant positive inbreeding depression. Pusa Sugandh-2 x BPT-5204 showed high significant positive inbreeding depression. For these two crosses dominance gene action played a major role in inheritance of this trait while for other crosses high heterosis over better parent and standard checks and non significant inbreeding depression value suggests that the trait was governed by non-additive or interallelic epistatic gene interactions. Further, Minvielle (1987) suggested that dominance may not be necessary for heterosis with the presence of epistasis.

Positive heterosis is desirable for number of grains per panicle as it affects grain yield per plant directly. All crosses showed significant positive heterosis over standard checks and six crosses showed significant positive heterosis over better parent. Cross Pusa Sugandh-2 x BPT-5204 showed highest significant positive heterosis over better parent and both standard checks. Nayak *et al.*, (2015) reported significant negative heterosis over standard checks for the trait while Rani *et al.*, (2015) reported significant positive heterobeltiosis for grains per panicle. All the crosses observed significant inbreeding depression.

For 100-grain weight positive heterosis is desirable. None of the crosses showed positive significant heterosis over better parent. However, four crosses showed significant positive heterosis over standard checks. Cross Pusa 1121 x Kasturi showed highest significant positive heterosis over standard checks. Similar heterotic values for 100 grain weight were observed by Virmani *et al.* (1981), Tseng and Huang (1987), Rahimi (2010), Tiwari *et al.* (2011), Gokulakrishnan and Kumar (2013), Rani *et al.*, (2015), Balakrishna and Satyanarayana (2015) and Nayak *et al.*, (2015). However, Vaithiyalingan and Nadarajan (2010), Latha *et al.* (2013), Sunil *et al.*, (2014) reported only negative heterotic values for test weight. All the crosses showed significant inbreeding depression. Verma and Srivastava (2005) reported significant inbreeding depression.

Heterosis in positive direction for grain yield is desirable as higher grain yield is the main objective for all breeding programmes. Virmani *et al.* (1981) suggested that the yield advantage of 20% to 30% over best available standard variety should be

sufficient to encourage farmers for adopting the hybrid rice varieties. All crosses exhibited significant positive heterosis over better parent and Pusa Basmati-1 and four crosses exhibited significant positive heterosis over Pusa RH-10. Cross Type-3 x Adamchini recorded highest significant positive heterosis over better parent. However, highest significant positive standard heterosis over the both checks was exhibited by Pusa Sugandh-2 x BPT-5204. High magnitude of standard heterosis for grain yield in rice was earlier observed by Kumar *et al.* (2010), Rahimi *et al.* (2010), Reddy *et al.* (2012), Sunil *et al.*, (2014), Rani *et al.*, (2015), Balakrishna and Satyanarayana (2015) and Nayak *et al.*, (2015). However, a wide range of heterosis between negative and positive values for grain yield have been reported by Lingaraju *et al.* (1999), Vaithiyalingan and Nadarajan (2010), Tiwari *et al.* (2011), Gokulakrishnan and Kumar (2013) and Latha *et al.* (2013).

All the crosses observed significant inbreeding depression. Cross Pusa Sugandh-2 x BPT-5204 recorded highest significant inbreeding depression. Singh *et al.*, (2015) reported non-significant inbreeding depression for one cross. Ram, (1992), Reddy and Nerkar, (1995), Verma and Srivastava (2005), Venkanna *et al.*, (2010) reported significant inbreeding depression for this trait.

5.3.1 Estimation of heterosis and inbreeding depression for quality traits

In the present study, relative performance for various quality traits over the respective better parents, over standard inbred check (Taraori Basmati-1) and over standard Cross check (Pusa RH-10) were estimated for all the nine cross combinations. The characters grain breadth, brown rice breadth, kernel breadth and kernel breadth after cooking negative heterotic values were considered to be desirable, while for others positive heterotic estimates were usually preferable.

For hulling recovery positive heterosis was desirable as it decides the amount of marketable produce. One Cross displayed significant positive heterosis over the better parent, five crosses showed significant positive heterosis over Pusa RH-10 and six crosses showed significant positive heterosis over Pusa Basmati-1. The highest value of better parent heterosis was exhibited by Pusa 1121 x BPT-5204, whereas the highest significant positive heterosis over standard checks was shown by Type-3 x

Adamchini. Singh (2000) observed significant negative standard heterosis for hulling recovery in majority of the Hybrids studied. All the crosses showed significant inbreeding depression.

Milling recovery is also an important factor deciding the amount of marketable produce and its positive heterosis is desirable. For milling recovery, heterosis over respective better parents and over the standard checks varied both in positive and negative directions depending upon the cross combination. Two crosses showed significant heterosis over better parent and six crosses showed significant positive heterosis over standard checks. The highest value of better parent heterosis was exhibited by Pusa 1121 x BPT-5204, whereas the highest significant positive heterosis over standard checks was shown by Type-3 x Adanchinni. The range of heterosis reported by Sarawgi *et al.* (2000) for milling recovery was similar to the present finding. Babu *et al.* (2013) tested various rice hybrids and reported statistically similar milling percentage. All the crosses showed significant inbreeding depression.

Higher magnitude of heterosis is desirable for head rice recovery as it leads to substantial production of marketable produce. All crosses recorded significant positive heterosis over standard checks and three crosses recorded significant positive heterosis over better parent. Cross Pusa Sugandh-2 x Adamchini showed highest significant positive heterosis over better parent and standard checks. Sarawgi *et al.* (2000) reported that the range of heterosis for head rice recovery varied in both positive and negative directions, which is quite similar to the results of present investigation. All the crosses showed significant inbreeding depression.

For trait grain length positive heterosis was desirable. One Cross showed significant positive heterosis over better parent and Taraori Basmati and two Hybrids showed significant positive heterosis over Pusa RH-10. Cross Pusa 1121 x Kasturi showed significant positive heterosis over better parent and standard checks.

Seven crosses showed significant inbreeding depression. Chauhan and Chauhan, (1995) and Venkanna *et al.*, (2010) reported neither heterosis nor inbreeding depression.

Negative heterosis was desirable for grain breadth. None of the crosses showed significant negative heterosis over better parent, whereas seven crosses showed significant negative heterosis over Pusa RH-10 and six crosses showed significant negative heterosis over Taraori Basmati. Cross Type-3 x BPT-5204 recorded the highest negative value of heterosis over both the check varieties.

Six crosses recorded significant inbreeding depression. Venkanna *et al.*, (2010) reported significant inbreeding depression for grain breadth.

For trait brown rice length positive heterosis was desirable. None of the crosses showed significant positive heterosis over better parent, two crosses showed significant positive heterosis over standard checks. Cross Pusa Sugandh-2 x Kasturi showed highest significant positive heterosis over both standard checks. Five crosses showed significant inbreeding depression.

Negative heterosis is desirable for character brown rice breadth. None of the crosses showed significant negative heterosis over better parents and standard checks. Two crosses showed significant inbreeding depression

The kernel length is the most important trait which decides the market price of rice hence positive significant heterosis was desirable for this trait. Two crosses showed significant positive heterosis over standard checks and none of the crosses showed significant positive heterosis over better parent. Pusa Sugandh-2 x Kasturi showed highest significant positive heterosis over both standard checks. Rahimi *et al.* (2010), Sanghera and Hussain (2012), Reddy *et al.* (2012) and Priyanka *et al.* (2014) reported positive estimates of standard heterosis for kernel length. In contrast, Sarawgi *et al.* (2000) reported the estimates of standard heterosis in negative direction only. Five crosses showed significant inbreeding depression. Verma and Srivastava (2005) reported low inbreeding depression.

Lower magnitude of kernel breadth ensures grain fineness. Thus, negative value of heterosis for kernel breadth before cooking would be desirable. None of the crosses showed significant negative heterosis over better parents and standard checks. Significant positive heterosis for kernel breadth was observed by Sarawgi *et al.*

(2000), Rahimi *et al.* (2010), Sanghera and Hussain (2012), and Reddy *et al.* (2012). Which may be due to differences in the material they studied. One cross Pusa Sugandh-2 x Adamchini showed significant inbreeding depression.

Kernel length/breadth ratio is one of the important physical traits determining the quality of rice grain. A higher magnitude of kernel length/breadth ratio was desirable. None of the crosses showed significant positive heterosis over better parents and standard checks. Reddy *et al.* (2012) reported lower values for kernel length/breadth ratio than the check varieties in most of the cross combinations studied.

Three crosses recorded significant inbreeding depression. Similar findings were observed by Reddy *et al.*, (1991) and Venkanna *et al.*, (2014). Verma and Srivastava (2005) reported significant low inbreeding depression.

Higher magnitude of kernel length after cooking is desirable. One cross Pusa 1121 x Kasturi exhibited significant positive heterosis over Taraori Basmati and none of the crosses exhibited significant positive heterosis over better parent and Pusa RH-10. A range of values from low to high for kernel length after cooking has been observed by Srivastava and Jaiswal (2013). Five crosses observed significant inbreeding depression.

Lower value of kernel breadth after cooking and thus its heterosis in negative direction was desirable. None of the crosses showed significant negative heterosis over better parents and standard checks. A range of values for kernel breadth after cooking has been observed by Srivastava and Jaiswal (2013).

The inbreeding depression for this trait ranges from -19.04 to 15.55. Eight crosses observed significant inbreeding depression. The positive inbreeding depression value suggests the mean of F_2 is lower than F_1 mean which means the kernel breadth after cooking is reducing in F_2 which was desirable.

Kernel elongation ratio is an important cooking quality character of the rice grain and positive heterosis is desirable for this trait. One cross showed significant positive heterosis over better parent and two crosses showed significant positive heterosis over standard checks. Pusa Sugandh-2 x Adamchini showed high significant

positive heterosis over better parent and standard checks. Sarawgi *et al.* (2000) reported both higher and lower values for kernel elongation ratio than the standard checks. Significant inbreeding depression was recorded for four crosses.

Elongation index is an important measure of kernel expansion upon cooking that involves both length-wise and breadth-wise components. Higher value of elongation index is considered to be desirable. One cross Type-3 x Adamchini showed significant positive heterosis over Pusa RH-10 and none of the crosses showed significant positive heterosis over better parent and Taraori Basmati.

The inbreeding depression for this trait ranges from -15.49 to 11.12. Three crosses showed significant inbreeding depression. Crosses Pusa Sugandh-2 x BPT-5204 and Pusa 1121 x Adamchini showed significant negative inbreeding depression but cross Type-3 x Adamchini showed significant positive inbreeding depression.

For alkali spread value intermediate value is preferable. Two crosses showed significant positive heterosis over better parent, one and seven crosses showed significant positive heterosis over Pusa RH-10 and Taraori Basmati respectively. Cross Type-3 x BPT-5204 showed highest significant positive heterosis over better parent, cross Pusa 1121 x Kasturi recorded highest significant positive heterosis over standard checks. Eight crosses recorded significant inbreeding depression.

For amylose content intermediate types (20-25) are preferable. Three crosses showed significant positive heterosis over better parent and seven crosses showed significant positive heterosis over standard checks. Cross Pusa 1121 x Adamchini showed highest significant positive heterosis over better parent and standard checks. Significant inbreeding depression was observed for four crosses.

For trait gel consistency higher value and positive heterosis was desirable. Four Hybrids showed significant positive heterosis over better parent, two crosses showed significant positive heterosis over Pusa RH-10 and none of the crosses showed significant positive heterosis over Taraori Basmati. Cross Pusa 1121 x Kasturi showed high significant positive heterosis over better parent and cross Pusa 1121 x

BPT-5204 showed highest significant positive heterosis over Pusa RH-10. All the crosses showed significant inbreeding depression.

For aroma significant positive heterosis was desirable. Two crosses showed significant positive heterosis over Pusa RH-10 while none of the crosses showed significant positive heterosis over better parents and Taraori Basmati. Cross Pusa Sugandh-2 x Kasturi showed highest significant positive heterosis over Pusa RH-10. Two crosses showed significant inbreeding depression.

5.4 Best performing Hybrids for yield and quality traits

A Hybrid is considered commercially useful when it shows significantly high standard heterosis over best locally adopted variety or hybrid. Heterosis over best check variety/ Cross was considered as most dependable criteria for evaluation of Hybrids (Sharma and Mani, 1990).

In the present study, no single Cross had expressed desirable performance for all yield and quality traits. Latha *et al.* (2013) also reported none of the cross combinations recorded significant heterosis for all the traits studied.

All the Hybrids evaluated in present study observed high magnitude of heterosis over better parent and standard check Pusa Basmati-1 for grain yield but only four Hybrids were shown significant heterosis over Pusa RH-10. High magnitude of heterosis over standard check for grain yield was earlier reported by Rahimi *et al.* (2010) and Reddy *et al.* (2012). Among the various crosses exhibiting desirable value of heterosis, Pusa Sugandh-2 x BPT-5204, Pusa 1121 x Adamchini and Type-3 x BPT-5204 were top performers for grain yield per plant in the present study. The Cross, Pusa Sugandh-2 x BPT-5204 observed highest yield per plant and best three performers for traits, plant height, effective tillers per plant, number of grains per panicle and 100-seed weight. It seems that standard heterosis for grain yield in this Cross was highly influenced by these traits. Earlier researchers have also reported high heterosis for grain yield in crosses being influenced by number of effective tillers per plant. Thus, taking only yield traits in consideration, Pusa Sugandh-2 x BPT-5204 may be considered as the best heterotic combination.

None of the three crosses showing best performance for grain yield, recorded superior performance over standard checks for all the quality traits studied. Vaithiyalingan and Nadarajan (2010) and Adilakshmi and Reddy (2011) also reported that most of the high yielding hybrids exhibit lower values of desirable heterosis for quality characters. Among the crosses in present study, cross combination Pusa Sugandh-2 x Kasturi was found to perform better for majority of the quality traits. When both yield and quality characters considered Type-3 x Adamchini was best cross combination.

For combining ability studies, none of the parents recorded significant desirable GCA effects simultaneously in desired direction for all the traits studied. Similar results have been reported by Tiwari *et al.* (2011) and Latha *et al.* (2013). However, none of the crosses showed significant and desirable SCA effects for all the characters revealing that no specific combination was desirable for all traits. These results are similar to earlier findings of Tiwari *et al.* (2011), Ghara *et al.* (2012), and Sanghera and Hussain (2012). Among the female parents, Pusa Sugandh-2 revealed significant desirable value of GCA effect for yield per plant but Type-3 showed desirable value of GCA for most of the quality traits. Among the male parents, BPT-5204 revealed significant desirable value of GCA effect for most of the yield traits. However, Kasturi revealed the significant desirable value of GCA effect for most of the quality traits. Cross combination Pusa Sugandh-2 x BPT-5204 evinced the highest significant value of SCA effect for grain yield per plant followed by Pusa 1121 x Adamchini. However, Pusa Sugandh-2 x Kasturi followed by Type-3 x BPT-5204 revealed the significant desirable value of SCA effect for most of the quality traits.

For the Cross Pusa Sugandh-2 x BPT-5204, the female parent showed significant desirable GCA effect for grain yield and did not show desirable GCA effect for most of the quality attributes. However, the male parent in this Cross recorded significant desirable GCA effect for grain yield and most of the yield as well as quality traits. This Cross recorded significant desirable SCA effect for grain yield and most of the yield traits but did not show desirable SCA effect for quality parameters. For Pusa Sugandh-2 x Kasturi, the female parent recorded significant desirable GCA effect for grain yield and did not show desirable GCA effect for most of the quality attributes. The male parent was observed to show negative value of

GCA effect for grain yield, but revealed desirable significant GCA effect for most of the quality traits. The Cross, Pusa Sugandh-2 x Kasturi did not show significant desirable SCA effect for grain yield and yield traits but showed significant desirable SCA effects for most of the quality traits.

It was observed that best cross combinations are not always found between high x high general combiners, but may also occur in other types of parental combinations. Chakraborty *et al.* (2009) and Tiwari *et al.* (2011) have reported that in order to obtain heterotic hybrids, it is better to select at least one parent possessing high GCA and other with low, average or high GCA. This is in accordance with the present findings. Moreover, the absence of significant desirable SCA effects for most of the quality traits in Pusa Sugandh-2 x BPT-5204 may be attributed to high x high GCA interaction as reported by Hariprasanna *et al.* (2006).

5.5 Estimate of gene actions through generation mean analysis

5.5.1 Scaling tests:

The estimation of epistasis speculates more significance in view of the fact that in its presence, variance component estimates are likely to be biased. Hence conclusions drawn from such estimates are more likely to be misleading. If epistasis component is left uncalculated it will inflate the measure of additive and dominance components. For estimating epistasis scaling test was proposed by Mather (1949) and joint scaling test was proposed by Cavalli (1952). The joint scaling test was more precise than any other tests in detecting epistasis because it uses information from all the six populations.

When epistasis was tested with both scaling test and joint scaling test the results obtained were in agreement in all cases except in fifteen cases where both joint scaling test and scaling tests showed significance but i, j, l were non-significant for eight cases. The joint scaling test and i, j, l values were significant but scaling test were not significant in three cases. The scaling tests were significant but joint scaling test and i, j, l values were not significant in two cases. The scaling tests and i, j, l values were significant but joint scaling test was not significant in one case. Both joint scaling test and scaling tests were non-significant but i, j, l values were significant in

one case. When comparison was made between scaling tests and joint scaling test, the later was more precise in detecting epistasis. Considering all the above facts the decision of presence or absence of epistasis one should mainly depend on the i , j and l values of six parameter model. Rani *et al.*, (2015) used scaling tests for prediction of epistasis out of 22 times 21 times scaling tests were in agreement with i , j and l values and Mahalingam and Nadarajan (2010) applied the scaling tests 24 times for prediction of epistasis and 17 times it was in concurrence with i , j and l values. Gnanamalar and Vivekanandan (2013) employed scaling tests 54 times for prediction of epistasis and 52 times it was accordance with the i , j and l values. These findings agree with those of the present study where a total of 225 tests were performed with each of the four scales 210 times it was in conformity with the i , j and l values. Thus to clearly depict the noninteracting crosses, it is suggested to adopt the six parameter model for the crosses shown to be interacting by the joint scaling test and to validate the results with values of i , j and l .

5.5.2. Estimation of gene effects in Noninteracting crosses:

The three parameter model was applied for the crosses which showed absence of epistatic interactions. Out of 225 cases sixteen were showed lack of epistatic interactions (table). Days to 50 per cent flowering and days to maturity recorded significant additive gene effect ($\hat{d}$) governing these traits. For effective tillers per plant dominance effects ($\hat{h}$) were significant which govern the inheritance for this trait which was in accordance with Gopikannan and Ganesh (2014) and contradictory with Agrawal *et al.*, (2006) who reported additive gene action; for this trait development of Hybrids would be a useful proposition. For grain breadth additive effects ($\hat{d}$) were significant which played a greater role in inheritance of this character which was akin with the Sharifi *et al.* (2011) and Roy and Senapathi (2012) reported similar results for the trait. Trait brown rice width showed additive effects ($\hat{d}$) were significant and played a major role in inheritance of the trait in both crosses. For kernel length additive effects ($\hat{d}$) were significant which govern the inheritance of this character which coincides with results of Roy and Senapathi (2012). Trait kernel breadth showed additive effects ($\hat{d}$) were significant for three crosses and it controls the inheritance of this character which was similarity with Roy and Senapathi (2012). For

kernel breadth after cooking additive effects ($\hat{d}$) were showed significant and govern the inheritance of the trait. For alkali digestion value additive and nonadditive effects ($\hat{d}$) were significant so both gene effects were control the inheritance of this trait while Agrawal *et al.*, (2006) reported nonadditive gene effects controls this character. For aroma additive effects ($\hat{d}$) were significant for both crosses which plays a major role in inheritance of this trait. For gel consistency additive effects ($\hat{d}$) were significant for both crosses and controls the inheritance of this trait which was similarity with results of Rani *et al.*, (2015). These findings signify that in sixteen crosses analysed by three parameter model, additive gene effects were controlling the most of the crosses. The additive gene effects ($\hat{d}$) can be fixed in later generations so, it offers scope for improvement through phenotypic selection based on pedigree method.

Yield related traits

For days to 50% flowering, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect and dominance x dominance ($\hat{l}$) type of interactions was important. Early maturing genotypes are desirable which can be used in multiple cropping systems. For days to maturity, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important. Hasib (2002) and Patil *et al.*, (2006a) revealed both additive (d) and dominant (h) gene effects for days to 50% flowering which supports the present findings. However, Kumar *et al.* (2005) reported additive and Patel (2015) reported dominance effect (h) for flowering traits. Duplicate epistasis was recorded in three crosses for days to 50% flowering and in five crosses for trait days to maturity. Duplicate epistasis for days to 50% flowering was also reported by Roy (1998), Hasib (2002), Gopikannan and Ganesh (2014) and Patel (2015). However, complimentary epistasis was shown by two and one cross for days to 50% flowering and days to maturity respectively.

Semi dwarf plants are desirable. Epistasis of duplicate type was present in four crosses while complimentary type was present in two crosses. Patel (2015) also reported duplicate epistasis for the trait. For plant height, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect and all type of interactions were equally important. Roy (1999)

reported additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$). Habib *et al.*, (2002) observed both additive effect (d) and dominance effect (h) for this trait. Kumar *et al.*, (2005) observed additive ($\hat{d}$) gene effects.

Plants with more number of tillers are desirable as it ultimately increases the yield. Duplicate type and complimentary type of epistasis were present in two crosses each for effective tillers per plant. Thirugnana Kumar *et al.* (2007), Mahalingam and Nadarajan (2010) and Patel (2015) reported duplicate epistasis for the trait whereas Patil *et al.*, (2006b) reported complementary epistasis which supports the present findings. Dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$) type of interactions were important for the trait. Singh and Katoch (1997) observed dominance ($\hat{h}$), additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions. However, Murugan and Ganesan (2006) reported additive ($\hat{d}$), additive x dominance ($\hat{j}$), dominance x dominance ($\hat{l}$). Patil *et al.*, (2006a) reported both additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects.

Panicles with more number of grains were desirable as it increase the grain yield per plant. For trait number of grains per panicle, duplicate type of epistasis was shown by four crosses, while complimentary epistasis was shown by three crosses. Thirugnana Kumar *et al.* (2007) and Patel (2015) reported duplicate epistasis. Dominance ($\hat{h}$) gene effects and Additive x additive (i) and dominance x dominance ($\hat{l}$) type of interactions played a major role in inheritance of this trait. Murugan and Ganesan (2006) reported dominance ($\hat{h}$), additive x additive ($\hat{i}$), additive x dominance ($\hat{j}$). However Mahalingam and Nadarajan (2010) observed dominance effect ($\hat{h}$) and additive effect ($\hat{d}$) and Saumya and Lal (2014) reported additive x additive ($\hat{i}$) type of interaction.

More 100-grain weight is desirable as it increases the yield directly. Complimentary type of epistasis was found in three crosses and duplicate type of epistasis was recorded in two crosses for trait 100-grain weight. Thirugnana Kumar *et.al.* (2007) and Patel (2015) reported duplicate epistasis for the trait. Patil *et al.*, (2006b) reported complementary epistasis. This is similar to the present findings. For this trait, additive ($\hat{d}$), and dominance ($\hat{h}$) gene effects in main effect, additive x

additive ($\hat{i}$) type of interactions were important. Patil *et al.*, (2006a) reported both additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects. Kumar and Mani (1998) reported additive ($\hat{d}$), dominance ($\hat{h}$) and additive x additive ($\hat{i}$) type of interaction. Habib *et al.*, (2002) observed both additive effect (d) and dominance effect (h) for this trait.

For grain yield per plant, four crosses recorded duplicate epistasis and two crosses showed complementary epistasis. Patil *et al.*, (2006b), Murugan and Ganesan (2006) Mahalingam and Nadarajan (2010) and Patel (2015) reported duplicate epistasis and Thirugnana Kumar *et al.* (2007) reported complementary epistasis for the trait which supports the present findings. For the trait, dominance ($\hat{h}$) gene effects in main effect, additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were important. Murugan and Ganesan (2006) reported dominance ($\hat{h}$), all interactions. Kumar *et al.*, (2005) observed predominant dominance ($\hat{h}$) gene effects. However Saumya and Lal (2014) reported additive x additive ($\hat{i}$) type of interaction.

Quality traits

Milling properties

Hulling recovery was the important factor which decides the marketable produce. Milling recovery is also an important factor deciding the amount of marketable produce. Higher value of head rice recovery leads to substantial production of marketable produce.

Duplicate epistasis was observed in six crosses in case of hulling. Mahalingam and Nadarajan (2010), Gnanamalar and Vivekanandan (2013) and Rani *et al.*, (2015) reported duplicate epistasis which is in agreement with present findings. In case of milling six crosses recorded duplicate epistasis and two crosses recorded complementary epistasis. Gnanamalar and Vivekanandan reported duplicate epistasis for milling. Complementary epistasis was observed in three crosses in case of head rice recovery. Rani *et al.*, (2015) also reported complementary epistasis for the trait which supports the present findings. For hulling recovery and head rice recovery dominance ($\hat{h}$) gene effects in main effect and additive x additive ($\hat{i}$) type of

interactions were important whereas for milling recovery along with dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important. Rani *et al.*, (2015) reported dominance effects ($\hat{h}$) for hulling recovery which supports the present findings. Rani *et al.*, (2015) reported dominance effects (h) and additive x additive effects (i) for milling recovery. However, Mahalingam and Nadarajan (2010) and Gnanamalar and Vivekanandan (2013) observed additive effect (d). Rani *et al.*, (2015) reported dominance effects ($\hat{h}$), additive x additive effects (i) for head rice recovery

Physical properties

Duplicate epistasis was recorded in five crosses for grain length, in three crosses for grain width, in five crosses for brown rice length, in four crosses for brown rice width, in five crosses for kernel length, in three crosses for kernel breadth and in four crosses for L/B ratio. Complementary epistasis was present in two crosses for grain length, in three crosses for grain width, in one cross for kernel length and three crosses for kernel width. Patel (2015) reported duplicate epistasis for grain length. Gnanamalar and Vivekanandan (2013) reported duplicate epistasis for kernel length, kernel breadth and L/B ratio. Patel (2015) also reported duplicate epistasis for L/B ratio.

Additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects in main effect and epistatic interactions were important for grain length, brown rice length, brown rice breadth, kernel length and L/B ratio. Dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important for grain breadth and kernel breadth. Verma *et al.*, (1994b) reported additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions for grain length and grain breadth. Habib *et al.*, (2002) observed both additive effect (d) and dominance effect (h) for grain length. Roy and Panwar (1993) and Vivekanandan and Giridharan (1995b) reported additive, dominance and all type of interactions for inheritance of kernel length. Nayak (2007) reported both additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects and Gnanamalar and Vivekanandan (2013) observed additive effect (d), dominance ($\hat{h}$), additive x dominance ($\hat{j}$) for kernel length. For kernel breadth,

Gnanamalar and Vivekanandan (2013) observed additive effect (d), dominance ($\hat{h}$), additive x dominance ($\hat{j}$) types of interaction. Vivekanandan and Giridharan (1995b), Nayak (2007) reported additive ($\hat{d}$), dominance ($\hat{h}$) and all type of interactions for L/B ratio. Gnanamalar and Vivekanandan (2013) observed additive effect (d), dominance ($\hat{h}$), additive x dominance ($\hat{j}$) and duplicate epistasis and Rani *et al.*, (2015) reported additive effects (d), dominance effects (i) for L/B ratio.

Cooking properties

Cooking properties are very important for consumers. Kernel length after cooking is one of the important grain quality parameters and its higher value is perceived to be desirable. Lesser value of kernel breadth after cooking is desirable. Elongation index is an important measure of kernel expansion upon cooking that involves both length-wise and breadth-wise components.

Duplicate epistasis was observed in seven crosses for kernel length after cooking, in three crosses for kernel breadth after cooking, in five crosses for elongation ratio and in seven crosses for elongation index. Complementary epistasis was recorded in two crosses for kernel breadth after cooking, in one cross for elongation ratio and elongation index each. Gnanamalar and Vivekanandan (2013) reported duplicate epistasis for kernel length after cooking. Vivekanandan and Giridharan (1995b), Nayak (2007) and Rani *et al.*, (2015) reported duplicate epistasis for elongation ratio. Vivekanandan and Giridharan (1995b) reported duplicate epistasis for elongation index. These results are similar to the present findings.

