STUDIES ON HETEROSIS AND GENETIC ANALYSIS OF MORPHO-PHYSIOLOGICAL AND BIOCHEMICAL CHARACTERS IN RICE

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STUDIES ON HETEROSIS AND GENETIC ANALYSIS OF MORPHO-PHYSIOLOGICAL AND BIOCHEMICAL CHARACTERS IN RICE

By

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CERTIFICATE

This is to certify that the thesis entitled, "**STUDIES ON HETEROSIS AND GENETIC ANALYSIS OF MORPHO-PHYSIOLOGICAL AND BIOCHEMICAL CHARACTERS IN RICE**" submitted to the Faculty of Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY IN GENETICS** embodies the results of a piece of *bona fide* research work carried out by **Mr. NARENDRAKUMAR YESHWANT KADOO** under my supervision and guidance and that no part of this thesis has so far been submitted for any other degree or diploma.

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

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(Narendrakumar Yeshwant Kadoo)

ABBREVIATIONS

AF_1	A x R
BF_1	B x R
RF_1	R x B
AF_2	F_2 of cross A x R
BF_2	F_2 of cross B x R
RF_2	F_2 of cross R x B
AF_1-1	PMS 2A x Pusa 1127
BF_1-1	PMS 2B x Pusa 1127
RF_1-1	Pusa 1127 x PMS 2B
AF_1-2	Pusa 5A x Pusa 1124
BF_1-2	Pusa 5B x Pusa 1124
RF_1-2	Pusa 1124 x Pusa 5B
AF_1-3	IR 58025A x PRR 78
BF_1-3	IR 58025B x PRR 78
RF_1-3	PRR 78 x IR 58025B
AF_2-1	F_2 of cross PMS 2A x Pusa 1127
BF_2-1	F_2 of cross PMS 2B x Pusa 1127
RF_2-1	F_2 of cross Pusa 1127 x PMS 2B
AF_2-2	F_2 of cross Pusa 5A x Pusa 1124
BF_2-2	F_2 of cross Pusa 5B x Pusa 1124
RF_2-2	F_2 of cross Pusa 1124 x Pusa 5B
AF_2-3	F_2 of cross IR 58025A x PRR 78
BF_2-3	F_2 of cross IR 58025B x PRR 78
RF_2-3	F_2 of cross PRR 78 x IR 58025B

CMS	Cytoplasmic male sterility
	Cytoplasmic male sterile (line)
WA	Wild abortive (cytoplasm)
CGR	Crop growth rate
RGR	Relative growth rate
NAR	Net assimilation rate
NRA	Nitrate reductase activity
LAR	Leaf area ratio
LAD	Leaf area duration
LAI	Leaf area index
HI	Harvest index
Ha	Mid-parent heterosis
Hb	Better-parent heterosis (Heterobeltiosis)
Hc	Standard heterosis
MP	Mid-parent
BP	Better parent
SC	Standard check
GCV	Coefficient of genotypic variation
PCV	Coefficient of phenotypic variation
ECV	Coefficient of environmental variation
QTLs	Quantitative trait loci
KS test	Kolmogorov-Smirnov test
GM	Grand / General mean
h^2(bs)	Heritability (broad sense)

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INTRODUCTION

Rice, which has been documented as a source of food as far back as 2500 BC in history books, has fed more people over longer period of time than any other crop in the world. It is the main source of food for approximately half of the world's population and hence, may be the most important plant on the earth (Shimamoto, 1995; Goff, 1999). Rice is one of the most important cereals produced annually at worldwide levels of approximately half a billion tons. However, unlike other major cereals, more than 90% of the rice is milled almost exclusively as food for human consumption (Goff, 1999) and forms three fourths of the total diet of millions of people. This member of the grass family (Gramineae) is abundant in carbohydrates and is a major source of protein for the masses of Asia (Chang, 1984).