For kernel length after cooking and kernel breadth after cooking along with additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects in main effect, epistatic interactions were important. Gnanamalar and Vivekanandan (2013) observed additive effect (d), dominance ($\hat{h}$), additive x dominance ($\hat{j}$) for kernel length after cooking. Nayak (2007) reported both additive ($\hat{d}$) gene effect and additive x additive ($\hat{i}$) type of interactions. For elongation ratio and elongation index along with dominance ($\hat{h}$) gene effects in main effect, epistatic interactions were important. Vivekanandan and Giridharan (1995b) reported additive ($\hat{d}$), dominance ($\hat{h}$), additive x additive ($\hat{i}$),

dominance x dominance ($\hat{l}$) and Nayak (2007) reported both additive ($\hat{d}$) and dominant ($\hat{h}$) gene effect, additive x additive ($\hat{i}$), dominance x dominance ($\hat{l}$) for elongation ratio. Rani *et al.*, (2015) reported additive effects ($\hat{d}$) and dominance effects ($\hat{h}$) for elongation ratio and dominance effects ($\hat{h}$) for elongation index.

Chemical properties

For alkali digestion value, intermediate value are preferable. Seven crosses revealed duplicate type of epistasis. Rani *et al.*, (2015) and Gnanamalar and Vivekanandan (2013) reported duplicate epistasis for this trait which is in agreement with present findings. For this trait, dominance ($\hat{h}$) gene effects in main effect and all type of interactions were important. Nayak (2007) reported both additive ($\hat{d}$), dominance ($\hat{h}$) gene effects and all type of interactions were important for the trait. Rani *et al.*, (2015) and Gnanamalar and Vivekanandan (2013) reported additive x additive effects (i) for this trait.

Dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions along with duplicate epistasis were important for all the three traits i.e. amylose content, gel consistency and aroma. Rani *et al.*, (2015) reported additive effects ($\hat{d}$), dominance effects ($\hat{h}$) and additive x additive effects (i) for amylose content. Gnanamalar and Vivekanandan (2013) observed non additive gene action for gel consistency. Duplicate epistasis was revealed by nine crosses for trait amylose content, six crosses for gel consistency and two crosses for aroma. Nayak (2007) and Rani *et al.*, (2015) reported duplicate epistasis for amylose content.

Additive gene action (d) and dominance x dominance (l) type of interaction was important in most diverse cross for characters days to 50 per cent flowering, days to maturity in Pusa Sugandh-2 x Adamchini.

Additive gene action (d) and additive x additive (i) type of interaction was important in most diverse cross Pusa 1121 x Adamchini for character grain length.

Additive gene action (d) and additive x dominance (j) type of interaction was important for diverse cross Pusa 1121 x Adamchini for traits brown rice length, kernel length and kernel length after cooking.

Dominance gene action (h) and additive x additive (i) type of interaction was important in most diverse crosses for traits plant height and effective tillers per plant in Pusa Sugandh-2 x Adamchini and Type-3 x Adamchini respectively. For characters number of grains per panicle and 100-grain weight in cross Pusa 1121 x Adamchini. Dominance gene action (h) and dominance x dominance (l) type of interaction was important in most diverse crosses for traits grain yield per plant and gel consistency in Pusa Sugandh-2 x Adamchini and Pusa 1121 x Adamchini respectively.

In all the studied yield and quality traits duplicate epistasis was important. Duplicate epistasis likely to cancel the effect of each other in Cross combination and reduces the progress made under selection so selection should be postponed to later generations of segregation where dominance effects were depleted. However, in some crosses complementary epistasis was recorded. For such crosses, biparental mating in early segregating generations followed by selection in advanced generations would be more effective rather than direct selection in early segregating generations.

5.6 Frequency Distribution

The frequency distribution in F_2 for most of the traits in the nine crosses was near to normal distribution. The characters which show skewness towards lower value were days to 50 per cent flowering, days to maturity, grains per panicle, hulling recovery, milling recovery, grain length, brown rice length, kernel length, L/B ratio, kernel length after cooking, elongation ratio and elongation index. Transgressive segregants in both the directions was observed indicating that variability created by segregation and recombination in these Hybrids.

For days to 50 per cent flowering, the diverse cross Pusa Sugandh-2 x Adamchini showed distinct bimodal distribution indicates two genes or group of genes controlling the trait. Eight crosses showed nearly normal distribution in F_2 reveals more than two genes or group of genes controlling the trait.

Eight crosses showed normal distribution for days to maturity which suggests polygenic control. Diverse cross Pusa Sugandh-2 x Adamchini recorded bimodal distribution suggests two genes or group of genes controlling the inheritance of this trait.

For plant height diverse cross Pusa Sugandh-2 x Adamchini along with six crosses showed normal distribution suggests more than two genes or group of genes controlling the inheritance of this trait while two crosses showed bimodal distribution which reveals two genes or group of genes were governing this trait.

For the character effective tillers per plant all crosses recorded normal distribution which shows polygenic control of inheritance of the trait.

For trait number of grains per panicle, diverse cross Pusa 1121 x Adamchini and all crosses showed normal distribution indicates polygenes controlling the inheritance of the trait.

All the crosses along with diverse cross Pusa 1121 x Adamchini showed normal distribution for trait hundred grain weight shows polygenic control for the trait

For the trait grain yield per plant all crosses with diverse cross Pusa 1121 x Adamchini showed normal distribution reveals more than one gene or group of genes controlling the inheritance of the trait.

For trait hulling recovery diverse cross Pusa 1121 x Adamchini along with four crosses showed bimodal distribution which suggest two genes or group of genes governing the trait. Four crosses showed near normal distribution indicates polygenic control of the trait.

For milling recovery and head rice recovery all the crosses showed normal distribution along with diverse cross Pusa 1121 x Adamchini which indicates polygenic control of the inheritance of these two traits except three crosses which shows bimodal distribution suggests two genes governing the inheritance of the trait.

For the trait grain length, all the crosses along with diverse cross Pusa 1121 x Adamchini showed normal distribution suggests more than two genes or group of

genes controlling the inheritance of the trait. Veni and Rani (2008) reported inheritance of grain length was under monogenic control

All crosses along with diverse cross Pusa 1121 x BPT-5204 showed near normal distribution for the trait grain breadth which suggests polygenic control of the inheritance of the trait.

All crosses showed near normal distribution along with diverse cross Pusa 1121 x Adamchini for trait brown rice length suggest more than two gene or group of genes controlling the inheritance of the trait.

All crosses along with diverse cross Type-3 x Kasturi showed normal distribution for this trait brown rice breadth which indicates polygenic control of the trait

All crosses along with diverse cross Pusa 1121 x Adamchini showed normal distribution for the trait kernel length suggest polygenic control the inheritance of the trait.

For the trait kernel breadth all crosses showed normal distribution along with diverse cross Type-3 x Kasturi which indicates more than two genes or group of genes control the inheritance of the trait.. Veni and Rani (2008) reported kernel breadth was under polygenic control along with few modifier genes.

All crosses showed near normal distribution for this trait L/B ratio which reveals polygenes controlling the trait.

For the trait kernel length after cooking all the crosses along with diverse cross Pusa 1121 x Adamchini showed normal distribution indicates more than two genes or group of genes governing the inheritance of the trait.

For trait kernel breadth after cooking all crosses along with most diverse cross was Pusa 1121 x BPT-5204 exhibited normal distribution which reveals polygenic control of the trait. One cross exhibits bimodal distribution which suggests two genes or group of genes controlling the trait in this cross.

All crosses recorded near normal distribution for trait elongation ratio which suggests that more than two genes or group of genes controlling the inheritance of the trait. Faruq *et al.*, (2004) reported the inheritance pattern of cooked kernel elongation, distribution curve always formed a bimodal curve. It can be assumed as that this character may be governed by one or two genes for one cross and more than two genes or group of genes along with few modifier genes for another cross.

For trait elongation index all crosses showed near normal distribution which reveals that polygenes were controlling the inheritance of the trait

All the crosses showed normal distribution for the trait alkali digestion value which suggests more than two genes or group of genes controlling the inheritance of this trait.

For the trait amylose content all the crosses showed normal distribution which suggests polygenic control of this trait.

All the crosses showed normal distribution for the trait gel consistency which confirms more than two genes or group of genes governing the trait.

For the trait aroma, one cross exhibited normal distribution suggests polygenic control of the trait. Five crosses showed bimodal distribution indicates two genes or group of genes were controlling the trait and two crosses showed trimodel distribution which indicates three genes or group of genes were controlling the trait. Sood and Siddiq (1978), Berner and Hoff (1986) and Reddy and Reddy (1987) reported single recessive gene controlling the aroma. Kadam and Patankar (1983) observed single dominant gene. Reddy and Sathyanarayanaiah (1980) concluded that there were three complementary recessive aroma genes. Dhulappanavar (1976) reported there were four complementary recessive aroma genes.





SUMMARY AND CONCLUSION

SUMMARY

The present investigation entitled “**Genetics of yield and quality characters in aromatic rice (*Oryza sativa* .L)**” was conducted at the Agriculture Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi to achieve the following objectives.

1. To access genetic diversity at molecular level.
2. To study the nature and magnitude of gene action controlling the inheritance of grain quality, yield and yield contributing characters.
3. To estimate the general and specific combining ability effects for grain yield and quality parameters.
4. To study the nature and magnitude of heterosis and inbreeding depression.

The experimental material consisted of six parental genotypes which were selected from 100 genotypes of rice on the basis of yield, quality parameters and molecular diversity. Pusa 1121, Pusa Sugandh-2, Type-3 were used as female parents and Kasturi, BPT-5204 and Adamchini used as male parents in the hybridization programme. Pusa basmati-1 (yield check), Taraori basmai (quality check) and Pusa RH-10 (hybrid check for both yield and quality) were used as checks for comparison of yield and quality attributes of the F₁ hybrids obtained. All the genotypes were obtained from the ‘All India Coordinated Rice Improvement Project (AICRIP), Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

The molecular diversity analysis revealed that the genetic distance among the 24 rice accessions, based on SSR data obtained, were highly diverse as the 24 genotypes were clustered into seven groups. Treatment variations showed highly significant differences for all the characters studied during *Kharif* 2015. The differences among the parents were highly significant for most of the traits, indicating

the parents differed genetically for most of the traits studied. Similarly a wide range of variation was observed in the estimates of genetic components of variance for all the traits. On the other hand, the estimates of general combining ability variances (σ^2_{gca}) were higher than specific combining ability variances (σ^2_{sca}) for most of the traits.

The estimates of additive genetic variance (σ^2_A) was higher than dominance genetic variance (σ^2_D) for the characters, days to 50% flowering, days to maturity, plant height, number of grains per panicle, 100- grain weight, hulling recovery, head rice recovery, grain length, grain breadth, brown rice length, brown rice breadth, kernel length, kernel breadth, L/B ratio, kernel length before cooking, alkali digestion value and aroma, suggesting the preponderance of additive gene action for these traits. However, for the traits effective tillers per plant, grain yield per plant, elongation ratio, elongation index, amylose content and gel consistency, value of σ^2_A was observed to be lower than σ^2_D , indicating the preponderance of non additive gene action. For the traits milling recovery and kernel breadth after cooking the ratio of σ^2_A / σ^2_D showed value of near unity indicates importance of both additive and non additive gene action for these traits.

The mean performance of nine rice hybrids obtained from three females and three male parent, along with their parental lines and checks were studied for both yield and quality traits. Heterosis was estimated as per cent increase or decrease in estimates of various traits over respective better parents and over the standard varieties (checks). For yield traits, the heterosis was calculated for days to 50 percent flowering, days to maturity, plant height, number of effective tillers per plant, number of grains per panicle, 100 grain weight and grain yield per plant. In case of quality traits, the heterosis was estimated for grain length, grain breadth, brown rice length, brown rice breadth, kernel length, kernel breadth, kernel length after cooking, kernel breadth after cooking and gel consistency. For the quality parameters viz., hulling recovery, milling recovery, head rice recovery, L/B ratio, elongation ratio, elongation index, alkali spread value, amylose content and aroma were converted to arc sine values for calculations of heterosis.

The findings of present study indicated that majority of the hybrids recorded high heterosis for grain yield. Among the various hybrids exhibiting desirable value of heterosis, Pusa Sugandh-2 x BPT-5204, Pusa 1121 x Adamchini and Type-3 x BPT-5204 were top performers for grain yield per plant. The hybrid, Pusa Sugandh-2 x BPT-5204 recorded highest yield per plant, and was among the best three performers for traits, plant height, effective tillers per plant, number of grains per panicle and hundred seed weight. For quality traits, cross Pusa Sugandh-2 x Kasturi revealed better performance for majority of the traits. When both yield and quality characters were considered Type-3 x Adamchini was the best cross combination. Significant inbreeding depression was recorded for yield attributing traits and most of the quality related traits except brown rice breadth, kernel breadth, L/B ratio, elongation ratio, elongation index, amylose content and aroma.

For the hybrid Pusa Sugandh-2 x BPT-5204, the female parent showed significant desirable GCA effect for grain yield but did not show desirable GCA effect for most of the quality attributes. However, the male parent in this hybrid recorded significant desirable GCA effect for grain yield and most of the yield and quality traits. For Pusa Sugandh-2 x Kasturi, the female parent recorded significant desirable GCA effect for grain yield but did not show desirable GCA effect for most of the quality attributes. The male parent recorded negative value of GCA effect for grain yield, but revealed desirable significant GCA effect for most of the quality traits. For Type-3 x BPT-5204, the female parent did not show desirable GCA effect for grain yield but showed desirable GCA effect for most of the quality traits. However, the male parent in this hybrid recorded significant desirable GCA effect for grain yield and most of the yield as well as quality traits.

Estimates of gene actions and their interactions were studied through generation mean analysis. Nine crosses for twenty five traits were studied during *kharif* 2015. Of 225 tests performed using both scaling tests and joint scaling test the results of joint scaling tests obtained were in agreement for 213 times while the A, B, C scales were in agreement for 210 times. The foregoing indicates that the joint scaling test was more precise in predicting the presence of epistasis than any of the A B or C scales. Three parameter model was applied for the crosses which showed absence of epistatic interactions. Out of 225 cases 16 were showed lack of epistatic

interactions. Among 16 non interacting crosses of 11 traits, 14 crosses of nine traits recorded additive ($\hat{d}$) gene effect while crosses Pusa 1121 x Adamchini and Type-3 x BPT-5204 for traits effective tillers per plant and alkali digestion value respectively, recorded dominance ($\hat{h}$) gene effect.

In interacting crosses, duplicate epistasis was recorded for all traits studied except head rice recovery, while complementary epistasis was observed in all yield attributing traits, milling traits except hulling recovery and in all cooking properties except kernel length after cooking. In physical properties complementary epistasis was observed for grain length, grain breadth and kernel length, while absent in all chemical properties viz., alkali digestion value, amylose content, gel consistency and aroma.

For yield attributing traits, days to 50 per cent flowering, days to maturity, plant height and 100-grain weight were governed by additive gene effects ($\hat{d}$), dominance gene effects ($\hat{h}$) and $\hat{i}$ and $\hat{l}$ type of interactions were important, while effective tillers per plant, number of grains per panicle and grain yield per plant were controlled by dominance gene effects ($\hat{h}$) and all type of interactions were important.

The quality traits, for milling properties were mainly governed by dominance gene effects ($\hat{h}$) and additive x additive ($\hat{i}$) type of interactions. Physical properties namely grain length, brown rice length, brown rice width, kernel length and L/B ratio were controlled by additive gene effects ($\hat{d}$), dominance gene effects ($\hat{h}$) and all type of interactions while grain breadth and kernel breadth were controlled by dominance gene effects ($\hat{h}$) and $\hat{i}$ and $\hat{l}$ type of interactions. Cooking properties namely kernel length after cooking, kernel breadth after cooking were controlled by additive gene effects ($\hat{d}$), dominance gene effects ($\hat{h}$) and all type of interactions, while elongation ratio and elongation index were governed by dominance gene effects ($\hat{h}$) and all type of interactions. All the chemical properties were controlled by dominance gene effects ($\hat{h}$) and $\hat{i}$ and $\hat{l}$ type of interactions.

The generation mean analysis showed that for most of the traits both additive and dominant types of gene effects were important. However, dominance gene effects ($\hat{h}$), in general, were higher than additive gene effects ($\hat{d}$). In the presence of epistasis,

most of the crosses showed duplicate type of gene interaction. With regards to epistatic gene effects, additive $\times$ additive ($\hat{i}$) and dominance $\times$ dominance ($\hat{l}$) gene effects, in general, were higher than additive $\times$ dominance ($\hat{j}$). In such crosses, the selection intensity should be mild in the earlier and intense in the later generations to dissipate non additive gene action. Simple pedigree method for improvement of quality traits would not be much beneficial. Therefore breeding methods which can exploit non-additive gene effect and take care of non-allelic interactions should be employed. Restricted recurrent selection by way of intermating the most desirable segregants followed by selection or diallel selective mating or multiple crosses or biparental mating in early segregating generations would be rewarding for simultaneous improvement of grain yield and quality traits.



CONCLUSION

Following conclusions can be drawn from the results of present investigation

- For the characters, days to 50% flowering, days to maturity, plant height, number of grains per panicle, 100- grain weight, hulling recovery, head rice recovery, grain length, grain breadth, brown rice length, brown rice breadth, kernel length, kernel breadth, L/B ratio, kernel length before cooking, alkali digestion value and aroma the estimates of additive genetic variance (σ^2A) was higher than dominance genetic variance (σ^2D). However, for the traits effective tillers per plant, grain yield per plant, elongation ratio, elongation index, amylose content and gel consistency, value of σ^2A was observed to be lower than σ^2D . For the traits milling recovery and kernel breadth after cooking the ratio of σ^2A/ σ^2D showed value of near unity.
- The highest positive significant GCA effect for grain yield per plant was recorded by the male parent BPT-5204 whereas; among female parents Pusa Sugandh-2 exhibited positive and significant GCA effect.
- For most of the quality related traits, male parent Kasturi and female parent Pusa 1121 were found superior general combiners.
- Pusa Sugandh-2 x BPT-5204 (H x H) was recorded high SCA effect and the best heterotic combination for grain yield.
- Pusa Sugandh-2 x Kasturi (L x H) was recorded high SCA effect and the best heterotic combination for grain quality traits.
- Type-3 x Adamchini (H x L) may be considered as the best heterotic cross combination if both yield and quality traits are taken into consideration.

- The generation mean analysis showed that for most of the traits both additive and dominant types of gene effects were important. However, dominance gene effects ($\hat{h}$), in general, were higher than additive gene effects ($\hat{d}$). In the presence of epistasis, most of the crosses showed duplicate type of gene interaction.
- Among the interactions, additive $\times$ additive ($\hat{i}$) and dominance $\times$ dominance ($\hat{l}$) gene effects, in general, were higher than additive $\times$ dominance ($\hat{j}$).





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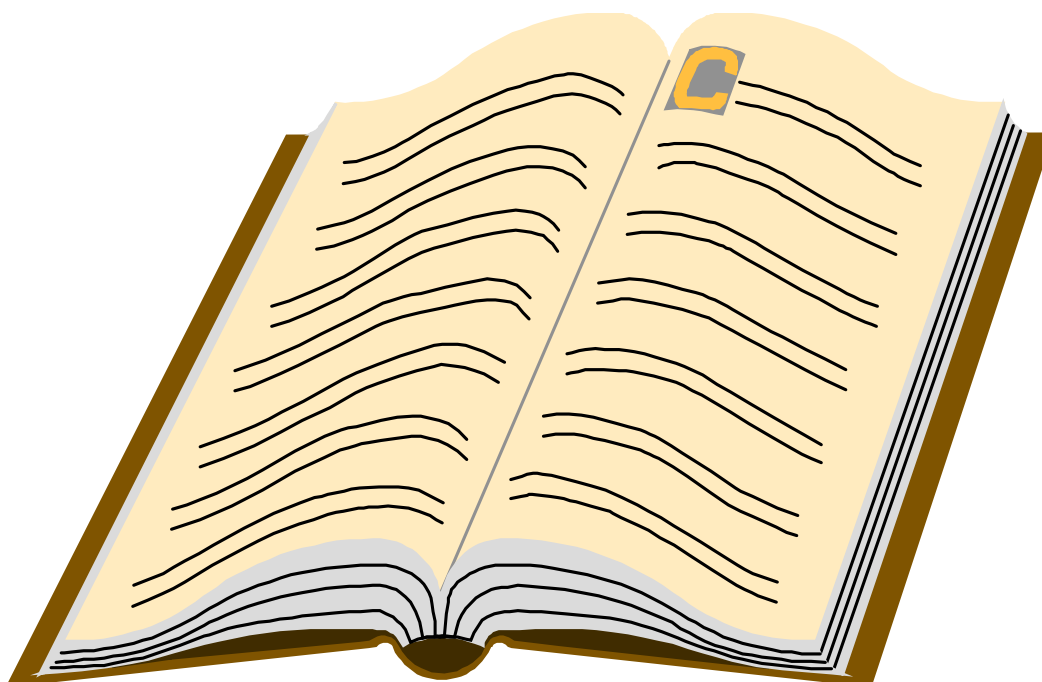
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APPENDICES

APPENDICES

Appendix I: Estimation of Generation means and standard errors of nine crosses for yield and yield attributing traits

Cross combination	P1	P2	F1	F2	B1	B2
	Days to 50% flowering					
Type-3 x Adamchinni	97.233 $\pm$ 0.789	127.9 $\pm$ 0.210	117.43 $\pm$ 1.044	103.96 $\pm$ 0.875	110.817 $\pm$ 1.606	117.75 $\pm$ 1.410
Type-3 x BPT-5204	99.33 $\pm$ 0.644	117.53 $\pm$ 0.531	104.67 $\pm$ 0.522	92.07 $\pm$ 0.672	101.6 $\pm$ 0.95	109.23 $\pm$ 1.01
Type-3 x Kasturi	97.2 $\pm$ 0.807	86.23 $\pm$ 0.433	81.57 $\pm$ 0.443	94.74 $\pm$ 0.463	94.93 $\pm$ 0.854	87.61 $\pm$ 0.573
Pusa Sugandh-2 x Adamchinni	93.93 $\pm$ 0.68	127.93 $\pm$ 0.21	119.067 $\pm$ 0.389	111.81 $\pm$ 0.883	102.47 $\pm$ 1.24	113.2 $\pm$ 1.14
Pusa Sugandh-2 x BPT-5204	95.23 $\pm$ 0.560	117.03 $\pm$ 0.436	109.87 $\pm$ 0.581	104.34 $\pm$ 0.537	99.53 $\pm$ 0.76	106.3 $\pm$ 0.928
Pusa Sugandh-2 x Kasturi	95.7 $\pm$ 0.59	83.9 $\pm$ 0.492	80.83 $\pm$ 0.587	87.74 $\pm$ 0.356	92.2 $\pm$ 0.783	85.13 $\pm$ 0.544
Pusa 1121 x Adamchinni	110.63 $\pm$ 0.68	127.73 $\pm$ 0.249	117.67 $\pm$ 0.572	107.48 $\pm$ 0.599	113.7 $\pm$ 0.613	119.63 $\pm$ 0.664
Pusa 1121 x BPT-5204	111.83 $\pm$ 0.633	117.8 $\pm$ 0.558	115.73 $\pm$ 0.455	109.61 $\pm$ 0.561	112.27 $\pm$ 0.465	116.67 $\pm$ 0.61
Pusa 1121 x Kasturi	112.6 $\pm$ 0.454	85.7 3 $\pm$ 0.587	93.93 $\pm$ 0.732	100.43 $\pm$ 0.433	106.37 $\pm$ 0.89	92.57 $\pm$ 0.707
	Days to maturity					
Type-3 x Adamchinni	125.97 $\pm$ 0.868	156.13 $\pm$ 0.371	143.6 $\pm$ 1.11	130.28 $\pm$ 0.895	137.18 $\pm$ 1.598	143.98 $\pm$ 1.45
Type-3 x BPT-5204	127.93 $\pm$ 0.714	146.13 $\pm$ 0.538	131.23 $\pm$ 0.544	118.39 $\pm$ 0.694	127.97 $\pm$ 0.97	135.47 $\pm$ 1.06
Type-3 x Kasturi	125.43 $\pm$ 0.844	115.03 $\pm$ 0.556	107.87 $\pm$ 0.581	121.07 $\pm$ 0.492	121.17 $\pm$ 0.894	113.98 $\pm$ 0.618
Pusa Sugandh-2 x Adamchinni	122.73 $\pm$ 0.70	156.73 $\pm$ 0.44	145.37 $\pm$ 0.606	138.13 $\pm$ 0.896	128.83 $\pm$ 1.235	139.43 $\pm$ 1.145
Pusa Sugandh-2 x BPT-5204	123.83 $\pm$ 0.682	145.63 $\pm$ 0.466	136.43 $\pm$ 0.58	130.66 $\pm$ 0.556	125.77 $\pm$ 0.799	132.67 $\pm$ 1.00
Pusa Sugandh-2 x Kasturi	123.93 $\pm$ 0.706	112.13 $\pm$ 0.598	107.00 $\pm$ 0.636	114.11 $\pm$ 0.392	118.57 $\pm$ 0.821	111.37 $\pm$ 0.574
Pusa 1121 x Adamchinni	139.23 $\pm$ 0.717	156.33 $\pm$ 0.408	144.23 $\pm$ 0.628	133.8 $\pm$ 0.617	139.93 $\pm$ 0.644	146 .00 $\pm$ 0.695
Pusa 1121 x BPT-5204	140.07 $\pm$ 0.753	146.03 $\pm$ 0.615	142.03 $\pm$ 0.490	135.88 $\pm$ 0.569	138.63 $\pm$ 0.485	142.9 $\pm$ 0.653
Pusa 1121 x Kasturi	141.40 $\pm$ 0.571	114.53 $\pm$ 0.627	120.1 $\pm$ 0.777	126.69 $\pm$ 0.448	132.6 $\pm$ 0.865	118.93 $\pm$ 0.708

	Plant Height					
Type-3 x Adamchinni	148.73±1.81	156.73±1.93	164.33±1.80	135.24±1.55	142.08±1.68	149.91±1.72
Type-3 x BPT-5204	152.7±1.25	94.67±1.632	140.77±1.07	136.87±1.173	121.93±1.10	92.62±1.36
Type-3 x Kasturi	148.73±1.81	107.03±1.54	130.6±1.56	111.93±0.654	128.55±1.09	119.25±1.32
Pusa Sugandh-2 x Adamchinni	109.83±1.30	163.13±1.51	173.86±2.35	147.87±1.481	146.2±1.85	159.6±1.49
Pusa Sugandh-2 x BPT-5204	111.93±1.37	94.57±1.48	97.87±1.08	96.21±0.59	107.65±1.13	101.87±1.21
Pusa Sugandh-2 x Kasturi	113.83±1.38	108.47±1.59	123.37±1.142	97.81±0.653	106.55±1.07	100.92±1.32
Pusa 1121 x Adamchinni	109.83±1.31	163.13±1.52	114.9±1.252	111.23±1.35	142.08±1.66	149.92±1.69
Pusa 1121 x BPT-5204	109.82±1.30	93.9±1.25	104.9±1.26	111.50±0.743	111.51±1.10	97.58±1.33
Pusa 1121 x Kasturi	111.5±1.20	108.16±1.56	116.8±1.29	94.67±0.664	102.52±1.30	95.01±1.36
	Effective tillers/plant					
Type-3 x Adamchinni	11.13±0.283	8.37±0.222	17.9±0.372	11.16±0.288	14.92±0.358	11.83±0.162
Type-3 x BPT-5204	11.40±0.306	13.23±0.317	16.03±0.433	10.31±0.209	12.42±0.188	13.25±0.237
Type-3 x Kasturi	11.00±0.280	9.30±0.284	15.57±0.53	10.45±0.236	13.30±0.298	10.67±0.283
Pusa Sugandh-2 x Adamchinni	9.80±0.242	7.83±0.198	14.77±0.278	10.95±0.300	12.42±0.188	10.45±0.186
Pusa Sugandh-2 x BPT-5204	10.03±0.323	13.17±0.356	20.30±0.468	10.81±0.267	13.47±0.305	11.70±0.272
Pusa Sugandh-2 x Kasturi	9.27±0.271	8.10±0.269	14.23±0.338	9.24±0.220	11.38±0.192	9.70±0.212
Pusa 1121 x Adamchinni	11.40±0.306	8.53±0.234	19.33±0.369	13.97±0.296	15.50±0.326	13.48±0.192
Pusa 1121 x BPT-5204	10.93±0.332	13.30±0.292	18.83±0.336	11.12±0.231	12.80±0.224	14.12±0.279
Pusa 1121 x Kasturi	10.40±0.324	8.63±0.360	15.30±0.393	10.80±0.272	11.98±0.267	10.08±0.240
	No. of grains per panicle					
Type-3 x Adamchinni	128.23±1.30	196.03±2.014	208.80±2.097	149.02±3.084	153.47±1.643	168.40±1.696
Type-3 x BPT-5204	123.53±1.525	164.80±2.351	154.43±1.963	104.60±3.015	126.88±1.359	144.12±1.634
Type-3 x Kasturi	125.50±1.167	114.40±1.560	153.30±1.879	124.63±1.913	141.48±1.764	133.88±1.536
Pusa Sugandh-2 x Adamchinni	136.43±1.266	192.13±2.281	202.17±2.07	134.82±2.242	142.62±1.568	154.45±1.620

Pusa Sugandh-2 x BPT-5204	132.03±1.541	168.17±2.20	231.70±3.160	163.06±3.084	135.58±1.550	178.48±2.313
Pusa Sugandh-2 x Kasturi	130.03±1.461	113.53±1.577	140.70±1.620	93.63±1.925	123.90±1.507	115.52±1.460
Pusa 1121 x Adamchinni	75.53±1.116	197.37±2.256	134.67±1.710	106.00±2.542	102.12±1.510	162.68±1.724
Pusa 1121 x BPT-5204	74.47±1.356	158.57±1.662	139.367±1.311	111.927±2.568	107.42±1.860	132.62±1.525
Pusa 1121 x Kasturi	72.03±1.168	115.63±1.510	132.20±1.702	94.23±1.949	98.02±1.360	107.70±1.468
	Hundred grain weight					
Type-3 x Adamchinni	2.05±0.033	1.56±0.022	1.84±0.027	2.46±0.027	1.97±0.027	1.73±0.026
Type-3 x BPT-5204	2.11±0.030	1.92±0.026	1.96±0.031	2.45±0.033	2.40±0.034	2.29±0.035
Type-3 x Kasturi	2.09±0.032	2.25±0.030	1.95±0.029	2.35±0.039	2.13±0.033	2.19±0.041
Pusa Sugandh-2 x Adamchinni	2.54±0.039	1.59±0.022	1.82±0.026	2.20±0.033	2.42±0.037	2.26±0.041
Pusa Sugandh-2 x BPT-5204	2.52±0.040	1.86±0.030	2.43±0.032	2.94±0.046	2.82±0.040	2.62±0.036
Pusa Sugandh-2 x Kasturi	2.56±0.038	2.25±0.030	2.52±0.034	2.45±0.024	2.63±0.036	2.40±0.026
Pusa 1121 x Adamchinni	2.79±0.040	1.54±0.025	1.63±0.026	2.74±0.034	2.67±0.041	2.16±0.040
Pusa 1121 x BPT-5204	2.81±0.046	1.85±0.030	2.49±0.035	2.82±0.027	2.72±0.039	2.58±0.033
Pusa 1121 x Kasturi	2.80±0.037	2.18±0.029	2.85±0.036	2.73±0.026	2.76±0.032	2.60±0.039
	Grain yield per plant					
Type-3 x Adamchinni	13.93±0.362	11.47±0.383	34.16±0.569	29.49±0.843	23.77±0.477	20.52±0.472
Type-3 x BPT-5204	13.50±0.454	16.08±0.424	32.02±0.534	25.02±0.640	17.12±0.602	20.64±0.387
Type-3 x Kasturi	14.34±0.361	12.88±0.322	23.23±0.388	19.67±0.488	21.57±0.370	19.62±0.401
Pusa Sugandh-2 x Adamchinni	16.97±0.426	12.12±0.331	25.69±0.516	21.26±0.500	23.51±0.510	21.03±0.436
Pusa Sugandh-2 x BPT-5204	15.85 ± 0.332	16.54 ± 0.310	37.15 ± 0.680	29.63 ± 0.893	23.75 ± 0.391	28.87 ± 0.424
Pusa Sugandh-2 x Kasturi	16.12±0.383	13.22±0.358	26.04±0.451	20.87±0.477	21.57±0.441	17.99±0.387
Pusa 1121 x Adamchinni	14.75 ± 0.304	12.11 ± 0.297	35.17 ± 0.568	28.47 ± 1.024	28.91 ± 0.376	24.20 ± 0.387
Pusa 1121 x BPT-5204	15.33±0.382	17.20±0.376	25.75±0.483	19.94±0.541	18.43±0.350	21.11±0.400
Pusa 1121 x Kasturi	14.49±0.357	13.16±0.352	23.27±0.450	18.42±0.486	19.08±0.406	16.93±0.321

Appendix II: Estimation of Generation means and standard errors of nine crosses for quality traits

Cross combination	P1	P2	F1	F2	B1	B2
	Hulling %					
Type-3 x Adamchinni	78.43±0.621	80.90±0.715	81.03±0.533	72.24±0.520	78.60±0.620	78.97±0.631
Type-3 x BPT-5204	78.37±0.669	75.60±0.707	76.93±0.657	69.99±0.467	77.98±0.584	73.95±0.828
Type-3 x Kasturi	78.27±0.593	72.33±0.892	73.87±0.585	67.83±0.437	72.90±0.590	68.97±0.585
Pusa Sugandh-2 x Adamchinni	76.87±0.895	80.27±0.614	79.93±0.610	71.36±0.600	77.83±0.564	79.88±0.443
Pusa Sugandh-2 x BPT-5204	76.57±0.755	75.47±0.625	78.73±0.542	70.60±0.549	74.78±0.628	72.95±0.883
Pusa Sugandh-2 x Kasturi	77.13±0.733	72.57±0.755	72.93±0.496	66.11±0.539	73.78±0.584	68.93±0.618
Pusa 1121 x Adamchinni	74.93±0.557	80.63±0.526	74.83±0.512	69.33±0.604	73.93±0.547	77.90±0.570
Pusa 1121 x BPT-5204	74.97±0.533	76.03±0.568	78.90±0.506	70.09±0.589	72.82±0.709	73.93±0.753
Pusa 1121 x Kasturi	74.67±0.530	72.43±0.730	72.90±0.424	64.23±0.452	71.95±0.609	68.00±0.574
	Milling %					
Type-3 x Adamchinni	70.83±0.279	73.77±0.367	75.13±0.340	63.32±0.307	68.90±0.380	71.80±0.330
Type-3 x BPT-5204	70.63±0.290	67.77±0.397	71.80±0.416	63.07±0.310	67.33±0.375	64.63±0.532
Type-3 x Kasturi	71.60±0.404	65.67±0.558	69.87±0.354	60.91±0.271	64.67±0.356	62.97±0.367
Pusa Sugandh-2 x Adamchinni	67.80±0.471	73.60±0.407	74.60±0.418	63.44±0.323	67.73±0.386	70.75±0.556
Pusa Sugandh-2 x BPT-5204	67.40±0.290	67.63±0.343	68.73±0.315	60.68±0.271	65.02±0.339	66.52±0.330
Pusa Sugandh-2 x Kasturi	67.63±0.468	66.07±0.464	65.43±0.354	58.85±0.323	65.02±0.387	62.83±0.383
Pusa 1121 x Adamchinni	65.43±0.322	74.13±0.398	66.67±0.361	61.07±0.369	63.83±0.339	70.80±0.367
Pusa 1121 x BPT-5204	65.47±0.310	67.20±0.343	70.40±0.320	63.17±0.373	64.72±0.442	66.83±0.492
Pusa 1121 x Kasturi	65.50±0.309	65.93±0.456	68.07±0.315	56.98±0.280	62.85±0.370	63.90±0.346
	Head rice recovery					
Type-3 x Adamchinni	56.77±0.272	59.77±0.351	60.87±0.330	53.40±0.305	54.17±0.373	55.15±0.299

Type-3 x BPT-5204	57.63±0.290	58.77±0.382	61.80±0.424	51.15±0.340	53.68±0.405	55.65±0.542
Type-3 x Kasturi	57.60±0.404	55.67±0.549	58.87±0.351	47.99±0.292	52.02±0.378	51.32±0.391
Pusa Sugandh-2 x Adamchinni	53.80±0.451	58.60±0.396	62.60±0.406	50.52±0.372	54.08±0.365	56.10±0.339
Pusa Sugandh-2 x BPT-5204	53.40±0.492	58.63±0.434	59.73±0.463	48.76±0.331	51.37±0.402	53.87±0.556
Pusa Sugandh-2 x Kasturi	53.63±0.480	55.07±0.466	56.43±0.402	46.93±0.334	49.62±0.380	52.18±0.417
Pusa 1121 x Adamchinni	54.43±0.342	59.13±0.421	60.33±0.393	52.15±0.384	53.18±0.375	55.15±0.374
Pusa 1121 x BPT-5204	55.47±0.328	58.20±0.378	61.40±0.349	50.25±0.381	52.07±0.466	56.18±0.538
Pusa 1121 x Kasturi	55.50±0.333	54.93±0.471	56.07±0.365	49.06±0.301	51.20±0.401	53.25±0.360
	Grain length					
Type-3 x Adamchinni	9.54±0.120	5.37±0.073	6.27±0.050	9.32±0.11	8.75±0.052	7.86±0.052
Type-3 x BPT-5204	9.56±0.120	7.24±0.143	7.87±0.179	9.08±0.11	9.18±0.045	8.81±0.041
Type-3 x Kasturi	9.52±0.099	10.42±0.112	10.02±0.124	9.22±0.06	9.77±0.083	11.47±0.151
Pusa Sugandh-2 x Adamchinni	10.65±0.158	5.38±0.070	7.13±0.237	8.55±0.085	9.43±0.214	8.40±0.184
Pusa Sugandh-2 x BPT-5204	10.66±0.159	7.24±0.143	7.87±0.179	9.06±0.077	11.67±0.139	10.07±0.146
Pusa Sugandh-2 x Kasturi	11.14±0.197	10.51±0.167	11.15±0.220	11.82±0.062	11.35±0.129	10.77±0.119
Pusa 1121 x Adamchinni	11.39±0.191	5.34±0.063	9.18±0.114	9.27±0.063	10.14±0.148	7.31±0.161
Pusa 1121 x BPT-5204	11.10±0.198	7.57±0.160	9.30±0.202	8.46±0.078	10.36±0.156	9.45±0.156
Pusa 1121 x Kasturi	10.58±0.223	10.20±0.176	12.02±0.188	10.62±0.060	11.36±0.152	10.49±0.172
	Grain width					
Type-3 x Adamchinni	2.19±0.019	2.03±0.020	2.03±0.019	2.26±0.010	2.22±0.013	2.14±0.015
Type-3 x BPT-5204	2.20±0.015	2.03±0.015	2.02±0.014	2.24±0.009	2.24±0.014	2.167±0.012
Type-3 x Kasturi	2.20±0.014	2.15±0.016	2.07±0.021	2.28±0.018	2.29±0.016	2.19±0.018
Pusa Sugandh-2 x Adamchinni	2.35±0.029	2.06±0.018	2.11±0.028	2.55±0.018	2.31±0.017	2.19±0.018
Pusa Sugandh-2 x BPT-5204	2.35±0.025	2.06±0.017	2.14±0.025	2.20±0.007	2.25±0.023	2.17±0.019
Pusa Sugandh-2 x Kasturi	2.36±0.023	2.15±0.013	2.20±0.023	2.53±0.018	2.29±0.019	2.19±0.019

Pusa 1121 x Adamchinni	2.42±0.020	2.08±0.016	2.22±0.018	2.18±0.007	2.35±0.019	2.26±0.017
Pusa 1121 x BPT-5204	2.42±0.017	2.07±0.016	2.55±0.023	2.24±0.007	2.42±0.018	2.29±0.019
Pusa 1121 x Kasturi	2.42±0.016	2.15±0.014	2.31±0.024	2.42±0.018	2.38±0.018	2.29±0.019
	Brown rice length					
Type-3 x Adamchinni	7.24±0.125	3.97±0.081	4.48±0.058	6.32±0.103	6.84±0.054	6.75±0.052
Type-3 x BPT-5204	7.26±0.126	5.15±0.140	6.85±0.177	6.82±0.105	7.07±0.047	6.31±0.042
Type-3 x Kasturi	7.21±0.105	7.68±0.047	7.76±0.125	6.31±0.060	7.46±0.084	7.60±0.153
Pusa Sugandh-2 x Adamchinni	8.73±0.158	3.98±0.078	4.90±0.237	5.76±0.082	6.50±0.212	5.26±0.180
Pusa Sugandh-2 x BPT-5204	8.73±0.159	5.15±0.140	5.96±0.177	6.51±0.074	7.91±0.142	7.24±0.147
Pusa Sugandh-2 x Kasturi	8.56±0.156	7.65±0.041	8.48±0.219	8.23±0.059	7.90±0.129	7.78±0.120
Pusa 1121 x Adamchinni	8.82±0.195	3.94±0.071	6.67±0.114	6.68±0.060	8.11±0.148	5.10±0.160
Pusa 1121 x BPT-5204	8.83±0.197	5.16±0.160	6.73±0.202	5.94±0.077	7.60±0.157	6.85±0.150
Pusa 1121 x Kasturi	8.85±0.223	7.61±0.035	8.20±0.184	6.36±0.061	7.81±0.152	7.42±0.171
	Brown rice width					
Type-3 x Adamchinni	2.01±0.019	1.98±0.020	1.90±0.020	1.94±0.009	1.97±0.013	1.91±0.015
Type-3 x BPT-5204	2.01±0.016	1.95±0.016	1.92±0.015	1.96±0.009	2.06±0.014	2.04±0.012
Type-3 x Kasturi	2.01±0.014	1.92±0.015	1.94±0.021	1.97±0.018	2.05±0.016	1.99±0.018
Pusa Sugandh-2 x Adamchinni	1.93±0.029	1.97±0.017	1.92±0.028	2.04±0.016	2.04±0.017	2.15±0.019
Pusa Sugandh-2 x BPT-5204	1.92±0.026	1.95±0.017	1.91±0.025	2.03±0.007	2.01±0.023	2.08±0.019
Pusa Sugandh-2 x Kasturi	1.93±0.023	1.93±0.014	1.85±0.023	1.94±0.016	2.05±0.020	2.04±0.019
Pusa 1121 x Adamchinni	1.99±0.020	1.98±0.016	1.96±0.018	2.02±0.007	2.01±0.019	2.08±0.018
Pusa 1121 x BPT-5204	1.98±0.017	1.95±0.016	1.99±0.022	2.00±0.007	2.04±0.018	2.05±0.019
Pusa 1121 x Kasturi	1.98±0.016	1.93±0.014	1.96±0.024	2.01±0.018	2.03±0.018	1.97±0.019
	Kernel length					
Type-3 x Adamchinni	7.10±0.125	3.56±0.068	4.07±0.057	6.02±0.099	6.18±0.054	5.03±0.052

Type-3 x BPT-5204	7.11±0.127	5.03±0.139	6.73±0.176	6.62±0.092	6.90±0.047	6.20±0.042
Type-3 x Kasturi	7.12±0.105	7.23±0.048	7.51±0.125	6.18±0.062	7.20±0.084	6.94±0.153
Pusa Sugandh-2 x Adamchinni	8.22±0.114	3.53±0.079	4.65±0.165	5.58±0.083	6.43±0.213	5.16±0.18
Pusa Sugandh-2 x BPT-5204	8.00±0.131	5.03±0.139	5.86±0.176	6.21±0.076	7.81±0.143	7.11±0.147
Pusa Sugandh-2 x Kasturi	8.11±0.156	7.20±0.041	8.22±0.220	7.91±0.057	7.84±0.129	7.64±0.121
Pusa 1121 x Adamchinni	8.32±0.072	3.59±0.072	6.55±0.113	6.33±0.062	8.04±0.148	4.97±0.135
Pusa 1121 x BPT-5204	8.06±0.111	5.03±0.160	6.63±0.202	5.77±0.078	7.51±0.157	6.68±0.150
Pusa 1121 x Kasturi	8.20±0.120	7.26±0.035	8.09±0.100	6.25±0.063	7.69±0.108	7.16±0.126
	Kernel width					
Type-3 x Adamchinni	1.93±0.019	1.91±0.020	1.83±0.021	1.92±0.009	1.93±0.014	1.88±0.015
Type-3 x BPT-5204	1.93±0.016	1.92±0.016	1.85±0.016	1.86±0.009	1.96±0.014	1.94±0.012
Type-3 x Kasturi	1.93±0.014	1.82±0.015	1.84±0.021	1.89±0.019	1.94±0.017	1.89±0.018
Pusa Sugandh-2 x Adamchinni	1.86±0.030	1.90±0.018	1.80±0.028	1.96±0.017	1.87±0.018	1.99±0.019
Pusa Sugandh-2 x BPT-5204	1.85±0.026	1.92±0.018	1.90±0.025	1.93±0.007	1.91±0.024	1.96±0.019
Pusa Sugandh-2 x Kasturi	1.85±0.024	1.82±0.014	1.81±0.023	1.90±0.016	1.95±0.020	1.94±0.019
Pusa 1121 x Adamchinni	1.89±0.020	1.91±0.016	1.89±0.018	1.90±0.007	1.92±0.019	1.98±0.018
Pusa 1121 x BPT-5204	1.88±0.017	1.90±0.017	1.95±0.022	1.91±0.007	1.93±0.018	1.96±0.020
Pusa 1121 x Kasturi	1.88±0.016	1.82±0.014	1.86±0.024	1.94±0.018	1.93±0.018	1.87±0.019
	L/B ratio					
Type-3 x Adamchinni	3.68±0.114	1.87±0.073	2.46±0.084	3.16±0.093	3.21±0.045	2.68±0.065
Type-3 x BPT-5204	3.69±0.106	2.62±0.141	3.65±0.147	3.57±0.077	3.53±0.061	3.19±0.035
Type-3 x Kasturi	3.69±0.092	3.98±0.060	4.11±0.126	3.33±0.080	3.72±0.085	3.71±0.148
Pusa Sugandh-2 x Adamchinni	4.46±0.133	1.86±0.097	2.58±0.141	2.87±0.084	3.45±0.181	2.63±0.189
Pusa Sugandh-2 x BPT-5204	4.35±0.124	2.63±0.140	3.10±0.161	3.21±0.065	4.11±0.124	3.63±0.117
Pusa Sugandh-2 x Kasturi	4.39±0.136	3.96±0.043	4.55±0.163	4.21±0.069	4.04±0.112	3.96±0.010

Pusa 1121 x Adamchinni	4.41±0.061	1.88±0.082	3.46±0.104	3.32±0.055	4.23±0.138	2.54±0.149
Pusa 1121 x BPT-5204	4.29±0.103	2.65±0.151	3.44±0.204	3.03±0.069	3.90±0.116	3.41±0.123
Pusa 1121 x Kasturi	4.37±0.091	4.00±0.055	4.36±0.093	3.27±0.071	4.02±0.115	3.87±0.132
	Kernel length after cooking					
Type-3 x Adamchinni	12.60±0.129	7.36±0.073	9.33±0.06	10.83±0.107	10.21±0.058	8.99±0.053
Type-3 x BPT-5204	12.62±0.131	9.20±0.139	10.50±0.176	11.85±0.107	11.40±0.049	10.54±0.044
Type-3 x Kasturi	12.56±0.109	12.38±0.05	12.06±0.12	10.56±0.063	12.91±0.086	12.65±0.154
Pusa Sugandh-2 x Adamchinni	14.68±0.115	7.38±0.08	10.10±0.164	9.69±0.085	11.27±0.212	10.20±0.178
Pusa Sugandh-2 x BPT-5204	14.45±0.131	9.28±0.139	9.31±0.176	10.86±0.076	12.25±0.145	10.85±0.148
Pusa Sugandh-2 x Kasturi	14.56±0.157	12.45±0.042	13.18±0.219	13.60±0.062	14.29±0.129	13.78±0.122
Pusa 1121 x Adamchinni	18.72±0.198	7.33±0.078	10.49±0.112	11.25±0.063	13.58±0.148	9.12±0.134
Pusa 1121 x BPT-5204	18.51±0.113	9.28±0.160	11.78±0.200	9.88±0.079	14.27±0.157	12.13±0.148
Pusa 1121 x Kasturi	18.74±0.118	12.41±0.035	14.13±0.099	11.52±0.063	14.43±0.109	13.91±0.01
	Kernel breadth after cooking					
Type-3 x Adamchinni	2.92±0.019	2.80±0.02	2.82±0.021	3.047±0.010	3.09±0.014	2.89±0.015
Type-3 x BPT-5204	2.93±0.016	2.13±0.016	2.62±0.016	2.89±0.009	3.05±0.015	2.91±0.013
Type-3 x Kasturi	2.92±0.014	2.71±0.015	2.97±0.021	2.95±0.018	2.98±0.017	2.86±0.018
Pusa Sugandh-2 x Adamchinni	2.79±0.029	2.81±0.018	3.27±0.028	2.85±0.017	2.86±0.018	3.06±0.019
Pusa Sugandh-2 x BPT-5204	2.78±0.026	2.12±0.017	3.20±0.024	2.70±0.007	3.14±0.024	2.84±0.019
Pusa Sugandh-2 x Kasturi	2.79±0.023	2.73±0.013	2.80±0.023	2.94±0.015	2.92±0.020	2.85±0.019
Pusa 1121 x Adamchinni	2.94±0.020	2.80±0.016	2.85±0.018	2.718±0.007	2.76±0.019	2.41±0.018
Pusa 1121 x BPT-5204	2.93±0.017	2.11±0.018	2.76±0.022	2.91±0.007	2.92±0.018	2.56±0.020
Pusa 1121 x Kasturi	2.94±0.016	2.72±0.013	2.63±0.02	3.13±0.017	3.01±0.018	2.82±0.01
	Elongation ratio					
Type-3 x Adamchinni	1.78±0.028	2.07±0.040	2.09±0.027	1.70±0.028	1.65±0.012	1.79±0.018

Type-3 x BPT-5204	1.78±0.028	1.85±0.051	1.57±0.037	1.80±0.028	1.65±0.010	1.70±0.010
Type-3 x Kasturi	1.77±0.022	1.71±0.011	1.61±0.023	1.72±0.018	1.80±0.020	1.85±0.040
Pusa Sugandh-2 x Adamchinni	1.79±0.024	2.11±0.049	2.21±0.078	1.77±0.026	1.81±0.063	2.05±0.074
Pusa Sugandh-2 x BPT-5204	1.81±0.028	1.86±0.052	1.61±0.045	1.77±0.021	1.58±0.025	1.54±0.025
Pusa Sugandh-2 x Kasturi	1.80±0.035	1.73±0.009	1.61±0.040	1.70±0.013	1.84±0.030	1.82±0.027
Pusa 1121 x Adamchinni	2.25±0.035	2.06±0.040	1.61±0.025	1.79±0.016	1.70±0.029	1.87±0.054
Pusa 1121 x BPT-5204	2.30±0.036	1.87±0.062	1.80±0.055	1.74±0.023	1.92±0.041	1.84±0.043
Pusa 1121 x Kasturi	2.29±0.042	1.71±0.008	1.75±0.022	1.86±0.020	1.89±0.028	1.96±0.037
	Elongation index					
Type-3 x Adamchinni	1.18±0.025	1.41±0.030	1.35±0.028	1.07±0.022	1.03±0.011	1.17±0.018
Type-3 x BPT-5204	1.17±0.024	1.67±0.049	1.11±0.030	1.17±0.020	1.06±0.013	1.14±0.008
Type-3 x Kasturi	1.17±0.122	1.15±0.117	0.99±0.095	1.10±0.0191	1.17±0.019	1.22±0.037
Pusa Sugandh-2 x Adamchinni	1.19±0.027	1.43±0.042	1.22±0.053	1.07±0.027	1.18±0.049	1.33±0.065
Pusa Sugandh-2 x BPT-5204	1.20±0.026	1.68±0.049	0.95±0.035	1.26±0.018	0.96±0.023	1.06±0.022
Pusa Sugandh-2 x Kasturi	1.20±0.029	1.15±0.008	1.04±0.030	1.11±0.018	1.22±0.026	1.23±0.023
Pusa 1121 x Adamchinni	1.44±0.031	1.40±0.033	1.07±0.022	1.26±0.014	1.18±0.028	1.54±0.051
Pusa 1121 x BPT-5204	1.48±0.032	1.69±0.058	1.27±0.052	1.13±0.018	1.27±0.032	1.41±0.037
Pusa 1121 x Kasturi	1.47±0.034	1.14±0.011	1.24±0.019	1.14±0.019	1.21±0.042	1.30±0.035
	Alkali digestion value					
Type-3 x Adamchinni	4.98±0.077	3.78±0.064	4.46±0.058	4.82±0.083	5.09±0.059	4.79±0.055
Type-3 x BPT-5204	4.97±0.065	4.09±0.064	6.17±0.056	5.11±0.098	5.45±0.051	4.88±0.056
Type-3 x Kasturi	4.95±0.062	4.46±0.058	5.87±0.060	5.42±0.053	6.41±0.041	5.74±0.041
Pusa Sugandh-2 x Adamchinni	6.84±0.032	3.81±0.052	4.77±0.046	5.18±0.097	6.27±0.035	5.36±0.047
Pusa Sugandh-2 x BPT-5204	6.82±0.032	4.17±0.056	5.88±0.050	4.96±0.079	6.26±0.040	5.56±0.040
Pusa Sugandh-2 x Kasturi	6.83±0.025	4.44±0.055	6.07±0.047	6.22±0.046	6.25±0.036	5.95±0.043

Pusa 1121 x Adamchinni	6.75±0.037	3.84±0.052	5.66±0.055	5.17±0.104	6.27±0.045	5.87±0.051
Pusa 1121 x BPT-5204	6.80±0.031	4.21±0.051	5.76±0.067	5.46±0.077	6.37±0.052	5.18±0.072
Pusa 1121 x Kasturi	6.80±0.032	4.52±0.067	6.38±0.066	5.95±0.048	6.47±0.057	5.75±0.056
	Amylose content					
Type-3 x Adamchinni	22.77±0.38	20.70±0.369	21.60±0.364	22.17±0.186	21.07±0.306	20.02±0.262
Type-3 x BPT-5204	22.67±0.251	22.80±0.354	23.70±0.346	24.04±0.213	20.95±0.301	21.85±0.334
Type-3 x Kasturi	22.93±0.230	21.87±0.341	24.60±0.306	24.45±0.290	23.70±0.280	21.87±0.337
Pusa Sugandh-2 x Adamchinni	24.70±0.410	20.10±0.372	21.77±0.470	25.81±0.243	23.68±0.338	20.10±0.269
Pusa Sugandh-2 x BPT-5204	24.63±0.351	22.73±0.342	25.7±0.319	26.86±0.233	26.20±0.233	23.85±0.309
Pusa Sugandh-2 x Kasturi	24.73±0.253	22.27±0.239	24.63±0.341	25.24±0.205	24.17±0.360	21.55±0.381
Pusa 1121 x Adamchinni	21.83±0.326	20.97±0.265	25.83±0.359	27.13±0.229	20.85±0.274	19.73±0.308
Pusa 1121 x BPT-5204	21.97±0.277	22.63±0.347	23.67±0.353	25.04±0.306	21.52±0.280	22.80±0.312
Pusa 1121 x Kasturi	22.80±0.277	22.63±0.334	24.63±0.341	24.19±0.245	22.82±0.311	21.20±0.321
	Gel consistency					
Type-3 x Adamchinni	47.70±0.918	63.63±0.835	51.97±0.723	56.03±0.760	51.05±0.915	58.97±0.955
Type-3 x BPT-5204	47.93±0.847	43.77±0.758	48.57±1.16	42.49±1.02	45.97±0.731	42.95±0.771
Type-3 x Kasturi	47.40±0.800	33.73±0.709	49.98±1.03	44.29±0.840	41.22±0.875	31.03±0.551
Pusa Sugandh-2 x Adamchinni	35.70±0.862	63.93±0.901	54.43±1.05	44.53±1.02	51.72±1.002	60.53±1.067
Pusa Sugandh-2 x BPT-5204	35.60±0.805	43.90±0.675	28.80±0.617	47.54±1.126	34.15±0.542	40.90±0.849
Pusa Sugandh-2 x Kasturi	36.07±0.709	33.73±0.709	38.93±1.02	47.31±0.865	43.87±0.825	39.90±0.838
Pusa 1121 x Adamchinni	27.93±0.525	64.10±1.33	50.87±1.07	42.21±0.808	53.78±1.01	57.87±0.905
Pusa 1121 x BPT-5204	27.67±0.440	43.73±0.616	54.80±0.935	47.37±0.857	31.80±0.600	45.88±0.935
Pusa 1121 x Kasturi	27.83±0.565	33.30±0.579	51.67±1.01	42.23±0.829	31.91±0.555	36.07±0.712
	Aroma					
Type-3 x Adamchinni	3.73±0.128	3.10±0.187	3.17±0.230	2.93±0.107	3.58±0.156	3.20±0.130

Type-3 x BPT-5204	3.63±0.140	1.13±0.151	2.00±0.507	2.36±0.161	2.67±0.336	1.65±0.238
Type-3 x Kasturi	3.67±0.062	2.97±0.058	3.00±0.060	2.89±0.053	3.55±0.041	3.12±0.041
Pusa Sugandh-2 x Adamchinni	3.50±0.145	2.93±0.232	2.80±0.226	3.03±0.096	3.23±0.167	2.92±0.183
Pusa Sugandh-2 x BPT-5204	3.53±0.145	1.17±0.165	1.90±0.297	2.37±0.207	2.98±0.179	2.20±0.327
Pusa Sugandh-2 x Kasturi	3.50±0.145	2.97±0.224	3.40±0.204	3.03±0.082	3.45±0.144	3.10±0.082
Pusa 1121 x Adamchinni	3.77±0.123	2.97±0.239	3.20±0.219	3.11±0.083	3.52±0.132	3.15±0.154
Pusa 1121 x BPT-5204	3.70±0.133	1.23±0.188	2.80±0.467	3.11±0.131	3.30±0.156	3.13±0.163
Pusa 1121 x Kasturi	3.67±0.137	3.00±0.245	3.33±0.232	3.27±0.061	3.42±0.149	3.22±0.155

Genetics of yield and quality characters in aromatic rice (*Oryza sativa* L.)