In Asia alone, 90% of the world's rice is produced and consumed. Most of the consumers, who depend on rice as their primary food, live in less developed countries. It is foreseen that the world's population may exceed 8 billion by 2025 and will need about 765 m tons of rice, 70% more than what is consumed today. This increase in rice production must be achieved through utilization of less land, less water, fewer agrochemical and other inputs. It is thus imperative to find ways and means to lift the present yield level, optimize the use of various inputs such as water and fertilizer in order to make the rice production efficient, cost effective, suitable for resource-poor farmers, sustainable and environment friendly (Riveros, 2000).

Rice will continue to occupy a pivotal place in global food and livelihood security systems. Accounting for 42% of India's food grain production, sustained self-sufficiency of rice is vital for the country's food security. With practically no scope for expansion of net area under rice, limited opportunities for bringing more area under irrigated crop and the lack of ideal high yielding varieties to cater the needs of the vast rainfed ecosystem, increase in rice production has to come from alternative technological options. With Green Revolution, a series of high yielding rice varieties became available and most of the rice growing countries in Asia, where almost 90% of the world's rice is grown, became self-sufficient in rice production (Lampe, 1991). However, a fear of food shortage looms again as the yields of the high yielding varieties has reached a plateau and now the major challenge faced by today's breeders is breaking the yield barrier.

Nonetheless, opportunities do exist to meet the future production demands. They broadly include: consolidation of untapped yield potential of the currently available high yielding varieties, maximization of yield level of rainfed ecologies and raising the genetic ceiling of yield. For raising the yield potential, three major strategies are being contemplated. They are (i) exploitation of hybrid vigor, (ii) plant type improvement with more efficient physio-morphological frame and (iii) engineering the starch biosynthetic pathway. Of the three, the first one is readily an adoptable technology since identification of the strong and stable source of cytoplasmic male sterility in the early seventies and development of commercially viable hybrid rice technology by late seventies in China (Yuan, 1987; Lin and Yuan, 1980).

Conviction of its more than one ton yield advantage over the best high yielding varieties prompted Chinese farmers to adopt the hybrid rice technology extensively. More than 55% of the total rice area is planted presently to hybrid rice in China accounting for about 66% of rice production. The impact of 25-30 m tons of rice added annually through adoption of this technology has led China, a chronically food deficient country, to become self-sufficient and to have surplus enough to divert over 3 m ha. of prime rice land for non-food crops of commercial value (Yuan, 1996). If the success story of hybrid rice technology is replicated anywhere outside China, it is in India. Hybrid rice breeding research was augmented in India in 1990; taking advantage of IRRI developed CMS lines, well suited to tropical environment; which enabled India to come out with as many as one dozen hybrids for commercial planting by 1995 (Siddiq, 2000). The hybrids, largely of medium early maturity combining fine grains with yield advantages comparable to that in China, have been planted over 2 lakh ha. during the wet season of 2000.

Nevertheless, the technology is yet to catch imagination of the growers, given the slow pace of adoption. Early maturity as against widely preferred varieties of medium to medium-late maturity, aroma and unacceptable cooking quality in the traditional rice-eating regions and high vulnerability to diseases and pests, characteristics of the first and second generation hybrids, are some of the major factors attributable to the slow pace of adoption. Envisaged spread of the technology crossing 10 m ha. mark by 2010 and its sustainability would however depend on how successful we would be in shaping the future hybrids with progressively higher yields, better grain quality to meet the changing socio-economic needs and enhanced level of tolerance to major biotic and abiotic stresses (Siddiq, 1997).

Exploitation of hybrid vigor is one of the means to raise the genetic yield ceiling in crop plants. In open pollinated crops like maize and pearl millet and often cross-pollinated crops like sorghum, the phenomenon of heterosis is being exploited since decades. For commercial hybrid seed production in any crop, male sterility is important, which is achieved through various approaches that include manual, chemical and genetic means. In rice, which is a strictly self-pollinated crop, identification of a stable and strong source of cytoplasmic male sterility (wild abortive, WA) has helped develop commercially viable three line hybrids since late seventies in China (Yuan, 1996).