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Abstract

The gene effects for grain yield and its components and grain quality characters were studied using P₁, P₂, F₁, F₂, B₁, and B₂ generations in nine crosses of rice involving long, medium and short grain varieties. Epistasis was present in the majority of traits for all crosses. Additive and dominance effects had predominant role in the expression of days to 50 per cent flowering, days to maturity, plant height and 100-grain weight in yield characters, grain length, brown rice length, brown rice breadth, kernel length, L/B ratio, kernel length after cooking and kernel breadth after cooking in quality traits in most of the crosses. While dominance effects had major role in most of the crosses for the expression of plant height, effective tillers per plant and number of grains per panicle in yield characters and milling and chemical properties in grain quality traits. In the presence of epistasis, most of the crosses showed duplicate type of gene interaction. With regards to epistatic gene effects, additive $\times$ additive ($\hat{i}$) and dominance $\times$ dominance ($\hat{l}$) gene effects, in general, were higher than additive $\times$ dominance ($\hat{j}$). Biparental mating, recurrent selection and diallel selective mating system could be used to obtain desirable recombinants.

Key words: Rice, yield traits, quality traits.

Introduction

Rice is a most important food crop for developing world. It was cultivated worldwide in 160.9 m. ha with production of 481.73 million tonnes (on milled basis). In India it occupied 44.5 m. ha with production of 106.5 million tons (2015-16). The major production and productivity gains have enabled the country to attain self sufficiency in rice since mid 1980's. Indian exporters entered into the world rice trade largely through the export of small quantities of highly priced basmati rice which was less than 5% in mid 1980's.

The exporting of aromatic/ basmati rice will fetch high premium price over non aromatic rice varieties in the international market. So breeding programmes for aromatic rices was gaining more importance in countries which are self sufficient in their rice production. As per capita income increases consumers prefer quality rice.

Consumers base their concept of quality on the appearance, size, shape of the grain, kernel elongation after cooking, tenderness, taste and flavours of cooked rice (Shobha Rani *et al.*, 2006). For commercial purposes, the rices are classified according to the kernel length as short grain, medium grain, long grain and long slender grain. The long slender grain type scented rice varieties fetch the maximum premium in the world market.

Quality characters can be classified as physical, cooking and chemical traits. Physical properties such as grain dimensions (kernel length, kernel breadth and L/B ratio) and milling traits (hulling %, milling % and head rice recovery) are major factors defining market value. Physical properties also include yield of edible and marketable polished grain, uniform shape, whiteness and translucence. These traits are immediately obvious to consumers and so are major factors defining market value. The traits that exert major effects on the eating and cooking qualities are related to the chemical properties of rice grains such as amylose content, alkali spreading value and gel consistency and cooking characteristics volume expansion ratio and kernel elongation ratio. Hence there is an imperative need for a shift in emphasis towards development of high quality rice besides yield.

The complex genetic nature coupled with poor combining ability of parents for quality traits was responsible for the slow success in breeding for good quality grain varieties. Therefore; information about the nature of gene action of complex quality traits will be helpful in breeding high yielding cultivars with good quality. Generation mean analysis is one of the common approaches followed to understand the nature of gene effect. Thus present study was carried out to estimate different kinds of gene effects in the inheritance of yield and quality related traits through generation mean analysis.

Materials and methods

The present research work was conducted during three seasons viz., kharif-2013, kharif-2014 and kharif-2015 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (UP). The research material in the present study consisted of six parental genotypes in which Pusa 1121, Pusa Sugandh-2, Type-3 were used as female parents and Kasturi, BPT-5204 and Adamchinni used as male parents in the hybridization programme. During kharif-2013, all the genotypes were seeded in nursery at 3 dates, 10 days apart and transplanted in crossing blocks at 21 days after sowing. The three male parents were

crossed with the three female parents to generate the set of nine rice hybrids in line x tester mating design. In kharif-2014 the seed of F_1 hybrids generated during previous season along with parental lines were raised. The F_1 's were backcrossed with both the parents to produce back crosses (B_1 and B_2) and remaining F_1 's were selfed to produce F_2 seeds. Fresh F_1 's were prepared for the nine cross combinations. In kharif-2015 all six generations (parents (P_1 , P_2), F_1 's, F_2 's and back crosses (B_1 , B_2)) of nine crosses were raised at a standard spacing of 20 x 15 cm in 5 m rows in compact family random block design with three replications.

The recommended package of practices was followed to raise a good crop. Observations were recorded for ten plants of parents and F_1 's, 20 plants from backcrosses (B_1 and B_2) and 50 plants from each F_2 population from each replication for both yield and quality traits viz., days to 50 per cent flowering, days to maturity, plant height, number of effective tillers per plant, number of grains per panicle, 100 grain weight, yield per plant, hulling recovery, milling recovery, head rice recovery, grain length, grain breadth, brown rice length, brown rice breadth, kernel length, kernel breadth, L/B ratio, kernel length after cooking, kernel breadth after cooking, elongation ratio, elongation index, alkali digestion value, amylose content, gel consistency test and aroma. Grain, brown rice and kernel dimensional analysis was done with the help of electronic grain analyzer. The observations for various traits were recorded as per the standard evaluation system of IRRI (1988). The ratio's and percentages are converted in to arc sine values for applying stastical methods.

The individual scaling tests (Mather 1949 and Hayman and Mather 1955) and joint scaling test (Cavalli 1952) were applied to test the adequacy of additive- dominance model. When the model was adequate the genetic parameters were estimated by three parameter model of Jinks and Jones (1958). Otherwise six parameters model by Hayman (1958) and Jinks and Jones (1958) was applied.

Results and discussion

Results of individual scaling test and joint scaling test were non significant for days to flowering and days to maturity in Pusa 1121 x Kasturi, effective tillers per plant in Pusa 1121 x Adamchini, grain breadth in Pusa Sugandh-2 x BPT-5204, brown rice breadth in Type-3 x Adamchini and Pusa 1121 x Kasturi, kernel length in Pusa Sugandh-2 x Kasturi, kernel breadth in Type-3 x Adamchini, Pusa Sugandh-2 x BPT-5204 and Pusa 1121 x Kasturi, kernel breadth after cooking in Type-3 x Kasturi,

alkali digestion value in Type-3 x BPT-5204, gel consistency in Type-3 x Adamchini and aroma in Pusa Sugandh-2 x Adamchini and Pusa 1121 x Kasturi, indicating the absence of epistatic interaction. The above mentioned traits in respective crosses showed simple type of inheritance, while epistasis contributed significantly towards the inheritance of remaining characters of all crosses.

For days to 50% flowering, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect and dominance x dominance ($\hat{l}$) type of interactions was important. Early maturing genotypes are desirable which can be used in multiple cropping systems. For days to maturity, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important. Hasib (2002) and Patil *et al.*, (2006a) revealed both additive (d) and dominant (h) gene effects for days to 50% flowering which supports the present findings. However, Kumar *et al.* (2005) reported additive and Patel (2015) reported dominance effect (h) for flowering traits. Duplicate epistasis was recorded in three crosses for days to 50% flowering and in five crosses for trait days to maturity. Duplicate epistasis for days to 50% flowering was also reported by Roy (1998), Hasib (2002), Gopikannan and Ganesh (2014) and Patel (2015). However, complimentary epistasis was shown by two and one cross for days to 50% flowering and days to maturity respectively.

Semi dwarf plants are desirable. Epistasis of duplicate type was present in four crosses while complimentary type was present in two crosses. Patel (2015) also reported duplicate epistasis for the trait. For plant height, additive ($\hat{d}$), dominance ($\hat{h}$) in main effect and all type of interactions were equally important. Roy (1999) reported additive x additive ($\hat{i}$) and additive x dominance ($\hat{j}$). Habib *et al.*, (2002) observed both additive effect (d) and dominance effect (h) for this trait. Kumar *et al.*, (2005) observed additive ($\hat{d}$) gene effects.

Plants with more number of tillers are desirable as it ultimately increases the yield. Duplicate type and complimentary type of epistasis were present in two crosses each for effective tillers per plant. Thirugnana Kumar *et.al.* (2007), Mahalingam and Nadarajan (2010) and Patel (2015) reported duplicate epistasis for the trait whereas Patil *et al.*, (2006b) reported complementary epistasis which supports the present findings. Dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and

additive x dominance ($\hat{j}$) type of interactions were important for the trait. Singh and Katoch (1997) observed dominance ($\hat{h}$), additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions. However, Murugan and Ganesan (2006) reported additive ($\hat{d}$), additive x dominance ($\hat{j}$), dominance x dominance ($\hat{l}$). Patil *et al.*, (2006a) reported both additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects.

Panicles with more number of grains were desirable as it increase the grain yield per plant. For trait number of grains per panicle, duplicate type of epistasis was shown by four crosses, while complimentary epistasis was shown by three crosses. Thirugnana Kumar *et.al.* (2007) and Patel (2015) reported duplicate epistasis. Dominance ($\hat{h}$) gene effects and Additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions played a major role in inheritance of this trait. Murugan and Ganesan (2006) reported dominance ($\hat{h}$), additive x additive ($\hat{i}$), additive x dominance ($\hat{j}$). However Mahalingam and Nadarajan (2010) observed dominance effect ($\hat{h}$) and additive effect ($\hat{d}$) and Saumya and Lal (2014) reported additive x additive ($\hat{i}$) type of interaction.

More 100-grain weight is desirable as it increases the yield directly. Complimentary type of epistasis was found in three crosses and duplicate type of epistasis was recorded in two crosses for trait 100-grain weight. Thirugnana Kumar *et.al.* (2007) and Patel (2015) reported duplicate epistasis for the trait. Patil *et al.*, (2006b) reported complementary epistasis. This is similar to the present findings. For this trait, additive ($\hat{d}$), and dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) type of interactions were important. Patil *et al.*, (2006a) reported both additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects. Kumar and Mani (1998) reported additive ($\hat{d}$), dominance ($\hat{h}$) and additive x additive ($\hat{i}$) type of interaction. Habib *et al.*, (2002) observed both additive effect ($\hat{d}$) and dominance effect ($\hat{h}$) for this trait.

For grain yield per plant, four crosses recorded duplicate epistasis and two crosses showed complementary epistasis. Patil *et al.*, (2006b), Murugan and Ganesan (2006) Mahalingam and Nadarajan (2010) and Patel (2015) reported duplicate epistasis and Thirugnana Kumar *et.al.* (2007) reported complementary epistasis for the trait which supports the present findings. For the trait, dominance ($\hat{h}$) gene effects in main effect,

additive x dominance ($\hat{j}$) and dominance x dominance ($\hat{l}$) type of interactions were important. Murugan and Ganesan (2006) reported dominance ($\hat{h}$), all interactions. Kumar *et al.*, (2005) observed predominant dominance ($\hat{h}$) gene effects. However Saumya and Lal (2014) reported additive x additive ($\hat{i}$) type of interaction.

Quality traits

Milling properties

Hulling recovery was the important factor which decides the marketable produce. Milling recovery is also an important factor deciding the amount of marketable produce. Higher value of head rice recovery leads to substantial production of marketable produce.

Duplicate epistasis was observed in six crosses in case of hulling. Mahalingam and Nadarajan (2010), Gnanamalar and Vivekanandan (2013) and Rani *et al.*, (2015) reported duplicate epistasis which is in agreement with present findings. In case of milling six crosses recorded duplicate epistasis and two crosses recorded complementary epistasis. . Gnanamalar and Vivekanandan reported duplicate epistasis for milling. Complementary epistasis was observed in three crosses in case of head rice recovery. Rani *et al.*, (2015) also reported complementary epistasis for the trait which supports the present findings. For hulling recovery and head rice recovery dominance ($\hat{h}$) gene effects in main effect and additive x additive ($\hat{i}$) type of interactions were important whereas for milling recovery along with dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important. Rani *et al.*, (2015) reported dominance effects ($\hat{h}$) for hulling recovery which supports the present findings. Rani *et al.*, (2015) reported dominance effects (h) and additive x additive effects (i) for milling recovery. However, Mahalingam and Nadarajan (2010) and Gnanamalar and Vivekanandan (2013) observed additive effect (d). Rani *et al.*, (2015) reported dominance effects ($\hat{h}$), additive x additive effects (i) for head rice recovery

Physical properties

Duplicate epistasis was recorded in five crosses for grain length, in three crosses for grain width, in five crosses for brown rice length, in four crosses for brown rice width, in five crosses for kernel length, in three crosses for kernel breadth and in four crosses for L/B ratio. Complementary epistasis was present in two crosses for grain length, in three crosses for grain width, in one cross for kernel length and three crosses for kernel width. Patel (2015) reported duplicate epistasis for grain length. Gnanamalar and Vivekanandan (2013) reported duplicate epistasis for kernel length, kernel breadth and L/B ratio. Patel (2015) also reported duplicate epistasis for L/B ratio.

Additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects in main effect and epistatic interactions were important for grain length, brown rice length, brown rice breadth, kernel length and L/B ratio. Dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions were important for grain breadth and kernel breadth. Verma *et al.*, (1994b) reported additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions for grain length and grain breadth. Habib *et al.*, (2002) observed both additive effect (d) and dominance effect (h) for grain length. Roy and Panwar (1993) and Vivekanandan and Giridharan (1995b) reported additive, dominance and all type of interactions for inheritance of kernel length. Nayak (2007) reported both additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects and Gnanamalar and Vivekanandan (2013) observed additive effect (d), dominance ($\hat{h}$), additive x dominance ($\hat{j}$) for kernel length. For kernel breadth, Gnanamalar and Vivekanandan (2013) observed additive effect (d), dominance ($\hat{h}$), additive x dominance ($\hat{j}$) types of interaction. Vivekanandan and Giridharan (1995b), Nayak (2007) reported additive ($\hat{d}$), dominance ($\hat{h}$) and all type of interactions for L/B ratio. Gnanamalar and Vivekanandan (2013) observed additive effect (d), dominance ($\hat{h}$), additive x dominance ($\hat{j}$) and duplicate epistasis and Rani *et al.*, (2015) reported additive effects (d), dominance effects (i) for L/B ratio.

Cooking properties

Cooking properties are very important for consumers. Kernel length after cooking is one of the important grain quality parameters and its higher value is perceived to be desirable. Lesser value of kernel breadth after cooking is desirable. Elongation index

is an important measure of kernel expansion upon cooking that involves both length-wise and breadth-wise components.

Duplicate epistasis was observed in seven crosses for kernel length after cooking, in three crosses for kernel breadth after cooking, in five crosses for elongation ratio and in seven crosses for elongation index. Complementary epistasis was recorded in two crosses for kernel breadth after cooking, in one cross for elongation ratio and elongation index each.. Gnanamalar and Vivekanandan (2013) reported duplicate epistasis for kernel length after cooking. Vivekanandan and Giridharan (1995b), Nayak (2007) and Rani *et al.*, (2015) reported duplicate epistasis for elongation ratio. Vivekanandan and Giridharan (1995b) reported duplicate epistasis for elongation index. These results are similar to the present findings.

For kernel length after cooking and kernel breadth after cooking along with additive ($\hat{d}$) and dominance ($\hat{h}$) gene effects in main effect, epistatic interactions were important. Gnanamalar and Vivekanandan (2013) observed additive effect (d), dominance ($\hat{h}$), additive x dominance ($\hat{j}$) for kernel length after cooking. Nayak (2007) reported both additive ($\hat{d}$) gene effect and additive x additive ($\hat{i}$) type of interactions. For elongation ratio and elongation index along with dominance ($\hat{h}$) gene effects in main effect, epistatic interactions were important. Vivekanandan and Giridharan (1995b) reported additive ($\hat{d}$), dominance ($\hat{h}$), additive x additive ($\hat{i}$), dominance x dominance ($\hat{l}$) and Nayak (2007) reported both additive ($\hat{d}$) and dominant ($\hat{h}$) gene effect, additive x additive ($\hat{i}$), dominance x dominance ($\hat{l}$) for elongation ratio. Rani *et al.*, (2015) reported additive effects ($\hat{d}$) and dominance effects ($\hat{h}$) for elongation ratio and dominance effects ($\hat{h}$) for elongation index.

Chemical properties

For alkali digestion value, intermediate value are preferable. Seven crosses revealed duplicate type of epistasis. Rani *et al.*, (2015) and Gnanamalar and Vivekanandan (2013) reported duplicate epistasis for this trait which is in agreement with present findings. For this trait, dominance ($\hat{h}$) gene effects in main effect and all type of interactions were important. Nayak (2007) reported both additive ($\hat{d}$), dominance ($\hat{h}$) gene effects and all type of interactions were important for the trait. Rani *et al.*, (2015)

and Gnanamalar and Vivekanandan (2013) reported additive x additive effects (i) for this trait.

Dominance ($\hat{h}$) gene effects in main effect, additive x additive ($\hat{i}$) and dominance x dominance ($\hat{l}$) type of interactions along with duplicate epistasis were important for all the three traits i.e. amylose content, gel consistency and aroma. Rani *et al.*, (2015) reported additive effects ($\hat{d}$), dominance effects ($\hat{h}$) and additive x additive effects (i) for amylose content. Gnanamalar and Vivekanandan (2013) observed non additive gene action for gel consistency. Duplicate epistasis was revealed by nine crosses for trait amylose content, six crosses for gel consistency and two crosses for aroma. Nayak (2007) and Rani *et al.*, (2015) reported duplicate epistasis for amylose content.

Conclusion

The generation mean analysis showed that for most of the traits both additive and dominant types of gene effects were important. However, dominance gene effects ($\hat{h}$), in general, were higher than additive gene effects ($\hat{d}$). In the presence of epistasis, most of the crosses showed duplicate type of gene interaction. With regards to epistatic gene effects, additive $\times$ additive ($\hat{i}$) and dominance $\times$ dominance ($\hat{l}$) gene effects, in general, were higher than additive $\times$ dominance ($\hat{j}$). In such crosses, the selection intensity should be mild in the earlier and intense in the later generations to dissipate non additive gene action. Simple pedigree method for improvement of quality traits would not be much beneficial. Therefore breeding methods which can exploit non-additive gene effect and take care of non-allelic interactions should be employed. Restricted recurrent selection by way of intermating the most desirable segregants followed by selection or diallel selective mating or multiple crosses or biparental mating in early segregating generations would be rewarding for simultaneous improvement of grain yield and quality traits.

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Table 1: Significance of the A,B and C scales and of Joint scaling test (JST) for yield and yield traits

Cross combination	A	B	C	JST	i	j	l
	Days to 50% flowering						
Type-3 x Adamchinni	6.97**±3.47	-9.83**±3.02	-44.16**±4.16	133.06**	41.30±5.53	8.4±2.18	41.30**±5.53
Type-3 x BPT-5204	-0.80±2.07	-3.73±2.15	-57.93**±3.00	379.88**	53.4**±3.86	1.47**±1.01	-48.87**±6.30
Type-3 x Kasturi	11.1**±1.94	7.43**±1.30	32.42**±2.25	221.16**	-13.89**±2.77	1.83±1.13	-4.65±4.69
Pusa Sugandh-2 x Adamchinni	-8.07**±2.61	-20.6**±2.32	-12.75**±3.69	95.31**	-15.92**±4.88	6.27**±3.64	44.59**±7.69
Pusa Sugandh-2 x BPT-5204	-6.03**±1.72	-14.30**±1.99	-14.64**±2.54	76.19**	-5.70±3.22	4.13**±1.25	26.03**±5.43
Pusa Sugandh-2 x Kasturi	7.87**±1.77	5.53**±1.33	9.72**±2.00	39.66**	3.68±2.38	1.17±1.03	-17.08**±3.97
Pusa 1121 x Adamchinni	-0.90±1.51	-6.13**±1.47	-43.78**±2.75	271.08**	36.75**±3.00	2.62*±0.97	-29.71**±4.54
Pusa 1121 x BPT-5204	-3.03*±1.21	-0.20±1.42	-22.65**±2.57	82.37**	19.41**±2.72	-1.42±0.88	-16.18**±4.00
Pusa 1121 x Kasturi	6.20*±1.98	5.47±1.70	15.51**±2.39	45.13**	-3.84±2.86	0.37±1.20	-7.83±5.13
	Days to maturity						
Type-3 x Adamchinni	4.80±3.50	-11.77**±3.13	-48.18**±4.31	143.35**	41.21**±5.61	8.28**±2.21	-34.25**±9.65
Type-3 x BPT-5204	-3.23±2.14	-6.43*±2.26	-62.99**±3.11	413.09**	53.32**±4.00	1.6±1.51	-43.65**±6.54
Type-3 x Kasturi	9.03**±4.38	5.07**±1.48	28.07**±2.50	128.33**	-13.97**±4.76	1.98±2.93	-0.13±5.01
Pusa Sugandh-2 x Adamchinni	-10.43**±2.65	-23.23**±2.42	-17.67**±3.77	115.17**	-16.00**±4.89	6.40**±1.75	49.67**±7.79
Pusa Sugandh-2 x BPT-5204	-8.73**±1.83	-16.73**±2.13	-19.69**±2.64	108.8**	-5.77±3.39	4.00*±1.34	31.24**±5.76
Pusa Sugandh-2 x Kasturi	6.20**±1.90	3.60*±1.44	6.39*±2.22	16.64**	3.41±2.54	1.30±1.10	-13.21**±4.58
Pusa 1121 x Adamchinni	-3.60*±1.60	-8.57**±1.58	-48.83**±2.90	297.33**	36.67**±3.11	2.48*±1.03	-24.5**±4.76
Pusa 1121 x BPT-5204	-4.83**±1.32	-2.27±1.52	-26.65**±2.66	103.22**	19.55**±2.80	-1.28±0.95	-12.45**±4.20
Pusa 1121 x Kasturi	3.70±1.98	3.23±1.73	10.64**±2.51	18.28**	-3.70±2.87	0.233±1.20	-3.23±5.13
	Plant Height						
Type-3 x Adamchinni	-28.90**±4.17	-21.23**±4.27	-93.14**±7.57	163.58**	43.00**±7.78	-3.83±2.71	7.13±12.14
Type-3 x BPT-5204	-49.60**±2.74	-50.2**±3.35	18.60**±5.56	628.18**	-118.40**±5.85	0.30±0.15	218.20**±8.93
Type-3 x Kasturi	-22.23**±3.24	0.87±3.44	-69.23**±4.71	277.10**	47.87**±4.31	-11.55**±2.09	-26.50**±8.33
Pusa Sugandh-2 x Adamchinni	8.7±4.57	-17.8**±4.09	-29.23**±7.83	39.93**	20.13**±7.59	13.25**±2.57	-11.03±12.29
Pusa Sugandh-2 x BPT-5204	-6.03**±1.72	-14.3**±1.99	-14.64**±2.54	76.19**	-5.69±3.22	4.13**±1.25	26.03**±5.43
Pusa Sugandh-2 x Kasturi	7.87**±1.77	5.53**±1.33	9.72**±4.86	39.66**	3.68±2.38	1.17±1.03	-17.08**±4.31
Pusa 1121 x Adamchinni	59.43**±3.78	21.80**±3.92	-57.87**±6.28	452.31**	139.11**±7.19	18.82**±2.58	-220.34**±11.38
Pusa 1121 x BPT-5204	-1.70±2.83	-13.63**±3.18	12.49**±4.28	43.15**	-27.83**±4.53	5.97**±1.94	43.16**±8.07
Pusa 1121 x Kasturi	-23.28**±3.15	-34.93**±3.39	-74.60**±4.20	328.25**	16.40**±4.60	5.83**±2.13	41.80**±8.61
	Effective tillers/plant						
Type-3 x Adamchinni	0.80±0.86	-2.60**±0.54	-10.66**±1.42	73.50**	8.86**±1.40	1.70**±0.43	-7.06**±2.11
Type-3 x BPT-5204	-2.60**±0.65	-2.77**±0.72	-15.45**±1.28	161.78**	10.08**±1.03	0.08±0.37	-4.71**±1.76
Type-3 x Kasturi	0.03±0.84	-3.53**±0.82	-9.65**±1.47	61.58**	6.15**±1.25	1.78**±0.46	-2.65±2.21
Pusa Sugandh-2 x Adamchinni	0.27±0.53	-1.70**±0.50	-3.38*±1.35	17.85**	1.95±1.31	0.98**±0.31	-0.51±1.71
Pusa Sugandh-2 x BPT-5204	-3.40**±0.83	-10.07**±0.80	-20.55**±1.50	246.23**	7.08**±1.35	3.33**±0.47	6.39**±2.22
Pusa Sugandh-2 x Kasturi	-0.73±0.58	-2.93**±0.61	-8.87**±1.17	67.74**	5.21**±1.05	1.10**±0.34	-1.54±1.64
Pusa 1121 x Adamchinni	0.27±0.81	-0.90±0.58	-2.71±1.45	5.61	0.27±0.81	-0.90±0.58	-2.71±1.45
Pusa 1121 x BPT-5204	-4.17**±0.65	-3.90**±0.71	-17.42**±1.22	202.82**	9.35**±1.17	-0.13±0.42	-1.29±1.88
Pusa 1121 x Kasturi	-1.73*±0.74	-3.77**±0.72	-6.43**±1.43	33.79**	0.93±1.31	1.02*±0.43	4.57*±2.03

Cross combination	A	B	C	JST	i	j	l
	No. of grains per panicle						
Type-3 x Adamchinni	-30.10**±4.11	-68.03**±4.47	-145.78**±13.24	301.06**	47.65**±13.21	18.97**±2.65	50.48**±16.27
Type-3 x BPT-5204	-24.20**±3.68	-31.00**±4.48	-178.8**±12.99	216.34**	123.60**±12.78	3.4±2.54	-68.4**±15.52
Type-3 x Kasturi	4.17±4.16	0.08±15.40	-47.97**±8.75	37.03**	52.20**±8.97	2.05±2.53	-56.43**±12.80
Pusa Sugandh-2 x Adamchinni	-53.37**±3.96	-85.40**±4.47	-193.62**±10.22	599.91**	54.85**±10.04	16.02**±2.60	83.91**±13.63
Pusa Sugandh-2 x BPT-5204	-92.57**±4.69	-42.90**±6.02	-111.36**±14.12	391.51**	-24.11±13.54	-24.83**±3.09	159.57**±17.99
Pusa Sugandh-2 x Kasturi	-22.93**±3.66	-23.20**±3.67	-150.43**±8.67	309.92**	104.30**±8.81	0.133±0.057	-58.16**±12.00
Pusa 1121 x Adamchinni	-5.97±3.65	-6.67±4.46	-118.26**±11.02	116.00**	105.63**±11.15	0.35±2.62	-92.99**±14.33
Pusa 1121 x BPT-5204	1.00±4.17	-32.70**±3.72	-64.06**±10.82	101.83**	32.36**±11.34	16.85**±2.63	-0.66±14.47
Pusa 1121 x Kasturi	-8.20*±3.42	-32.43**±3.71	-75.16**±8.72	121.37**	34.53**±8.76	12.11**±2.22	6.11±11.84
	100 grain weight						
Type-3 x Adamchinni	0.05±0.07	0.057±0.06	2.57**±0.13	449.72**	-2.47**±0.13	-0.005±0.04	2.36**±0.20
Type-3 x BPT-5204	0.73**±0.08	0.70**±0.08	1.84**±0.15	218.27**	-0.41*±0.17	0.017±0.05	-1.02**±0.25
Type-3 x Kasturi	0.23**±0.08	0.18*±0.09	1.16**±0.17	47.37**	-0.74**±0.19	0.023±0.06	0.33±0.27
Pusa Sugandh-2 x Adamchinni	0.48**±0.09	1.12**±0.09	1.04**±0.15	196.12**	0.55**±0.17	-0.32**±0.06	-2.15**±0.27
Pusa Sugandh-2 x BPT-5204	0.68**±0.10	0.94**±0.08	2.53**±0.20	259.06**	-0.91**±0.21	-0.13*±0.06	-0.71*±0.30
Pusa Sugandh-2 x Kasturi	0.19*±0.09	0.02±0.07	-0.06±0.13	5.75	0.26*±0.13	0.08±0.05	-0.46*±0.22
Pusa 1121 x Adamchinni	0.91**±0.10	1.16**±0.09	3.35**±0.15	599.12**	-1.28**±0.18	-0.12*±0.06	-0.79**±0.28
Pusa 1121 x BPT-5204	0.13±0.09	0.83**±0.08	1.64**±0.14	195.21**	-0.68**±0.15	-0.35**±0.06	-0.28±0.25
Pusa 1121 x Kasturi	-0.14±0.08	0.16±0.09	0.24±0.13	11.32*	-0.21±0.14	-0.15*±0.05	0.19±0.24
	Grain yield per plant						
Type-3 x Adamchinni	-0.56±1.17	-4.59**±1.17	24.24**±3.60	74.05**	-29.40**±3.63	2.02**±0.72	34.56**±4.49
Type-3 x BPT-5204	-11.29**±1.39	-6.82**±1.03	6.43*±2.84	118.84**	-24.53**±2.93	-2.23**±0.78	42.64**±4.04
Type-3 x Kasturi	5.58**±0.91	3.13**±0.95	4.99*±2.16	43.13**	3.72±2.24	1.23*±0.60	-12.42**±3.07
Pusa Sugandh-2 x Adamchinni	4.36**±1.22	4.25**±1.07	4.56*±2.31	23.99**	4.05±2.40	0.057±0.72	-12.66**±3.54
Pusa Sugandh-2 x BPT-5204	-5.5** ± 1.089	4.06** ± 1.13	11.83** ± 3.85	95.08**	-13.28**±3.75	-4.77**±0.62	14.71**±4.49
Pusa Sugandh-2 x Kasturi	0.98±1.06	-3.28**±0.97	2.07±2.18	16.72**	-4.37±2.24	2.13**±0.64	6.67*±3.20
Pusa 1121 x Adamchinni	7.90**±0.99	1.12±1.01	16.67**±4.27	132.75**	-7.64±4.23	3.39**±0.58	-1.38±4.78
Pusa 1121 x BPT-5204	-4.22**±0.93	-0.73±1.00	-4.26±2.43	21.08**	-0.69±2.41	-1.75**±0.59	5.64±3.23
Pusa 1121 x Kasturi	0.40±0.99	-2.57**±0.86	-0.51±2.20	10.39*	-1.66±2.20	1.48*±0.58	3.82±3.02

Table 2: Significance of the A,B and C scales and of Joint scaling test (JST) for quality traits.

Cross combination	A	B	C	JST	i	j	l
	Hulling %						
Type-3 x Adamchinni	-2.27±1.49	-4.00**±1.55	-32.44**±2.52	171.21**	26.17**±2.73	0.87±1.00	-19.91**±4.34
Type-3 x BPT-5204	0.67±1.50	-4.63**±1.92	-27.89**±2.48	151.74**	23.92**±2.76	2.65*±1.12	-19.95**±4.75
Type-3 x Kasturi	-6.33**±1.45	-8.27**±1.58	-27.00**±2.36	132.37**	12.40**±2.41	0.97±0.99	2.20±4.08
Pusa Sugandh-2 x Adamchinni	-1.13±1.56	-0.43±1.24	-31.56**±2.91	138.21**	29.99**±2.80	-0.35±0.90	-28.43**±4.08
Pusa Sugandh-2 x BPT-5204	-5.73**±1.56	-8.30**±1.95	-27.10**±2.64	112.11**	13.07**±3.09	1.28±1.19	0.97±5.07
Pusa Sugandh-2 x Kasturi	-2.50±1.47	-7.63**±1.53	-31.14**±2.59	150.30**	21.01**±2.75	2.57*±1.00	-10.87*±4.28
Pusa 1121 x Adamchinni	-1.90±1.33	0.33±1.36	-27.93**±2.74	111.05**	26.36**±2.89	-1.12±0.88	-24.79**±4.18
Pusa 1121 x BPT-5204	-8.23**±1.60	-7.07**±1.69	-28.43**±2.68	129.56**	13.13**±3.13	-0.58±1.11	2.17±4.93
Pusa 1121 x Kasturi	-3.67*±1.40	-9.33**±1.43	-35.97**±2.19	273.77**	22.97**±9.32	2.83**±0.95	-9.97*±4.00
	Milling %						
Type-3 x Adamchinni	-5.12**±0.88	-3.39**±0.83	-25.62**±1.48	306.22**	17.10**±1.59	-0.87±0.55	-8.59**±2.50
Type-3 x BPT-5204	-4.79**±0.91	-6.21**±1.21	-18.01**±1.57	139.24**	7.01**±1.80	0.71±0.70	3.98±3.04
Type-3 x Kasturi	-7.43**±0.89	-5.81**±0.99	-20.11**±1.47	206.68**	6.86**±1.49	-0.81±0.62	6.39*±2.52
Pusa Sugandh-2 x Adamchinni	-3.46**±0.72	3.35**±0.62	-18.42**±1.45	226.28**	11.60**±1.45	-0.12±0.84	-4.78*±4.02
Pusa Sugandh-2 x BPT-5204	-3.69**±1.00	-1.88±1.26	-17.76**±1.66	117.38**	12.19**±1.87	-0.90±0.75	-6.62*±3.18
Pusa Sugandh-2 x Kasturi	-1.81±0.97	-3.47**±0.96	-17.18**±1.61	115.40**	11.90**±1.69	0.83±0.63	-6.62*±2.71
Pusa 1121 x Adamchinni	-2.64**±0.83	0.48±0.91	-17.04**±1.72	110.07**	14.88**±1.78	-1.56**±0.56	-12.71**±2.64
Pusa 1121 x BPT-5204	-3.85**±0.99	-2.30*±1.09	-12.24**±1.69	59.84**	6.09**±2.00	-0.77±0.70	0.06**±3.14
Pusa 1121 x Kasturi	-4.70**±0.86	-3.72**±0.89	-23.40**±1.40	288.72**	14.98**±1.51	-0.49±0.58	-6.57**±2.46
	Head Rice Recovery						
Type-3 x Adamchinni	-5.42**±0.86	-6.00**±0.77	-14.25**±1.45	135.50**	2.83±1.55	0.29±0.55	8.60**±2.40
Type-3 x BPT-5204	-7.00**±0.96	-5.36**±1.23	-20.50**±1.67	168.94**	8.14**±1.92	-0.82±0.72	4.22±3.18
Type-3 x Kasturi	-7.18**±0.93	-6.87**±1.02	-22.54**±1.52	234.69**	8.48**±1.60	-0.15±0.64	5.57*±2.66
Pusa Sugandh-2 x Adamchinni	-4.80**±0.95	-5.25**±0.88	-20.56**±1.80	139.00**	10.51**±1.79	0.22±0.58	-0.46±2.68
Pusa Sugandh-2 x BPT-5204	-6.02**±1.05	-6.14**±1.28	-21.09**±1.74	151.59**	8.94**±1.91	0.06±0.76	3.22±3.25
Pusa Sugandh-2 x Kasturi	-6.24**±0.98	-4.11**±1.04	-19.51**±1.70	140.17**	9.16**±1.75	-1.07±0.66	1.19±2.83
Pusa 1121 x Adamchinni	-4.86**±0.91	-5.32**±0.94	-14.75**±1.81	87.23**	4.57*±1.87	0.23±0.59	5.62*±2.78
Pusa 1121 x BPT-5204	-7.36**±1.05	-4.17**±1.19	-20.46**±1.75	161.72**	8.93**±2.09	-1.60*±0.76	2.61±3.34
Pusa 1121 x Kasturi	-5.28**±0.94	-2.59**±0.93	-15.14**±1.52	111.29**	7.27**±1.61	-1.35*±0.61	0.61±2.64
	Grain length						
Type-3 x Adamchinni	1.68**±0.17	4.08**±0.14	9.84**±0.46	1179.67**	-4.07**±0.45	-1.20**±0.10	-1.69**±0.54
Type-3 x BPT-5204	0.92**±0.23	2.51**±0.24	3.76**±0.59	115.92**	-0.34±0.45	-0.80**±0.11	-3.09**±0.64
Type-3 x Kasturi	0.01±0.23	2.50**±0.35	-3.1**±0.38	195.43**	5.60**±0.42	-1.24**±0.19	-8.11**±0.79
Pusa Sugandh-2 x Adamchinni	1.07*±0.52	4.28**±0.44	3.92**±0.61	101.42**	1.43*±0.66	-1.61**±0.30	-6.77**±1.28
Pusa Sugandh-2 x BPT-5204	4.80**±0.37	5.02**±0.37	2.58**±0.52	323.78**	7.24**±0.51	-0.11±0.23	-17.10**±0.96
Pusa Sugandh-2 x Kasturi	0.42±0.39	-0.12±0.36	3.34**±0.57	70.25**	-3.04**±0.43	0.27±0.22	2.74**±0.90
Pusa 1121 x Adamchinni	-0.30±0.37	0.12±0.35	1.99±0.39	36.31**	-2.17**±0.51	-0.21±0.24	2.35*±0.96
Pusa 1121 x BPT-5204	0.33±0.42	2.04**±0.41	-3.43**±0.57	134.30**	5.80**±0.54	-0.86**±0.25	-8.17**±1.05
Pusa 1121 x Kasturi	0.12±0.42	-1.25**±0.43	-2.34**±0.53	30.33**	1.21*±0.52	0.69*±0.27	-0.07±1.06

Cross combination	A	B	C	JST	i	j	l
	Grain breadth						
Type-3 x Adamchinni	0.22**±0.04	0.23**±0.04	0.78**±0.06	161.47**	-0.33**±0.06	-0.006±0.024	-0.13±0.10
Type-3 x BPT-5204	0.25**±0.03	0.28**±0.03	0.69**±0.05	203.80**	-0.16**±0.05	-0.015±0.021	-0.38**±0.09
Type-3 x Kasturi	0.31**±0.04	0.16**±0.04	0.65**±0.09	89.33**	-0.19*±0.09	0.07**±0.03	-0.28*±0.13
Pusa Sugandh-2 x Adamchinni	0.16**±0.05	0.21**±0.05	1.58**±0.10	298.99**	-1.21**±0.09	-0.02±0.03	0.85**±0.14
Pusa Sugandh-2 x BPT-5204	0.02±0.06	0.14**±0.05	0.11±0.06	10.79*	0.05±0.07	-0.06±0.03	-0.21±0.14
Pusa Sugandh-2 x Kasturi	0.02±0.05	0.03±0.05	1.19**±0.09	198.14**	-1.13**±0.09	-0.001±0.031	1.08**±0.14
Pusa 1121 x Adamchinni	0.07±0.05	0.23**±0.04	-0.21**±0.05	93.55**	0.51**±0.06	-0.08**±0.03	-0.80**±0.12
Pusa 1121 x BPT-5204	-0.13**±0.05	-0.05±0.05	-0.61**±0.06	136.90**	0.43**±0.06	-0.04±0.03	-0.25*±0.12
Pusa 1121 x Kasturi	0.03±0.05	0.12*±0.05	0.49**±0.09	32.62**	-0.34**±0.09	-0.05±0.03	0.19±0.14
	Brown rice length						
Type-3 x Adamchinni	1.96**±0.17	5.05**±0.14	5.12**±0.45	1281.24**	1.88**±0.44	-1.55**±0.11	-8.89**±0.54
Type-3 x BPT-5204	0.02±0.24	0.62*±0.24	1.14*±0.58	10.68*	-0.50±0.44	-0.30*±0.11	-0.13±0.63
Type-3 x Kasturi	-0.05±0.23	-0.24±0.33	-5.17**±0.37	266.94**	4.88**±0.43	0.09±0.18	-4.59**±0.79
Pusa Sugandh-2 x Adamchinni	-0.63±0.51	1.63**±0.44	0.52±0.60	18.88**	0.48±0.65	-1.13**±0.29	-1.48±1.27
Pusa Sugandh-2 x BPT-5204	1.12**±0.37	3.36**±0.37	0.25±0.51	105.64**	4.24**±0.51	-1.12**±0.23	-8.72**±0.96
Pusa Sugandh-2 x Kasturi	-1.24**±0.37	-0.58±0.33	-0.25±0.52	19.22**	-1.57**±0.42	-0.33±0.19	3.38**±0.87
Pusa 1121 x Adamchinni	0.72±0.37	-0.40±0.35	0.65±0.39	9.32	-0.32±0.50	0.56*±0.24	-0.01±0.96
Pusa 1121 x BPT-5204	-0.35±0.42	1.82**±0.39	-3.68±0.57	126.28**	5.15**±0.53	-1.09**±0.25	-6.62**±1.04
Pusa 1121 x Kasturi	-1.43**±0.42	-0.98*±0.39	-7.42**±0.50	271.22**	5.01**±0.52	-0.22±0.26	-2.61*±1.04
	Brown rice width						
Type-3 x Adamchinni	0.03±0.04	-0.05±0.04	-0.02±0.06	2.67	0.03±0.04	-0.05±0.04	-0.02±0.06
Type-3 x BPT-5204	0.20**±0.04	0.20**±0.03	0.06±0.05	69.38**	0.35**±0.05	0.00±0.02	-0.75**±0.09
Type-3 x Kasturi	0.16**±0.04	0.12**±0.04	0.09±0.09	19.54**	0.19*±0.09	0.02±0.03	-0.48**±0.13
Pusa Sugandh-2 x Adamchinni	0.23**±0.05	0.41**±0.05	0.41**±0.09	70.69**	0.23*±0.08	-0.09**±0.03	-0.86**±0.14
Pusa Sugandh-2 x BPT-5204	0.20**±0.06	0.30**±0.05	0.44**±0.06	57.48**	0.06±0.07	-0.05±0.03	-0.55**±0.14
Pusa Sugandh-2 x Kasturi	0.33**±0.05	0.30**±0.05	0.22**±0.08	69.67**	0.41**±0.08	0.01±0.03	-1.03**±0.14
Pusa 1121 x Adamchinni	0.09*±0.05	0.23**±0.04	0.19**±0.05	31.00**	0.14*±0.06	-0.07*±0.03	-0.46**±0.12
Pusa 1121 x BPT-5204	0.11*±0.05	0.15**±0.05	0.11±0.06	14.20**	0.15*±0.06	-0.02±0.03	-0.41**±0.12
Pusa 1121 x Kasturi	0.11*±0.05	0.05±0.05	0.21*±0.09	8.61*	-0.04±0.09	0.03±0.03	-0.12±0.14
	Kernel length						
Type-3 x Adamchinni	1.19**±0.18	2.42**±0.14	5.3**±0.44	398.02**	-1.68**±0.42	-0.62**±0.10	-1.93**±0.53
Type-3 x BPT-5204	-0.03±0.24	0.64**±0.24	0.87±0.54	11.16*	-0.26±0.39	-0.34**±0.11	-0.34±0.60
Type-3 x Kasturi	-0.22±0.24	-0.86*±0.33	-4.66**±0.37	195.55**	3.58**±0.43	0.32±0.18	-2.50**±0.79
Pusa Sugandh-2 x Adamchinni	-0.03±0.47	2.13**±0.40	1.25*±0.49	30.10**	0.85±0.65	-1.08**±0.29	-2.96*±0.29
Pusa Sugandh-2 x BPT-5204	1.74**±0.36	3.32**±0.37	0.06±0.50	124.43**	5.00**±0.51	-0.79**±0.23	-10.05**±0.96
Pusa Sugandh-2 x Kasturi	-0.66±0.37	-0.16±0.33	-0.14±0.52	4.35	-0.66±0.37	-0.16±0.33	-0.14±0.52
Pusa 1121 x Adamchinni	1.23**±0.33	-0.19±0.30	0.32±0.35	15.53**	0.72±0.47	0.71**±0.21	-1.76*±0.87
Pusa 1121 x BPT-5204	0.331±0.39	1.71**±0.39	-3.28**±0.55	122.05**	5.33**±0.53	-0.69**±0.24	-7.37**±1.02
Pusa 1121 x Kasturi	-0.92**±0.27	-1.02**±0.27	-6.62**±0.34	388.10**	4.68**±0.42	0.05±0.18	-2.74**±0.75

Cross combination	A	B	C	JST	i	j	l
	Kernel breadth						
Type-3 x Adamchinni	0.10**±0.04	0.03±0.04	0.18**±0.06	10.1**	-0.05±0.06	0.03±0.03	-0.07±0.10
Type-3 x BPT-5204	0.15**±0.04	0.12**±0.04	-0.12*±0.05	55.43**	0.38**±0.05	0.02±0.02	-0.65**±0.09
Type-3 x Kasturi	0.12**±0.04	0.12*±0.05	0.13±0.09	12.40*	0.11±0.09	0.002±0.03	-0.35**±0.13
Pusa Sugandh-2 x Adamchinni	0.08±0.05	0.27**±0.05	0.49**±0.09	43.41**	-0.14±0.09	-0.10**±0.03	-0.21±0.14
Pusa Sugandh-2 x BPT-5204	0.08±0.06	0.11*±0.05	0.17**±0.07	11.52*	0.02±0.07	-0.02±0.03	-0.21±0.14
Pusa Sugandh-2 x Kasturi	0.23**±0.05	0.25**±0.05	0.30**±0.08	42.46**	0.18*±0.08	-0.01±0.03	-0.66**±0.14
Pusa 1121 x Adamchinni	0.05±0.05	0.16**±0.04	0.05±0.05	16.07**	0.15*±0.06	-0.05±0.03	-0.36**±0.12
Pusa 1121 x BPT-5204	0.02±0.05	0.08±0.05	-0.05±0.06	7.94	0.15*±0.06	-0.03±0.03	-0.25*±0.12
Pusa 1121 x Kasturi	0.11*±0.05	0.06±0.05	0.31**±0.09	14.35**	-0.15±0.09	0.03±0.03	-0.03±0.14
	L/B ratio						
Type-3 x Adamchinni	0.56**±0.17	1.97**±0.17	3.77**±0.43	169.10**	-1.25**±0.41	-0.70**±0.11	-1.28*±0.54
Type-3 x BPT-5204	-0.40±0.22	0.30±0.22	1.07*±0.46	19.18**	-1.17**±0.34	-0.35**±0.11	1.26*±0.54
Type-3 x Kasturi	-0.53*±0.23	-1.08**±0.33	-4.06**±0.42	98.64**	2.45**±0.47	0.27±0.18	-0.85±0.80
Pusa Sugandh-2 x Adamchinni	-0.16±0.41	1.41**±0.42	0.40±0.47	12.32**	0.86±0.62	-0.79**±0.27	-2.11±1.15
Pusa Sugandh-2 x BPT-5204	1.21**±0.32	2.48**±0.32	-0.35±0.45	109.50**	4.04**±0.43	-0.64**±0.19	-7.73**±0.82
Pusa Sugandh-2 x Kasturi	-1.22**±0.31	-0.87**±0.26	-0.87±0.45	22.36**	-1.22**±0.41	-0.18±0.17	3.30**±0.75
Pusa 1121 x Adamchinni	0.82**±0.30	-0.38±0.33	0.50±0.32	11.22*	-0.06±0.46	0.60**±0.21	-0.39±0.87
Pusa 1121 x BPT-5204	0.15±0.33	1.27**±0.35	-2.60**±0.53	99.50**	4.02**±0.44	-0.56**±0.19	-5.44**±0.86
Pusa 1121 x Kasturi	-1.03**±0.27	-0.97**±0.29	-6.11**±0.36	294.06**	4.12**±0.45	-0.03±0.18	-2.12*±0.79
	Kernel length after cooking						
Type-3 x Adamchinni	-1.52**±0.19	1.30**±0.14	1.72**±0.47	196.31**	-1.93**±0.46	-1.41**±0.11	2.15**±0.57
Type-3 x BPT-5204	-0.32±0.24	1.38**±0.24	4.55**±0.59	122.94**	-3.51**±0.45	-0.85**±0.12	2.45**±0.64
Type-3 x Kasturi	1.19**±0.24	0.86*±0.34	-6.81**±0.38	620.99**	8.86**±0.43	0.16±0.19	-10.91**±0.80
Pusa Sugandh-2 x Adamchinni	-2.24**±0.47	2.92**±0.40	-3.51**±0.50	160.50**	4.19**±0.65	-2.58**±0.29	-4.87**±1.21
Pusa Sugandh-2 x BPT-5204	0.73*±0.36	3.11**±0.37	1.09*±0.51	73.15**	2.75**±0.52	-1.19**±0.23	-6.58**±0.97
Pusa Sugandh-2 x Kasturi	0.83*±0.37	1.93**±0.33	1.03±0.53	37.60**	1.73**±0.43	-0.55**±0.20	-4.49**±0.89
Pusa 1121 x Adamchinni	-2.04**±0.37	0.40±0.30	-2.07**±0.40	47.31**	0.43±0.47	-1.22**±0.23	1.21±0.89
Pusa 1121 x BPT-5204	-1.76**±0.39	3.20**±0.39	-11.81**±0.55	958.73**	13.26**±0.53	-2.48**±0.24	-14.70**±1.02
Pusa 1121 x Kasturi	-4.02**±0.27	1.27**±0.27	-13.34**±0.35	1677.60**	10.59**±0.42	-2.64**±0.18	-7.84**±0.75
	Kernel breadth after cooking						
Type-3 x Adamchinni	0.45**±0.04	0.15**±0.04	0.82**±0.06	207.93**	-0.23**±0.06	0.15**±0.03	-0.36**±0.11
Type-3 x BPT-5204	0.55**±0.04	1.07**±0.03	1.25**±0.05	1109.58**	0.37**±0.05	-0.26**±0.02	-1.98**±0.09
Type-3 x Kasturi	0.07±0.04	0.04±0.04	0.21*±0.09	6.74	-0.11±0.09	0.02±0.03	-0.00±0.13
Pusa Sugandh-2 x Adamchinni	-0.34**±0.06	0.05±0.05	-0.73**±0.09	91.20**	0.45**±0.09	-0.19**±0.03	-0.16±0.14
Pusa Sugandh-2 x BPT-5204	0.31**±0.06	0.35**±0.05	-0.50**±0.06	330.25**	1.16**±0.06	-0.02±0.03	-1.82**±0.14
Pusa Sugandh-2 x Kasturi	0.26**±0.05	0.19**±0.05	0.64**±0.08	67.33**	-0.19*±0.08	0.04±0.03	-0.26±0.14
Pusa 1121 x Adamchinni	-0.27**±0.05	-0.83**±0.04	-0.57**±0.05	371.74**	-0.52**±0.06	0.28**±0.03	1.62**±0.12
Pusa 1121 x BPT-5204	0.14**±0.05	0.25**±0.05	1.10**±0.06	401.55**	-0.71**±0.06	-0.05±0.03	0.32*±0.13
Pusa 1121 x Kasturi	0.46**±0.05	0.30**±0.05	1.62**±0.09	352.56**	-0.86**±0.09	0.08**±0.03	0.11±0.14

Cross combination	A	B	C	JST	i	j	l
	Elongation ratio						
Type-3 x Adamchinni	-1.20**±0.05	-1.20**±0.06	-2.60**±0.13	931.05**	0.21±0.12	0.00±0.03	2.17**±0.16
Type-3 x BPT-5204	-0.10±0.05	-0.02±0.07	0.90**±0.15	78.23**	-1.01**±0.12	-0.04±0.03	1.13**±0.16
Type-3 x Kasturi	0.47**±0.05	0.78**±0.08	0.41**±0.09	152.36**	0.85**±0.11	-0.15**±0.05	-2.10**±0.20
Pusa Sugandh-2 x Adamchinni	-0.79**±0.15	-0.45*±0.17	-2.59**±0.20	184.68**	1.34**±0.22	-0.17±0.10	-0.10±0.43
Pusa Sugandh-2 x BPT-5204	-0.57**±0.07	-0.87**±0.09	0.42**±0.14	315.88**	-1.85**±0.11	0.15**±0.05	3.29**±0.20
Pusa Sugandh-2 x Kasturi	0.55**±0.08	0.63**±0.07	0.10±0.10	150.19**	1.08**±0.10	-0.04±0.04	-2.26**±0.19
Pusa 1121 x Adamchinni	-0.92**±0.07	0.18±0.12	-0.72**±0.10	187.29**	-0.02±0.14	-0.55**±0.07	0.76**±0.26
Pusa 1121 x BPT-5204	-0.50**±0.11	0.02±0.12	-1.74**±0.16	161.98**	1.26**±0.15	-0.26**±0.07	-0.78**±0.29
Pusa 1121 x Kasturi	-0.52**±0.07	0.97**±0.08	-0.12±0.10	224.90**	0.57**±0.12	-0.74**±0.05	-1.02**±0.02
	Elongation index						
Type-3 x Adamchinni	-1.25**±0.04	-1.08**±0.05	-2.67**±0.11	1040.90**	0.34**±0.10	-0.08**±0.03	2.00**±0.14
Type-3 x BPT-5204	-0.42**±0.05	-1.22**±0.06	-0.94**±0.11	470.74**	-0.69**±0.09	0.40**±0.03	2.33**±0.13
Type-3 x Kasturi	0.88**±0.16	1.17**±0.17	1.02**±0.27	117.92**	1.02**±0.11	-0.15±0.09	-3.06**±0.31
Pusa Sugandh-2 x Adamchinni	-0.14±0.12	0.04±0.15	-2.09**±0.16	209.26**	2.00**±0.20	-0.09±0.09	-1.90**±0.36
Pusa Sugandh-2 x BPT-5204	-0.65**±0.06	-1.20**±0.07	0.89**±0.12	911.65**	-2.74**±0.10	0.28**±0.04	4.60**±0.17
Pusa Sugandh-2 x Kasturi	0.54**±0.07	0.71**±0.06	0.04±0.10	230.33**	1.21**±0.10	-0.08*±0.04	-2.47**±0.17
Pusa 1121 x Adamchinni	-0.36**±0.07	1.50**±0.11	0.17*±0.09	225.33**	0.96**±0.13	-0.93**±0.06	-2.10**±0.25
Pusa 1121 x BPT-5204	-0.52**±0.09	-0.29**±0.11	-2.92**±0.14	558.35**	2.11**±0.12	-0.12*±0.06	-1.30**±0.24
Pusa 1121 x Kasturi	-0.72**±0.09	0.54**±0.07	-1.34**±0.09	329.18**	1.16**±0.13	-0.63**±0.06	-0.97**±0.24
	Alkali spread value						
Type-3 x Adamchinni	1.00**±0.15	1.89**±0.14	2.15**±0.37	204.14**	0.73*±0.37	-0.45**±0.10	-3.60**±0.50
Type-3 x BPT-5204	-0.28*±0.13	-0.52**±0.14	-1.23**±0.42	20.58**	0.43±0.42	0.12±0.09	0.37±0.52
Type-3 x Kasturi	2.47**±0.12	1.52**±0.12	0.70**±0.26	548.80**	3.29**±0.24	0.47**±0.07	-7.27**±0.35
Pusa Sugandh-2 x Adamchinni	1.21**±0.09	2.89**±0.12	0.75±0.40	694.57**	3.34**±0.40	-0.84**±0.07	-7.44**±0.47
Pusa Sugandh-2 x BPT-5204	-0.20±0.10	1.46**±0.11	-3.62**±0.34	379.98**	4.88**±0.34	-0.83**±0.07	-6.14**±0.41
Pusa Sugandh-2 x Kasturi	-0.47**±0.09	1.80**±0.11	1.87**±0.22	373.96**	-0.55*±0.22	-1.14**±0.06	-0.78*±0.31
Pusa 1121 x Adamchinni	0.17±0.11	3.00**±0.13	-1.53**±0.44	608.44**	4.67**±0.45	-1.40**±0.08	-7.81**±0.52
Pusa 1121 x BPT-5204	0.24±0.13	0.57**±0.17	-0.77*±0.34	24.26**	1.58**±0.35	-0.16±0.09	-2.40**±0.49
Pusa 1121 x Kasturi	-0.29*±0.13	0.85**±0.15	-0.21±0.24	52.72**	0.77**±0.25	-0.57**±0.09	-1.34**±0.40
	Amylose content						
Type-3 x Adamchinni	-2.23**±0.81	-2.27**±0.74	2.02±1.17	36.97**	-6.52**±1.10	0.02±0.48	11.02**±1.99
Type-3 x BPT-5204	-4.47**±0.74	-2.80**±0.83	3.30**±1.18	86.64**	-10.57**±1.24	-0.83±0.50	17.83**±2.15
Type-3 x Kasturi	-0.13±0.68	-2.73**±0.82	3.80**±1.37	26.00**	-6.66**±1.45	1.30**±0.48	9.52**±2.22
Pusa Sugandh-2 x Adamchinni	0.90±0.92	-1.67*±0.81	14.92**±1.46	183.04**	-15.69**±1.30	1.28*±0.51	16.45**±2.26
Pusa Sugandh-2 x BPT-5204	2.07**±0.66	-0.73±0.78	8.71**±1.31	55.29**	-7.37**±1.29	1.40**±0.46	6.04**±2.03
Pusa Sugandh-2 x Kasturi	-1.03±0.84	-3.80**±0.87	4.69**±1.12	57.26**	-9.53**±1.33	1.38*±0.55	14.36**±2.40
Pusa 1121 x Adamchinni	-5.97**±0.73	-7.33**±0.76	14.04**±1.24	492.53**	-27.34**±1.23	0.68±0.46	40.64**±2.06
Pusa 1121 x BPT-5204	-2.60**±0.72	-0.70±0.80	8.26**±1.48	66.62**	-11.56**±1.48	-0.95*±0.47	14.86**±2.24
Pusa 1121 x Kasturi	-1.80*±0.76	-4.87**±0.81	2.05±1.27	57.81**	-8.71**±1.33	1.53**±0.50	15.38**±2.19