Hence a breakthrough in breaching the existing yield barrier in rice seems possible through exploitation of heterosis for which a critical understanding of morpho-physiological and biochemical characters affecting heterosis is essential in order to enhance the present level of heterosis (Singh *et al.*, 1996). The lack of information on these characters appears to be a major hindrance in enhancing the yield potential of hybrid rice. The physiological and biochemical explanation for phenotypic expression of the characters in heterotic hybrids like higher biomass yield, higher harvest index, higher photosynthetic efficiency, lower photorespiration, greater vigor in growth, leaf area, early flowering, etc. and the knowledge of interrelationship among these components and their direct and indirect effects on grain yield will be useful for plant breeders for better selection of parents (Akita, 1988). This approach should help to develop superior hybrids.

Heterosis or hybrid vigor is the evident superiority of a hybrid over its parents with respect to any measurable attribute. Since growth and yield are the results of a series of physiological processes, which are ultimately governed by biochemical reactions, heterosis may be manifested either in increased rates of metabolic reactions or in a more efficiently organized metabolic system, or both (Hongde, 1988). It is thus evident that a suitable approach to study the phenomenon of heterosis is to analyze the biochemical and physiological processes that control growth and development (Kim and Rutger, 1988; Banga, 1998).

Faster leaf area development at early vegetative stage, due to increase in leaf number and high tillering, has been reported to be highly correlated with shoot dry matter and thus vigorous growth rate (Ponnuthurai *et al.*, 1984). Hybrid rice has higher leaf area and better light distribution in the canopy, which favors photosynthesis, resulting in yield heterosis at later stages (Zhende, 1988). In addition, high heterosis for amylase and α-amylase activities has been reported to be the major factors for early germination and vigorous growth of seedlings (Hongde, 1988). Ramesha *et al.* (1999) found that yield heterosis in hybrids results mainly due to heterosis for biomass yield coupled with heterosis for panicle dry weight.

The physiological and biochemical characters are very important in determining grain yield, biological yield and harvest index. However, the nature and pathway of their influence is yet to be fully understood. Grain yield is the product of biological yield and harvest index. It can therefore be increased by increasing either biological yield or harvest index, or both (Akita, 1988). Biological yield is the product of the rate of dry matter accumulation and the duration of growth. Net photosynthesis assumes an important role in determining the biological yield. Hence, to improve the grain yield substantially, various physiological and biochemical characters influencing photosynthetic efficiency and the rate of dry matter accumulation such as crop growth rate (CGR), net assimilation rate (NAR), leaf area index (LAI), nitrate reductase activity, α-amylase activity etc. need to be taken into account.

Further, since heterosis is a phenomenon of superior growth, development, differentiation and maturation caused by the interaction of genes, metabolism and environment, a simple explanation of heterosis based solely on the nuclear genome heterozygosity appears untenable (Shrivastava, 1981). Therefore, a logical approach to explain heterosis would be to take into account the nuclear genome heterozygosity as well as the effect of cytoplasm. Similarly, the differences observed in reciprocal crosses should also be taken into account.

The knowledge of genetics of various morpho-physiological and biochemical characters influencing grain yield is also essential to select parents for hybridization to produce highly heterotic hybrids. There is a need to analyse the physiological and biochemical bases of heterosis and to understand the genetic bases of these characters influencing biomass, harvest index and yield in rice.

Keeping the foregoing problems in view, present investigations were undertaken with the following objectives:

1) To study heterosis for various morpho-physiological and biochemical parameters influencing yield components and their association with grain yield,
2) Genetic analysis of selected morpho-physiological and biochemical characters,
3) To study the reciprocal differences in relation to heterosis for yield and yield components.