Cross combination	A	B	C	JST	i	j	l
	Gel consistency						
Type-3 x Adamchinni	2.43±2.17	2.33±2.21	8.84*±3.5	6.62	-4.07±4.03	0.05±1.46	-0.69±6.39
Type-3 x BPT-5204	-4.57*±2.05	-6.43**±2.07	-18.86**±4.82	19.35**	7.86±4.60	0.93±1.21	3.14±6.43
Type-3 x Kasturi	-14.93**±2.18	-21.63**±1.67	-3.89±4.08	206.24**	-32.67**±3.95	3.35**±1.16	69.24**±5.81
Pusa Sugandh-2 x Adamchinni	13.30**±2.42	2.70±2.54	-30.37**±4.75	98.68**	46.37**±5.02	5.30**±1.59	-62.37**±7.54
Pusa Sugandh-2 x BPT-5204	3.90*±1.49	9.10**±1.93	53.06**±4.79	133.73**	-40.06**±4.93	-2.60*±1.14	27.06**±6.26
Pusa Sugandh-2 x Kasturi	12.73**±2.07	7.13**±2.09	41.59**±4.14	111.57**	-21.72**±4.18	2.80*±1.28	1.85±6.27
Pusa 1121 x Adamchinni	28.77**±2.36	0.77±2.49	-24.91**±4.14	243.45**	54.45**±4.22	14.00**±1.54	-83.98**±6.83
Pusa 1121 x BPT-5204	-18.87**±1.58	-6.77**±2.18	8.49*±3.98	180.79**	-34.13**±4.08	-6.05**±1.17	59.76**±5.96
Pusa 1121 x Kasturi	-15.67**±1.60	-12.83**±1.84	4.47±3.96	147.94**	-32.97**±3.77	-1.42±0.99	61.47**±5.36
	Aroma						
Type-3 x Adamchinni	0.40±0.40	0.25±0.40	-2.45**±0.67	29.67**	3.09**±0.59	0.08±0.23	-3.74**±1.05
Type-3 x BPT-5204	-0.95±0.85	0.31±0.71	2.12±1.22	10.68*	-2.76**±1.05	-0.63±0.42	3.40±2.05
Type-3 x Kasturi	0.70±0.41	0.40±0.51	-1.82*±0.71	21.86**	2.92**±0.65	0.15±0.28	-4.01**±1.20
Pusa Sugandh-2 x Adamchinni	0.25±0.43	0.13±0.49	0.16±0.65	0.36	0.22±0.63	0.06±0.28	-0.60±1.19
Pusa Sugandh-2 x BPT-5204	1.14*±0.49	2.43**±0.74	1.50±1.04	13.68**	2.06±1.12	-0.64±0.39	-5.63**±1.82
Pusa Sugandh-2 x Kasturi	-0.03±0.38	-0.18±0.34	-1.85**±0.59	16.69**	1.64**±0.47	0.08±0.21	-1.42±0.89
Pusa 1121 x Adamchinni	0.11±0.36	0.23±0.44	-1.03±0.61	10.18*	1.38**±0.53	-0.06±0.24	-1.73±1.02
Pusa 1121 x BPT-5204	0.42±0.57	4.64**±0.60	4.13**±1.10	88.20**	0.93±0.69	-2.11**±0.25	-5.99**±1.42
Pusa 1121 x Kasturi	-0.28±0.40	0.19±0.46	-0.22±0.60	1.29	0.13±0.27	-0.24±0.26	-0.05±1.05

Table 3: Estimates of Gene effects (six-parameter model) for yield and yield traits.

Cross combination	m	d	h	i	j	l	Type of interaction
Days to 50% flowering							
Type-3 x Adamchinni	103.96**±0.88	-6.93*±2.14	46.16**±5.63	41.30±5.53	8.4±2.18	41.30**±5.53	C
Type-3 x BPT-5204	92.08**±0.67	-7.63**±1.38	49.63**±3.92	53.4**±3.86	1.47**±1.01	-48.87**±6.30	D
Type-3 x Kasturi	94.75**±0.46	7.31**±1.03	-24.04**±2.84	-13.89**±2.77	1.83±1.13	-4.65±4.69	--
Pusa Sugandh-2 x Adamchinni	111.81**±0.88	-10.73**±1.69	-7.79±4.91	-15.92**±4.88	6.27**±3.64	44.59**±7.69	--
Pusa Sugandh-2 x BPT-5204	104.34**±0.54	-6.77**±1.20	-1.96±3.29	-5.70±3.22	4.13**±1.25	26.03**±5.43	--
Pusa Sugandh-2 x Kasturi	87.75**±0.36	7.07**±0.95	-5.29*±2.48	3.68±2.38	1.17±1.03	-17.08**±3.97	C
Pusa 1121 x Adamchinni	107.48**±0.60	-5.93**±0.90	35.23**±3.08	36.75**±3.00	2.62*±0.97	-29.71**±4.54	D
Pusa 1121 x BPT-5204	109.61**±0.56	-4.40**±0.77	20.33**±2.79	19.41**±2.72	-1.42±0.88	-16.18**±4.00	D
Days to maturity							
Type-3 x Adamchinni	130.28**±0.90	-6.80**±2.16	43.76**±5.74	41.21**±5.61	8.28**±2.21	-34.25**±9.65	D
Type-3 x BPT-5204	118.39**±0.69	-7.50**±1.44	47.52**±4.06	53.32**±4.00	1.6±1.51	-43.65**±6.54	D
Type-3 x Kasturi	121.07**±0.49	7.18**±1.09	-26.33**±8.69	-13.97**±4.76	1.98±2.93	-0.13±5.01	--
Pusa Sugandh-2 x Adamchinni	138.13**±0.88	-10.60**±1.70	-10.37*±4.94	-16.00**±4.89	6.40**±1.75	49.67**±7.79	D
Pusa Sugandh-2 x BPT-5204	130.66**±0.56	-6.90**±1.28	-4.07±3.46	-5.77±3.39	4.00*±1.34	31.24**±5.76	--
Pusa Sugandh-2 x Kasturi	114.11**±0.39	7.20**±1.00	-7.62*±2.66	3.41±2.54	1.30±1.10	-13.21**±4.58	C
Pusa 1121 x Adamchinni	133.80**±0.62	-6.07**±0.95	33.12**±3.20	36.67**±3.11	2.48*±1.03	-24.5**±4.76	D
Pusa 1121 x BPT-5204	135.88**±0.57	-4.27**±0.81	18.53**±2.88	19.55**±2.80	-1.28±0.95	-12.45**±4.20	D
Plant Height							
Type-3 x Adamchinni	135.25**±1.54	-7.83**±2.37	54.60**±8.08	43.00**±7.78	-3.83±2.71	7.13±12.14	--
Type-3 x BPT-5204	136.87**±1.17	29.32**±1.75	-101.31**±6.04	-118.40**±5.85	0.30±0.15	218.20**±8.93	D
Type-3 x Kasturi	111.93**±0.65	9.30**±1.72	50.58**±4.74	47.87**±4.31	-11.55**±2.09	-26.50**±8.33	D
Pusa Sugandh-2 x Adamchinni	147.87**±1.48	-13.40**±2.37	57.52**±8.01	20.13**±7.59	13.25**±2.57	-11.03±12.29	--
Pusa Sugandh-2 x BPT-5204	104.34**±0.54	-6.77**±1.20	-1.96±3.29	-5.69±3.22	4.13**±1.25	26.03**±5.43	--
Pusa Sugandh-2 x Kasturi	87.75**±0.36	7.07**±0.95	-5.29*±2.48	3.68±2.38	1.17±1.03	-17.08**±4.31	C
Pusa 1121 x Adamchinni	111.22**±1.35	-7.83±2.37	117.52**±7.36	139.11**±7.19	18.82**±2.58	-220.34**±11.38	D
Pusa 1121 x BPT-5204	111.50**±0.74	13.93**±1.71	-14.79**±4.79	-27.83**±4.53	5.97**±1.94	43.16**±8.07	D
Pusa 1121 x Kasturi	94.67**±0.66	7.50**±1.88	23.37**±4.88	16.40**±4.60	5.83**±2.13	41.80**±8.61	C
Effective tillers/plant							
Type-3 x Adamchinni	11.16**±0.29	3.08**±0.39	17.01**±1.45	8.86**±1.40	1.70**±0.43	-7.06**±2.11	D
Type-3 x BPT-5204	10.31**±0.21	-0.83**±0.30	13.78**±1.14	10.08**±1.03	0.08±0.37	-4.71**±1.76	D
Type-3 x Kasturi	10.45**±0.24	2.63**±0.41	11.56**±1.37	6.15**±1.25	1.78**±0.46	-2.65±2.21	--
Pusa Sugandh-2 x Adamchinni	10.94**±0.30	1.97**±0.26	7.90**±1.35	1.95±1.31	0.98**±0.31	-0.51±1.71	--
Pusa Sugandh-2 x BPT-5204	10.81**±0.27	1.77**±0.41	15.78**±1.44	7.08**±1.35	3.33**±0.47	6.39**±2.22	C
Pusa Sugandh-2 x Kasturi	9.24**±0.22	1.68**±0.28	10.76**±1.12	5.21**±1.05	1.10**±0.34	-1.54±1.64	--
Pusa 1121 x BPT-5204	11.12**±0.23	-1.32**±0.36	16.07**±1.23	9.35**±1.17	-0.13±0.42	-1.29±1.88	--
Pusa 1121 x Kasturi	10.80**±0.27	1.90**±0.36	6.72**±1.39	0.93±1.31	1.02*±0.43	4.57*±2.03	C

Cross combination	m	d	h	i	j	l	Type of interaction
No. of grains per panicle							
Type-3 x Adamchinni	149.02**±3.08	-14.93**±2.36	94.32**±13.42	47.65**±13.21	18.97**±2.65	50.48**±16.27	C
Type-3 x BPT-5204	104.60**±3.02	-17.23**±2.13	133.87**±13.01	123.60**±12.78	3.4±2.54	-68.4**±15.52	D
Type-3 x Kasturi	124.63**±1.91	7.60**±2.34	85.55**±9.22	52.20**±8.97	2.05±2.53	-56.43**±12.80	D
Pusa Sugandh-2 x Adamchinni	134.82**±2.24	-11.83**±2.25	92.73**±10.33	54.85**±10.04	16.02**±2.60	83.91**±13.63	C
Pusa Sugandh-2 x BPT-5204	163.06**±3.08	-42.90**±2.79	57.49**±13.96	-24.11±13.54	-24.83**±3.09	159.57**±17.99	C
Pusa Sugandh-2 x Kasturi	93.63**±1.94	8.38**±2.07	123.21**±9.01	104.30**±8.81	0.133±0.057	-58.16**±12.00	D
Pusa 1121 x Adamchinni	105.99**±2.54	-60.57**±2.29	103.84**±11.36	105.63**±11.15	0.35±2.62	-92.99**±14.33	D
Pusa 1121 x BPT-5204	111.93**±2.57	-25.20**±2.40	55.21**±11.47	32.36**±11.34	16.85**±2.63	-0.66±14.47	--
Pusa 1121 x Kasturi	94.23**±1.95	-9.68**±2.00	72.89**±8.98	34.53**±8.76	12.11**±2.22	6.11±11.84	--
100 grain weight							
Type-3 x Adamchinni	2.47**±0.03	0.24**±0.04	-2.43**±0.14	-2.47**±0.13	-0.005±0.04	2.36**±0.20	D
Type-3 x BPT-5204	2.45**±0.03	0.11*±0.05	-0.46**±0.17	-0.41*±0.17	0.017±0.05	-1.02**±0.25	C
Type-3 x Kasturi	2.35**±0.04	-0.056±0.053	-0.96**±0.19	-0.74**±0.19	0.023±0.06	0.33±0.27	--
Pusa Sugandh-2 x Adamchinni	2.20**±0.03	0.16**±0.06	0.31±0.17	0.55**±0.17	-0.32**±0.06	-2.15**±0.27	--
Pusa Sugandh-2 x BPT-5204	2.94**±0.05	0.20**±0.05	-0.67**±0.22	-0.91**±0.21	-0.13*±0.06	-0.71*±0.30	C
Pusa Sugandh-2 x Kasturi	2.45**±0.02	0.24**±0.04	0.38**±0.14	0.26*±0.13	0.08±0.05	-0.46*±0.22	D
Pusa 1121 x Adamchinni	2.74**±0.03	0.50**±0.06	-1.81**±0.18	-1.28**±0.18	-0.12*±0.06	-0.79**±0.28	C
Pusa 1121 x BPT-5204	2.82**±0.03	0.13*±0.05	-0.53**±0.16	-0.68**±0.15	-0.35**±0.06	-0.28±0.25	--
Pusa 1121 x Kasturi	2.73**±0.03	0.16**±0.05	0.14±0.15	-0.21±0.14	-0.15*±0.05	0.19±0.24	--
Grain yield per plant							
Type-3 x Adamchinni	29.49**±0.84	3.25**±0.67	-7.94*±3.68	-29.40**±3.63	2.02**±0.72	34.56**±4.49	D
Type-3 x BPT-5204	25.02**±0.64	-3.52**±0.72	-7.30*±3.00	-24.53**±2.93	-2.23**±0.78	42.64**±4.04	D
Type-3 x Kasturi	19.67**±0.49	1.96**±0.55	13.34**±2.28	3.72±2.24	1.23*±0.60	-12.42**±3.07	D
Pusa Sugandh-2 x Adamchinni	21.26**±0.50	2.48**±0.67	15.20**±2.47	4.05±2.40	0.057±0.72	-12.66**±3.54	D
Pusa Sugandh-2 x BPT-5204	29.63**±0.8934	-5.12**±0.577	7.68**±3.82	-13.28**±3.75	-4.77**±0.62	14.71**±4.49	C
Pusa Sugandh-2 x Kasturi	20.87**±0.48	3.58**±0.59	7.00**±2.30	-4.37±2.24	2.13**±0.64	6.67*±3.20	C
Pusa 1121 x Adamchinni	28.47**±1.024	4.71**±0.540	14.09**±4.28	-7.64±4.23	3.39**±0.58	-1.38±4.78	--
Pusa 1121 x BPT-5204	19.95**±0.54	-2.68**±0.53	8.80**±2.48	-0.69±2.41	-1.75**±0.59	5.64±3.23	--
Pusa 1121 x Kasturi	18.42**±0.49	2.15**±0.52	7.79**±2.26	-1.66±2.20	1.48*±0.58	3.82±3.02	--

Table 4.15: Estimates of Gene effects (six-parameter model) for quality traits

Cross combination	m	d	h	i	j	l	Type of interaction
Hulling %							
Type-3 x Adamchinni	72.24**±0.52	-0.37±0.88	27.54**±2.82	26.17**±2.73	0.87±1.00	-19.91**±4.34	D
Type-3 x BPT-5204	69.99**±0.47	4.03**±1.01	23.87**±2.87	23.92**±2.76	2.65*±1.12	-19.95**±4.75	D
Type-3 x Kasturi	67.83**±0.44	3.93**±0.83	10.97**±2.54	12.40**±2.41	0.97±0.99	2.20±4.08	--
Pusa Sugandh-2 x Adamchinni	71.36**±0.60	-2.05**±0.72	31.36**±2.92	29.99**±2.80	-0.35±0.90	-28.43**±4.08	D
Pusa Sugandh-2 x BPT-5204	70.60**±0.55	1.83±1.08	15.78**±3.17	13.07**±3.09	1.28±1.19	0.97±5.07	--
Pusa Sugandh-2 x Kasturi	66.10**±0.54	4.85**±0.85	19.09**±2.84	21.01**±2.75	2.57*±1.00	-10.87*±4.28	D
Pusa 1121 x Adamchinni	69.32**±0.60	-3.97**±0.79	23.41**±2.96	26.36**±2.89	-1.12±0.88	-24.79**±4.18	D
Pusa 1121 x BPT-5204	70.09**±0.59	-1.12±1.03	16.53**±3.20	13.13**±3.13	-0.58±1.11	2.17±4.93	--
Pusa 1121 x Kasturi	64.23**±0.45	3.95**±0.84	22.32**±2.54	22.97**±9.32	2.83**±0.95	-9.97*±4.00	D
Milling %							
Type-3 x Adamchinni	52.80**±0.31	-1.81**±0.50	18.95**±1.64	17.10**±1.59	-0.87±0.55	-8.59**±2.50	D
Type-3 x BPT-5204	52.64**±0.31	1.59*±0.65	8.66**±1.86	7.01**±1.80	0.71±0.70	3.98±3.04	--
Type-3 x Kasturi	51.35**±0.27	1.02*±0.51	7.58**±1.57	6.86**±1.49	-0.81±0.62	6.39*±2.52	C
Pusa Sugandh-2 x Adamchinni	50.68**±0.30	-1.50**±0.69	13.51**±1.46	11.60**±1.45	-0.12±0.84	-4.78*±4.02	D
Pusa Sugandh-2 x BPT-5204	51.22**±0.32	-0.97±0.68	12.94**±1.95	12.19**±1.87	-0.90±0.75	-6.62*±3.18	D
Pusa Sugandh-2 x Kasturi	50.16**±0.32	1.31*±0.55	11.02**±1.76	11.90**±1.69	0.83±0.63	-6.62*±2.71	D
Pusa 1121 x Adamchinni	51.49**±0.37	-4.29**±0.50	12.90**±1.84	14.88**±1.78	-1.56**±0.56	-12.71**±2.64	D
Pusa 1121 x BPT-5204	52.75**±0.37	-1.30*±0.66	8.60**±2.03	6.09**±2.00	-0.77±0.70	0.06**±3.14	C
Pusa 1121 x Kasturi	49.05**±0.28	-0.63±0.51	16.41**±1.57	14.98**±1.51	-0.49±0.58	-6.57**±2.46	D
Head Rice Recovery							
Type-3 x Adamchinni	46.97**±0.31	-0.59±0.48	4.34**±1.60	2.83±1.55	0.29±0.55	8.60**±2.40	C
Type-3 x BPT-5204	45.66**±0.34	-1.16±0.68	10.26**±1.98	8.14**±1.92	-0.82±0.72	4.22±3.18	--
Type-3 x Kasturi	43.84**±0.29	0.40±0.54	9.77**±1.67	8.48**±1.60	-0.15±0.64	5.57*±2.66	C
Pusa Sugandh-2 x Adamchinni	45.31**±0.37	-1.16*±0.50	14.25**±1.86	10.51**±1.79	0.22±0.58	-0.46±2.68	--
Pusa Sugandh-2 x BPT-5204	44.28**±0.33	-1.46*±0.68	11.10**±1.99	8.94**±1.91	0.06±0.76	3.22±3.25	--
Pusa Sugandh-2 x Kasturi	43.23**±0.33	-1.48*±0.56	10.36**±1.83	9.16**±1.75	-1.07±0.66	1.19±2.83	--
Pusa 1121 x Adamchinni	46.26**±0.38	-1.14*±0.53	6.63**±1.93	4.57*±1.87	0.23±0.59	5.62*±2.78	C
Pusa 1121 x BPT-5204	45.16**±0.38	-2.39**±0.71	11.59**±2.13	8.93**±2.09	-1.60*±0.76	2.61±3.34	--
Pusa 1121 x Kasturi	44.46**±0.30	-1.19*±0.54	7.76**±1.68	7.27**±1.61	-1.35*±0.61	0.61±2.64	--
Grain length							
Type-3 x Adamchinni	9.32**±0.11	0.89**±0.07	-5.26**±0.46	-4.07**±0.45	-1.20**±0.10	-1.69**±0.54	C
Type-3 x BPT-5204	9.08**±0.11	0.37**±0.06	-0.87±0.49	-0.34±0.45	-0.80**±0.11	-3.09**±0.64	C
Type-3 x Kasturi	9.22**±0.06	-1.70**±0.17	5.65**±0.45	5.60**±0.42	-1.24**±0.19	-8.11**±0.79	D
Pusa Sugandh-2 x Adamchinni	8.55**±0.08	1.03**±0.28	0.54±0.71	1.43*±0.66	-1.61**±0.30	-6.77**±1.28	--
Pusa Sugandh-2 x BPT-5204	9.06**±0.08	1.60**±0.20	6.17**±0.55	7.24**±0.51	-0.11±0.23	-17.10**±0.96	D
Pusa Sugandh-2 x Kasturi	11.82**±0.06	0.58**±0.18	-2.71**±0.50	-3.04**±0.43	0.27±0.22	2.74**±0.90	D
Pusa 1121 x Adamchinni	9.26**±0.06	2.82**±0.22	-1.36*±0.53	-2.17**±0.51	-0.21±0.24	2.35*±0.96	D
Pusa 1121 x BPT-5204	8.46**±0.08	0.91**±0.22	5.77**±0.59	5.80**±0.54	-0.86**±0.25	-8.17**±1.05	D
Pusa 1121 x Kasturi	10.62**±0.06	0.88**±3.83	2.84**±0.57	1.21*±0.52	0.69*±0.27	-0.07±1.06	--

Cross combination	m	d	h	i	j	l	Type of interaction
Grain breadth							
Type-3 x Adamchinni	2.26**±0.01	0.08**±0.02	-0.41**±0.06	-0.33**±0.06	-0.006±0.024	-0.13±0.10	--
Type-3 x BPT-5204	2.24**±0.01	0.07**±0.02	-0.26**±0.05	-0.16**±0.05	-0.015±0.021	-0.38**±0.09	C
Type-3 x Kasturi	2.28**±0.02	0.10**±0.02	-0.30**±0.09	-0.19**±0.09	0.07**±0.03	-0.28*±0.13	C
Pusa Sugandh-2 x Adamchinni	2.55**±0.02	0.12**±0.03	-1.31**±0.09	-1.21**±0.09	-0.02±0.03	0.85**±0.14	C
Pusa Sugandh-2 x Kasturi	2.53**±0.02	0.10**±0.03	-1.19**±0.10	-1.13**±0.09	-0.001±0.031	1.08**±0.14	D
Pusa 1121 x Adamchinni	2.18**±0.01	0.09**±0.03	0.48**±0.06	0.51**±0.06	-0.08**±0.03	-0.80**±0.12	D
Pusa 1121 x BPT-5204	2.24**±0.01	0.13**±0.03	0.73**±0.07	0.43**±0.06	-0.04±0.03	-0.25*±0.12	D
Pusa 1121 x Kasturi	2.42**±0.02	0.09**±0.03	-0.31**±0.09	-0.34**±0.09	-0.05±0.03	0.19±0.14	--
Brown rice length							
Type-3 x Adamchinni	6.32**±0.10	0.09±0.07	0.75±0.45	1.88**±0.44	-1.55**±0.11	-8.89**±0.54	--
Type-3 x BPT-5204	6.82**±0.11	0.76**±0.06	0.14±0.48	-0.50±0.44	-0.30*±0.11	-0.13±0.63	--
Type-3 x Kasturi	6.31**±0.06	-0.14±0.17	5.20**±0.45	4.88**±0.43	0.09±0.18	-4.59**±0.79	D
Pusa Sugandh-2 x Adamchinni	5.75**±0.08	1.24**±0.28	-0.97±0.69	0.48±0.65	-1.13**±0.29	-1.48±1.27	--
Pusa Sugandh-2 x BPT-5204	6.51**±0.07	0.67**±0.20	3.26**±0.55	4.24**±0.51	-1.12**±0.23	-8.72**±0.96	D
Pusa Sugandh-2 x Kasturi	8.23**±0.06	0.13±0.18	-1.19*±0.48	-1.57**±0.42	-0.33±0.19	3.38**±0.87	D
Pusa 1121 x Adamchinni	6.69**±0.06	3.00**±0.22	-0.03±0.52	-0.32±0.50	0.56*±0.24	-0.01±0.96	--
Pusa 1121 x BPT-5204	5.94**±0.08	0.75**±0.22	4.89**±0.22	5.15**±0.53	-1.09**±0.25	-6.62**±1.04	D
Pusa 1121 x Kasturi	6.36**±0.06	0.40±0.23	4.99**±0.56	5.01**±0.52	-0.22±0.26	-2.61*±1.04	D
Brown rice width							
Type-3 x BPT-5204	1.96**±0.01	0.03±0.02	0.28**±0.05	0.35**±0.05	0.00±0.02	-0.75**±0.09	D
Type-3 x Kasturi	1.97**±0.02	0.07**±0.02	0.16±0.09	0.19*±0.09	0.02±0.03	-0.48**±0.13	--
Pusa Sugandh-2 x Adamchinni	2.04**±0.02	-0.11**±0.03	0.20*±0.09	0.23*±0.08	-0.09**±0.03	-0.86**±0.14	D
Pusa Sugandh-2 x BPT-5204	2.03**±0.01	-0.06*±0.03	0.03±0.07	0.06±0.07	-0.05±0.03	-0.55**±0.14	--
Pusa Sugandh-2 x Kasturi	1.94**±0.02	0.01±0.03	0.33**±0.09	0.41**±0.08	0.01±0.03	-1.03**±0.14	D
Pusa 1121 x Adamchinni	2.02**±0.01	-0.06*±0.03	0.11±0.06	0.14*±0.06	-0.07*±0.03	-0.46**±0.12	--
Pusa 1121 x BPT-5204	2.00**±0.01	-0.01±0.03	0.17*±0.07	0.15*±0.06	-0.02±0.03	-0.41**±0.12	D
Kernel length							
Type-3 x Adamchinni	6.02**±0.10	1.15**±0.08	-2.95**±0.43	-1.68**±0.42	-0.62**±0.10	-1.93**±0.53	C
Type-3 x BPT-5204	6.62**±0.09	0.71**±0.06	0.40±0.44	-0.26±0.39	-0.34**±0.11	-0.34±0.60	--
Type-3 x Kasturi	6.17**±0.06	0.27±0.17	3.92**±0.45	3.58**±0.43	0.32±0.18	-2.50**±0.79	D
Pusa Sugandh-2 x Adamchinni	5.58**±0.08	1.27**±0.28	-0.37±0.67	0.85±0.65	-1.08**±0.29	-2.96*±0.29	--
Pusa Sugandh-2 x BPT-5204	6.21**±0.08	0.70**±0.21	4.34**±0.55	5.00**±0.51	-0.79**±0.23	-10.05**±0.96	D
Pusa 1121 x Adamchinni	6.33**±0.06	3.07**±0.20	1.32**±0.49	0.72±0.47	0.71**±0.21	-1.76*±0.87	D
Pusa 1121 x BPT-5204	5.77**±0.08	0.83**±0.22	5.41**±0.58	5.33**±0.53	-0.69**±0.24	-7.37**±1.02	D
Pusa 1121 x Kasturi	6.25**±0.06	0.52**±0.17	5.03**±0.43	4.68**±0.42	0.05±0.18	-2.74**±0.75	D

Cross combination	m	d	h	i	j	l	Type of interaction
Kernel breadth							
Type-3 x BPT-5204	1.86**±0.01	0.02±0.02	0.30**±5.43	0.38**±0.05	0.02±0.02	-0.65**±0.09	D
Type-3 x Kasturi	1.89**±0.02	0.06±0.03	0.07±0.09	0.11±0.09	0.002±0.03	-0.35**±0.13	--
Pusa Sugandh-2 x Adamchinni	1.96**±0.02	-0.12**±0.03	-0.21*±0.09	-0.14±0.09	-0.10**±0.03	-0.21±0.14	--
Pusa Sugandh-2 x Kasturi	1.90**±0.02	0.01±0.03	0.16±0.09	0.18*±0.08	-0.01±0.03	-0.66**±0.14	--
Pusa 1121 x Adamchinni	1.91**±0.01	-0.06*±0.03	0.15*±0.06	0.15*±0.06	-0.05±0.03	-0.36**±0.12	D
Pusa 1121 x BPT-5204	1.91**±0.01	-0.04±0.03	0.20**±0.07	0.15*±0.06	-0.03±0.03	-0.25*±0.12	D
L/B ratio							
Type-3 x Adamchinni	10.18**±0.09	0.90**±0.08	-1.68**±0.42	-1.25**±0.41	-0.70**±0.11	-1.28*±0.54	D
Type-3 x BPT-5204	10.85**±0.08	0.53**±0.07	-0.36±0.38	-1.17**±0.34	-0.35**±0.11	1.26*±0.54	--
Type-3 x Kasturi	10.47**±0.08	0.06±0.17	2.85**±0.49	2.45**±0.47	0.27±0.18	-0.85±0.80	--
Pusa Sugandh-2 x Adamchinni	9.71**±0.08	1.39**±0.26	0.07±0.64	0.86±0.62	-0.79**±0.27	-2.11±1.15	--
Pusa Sugandh-2 x BPT-5204	10.30**±0.07	0.72**±0.17	3.49**±0.47	4.04**±0.43	-0.64**±0.19	-7.73**±0.82	D
Pusa Sugandh-2 x Kasturi	11.82**±0.07	0.12±0.15	-0.71±0.45	-1.22**±0.41	-0.18±0.17	3.30**±0.75	--
Pusa 1121 x Adamchinni	10.48**±0.06	2.72**±0.20	0.65±0.47	-0.06±0.46	0.60**±0.21	-0.39±0.87	--
Pusa 1121 x BPT-5204	9.98**±0.07	0.75**±0.17	4.02**±0.49	4.02**±0.44	-0.56**±0.19	-5.44**±0.86	D
Pusa 1121 x Kasturi	10.39**±0.07	0.24±0.18	4.36**±0.47	4.12**±0.45	-0.03±0.18	-2.12*±0.79	D
Kernel length after cooking							
Type-3 x Adamchinni	10.08**±0.11	1.22**±0.08	-2.59**±0.46	-1.93**±0.46	-1.41**±0.11	2.15**±0.57	D
Type-3 x BPT-5204	11.84**±0.11	0.86**±0.07	-3.91**±0.49	-3.51**±0.45	-0.85**±0.12	2.45**±0.64	D
Type-3 x Kasturi	10.56**±0.06	0.26±0.18	8.45**±0.46	8.86**±0.43	0.16±0.19	-10.91**±0.80	D
Pusa Sugandh-2 x Adamchinni	9.69**±0.09	1.07**±0.28	3.26**±0.66	4.19**±0.65	-2.58**±0.29	-4.87**±1.21	D
Pusa Sugandh-2 x BPT-5204	10.87**±0.07	1.40**±6.76	0.19±0.34	2.75**±0.52	-1.19**±0.23	-6.58**±0.97	--
Pusa Sugandh-2 x Kasturi	13.60**±0.06	0.50**±0.18	1.41**±0.49	1.73**±0.43	-0.55**±0.20	-4.49**±0.89	D
Pusa 1121 x Adamchinni	11.25**±0.06	4.47**±0.20	-2.10**±0.50	0.43±0.47	-1.22**±0.23	1.21±0.89	--
Pusa 1121 x BPT-5204	9.88**±0.08	2.14**±0.22	11.14**±0.57	13.26**±0.53	-2.48**±0.24	-14.70**±1.02	D
Pusa 1121 x Kasturi	11.52**±0.06	0.52**±0.17	9.15**±0.44	10.59**±0.42	-2.64**±0.18	-7.84**±0.75	D
Kernel breadth after cooking							
Type-3 x Adamchinni	3.05**±0.01	0.21**±0.02	-0.27**±0.06	-0.23**±0.06	0.15**±0.03	-0.36**±0.11	C
Type-3 x BPT-5204	2.89**±0.01	0.14**±0.02	0.46**±0.06	0.37**±0.05	-0.26**±0.02	-1.98**±0.09	D
Pusa Sugandh-2 x Adamchinni	2.85**±0.02	-0.20**±0.03	0.92**±0.09	0.45**±0.09	-0.19**±0.03	-0.16±0.14	--
Pusa Sugandh-2 x BPT-5204	2.70**±0.01	0.31**±0.03	1.90**±0.07	1.16**±0.06	-0.02±0.03	-1.82**±0.14	C
Pusa Sugandh-2 x Kasturi	2.94**±0.02	0.07*±0.03	-0.16±0.09	-0.19*±0.08	0.04±0.03	-0.26±0.14	--
Pusa 1121 x Adamchinni	2.72**±0.01	0.35**±0.03	-0.55**±0.06	-0.52**±0.06	0.28**±0.03	1.62**±0.12	D
Pusa 1121 x BPT-5204	2.92**±0.01	0.36**±0.03	-0.47**±0.07	-0.71**±0.06	-0.05±0.03	0.32*±0.13	D
Pusa 1121 x Kasturi	3.13**±0.02	0.19**±0.03	-1.06**±0.09	-0.86**±0.09	0.08**±0.03	0.11±0.14	--

Cross combination	m	d	h	i	j	l	Type of interaction
Elongation ratio							
Type-3 x Adamchinni	7.49**±0.03	-0.31**±0.02	0.55**±0.13	0.21±0.12	0.00±0.03	2.17**±0.16	C
Type-3 x BPT-5204	7.69**±0.03	-0.11**±0.02	-1.55**±0.13	-1.01**±0.12	-0.04±0.03	1.13**±0.16	D
Type-3 x Kasturi	7.54**±0.02	-0.09*±0.05	0.55**±0.12	0.85**±0.11	-0.15**±0.05	-2.10**±0.20	D
Pusa Sugandh-2 x Adamchinni	7.63**±0.03	-0.50**±0.10	1.87**±0.24	1.34**±0.22	-0.17±0.10	-0.10±0.43	--
Pusa Sugandh-2 x BPT-5204	7.64**±0.02	0.10**±0.04	-2.37**±0.12	-1.85**±0.11	0.15**±0.05	3.29**±0.20	D
Pusa Sugandh-2 x Kasturi	7.49**±0.01	0.04±0.04	0.74**±0.11	1.08**±0.10	-0.04±0.04	-2.26**±0.19	D
Pusa 1121 x Adamchinni	7.68**±0.02	-0.36**±0.06	-1.17**±0.14	-0.02±0.14	-0.55**±0.07	0.76**±0.26	D
Pusa 1121 x BPT-5204	7.56**±0.02	0.17**±0.06	0.67**±0.17	1.26**±0.15	-0.26**±0.07	-0.78**±0.29	D
Pusa 1121 x Kasturi	7.83**±0.02	-0.147**±0.05	0.07±0.13	0.57**±0.12	-0.74**±0.05	-1.02**±0.02	--
Elongation index							
Type-3 x Adamchinni	5.93**±0.02	-0.38**±0.02	0.49**±0.10	0.34**±0.10	-0.08**±0.03	2.00**±0.14	C
Type-3 x BPT-5204	6.19**±0.02	-0.20**±0.01	-1.48**±0.10	-0.69**±0.09	0.40**±0.03	2.33**±0.13	D
Type-3 x Kasturi	6.02**±0.02	-0.11**±0.04	0.61**±0.17	1.02**±0.11	-0.15±0.09	-3.06**±0.31	D
Pusa Sugandh-2 x Adamchinni	5.92**±0.03	-0.39**±0.08	1.77**±0.20	2.00**±0.20	-0.09±0.09	-1.90**±0.36	D
Pusa Sugandh-2 x BPT-5204	6.45**±0.02	-0.30**±0.03	-4.03**±0.11	-2.74**±0.10	0.28**±0.04	4.60**±0.17	D
Pusa Sugandh-2 x Kasturi	6.05**±0.02	-0.03±0.04	0.85**±0.11	1.21**±0.10	-0.08*±0.04	-2.47**±0.17	D
Pusa 1121 x Adamchinni	6.43**±0.01	-0.87**±0.06	0.05±0.13	0.96**±0.13	-0.93**±0.06	-2.10**±0.25	--
Pusa 1121 x BPT-5204	6.11**±0.02	-0.36**±0.05	1.35**±0.14	2.11**±0.12	-0.12*±0.06	-1.30**±0.24	D
Pusa 1121 x Kasturi	6.13**±0.02	-0.22**±0.06	1.00**±0.14	1.16**±0.13	-0.63**±0.06	-0.97**±0.24	D
Alkali spread value							
Type-3 x Adamchinni	12.65**±0.08	0.39**±0.08	0.86*±0.38	0.73*±0.37	-0.45**±0.10	-3.60**±0.50	D
Type-3 x Kasturi	13.44**±0.05	0.80**±0.06	4.80**±0.25	3.29**±0.24	0.47**±0.07	-7.27**±0.35	D
Pusa Sugandh-2 x Adamchinni	13.10**±0.10	1.12**±0.06	2.74**±0.41	3.34**±0.40	-0.84**±0.07	-7.44**±0.47	D
Pusa Sugandh-2 x BPT-5204	12.84**±0.08	0.85**±0.06	5.46**±0.34	4.88**±0.34	-0.83**±0.07	-6.14**±0.41	D
Pusa Sugandh-2 x Kasturi	14.43**±0.05	0.36**±0.06	0.06±0.22	-0.55*±0.22	-1.14**±0.06	-0.78*±0.31	--
Pusa 1121 x Adamchinni	13.08**±0.11	0.48**±0.07	5.25**±0.45	4.67**±0.45	-1.40**±0.08	-7.81**±0.52	D
Pusa 1121 x BPT-5204	13.49**±0.08	1.48**±0.09	1.98**±0.36	1.58**±0.35	-0.16±0.09	-2.40**±0.49	D
Pusa 1121 x Kasturi	14.11**±0.05	0.86**±0.08	1.71**±0.26	0.77**±0.25	-0.57**±0.09	-1.34**±0.40	D
Amylose content							
Type-3 x Adamchinni	22.17**±0.19	1.05*±0.40	-6.65**±1.19	-6.52**±1.10	0.02±0.48	11.02**±1.99	D
Type-3 x BPT-5204	24.04**±0.21	-0.90*±0.45	-9.60**±1.31	-10.57**±1.24	-0.83±0.50	17.83**±2.15	D
Type-3 x Kasturi	24.45**±0.29	1.83**±0.44	-4.46**±1.50	-6.66**±1.45	1.30**±0.48	9.52**±2.22	D
Pusa Sugandh-2 x Adamchinni	25.81**±0.24	3.58**±0.43	-16.32**±1.41	-15.69**±1.30	1.28*±0.51	16.45**±2.26	D
Pusa Sugandh-2 x BPT-5204	26.87**±0.26	2.35**±0.39	-5.36**±1.35	-7.37**±1.29	1.40**±0.46	6.04**±2.03	D
Pusa Sugandh-2 x Kasturi	25.24**±0.21	2.62**±0.52	-8.39**±1.39	-9.53**±1.33	1.38*±0.55	14.36**±2.40	D
Pusa 1121 x Adamchinni	27.12**±0.23	1.12**±0.41	-22.91**±1.30	-27.34**±1.23	0.68±0.46	40.64**±2.06	D
Pusa 1121 x BPT-5204	25.04**±0.31	-1.28**±0.42	-10.19**±1.54	-11.56**±1.48	-0.95*±0.47	14.86**±2.24	D
Pusa 1121 x Kasturi	24.19**±0.25	1.62**±0.45	-6.79**±1.39	-8.71**±1.33	1.53**±0.50	15.38**±2.19	D

Cross combination	m	d	h	i	j	l	Type of interaction
Gel consistency							
Type-3 x Kasturi	44.29**±0.84	10.18**±1.03	-23.27**±4.11	-32.67**±3.95	3.35**±1.16	69.24**±5.81	D
Pusa Sugandh-2 x Adamchinni	44.53**±1.02	-8.82**±1.46	50.98**±5.17	46.37**±5.02	5.30**±1.59	-62.37**±7.54	D
Pusa Sugandh-2 x BPT-5204	47.54**±1.13	-6.75**±1.01	-51.01**±5.00	-40.06**±4.93	-2.60*±1.14	27.06**±6.26	D
Pusa Sugandh-2 x Kasturi	47.31**±0.87	3.97**±1.17	-17.69**±4.34	-21.72**±4.18	2.80*±1.28	1.85±6.27	--
Pusa 1121 x Adamchinni	42.21**±0.81	-4.08**±1.36	59.30**±4.42	54.45**±4.22	14.00**±1.54	-83.98**±6.83	D
Pusa 1121 x BPT-5204	47.37**±0.86	-14.08**±1.11	-15.03**±4.21	-34.13**±4.08	-6.05**±1.17	59.76**±5.96	D
Pusa 1121 x Kasturi	42.23**±0.83	-4.15**±0.90	-11.87**±3.93	-32.97**±3.77	-1.42±0.99	61.47**±5.36	D
Aroma							
Type-3 x Adamchinni	9.78**±0.10	0.59**±0.20	2.67**±0.64	3.09**±0.59	0.08±0.23	-3.74**±1.05	D
Type-3 x BPT-5204	8.62**±0.16	1.83**±0.41	-3.60**±1.17	-2.76**±1.05	-0.63±0.42	3.40±2.05	--
Type-3 x Kasturi	9.71**±0.11	0.73**±0.24	2.38**±0.71	2.92**±0.65	0.15±0.28	-4.01**±1.20	D
Pusa Sugandh-2 x BPT-5204	8.50**±0.21	1.69**±0.37	1.35±1.16	2.06±1.12	-0.64±0.39	-5.63**±1.82	--
Pusa Sugandh-2 x Kasturi	9.97**±0.08	0.53**±0.16	1.91**±0.53	1.64**±0.47	0.08±0.21	-1.42±0.89	--
Pusa 1121 x Adamchinni	10.12**±0.08	0.61**±0.20	1.12±0.59	1.38**±0.53	-0.06±0.24	-1.73±1.02	--
Pusa 1121 x BPT-5204	10.03**±0.13	0.28±0.23	1.56±0.84	0.93±0.69	-2.11**±0.25	-5.99**±1.42	--

Table 4. Estimation of m, d and h by three parameter model for non-interacting characters in nine crosses.

Cross combination	m	d	h
Days to 50% flowering			
Pusa 1121 x Kasturi	103.00**±2.88	13.433**±0.371	-1.247±7.76
Days to maturity			
Pusa 1121 x Kasturi	131.67**±2.896	13.43**±0.424	-8.347±7.747
Effective tillers per plant			
Pusa 1121 x Adamchinni	7.893**±1.42	1.433**±0.192	12.88**±3.35
Grain breadth			
Pusa Sugandh-2 x BPT-5204	2.154**±0.067	0.146**±0.015	0.191±0.984
Brown rice width			
Type-3 x Adamchinni	2.004**±0.056	0.018*±0.014	-0.136±0.148
Pusa 1121 x Kasturi	1.99**±0.09	0.026*±0.010	0.085±0.218
Kernel length			
Pusa Sugandh-2 x Kasturi	8.337**±0.428	0.455**±0.081	-1.60±1.198
Kernel breadth			
Type-3 x Adamchinni	1.974**± 0.06	0.013*±0.014	-0.076±0.151
Pusa Sugandh-2 x BPT-5204	1.87**±0.068	-0.035*±0.016	0.231±0.197
Pusa 1121 x Kasturi	1.995**±0.089	0.031**±0.010	-0.108±0.216
Kernel breadth after cooking			
Type-3 x Kasturi	2.923**±0.091	0.101**±0.010	0.048±0.215
Alkali digestion value			
Type-3 x BPT-5204	11.84**±0.421	0.611**±0.045	2.168*±0.916
Gel consistency			
Type-3 x Adamchinni	59.74**±4.07	-7.97**±0.620	-7.08±10.18
Type-3 x BPT-5204	37.99**±4.632	2.083**±0.568	7.437±10.55
Aroma			
Pusa Sugandh-2 x Adamchinni	10.05**±0.642	0.485*±0.137	0.104±1.74
Pusa 1121 x Kasturi	10.317**±0.514	0.563**±0.140	0.181±1.462

Heterosis and Inbreeding depression in aromatic rice (*Oryza sativa* L.)

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Abstract

The present study was undertaken to assess the heterosis and inbreeding depression for yield and quality traits in rice from nine F₁ hybrids derived from three male and three female lines. Majority of the hybrids recorded high heterosis for grain yield. Among the various hybrids exhibiting desirable value of heterosis, Pusa Sugandh-2 x BPT-5204, Pusa 1121 x Adamchini and Type-3 x BPT-5204 were top performers for grain yield per plant. For quality traits, cross Pusa Sugandh-2 x Kasturi revealed better performance for majority of the traits. When both yield and quality characters were considered Type-3 x Adamchini was the best cross combination. Significant inbreeding depression was recorded for yield attributing traits and most of the quality related traits.

Key words: heterosis, inbreeding depression, rice.

INTRODUCTION

Rice is the staple food for more than fifty per cent of world's population. It is cultivated in 114 countries across the globe, but 90 percent of world's rice is grown and consumed in Asia. It was cultivated worldwide in 160.9 m. ha with production of 481.73 million tonnes (on milled basis). In India it occupied 44.5 m. ha with production of 106.5 million tons (2015-16).

The major production and productivity gains have enabled the country to attain self sufficiency in rice since mid 1980's. Indian exporters entered into the world rice trade largely through the export of small quantities of highly priced basmati rice which was less than 5% in mid 1980's. Basmati, the unique aromatic quality rice is a nature's gift to Indian sub-continent. Epicureans acclaim its delightful fragrance, taste and texture which makes it the best among the aromatic rices of the world. During 2015-16 India exported 10.34 Mt of rice earning very high foreign exchange to the tune of Rs. 37,847.36 crores. Of this amount 22,718.35 crores was due to basmati (4.04 m.t) and 15,129.01 crores was due to non basmati rice (6.3 m.t) export (APEDA 2016). This statistics show the importance of increase in production of aromatic rice. But many of the aromatic rices are low yielders prone to lodging because of their tall stature and susceptible to pest and diseases.

Exploitation of hybrid vigour is one of the possible ways for increasing production and productivity of aromatic rices. The estimation of heterosis and inbreeding depression together provide information about the type of gene action involved in the expression of various quantitative traits. If high heterosis is followed by inbreeding depression, it indicates the presence of non additive gene action (dominance and epistasis). If the performance is almost same in F_1 and F_2 , it reveals the presence of additive genes. If the heterosis is negative in F_1 and there is increase in F_2 , it again indicates presence of additive gene action. Therefore, the present study was carried out with an objective to estimate extent of heterosis and inbreeding depression for grain quality, yield and yield contributing characters.

MATERIALS AND METHODS

The present investigation was carried out during three seasons viz., kharif-2013, kharif-2014 and kharif-2015 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (UP). The site of study is situated at $25^{\circ} 18' N$ latitude and $83^{\circ} 03' E$ longitude, at an elevation of 80.71 m above mean sea level. The research material in the present study consisted of six parental genotypes in which Pusa 1121, Pusa Sugandh-2, Type-3 were used as female parents and Kasturi, BPT-5204 and Adamchinni used as male parents in the hybridization programme. All the six genotypes were obtained from 'All India Coordinated Rice Improvement Project (AICRIP)' at the Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University.

During kharif-2013, all the genotypes were seeded in nursery at 3 dates, 10 days apart and transplanted in crossing blocks at 21 days after sowing. The three male parents were crossed with the three female parents to generate the set of nine rice hybrids in line x tester mating design. In kharif-2014 the seed of F_1 hybrids generated during previous season along with parental lines were raised. F_1 's were selfed to produce F_2 seeds. Fresh F_1 's were prepared for the nine cross combinations. In kharif-2015 the seed of F_1 's and F_2 's along with parental lines were raised at a standard spacing of 20 x 15 cm in 5 m rows in compact family random block design with three replications.

The recommended package of practices was followed to raise a good crop. Observations were recorded for ten plants of parents and F_1 's and 50 plants from each F_2 population from each replication for both yield and quality traits viz., days to 50 per cent flowering, days to maturity, plant height, number of effective tillers per plant, number of grains per panicle, 100 grain weight, yield per plant, hulling recovery,

milling recovery, head rice recovery, grain length, grain breadth, brown rice length, brown rice breadth, kernel length, kernel breadth, L/B ratio, kernel length after cooking, kernel breadth after cooking, elongation ratio, elongation index, alkali digestion value, amylose content, gel consistency test and aroma. Grain, brown rice and kernel dimensional analysis was done with the help of electronic grain analyzer. The observations for various traits were recorded as per the standard evaluation system of IRRI (1988). The ratio's and percentages are converted in to arc sine values for applying stastical methods

Heterosis was estimated as the percent change over the better parent and also over check varieties Pusa RH-10 (SH1) and Pusa Basmati-1(SH2) for yield and Pusa RH-10 (SH1) and Taraori Basmati (SH2) for quality parameters. Inbreeding depression was expressed as per cent decrease observed in F_2 over F_1 as $F_1 - F_2 \times 100 / F_1$, where F_2 is mean of F_2 'S (Srivastava (1991).

RESULTS AND DISCUSSION

For days to flowering and days to maturity significant negative heterosis was desirable so that early flowering and early maturing hybrids could be obtained. As compared to better parent and Pusa RH-10, significant early flowering and maturity was observed in two crosses and over Pusa Basmati-1, three and four crosses showed significant negative desirable heterosis for flowering and maturity respectively. Cross Pusa Sugandh-2 x Kasturi showed highest significant negative heterosis over better parent and standard checks. A wide range of standard heterosis from negative to positive values have been reported by Rani *et al.*, (2015), Balakrishna and Satyanarayana (2015) and Nayak *et al.*, (2015) for the trait days to 50 per cent flowering. Significant desirable standard heterosis for earliness has been reported by Jayasudha and Sharma (2009) and Rahimi *et al.* (2010). All the crosses showed significant inbreeding depression for days to flowering and maturity.

Semi dwarf plant phenotype is desirable for recording high yield in rice as partitioning of biomass is affected and it also reduces lodging. For plant height, all the F_1 's were taller than their respective better parents and standard check Pusa RH-10. Only one cross was negatively significant over Pusa Basmati-1. Sarawgi *et al.* (2000), Vaithiyalingan and Nadarajan (2010), Tiwary *et al.* (2011), and Sanghera and Hussain (2012) observed significant positive estimates of heterobeltiosis and standard

heterosis for tallness which support the findings of the present investigation. Careful selection of the parents for plant height, to be involved in crosses, would effectively reduce the height in the F_1 's. Eight out of nine crosses recorded significant inbreeding depression for trait plant height.

For effective tillers per plant, positive heterosis was desirable as it increases the more number of panicle bearing tillers and which directly increase grain yield per plant. In the present study, all crosses showed significant positive heterosis over better parent and Pusa Basmati-1 and five crosses showed significant positive heterosis over Pusa RH-10. Cross Pusa 1121 x Adamchini showed highest significant positive heterosis over better parent and Pusa Sugandh-2 x BPT-5204 recorded highest significant positive heterosis over both standard checks. For number of effective tillers significantly positive heterosis was earlier observed by Sunil *et al.*, (2014), Rani *et al.*, (2015), Balakrishna and Satyanarayana (2015) and Nayak *et al.*, (2015) . All the crosses recorded significant inbreeding depression.

Positive heterosis is desirable for number of grains per panicle as it affects grain yield per plant directly. All crosses showed significant positive heterosis over standard checks and six crosses showed significant positive heterosis over better parent. Cross Pusa Sugandh-2 x BPT-5204 showed highest significant positive heterosis over better parent and both standard checks. Nayak *et al.*, (2015) reported significant negative heterosis over standard checks for the trait while Rani *et al.*, (2015) reported significant positive heterobeltiosis for grains per panicle. All the crosses observed significant inbreeding depression.

For 100-grain weight positive heterosis is desirable. None of the crosses showed positive significant heterosis over better parent. However, four crosses showed significant positive heterosis over standard checks. Cross Pusa 1121 x Kasturi showed highest significant positive heterosis over standard checks. Similar heterotic values for 100 grain weight were observed by Rani *et al.*, (2015), Balakrishna and Satyanarayana (2015) and Nayak *et al.*, (2015). All the crosses showed significant inbreeding depression. Verma and Srivastava (2005) reported significant inbreeding depression.

Heterosis in positive direction for grain yield is desirable as higher grain yield is the main objective for all breeding programmes. Virmani *et al.* (1981) suggested that the yield advantage of 20% to 30% over best available standard variety should be sufficient to encourage farmers for adopting the hybrid rice varieties. All crosses

exhibited significant positive heterosis over better parent and Pusa Basmati-1 and four crosses exhibited significant positive heterosis over Pusa RH-10. Cross Type-3 x Adamchini recorded highest significant positive heterosis over better parent. However, highest significant positive standard heterosis over the both checks was exhibited by Pusa Sugandh-2 x BPT-5204. High magnitude of standard heterosis for grain yield in rice was earlier observed by Rani *et al.*, (2015), Balakrishna and Satyanarayana (2015) and Nayak *et al.*, (2015).

All the crosses observed significant inbreeding depression. Cross Pusa Sugandh-2 x BPT-5204 recorded highest significant inbreeding depression. Singh *et al.*, (2015) reported non significant inbreeding depression for one cross. Ram, (1992), Reddy and Nerkar, (1995), Verma and Srivastava (2005), Venkanna *et al.*, (2010) reported significant inbreeding depression for this trait.

For hulling and milling recovery positive heterosis was desirable as it decides the amount of marketable produce. One Cross (Pusa 1121 x BPT-5204) and two crosses (Pusa 1121 x BPT-5204, Pusa 1121 x Kasturi) displayed significant positive heterosis over the better parent for hulling and milling recovery respectively. Five and six crosses showed significant positive heterosis over Pusa RH-10 for hulling and milling recovery respectively. Six crosses showed significant positive heterosis over Pusa Basmati-1. The highest value of better parent heterosis was exhibited by Pusa 1121 x BPT-5204, whereas the highest significant positive heterosis over standard checks was shown by Type-3 x Adamchini. Singh (2000) observed significant negative standard heterosis for hulling recovery in majority of the Hybrids studied. The range of heterosis reported by Sarawgi *et al.* (2000) for milling recovery was similar to the present finding. Babu *et al.* (2013) tested various rice hybrids and reported statistically similar milling percentage. All the crosses showed significant inbreeding depression.