REVIEW OF LITERATURE

The term 'heterosis' was coined by Shull (1914) and may be defined as the superiority of F_1 over its parents with respect to yield, growth rate, vigor etc. and 'hybrid vigor' as the manifest effect of heterosis. East and Hays (1912) first suggested exploitation of heterosis as an alternative strategy for crop improvement. This concept was put to practical use by Jones (1917) who proposed the scheme for development of double cross hybrids and by Davis (1927), who demonstrated development of top cross hybrids in maize. Amazingly, by the year 1940, half of the world's maize acreage was under hybrids. The superiority of F_1 over mid-parent is known as 'mid-parent heterosis' or 'relative heterosis' while 'heterobeltiosis' refers to the superiority of F_1 over its 'better parent'. However, better parent of a hybrid may not always be better or even equal in performance to the commercial or standard variety. Therefore, from a Breeder's point of view, the superiority of F_1 over a 'commercial check' or 'standard variety', known as 'standard heterosis', has more significance (Mukherjee, 1995).

2.1 Genetic basis of heterosis

The genetic basis of heterosis has been debated for more than 80 years and is still not resolved (Xiao *et al.*, 1995). It is sought to find explanations for inbreeding depression in cross-pollinated crops and vigor expressed in hybrids in self-pollinated crops. Attempts have been made to explain these phenomena by three main hypotheses: i) dominance hypothesis, ii) overdominance hypothesis and iii) epistasis hypothesis.

According to the dominance hypothesis, proposed by Davenport in 1908, heterosis is due to cancellation of the deleterious effects of recessive alleles contributed by one parent, by favorable effects of the dominant alleles contributed by the other parent in the heterozygous F_1. If such an explanation holds true to account for heterosis in hybrids, it should be possible to accumulate all the favorable dominant alleles in inbreds, which should be able to perform as good as the hybrid. However, the large number of genes involved in governing quantitative characters like grain yield and linkage of deleterious recessive genes with favorable dominant genes preclude the possibility of recovering homozygous lines as vigorous as the hybrid.

The overdominance hypothesis, proposed independently by Shull and East in 1908, assumes that heterozygous combination of the alleles at a single locus is superior to either of the homozygotes for that locus. Hence, according to overdominance hypothesis, no homozygote can be obtained that equals in performance the overdominant heterozygote. Overdominance has been demonstrated in several characters that are controlled by single genes and hence it is argued that the hypothesis may not hold good for quantitative characters, which are governed by polygenes.

The epistasis hypothesis takes into account the non-allelic interactions to explain heterosis in F_1. Jinks and Jones (1958) observed a significant association between epistasis and heterosis in 80% of heterotic crosses in *Nicotiana rustica*. However, they pointed out that not all heterotic crosses showed significant non-allelic interactions and conversely, not all the crosses showing significant non-allelic interactions were heterotic. Multiplicative interaction between some loci has also been reported. Jinks (1983) observed inadequate evidence of genuine overdominance for quantitative characters and opined that apparent dominance due to epistasis and linkage disequilibrium were common contributors to heterosis. Schnell and Cockerham (1992) found that additive x additive epistasis resulting from multiplicatively acting gene effects could lead to heterosis. Zhang *et al.* (2001) also demonstrated epistasis underlying the genetic basis of quantitative characters and heterosis in rice.

These observations have important implications for genetic interpretation of mid-parent heterosis observed in self-pollinated crops that show little or no inbreeding depression. The heterosis observed might be primarily due to additive x additive epistasis, which does not contribute to inbreeding depression (Lamkey and Edwards, 1999).

2.2 Physiological basis of heterosis

Hybrid vigor is a product of many physiological and biochemical processes. Ashby (1930) proposed that heterosis resulted from a greater initial weight of the hybrid embryo (initial capital) resulting from some processes between fertilization and maturation of seeds and maintenance of this initial advantage throughout the growth period. Thus, according to him, hybrids did not differ from their parents in relative growth rate. Hybrids usually show a higher growth rate immediately after germination and maintenance of this initial advantage throughout the growth period to ultimately result in quantitative differences in size and yield (Singh *et al.*, 2000). They generally produce more grain yield per day per hectare, indicating their higher physiological efficiency (Yuan and Virmani, 1988).