Higher magnitude of heterosis is desirable for head rice recovery as it leads to substantial production of marketable produce. All crosses recorded significant positive heterosis over standard checks and three crosses recorded significant positive heterosis over better parent. Cross Pusa Sugandh-2 x Adamchini showed highest significant positive heterosis over better parent and standard checks. Sarawgi *et al.*

(2000) reported that the range of heterosis for head rice recovery varied in both positive and negative directions, which is quite similar to the results of present investigation. All the crosses showed significant inbreeding depression.

For trait grain length positive heterosis was desirable. One Cross showed significant positive heterosis over better parent and Taraori Basmati and two crosses showed significant positive heterosis over Pusa RH-10. Cross Pusa 1121 x Kasturi showed significant positive heterosis over better parent and standard checks. Seven crosses showed significant inbreeding depression. Chauhan and Chauhan, (1995) and Venkanna *et al.*, (2010) reported neither heterosis nor inbreeding depression.

Negative heterosis was desirable for grain breadth. None of the crosses showed significant negative heterosis over better parent, whereas seven crosses showed significant negative heterosis over Pusa RH-10 and six crosses showed significant negative heterosis over Taraori Basmati. Cross Type-3 x BPT-5204 recorded the highest negative value of heterosis over both the check varieties. Six crosses recorded significant inbreeding depression. Venkanna *et al.*, (2010) reported significant inbreeding depression for grain breadth.

For trait brown rice length positive heterosis was desirable. None of the crosses showed significant positive heterosis over better parent, two crosses showed significant positive heterosis over standard checks. Cross Pusa Sugandh-2 x Kasturi showed highest significant positive heterosis over both standard checks. Five crosses showed significant inbreeding depression.

Negative heterosis is desirable for character brown rice breadth. None of the crosses showed significant negative heterosis over better parents and standard checks. Two crosses showed significant inbreeding depression.

The kernel length is the most important trait which decides the market price of rice hence significant heterosis was desirable for this trait. Two crosses showed significant positive heterosis over standard checks and none of the crosses showed significant positive heterosis over better parent. Pusa Sugandh-2 x Kasturi showed highest significant positive heterosis over both standard checks. Sanghera and Hussain (2012), Reddy *et al.* (2012) and Priyanka *et al.* (2014) reported positive estimates of standard heterosis for kernel length. In contrast, Sarawgi *et al.* (2000)

reported the estimates of standard heterosis in negative direction only. Five crosses showed significant inbreeding depression. Verma and Srivastava (2005) reported low inbreeding depression for this trait.

Lower magnitude of kernel breadth ensures grain fineness. Thus, negative value of heterosis for kernel breadth before cooking would be desirable. None of the crosses showed significant negative heterosis over better parents and standard checks. Similar findings were observed by Sanghera and Hussain (2012), and Reddy *et al.* (2012) for kernel breadth. One cross Pusa Sugandh-2 x Adamchini showed significant inbreeding depression.

Kernel length/breadth ratio is one of the important physical traits determining the quality of rice grain. A higher magnitude of kernel length/breadth ratio was desirable. None of the crosses showed significant positive heterosis over better parents and standard checks. Reddy *et al.* (2012) reported lower values for kernel length/breadth ratio than the check varieties in most of the cross combinations studied. Three crosses recorded significant inbreeding depression. Similar findings were observed by Reddy *et al.*, (1991) and Venkanna *et al.*, (2014). Verma and Srivastava (2005) reported significant low inbreeding depression.

Higher magnitude of kernel length after cooking is desirable. One cross Pusa 1121 x Kasturi exhibited significant positive heterosis over Taraori Basmati and none of the crosses exhibited significant positive heterosis over better parent and Pusa RH-10. A range of values from low to high for kernel length after cooking has been observed by Srivastava and Jaiswal (2013). Five crosses observed significant inbreeding depression.

Lower value of kernel breadth after cooking and thus its heterosis in negative direction was desirable. None of the crosses showed significant negative heterosis over better parents and standard checks. A range of values for kernel breadth after cooking has been observed by Srivastava and Jaiswal (2013). Eight crosses observed significant inbreeding depression. The positive inbreeding depression value suggests the mean of F_2 is lower than F_1 mean which means the kernel breadth after cooking is reducing in F_2 which was desirable.

Kernel elongation ratio is an important cooking quality character of the rice grain and positive heterosis is desirable for this trait. One cross showed significant positive heterosis over better parent and two crosses showed significant positive

heterosis over standard checks. Pusa Sugandh-2 x Adamchini showed high significant positive heterosis over better parent and standard checks. Sarawgi *et al.* (2000) reported both higher and lower values for kernel elongation ratio than the standard checks. Significant inbreeding depression was recorded for four crosses.

Elongation index is an important measure of kernel expansion upon cooking that involves both length-wise and breadth-wise components. Higher value of elongation index is considered to be desirable. One cross Type-3 x Adamchini showed significant positive heterosis over Pusa RH-10 and none of the crosses showed significant positive heterosis over better parent and Taraori Basmati. Three crosses showed significant inbreeding depression.

For alkali spread value intermediate value is preferable. Two crosses showed significant positive heterosis over better parent, one cross and seven crosses showed significant positive heterosis over Pusa RH-10 and Taraori Basmati respectively. Cross Type-3 x BPT-5204 showed highest significant positive heterosis over better parent, cross Pusa 1121 x Kasturi recorded highest significant positive heterosis over standard checks. Eight crosses recorded significant inbreeding depression.

For amylose content intermediate types (20-25) are preferable. Three crosses showed significant positive heterosis over better parent and seven crosses showed significant positive heterosis over standard checks. Cross Pusa 1121 x Adamchini showed highest significant positive heterosis over better parent and standard checks. Significant inbreeding depression was observed for four crosses.

For trait gel consistency higher value and positive heterosis was desirable. Four Hybrids showed significant positive heterosis over better parent, two crosses showed significant positive heterosis over Pusa RH-10 and none of the crosses showed significant positive heterosis over Taraori Basmati. Cross Pusa 1121 x Kasturi showed high significant positive heterosis over better parent and cross Pusa 1121 x BPT-5204 showed highest significant positive heterosis over Pusa RH-10. All the crosses showed significant inbreeding depression.

For aroma significant positive heterosis was desirable. Two crosses showed significant positive heterosis over Pusa RH-10 while none of the crosses showed

significant positive heterosis over better parents and Taraori Basmati. Cross Pusa Sugandh-2 x Kasturi showed highest significant positive heterosis over Pusa RH-10. Two crosses showed significant inbreeding depression.

Conclusion

The findings of present study indicated that majority of the hybrids recorded high heterosis for grain yield. Among the various hybrids exhibiting desirable value of heterosis, Pusa Sugandh-2 x BPT-5204, Pusa 1121 x Adamchini and Type-3 x BPT-5204 were top performers for grain yield per plant. The hybrid, Pusa Sugandh-2 x BPT-5204 recorded highest yield per plant, and was among the best three performers for traits, plant height, effective tillers per plant, number of grains per panicle and hundred seed weight. For quality traits, cross Pusa Sugandh-2 x Kasturi revealed better performance for majority of the traits. When both yield and quality characters were considered Type-3 x Adamchini was the best cross combination. Significant inbreeding depression was recorded for yield attributing traits and most of the quality related traits except brown rice breadth, kernel breadth, L/B ratio, elongation ratio, elongation index, amylose content and aroma.

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Table 1 : Estimates of better parent heterosis, standard heterosis and inbreeding depression for yield traits of rice during *Kharif* – 2015

Traits Crosses	Days to 50% flowering				Days to Maturity				Plant Height				Effective tillers/plant			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	19.93**	29.94**	12.92**	11.47**	13.57**	21.35**	3.81**	9.28**	9.52**	64.33**	57.01**	17.69**	60.14**	27.86**	67.81**	37.65**
Type-3 x BPT-5204	6.89**	15.81**	0.64	12.04**	3.79**	10.90**	-5.13**	9.79**	49.15**	40.77**	34.49**	2.77*	21.16**	14.50*	50.31**	35.68**
Type-3 x Kasturi	-4.36*	-9.75**	21.57**	16.16**	-5.30**	-8.85**	22.02**	12.24**	21.05**	30.60**	24.78**	14.29**	39.27**	11.21	45.94**	32.89**
Pusa Sugandh-2 x Adamchinni	25.39**	31.74**	14.49**	6.09**	17.71**	22.85**	5.08**	4.98**	55.42**	73.87**	66.11**	14.95**	52.24**	5.50	38.44**	25.87**
Pusa Sugandh-2 x BPT-5204	15.70**	21.57**	5.64**	5.03**	10.47**	15.30**	-1.37	4.23**	3.7	-2.13	-6.50**	1.69	53.40**	45.00**	90.31**	46.73**
Pusa Sugandh-2 x Kasturi	-5.22**	10.56**	22.28**	-8.55**	-6.06**	-9.58**	22.65**	-6.65**	14.35**	23.37**	17.87**	20.71**	46.74**	1.64	33.44**	35.08**
Pusa 1121 x Adamchinni	5.35**	30.20**	13.14**	8.66**	2.85**	21.89**	4.27**	7.23**	4.09*	14.90**	9.78**	3.2*	77.19**	38.07**	81.25**	27.72**
Pusa 1121 x BPT-5204	3.62**	28.06**	11.28**	5.29**	1.28	20.03**	2.67*	4.33**	11.71**	4.9**	0.223	-5.92**	42.32**	34.50**	76.56**	40.96**
Pusa 1121 x Kasturi	10.14**	3.94*	-9.68**	-6.91**	5.44**	1.49	13.18**	-5.49**	8.26**	16.80**	11.59**	18.95**	40.22**	9.29	43.44**	29.41**
Range of heterosis& I.D	-5.22 to 25.39-	-10.56 to 31.74	-21.57 to 14.49	16.16to 12.04	-6.06 to 17.71	-9.58 to 22.85	-22.65 to 5.08	12.23to 9.789	3.7 to 55.42	-2.13 to 73.87	-6.50 to 66.11	1.69 to 20.71	21.16 to 77.19	1.64 to 45	33.44 to 90.31	25.87to 46.73
Number of hybrids with significant positive heterosis& I.D	7	7	5	6	6	6	4	6	8	8	7	8	9	5	9	9
Number of hybrids with significant negative heterosis& I.D	2	2	3	3	2	2	4	3	0	0	1	1	0	0	0	0

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Pusa Basmati-1. Inbreeding depression (I.D)

Cont..

Traits Crosses	No. of grains per panicle				100 grain weight				Grain yield per plant			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	6.98**	123.71**	78.97**	28.63* *	-11.72**	-20.23**	-13.48**	- 33.82* *	145.24**	37.88**	134.41**	13.66**
Type-3 x BPT-5204	-5.74**	65.46**	32.37**	32.27* *	-5.81**	-14.88**	-7.68**	- 24.65* *	86.31**	29.30**	119.82**	21.88**
Type-3 x Kasturi	21.90**	64.25**	31.40**	18.7**	-12.52**	-15.46**	-8.31**	- 20.31* *	61.99**	-6.20	59.44**	15.33**
Pusa Sugandh-2 x Adamchinni	3.58**	116.61**	73.29**	33.31* *	-28.28**	-20.95**	-14.26**	- 20.92* *	59.34**	3.71	76.29**	17.24**
Pusa Sugandh-2 x BPT-5204	41.41**	148.25**	98.60**	29.62* *	-4.16**	5.64**	14.58**	- 20.97* *	115.82**	49.78**	154.63**	25.38**
Pusa Sugandh-2 x Kasturi	5.92**	50.75**	20.60**	33.45* *	-0.75	9.39**	18.65**	2.92**	61.55**	5.41	78.74**	19.84**
Pusa 1121 x Adamchinni	-31.00**	44.29**	15.43**	21.29* *	-41.69**	-29.19**	-23.20**	- 67.47* *	142.40**	41.70**	140.91**	21.62**
Pusa 1121 x BPT-5204	-14.94**	49.32**	19.46**	19.68* *	-11.22**	7.80**	16.93**	- 13.36* *	49.82**	3.98	76.77**	22.55**
Pusa 1121 x Kasturi	15.44**	41.64**	13.31**	28.72* *	1.63	23.41**	33.86**	4.125* *	60.71**	-6.06	59.72**	20.84**
Range of heterosis & I.D	-31 to 41.41	41.64 to 148.25	13.31 to 98.60	18.7to 33.45	-41.69 to 1.63	-29.19 to 23.41	-23.20 to 33.86	-67.47 to4.13	49.82 to 145.24	-6.20 to 49.78	59.44 to 154.63	13.66to 25.38
Number of hybrids with significant positive heterosis & I.D	6	9	9	9	0	4	4	2	9	4	9	9
Number of hybrids with significant negative heterosis & I.D	3	0	0	0	7	5	5	7	0	0	0	0

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Pusa Basmati-1. Inbreeding depression (I.D)

Table 2: Estimates of better parent heterosis, standard heterosis and inbreeding depression for quality traits of rice during Kharif - 2015

Traits Crosses	Hulling				Milling				Head rice recovery				Grain length			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	0.48	8.14**	10.55**	10.85**	1.44	10.59**	10.89**	12.19**	1.98	26.94**	25.14**	8.43**	-	-	-	-
Type-3 x BPT-5204	-1.58	3.28*	5.58**	9.03**	0.86	6.61**	6.91**	9.18**	3.83**	28.30**	26.48**	11.93**	-	-	-	-
Type-3 x Kasturi	-	4.86**	-0.16	2.06	8.16**	-1.26	4.36**	4.66**	9.5**	1.81	24.05**	22.29**	12.53**	-3.41	-0.10	-8.46*
Pusa Sugandh-2 x Adamchinni	-0.76	6.81**	9.18**	10.72**	0.85	9.95**	10.25**	8.59**	4.01**	29.47**	27.64**	13.4**	-	-	-	-
Pusa Sugandh-2 x BPT-5204	2.10	5.37**	7.72**	10.33**	1.25	3.07*	3.37*	8.59**	1.40	25.30**	23.52**	12.55**	-	-	-	-
Pusa Sugandh-2 x Kasturi	-	4.25**	-1.18	1.02	9.36**	-2.39*	-0.64	-0.34	7.14**	1.45	20.55**	18.84**	11.25**	3.07	11.13**	1.83
Pusa 1121 x Adamchinni	-	6.24**	0.91	3.15*	7.35**	-	7.59**	0.74	1.04	5.97**	1.35	26.17**	24.38**	9.26**	-	-
Pusa 1121 x BPT-5204	3.62**	5.57**	7.92**	11.16**	3.21*	4.98**	5.28**	7.56**	3.36**	27.72**	25.91**	12.49**	-	-	-	-
Pusa 1121 x Kasturi	-2.13	-1.22	0.98	11.88**	2.44*	2.31	2.61	11.8**	1.01	20.03**	18.33**	8.3**	9.07*	19.83**	9.80**	11.64**
Range of heterosis	-6.24 to 3.62	-1.22 to 8.14	0.98 to 10.55	7.35 to 11.88	-7.59 to 3.21	-0.64 to 10.59	-0.34 to 10.89	5.97 to 12.19	1.01 to 4.01	20.03 to 29.47	18.33 to 27.64	8.3 to 13.4	-34.32 to 9.07	-37.54 to 19.83	-42.77 to 9.80	-48.75 to 11.64
Number of hybrids with significant positive heterosis	1	5	6	9	2	6	6	9	3	9	9	9	1	2	1	3
Number of hybrids with significant negative heterosis	3	0	0	0	2	0	0	0	0	0	0	0	6	5	7	4

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Taraori Basmati. Inbreeding depression (I.D)

Cont...

Traits Crosses	Grain width				Brown rice length				Brown rice width				Kernel length			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	-1.46	-16.60**	-13.14**	- 11.69 **	-38.18**	-38.62**	-38.95**	- 41.23 **	-4.05	1.25	2.89	-2.43	-42.81**	-42.86**	-43.33**	- 48.1* *
Type-3 x BPT-5204	-1.72	-16.87**	-13.43**	- 11.05 **	-5.36	-6.03	-6.55	0.57	-1.32	2.49	4.16	-2.4	-5.32	-5.39	-6.18	1.7
Type-3 x Kasturi	-3.88	-14.95**	-11.43**	- 10.6* *	1.54	6.44	5.86	18.68 **	0.52	3.38	5.06	-1.98	3.93	5.57	4.69	17.78 **
Pusa Sugandh-2 x Adamchinni	2.76	-13.03**	-9.43**	- 20.93 **	-43.50**	-32.82**	-33.18**	- 17.46 *	-0.17	2.67	4.34	- 6.02* *	-42.66**	-34.61**	-35.16**	- 19.9* *
Pusa Sugandh-2 x BPT-5204	3.96	-12.07**	-8.43**	-2.87	-31.25**	-18.24**	-18.68**	-9.19	-3.98	-1.25	0.36	-6.5*	-27.75**	-17.61**	-18.30**	-5.83
Pusa Sugandh-2 x Kasturi	2.33	-9.47**	-5.71*	- 14.7* *	-2.23	16.27**	15.64**	2.93	-3.98	-1.21	0.32	-5.01	1.41	15.64**	14.68**	3.91
Pusa 1121 x Adamchinni	7.78*	-8.78**	-5	1.7	-24.51**	-8.59	-9.09	-0.27	-1.01	4.45	6.15*	-3.03	-20.12**	-8.01	-8.78	3.33
Pusa 1121 x BPT-5204	23.91**	4.80	9.14**	11.88**	-23.83**	-7.77	-8.27	11.72*	2.11	6.05*	7.78*	-0.86	-19.14**	-6.89	-7.66	13.05**
Pusa 1121 x Kasturi	7.60*	-4.80	-0.86	-4.7	-7.11	12.48*	11.86*	22.45**	1.90	4.80	6.51*	-2.45	-1.29	13.68**	12.73*	22.64**
Range of heterosis	-3.88 to 23.91	-16.87 to 4.80	-13.43 to 9.14	-20.93 to 11.88	-43.50 to 1.54	-38.62 to 16.27	-38.95 to 15.64	-41.23 to 22.45	-4.05 to 2.11	-1.21 to 6.05	0.32 to -0.86	-6.5 to -0.86	-42.81 to 3.93	-42.86 to 15.64	-43.33 to 14.68	-48.1 to 1.7
Number of hybrids with significant positive heterosis	3	0	1	5	0	2	2	3	0	1	3	0	0	2	2	3
Number of hybrids with significant negative heterosis	0	7	6	1	5	3	3	2	0	0	0	2	5	3	3	2

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Taraori Basmati. Inbreeding depression (I.D)

Cont..

Crosses	Kernel width				L/B ratio				Kernel length after cooking				Kernel breadth after cooking			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	-4.20	7.66*	6.82	-5.01	-18.47**	23.85**	24.24**	-12.87*	25.97**	33.67**	30.26**	-8.11*	0.68	5.74*	19.13**	-7.99**
Type-3 x BPT-5204	-3.41	9.04*	8.19*	-0.57	-0.54	-7.11*	-7.59**	1.25	16.62**	25.30**	21.46**	-12.79	23.66**	-1.75	10.69**	-10.08**
Type-3 x Kasturi	0.92	8.25*	7.41*	-2.88	1.69	-1.28	-1.80	10.4*	-4.24	14.20**	-9.8**	12.41*	9.14**	11.24**	25.32**	0.79
Pusa Sugandh-2 x Adamchinni	-2.75	6.29	5.46	8.9**	23.66**	22.01**	22.42**	-5.32	30.64**	28.14**	24.45**	4.09	17.03**	22.35**	37.83**	12.73**
Pusa Sugandh-2 x BPT-5204	2.28	11.79**	10.92**	-2.02	16.15**	14.34**	14.78**	-1.84	36.06**	33.76**	30.36**	-16.64*	51.01**	19.98**	35.16**	15.55**
Pusa Sugandh-2 x Kasturi	-0.55	6.68	5.85	-4.82	1.75	3.95	3.41	3.85	-9.52**	-6.26*	-1.45	-3.19	2.89	4.87*	18.14**	-5.04*
Pusa 1121 x Adamchinni	0.71	11.79**	10.92**	-0.72	11.04**	-9.55**	10.02**	2.14	43.74**	25.34**	21.51**	-7.15	1.63	6.74**	20.25**	4.65*
Pusa 1121 x BPT-5204	3.36	14.73**	13.84**	1.98	11.54**	10.05**	10.52**	6.10	36.88**	16.24**	11.94**	16.1**	30.26**	3.5	16.60**	-5.62*
Pusa 1121 x Kasturi	2.38	9.82*	8.97*	-3.89	-0.05	1.63	1.10	13.71**	24.21**	0.57	5.73*	18.49**	-3.23	-1.37	11.11**	19.04**
Range of heterosis	-4.20 to 3.36	6.29 to 14.73	5.46 to 13.84	-8.9 to 1.98	-23.66 to 1.75	-23.85 to 3.95	-24.24 to 3.41	-12.87 to 13.71	-43.74 to -4.24	-33.76 to 0.57	-30.36 to 5.73	-16.64 to 18.49	-3.23 to 51.01	-1.75 to 22.35	10.69 to 37.83	-19.04 to 15.55
Number of hybrids with significant positive heterosis	0	7	6	0	0	0	0	2	0	0	1	3	5	6	9	3
Number of hybrids with significant negative heterosis	0	0	0	1	5	6	6	1	8	8	7	2	0	0	0	5

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Taraori Basmati. Inbreeding depression (I.D)

Cont..

Traits Crosses	Elongation ratio				Elongation index				Alkali spread value			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	0.24	3.28**	5.85**	9.85**	-2.22	2.88**	1.55	11.12	-5.36**	-14.35**	-8.23**	-3.84*
Type-3 x BPT-5204	-8.12**	-10.46**	-8.24**	-6.86*	-18.82**	-6.78**	-7.98**	-2.58	11.69**	1.09	8.31**	9.48**
Type-3 x Kasturi	-4.76**	-9.33**	-7.07**	-3.41	-8.05**	-11.83**	-12.97**	-8.36	8.92**	-1.43	5.62**	4.14**
Pusa Sugandh-2 x Adamchinni	3.08*	6.21**	8.85**	10.66*	-7.22**	-2.39	-3.64**	6.44	-16.74**	-11.33**	-5.00**	-3.87**
Pusa Sugandh-2 x BPT-5204	-7.15**	-9.52**	-7.26**	-4.97	-24.92**	-13.78**	-14.89**	-15.47*	-7.38**	-1.36	5.68**	8.50**
Pusa Sugandh-2 x Kasturi	-5.37**	-9.34**	-7.08**	-2.67	-6.56**	-9.49**	-10.66**	-3.25	-5.87**	0.25	7.41**	-1.15
Pusa 1121 x Adamchinni	-16.12**	-9.42**	-7.17**	-5.44*	-14.54**	-8.48**	-9.66**	-8.38	-8.85**	-3.29**	3.62**	4.88**
Pusa 1121 x BPT-5204	-11.40**	-4.32**	-1.93	1.79	-13.30**	-0.43	-1.72	5.40	-8.03**	-2.42*	4.55**	2.83*
Pusa 1121 x Kasturi	-12.45**	-5.45**	-3.10*	-2.92	-7.97**	-1.44	-2.72*	4.00	-3.08**	2.84*	10.18**	3.55**
Range of heterosis	-16.12 to 3.08	-10.46 to 6.21	-8.24 to 8.85	-6.86 to 10.66	-24.92 to -2.22	-13.78 to 2.88	-14.89 to 1.55	-15.47to 11.12	-16.74 to 11.69	-14.35 to 2.84	-8.23 to 10.18	-3.87 to 9.48
Number of hybrids with significant positive heterosis	1	2	2	2	0	1	0	0	2	1	7	6
Number of hybrids with significant negative heterosis	7	7	6	2	8	5	7	1	7	4	2	2

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Taraori Basmati. Inbreeding depression (I.D)

Traits Crosses	Amylose content				Gelconsistency				Aroma			
	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D	BPH	S.H1	S.H2	I.D
Type-3 x Adamchinni	-5.22	-3.47	4.31	-2.64	-18.66**	0.58	-36.88**	-7.81**	-7.29**	2.20	-10.39**	3.91
Type-3 x BPT-5204	4.0	5.91*	14.46* *	-1.44	1.86	-6.0**	-41.01**	12.50**	-26.51**	-18.99**	-28.97**	-12.40
Type-3 x Kasturi	7.95**	9.94**	18.80* *	0.62	4.8*	-3.29	-39.31**	11.35**	-9.82**	-0.59	-12.83**	1.87
Pusa Sugandh-2 x Adamchinni	-11.84**	-2.73	5.12	- 18.59* *	-14.80**	5.35**	-33.89**	18.19**	-10.81**	-3.97*	-15.79**	-4.15
Pusa Sugandh-2 x BPT-5204	4.09	14.85**	24.11* *	-4.54*	-34.25**	-44.26**	-65.02**	-65.06**	-26.65**	-21.02**	-30.75**	-9.40*
Pusa Sugandh-2 x Kasturi	-0.23	10.08**	18.96* *	-2.46	8.79**	-24.65**	-52.71**	-21.52**	-1.65	5.89**	-7.15**	5.65*
Pusa 1121 x Adamchinni	16.37**	15.45**	24.76* *	-5.00*	-20.38**	-1.55	-38.22**	17.01**	-7.22**	2.73	-9.92**	1.23
Pusa 1121 x BPT-5204	4.16	5.76*	14.29* *	-5.84*	25.11**	6.06**	-33.44**	13.55**	-13.28**	-3.97*	-15.79**	-7.73
Pusa 1121 x Kasturi	10.68**	10.08**	18.96* *	1.82	53.82**	0.004	-37.25**	18.26**	-5.29**	4.87*	-8.04**	0.50
Range of heterosis	-11.84 to 16.37	-3.47 to 15.45	4.31 to 24.76	-18.59 to 1.82	-34.25 to 53.82	-44.26 to 6.06	-65.02 to -33.44	-65.06 to 18.26	-26.65 to -1.65	-21.02 to 5.89	-30.75 to -7.15	-12.40 to 5.65
Number of hybrids with significant positive heterosis	3	7	7	0	4	2	0	6	0	2	0	1
Number of hybrids with significant negative heterosis	1	0	0	4	4	3	9	3	8	4	9	1

*, ** = Significant at 0.05 and 0.01 levels, respectively. Standard Heterosis 1 (S.H1) = PRH-10, Standard Heterosis 2 (S.H2) = Taraori Basmati. Inbreeding depression (I.D)

CURRICULUM VITAE

Personal Profile

Name : **Mr. T. Sravan**
Father's Name : Shri T. Sivudu
Mother's Name : Smt. T. Varalakshmi
Gender : Male
Marital Status : Married
Date of Birth : 29/05/1988
Nationality : Indian
Language Known : English, Hindi and Telugu
Permanent Address : H. No-2/361, Tirumala Nagar
Adoni, Distt.: Kurnool – 518302 (A.P)
☎ : 09795161176



Academic Qualification

Class	Board /University	Discipline	Year	Division	%
High School	S.S.C Board, A.P	-	2003	First	81.66
Intermediate	Board of Intermediate, A.P	Bi.P.C	2005	First	87.80
B.Sc. (Ag.)	ANGRAU	General Agriculture	2010	First	82.60
M.Sc. (Ag.)	SHIATS	Plant Breeding and Genetics	2012	First	94.52
Ph.D. (Ag.)	BHU, Varanasi (U.P.)	Genetics and Plant Breeding	Thesis to be submitted		
NET	ASRB (ICAR), New Delhi	Genetics and Plant Breeding	2013		

Thesis Title

M.Sc. (Ag.) : “Evaluation of upland rice germplasm for yield and yield attributing characters (*Oryza sativa* L.)”
Ph.D. (Ag.) : “Genetics of yield and quality characters in aromatic rice (*Oryza sativa* L.)”

Publications

Research papers : 15
Abstracts : 09

DECLARATION

I hereby declare that the above mentioned information is correct to the best of my knowledge and belief.

Date:

Place: Varanasi

(T. Sravan)