Heterosis in early seedling growth is associated with better absorption and assimilation of several nutrients. Hybrids usually absorb and utilize much more amount of nitrogen and phosphorus than their inbred parents. The dominant inheritance of greater branched root system in hybrids leads to higher nutrient absorption (Singh *et al.*, 2000). Since root growth depends on shoot growth, enhanced photosynthesis in hybrid resulting mainly due to greater leaf area index, leads to enhanced root growth. This in turn results in heterosis for nutrient absorption and mobilization, culminating in overall heterosis.

2.3 Biochemical basis of heterosis

Heterosis for growth and yield is a product of many physiological and biochemical processes, each of which is controlled by one or more specific enzymes, which are ultimately under genetic control. According to the 'bottleneck concept of heterosis', the inbred parents lack either of the favorable dominant genes that control a synthetic pathway and hence cannot synthesize the final product. However, both these dominant genes come together in the hybrid between them, which is capable of synthesizing the final product and subsequently expressing heterosis (Mukherjee, 1995).

Robbins (1952) supported this hypothesis based on his experiments with growth rates of excised tomato roots. The variety Red currant had a 'bottleneck' for pyridoxine production, while the variety Johannesfeuer had a 'bottleneck' for vitamin nicotinamide production. Hence, the roots of these two varieties needed artificial supply of the corresponding metabolite for growth. However, the hybrid between them was able to produce both the metabolites, by virtue of having the dominant active alleles for synthesis of the metabolites and did not need external supply of these for rapid root growth.

In maize, it was observed that hybrids had higher endogenous levels of GA_3 than their parents, which resulted in heterosis for shoot growth. On the contrary, low endogenous GA_3 content in the inbreds limited their growth (Mukherjee, 1995).

2.4 Molecular basis of heterosis

Heterotic expression of various characteristics can be traced to the genetic apparatus of the cell. Therefore, the nature of heterosis can be better understood by studying its expression at the cellular and genomic levels. Heterosis at the molecular level has a direct bearing on the physiological advantages in the hybrid through regulation of metabolism (Singh *et al.*, 2000).

Kostyshin and Masikevich (1984) showed that highly heterotic hybrids had significantly higher content of nuclear DNA than their parents. They suggested that inbreeding leads to reorganization and smoothening of the intra-molecular heterogeneity of the genome and decrease of nuclear DNA content in inbreds. Crossing of the inbreds leads to complementation of the parental genomes and recovery of the lost segments in the genome of the hybrid, thus reestablishing intra-molecular heterogeneity of nuclear DNA for expression of heterosis. Romagnoli *et al.* (1990) studied the relationship between gene expression and hybrid vigor in primary root tips of young maize plantlets and observed that there are sets of proteins and mRNAs that are differentially synthesized and expressed in the F_1 primary root tips in comparison to the parental lines. Similar observations were made by Qixin *et al.* (1999) in wheat.

Molecular marker based investigations have revealed that dominance is the major genetic basis of heterosis in rice (Xiao *et al.*, 1995), while overdominance plays an important role in heterosis in maize (Stuber *et al.*, 1992). In fact, the later identified heterotic QTLs in maize inbreds (TX 303 and Oh 43) and mobilized them using marker-assisted selection to improve the inbred parents (B 73 and MO 17) of a commercial hybrid. The inbred B 73 was improved with the QTLs from TX 303 and MO 17 was improved with the QTLs from Oh 43. When the improved inbreds were crossed, significant gain in yield of the existing commercial hybrid was obtained.

2.5 Biometrical basis of heterosis

Combining ability analysis has been useful in identifying potential parents to produce heterotic hybrids. Generally, the probability of getting heterotic hybrids is high in parental lines having high GCA effects. Studies conducted at IRRI indicate that the heterotic hybrids had at least one of the parents with high GCA effects, though sometimes, heterotic hybrids were observed among parents having low GCA effects. In addition, occasionally parents showing high GCA did not result in heterotic hybrids. Apparently, the prediction of heterotic combinations of parents cannot be made accurately based of combining ability studies alone (Nanda and Virmani, 2000). Studies on gene action and combining ability indicate that both GCA and SCA effects are important.

Biometrical studies carried out at Birmingham School, UK, provided a highly convincing proof in favor of dominance hypothesis. The biometrical aspects of heterosis can be briefly explained as follows:

Considering the joint effect of all loci, in which the two populations differ, the expression of heterosis can be illustrated as follows (Falconer, 1982):

$HF_1 = \Sigma\, dy^2$

Where, HF_1 = heterosis obtained in F_1 hybrid,

d = degree of dominance and,

y = differences in gene frequencies between the two populations.

Therefore, heterosis can be maximized by maximizing i) d, the degree of dominance, ii) y, the difference in gene frequency, or iii) both d and h.

Gallis (1988), however, opined that although biometrical analysis gives some insight into the relative importance of dominance and overdominance, such analyses are not powerful enough to elucidate the role of overdominance, if it exists only for a part of a set of loci involved in governing the quantitative characters of interest. It is difficult to establish conclusive proof for the genetic basis of heterosis for either the dominance or overdominance hypotheses because of the complexity of inheritance of quantitative characters such as yield. All types of gene interactions, both inter- and intra-allelic are probably involved. Heterozygosity for regulatory genes may lead to greater homeostasis in a variable environment and heterosis might be the result of genotype x environment interaction and such mechanism will be a fundamental property of the hybrid at the diploid level.

2.6 Maternal effects and heterosis

If Σ dy^2 is the sole cause of heterosis, all reciprocal hybrids should be equally heterotic as direct hybrids, as the degree of dominance and differences in gene frequencies will not change by making reciprocal crosses. However, in practice it has been observed that in majority of the cases, reciprocal hybrids were not equally heterotic, indicating the role of organelle genome and its interaction with nuclear genome in manifestation of heterosis (Singh *et al.*, 2000).

Maternal effects are present if the mean performance of reciprocal crosses differ. Mather and Jinks (1971) symbolized the maternal effects as $[d_m]$ for P_1 maternal parent and $-[d_m]$ for P_2 mother. Therefore, performance of the parents, F_1 and reciprocal F_1 (RF_1) can be expressed as follows (Banga, 1998):

$P_1 \quad = m + [d] + [d_m]$

$P_2 \quad = m - [d] - [d_m]$

$F_1 \quad = m + [h] + [d_m]$ (P_1 mother)

$RF_2 \quad = m + [h] - [d_m]$ (P_2 mother)

The positive or negative sign of the maternal component $[d_m]$ will depend on whether the P_1 mother contributes more or less than the P_2 mother. The maternal component can be calculated as:

$$F_1 - RF_1 = (m + [h] + [d_m]) - (m + [h] - [d_m])$$

$$\therefore F_1 - RF_1 = 2\,[d_m]$$

Therefore, $[d_m] = ½\,[F_1 - RF_1]$

2.7 Heterosis in rice

Ever since heterosis in rice was first reported by Jones (1926), the presence of significant standard heterosis for yield, yield components and several other characters has been reported by numerous rice researchers. The available literature with respect to various physiological, biochemical, biometrical and molecular biology aspects affecting yield components and grain yield in rice are presented below.

2.7.1 Yield and Yield components

Positive standard heterosis in grain yield reported in rice hybrids is attributed to the increased biomass yield, resulting due to increased leaf area index and higher crop growth rate and harvest index, resulting due to high spikelet number and increased grain weight (Ponnuthurai *et al.*, 1984). Heterosis in number of panicles per plant, spikelets per panicle and spikelet fertility varies highly among the crosses due to compensation of yield components and cultivation practices (Akita, 1988).

2.7.1.1 Plant height: Dwarfness may be one of the most important agronomic characters, because it is often accompanied by lodging resistance and thereby adapts well to heavy fertilizer application (Futsuhara and Kikuchi, 1984). Pillai (1961) and Singh and Singh (1978) reported negative heterosis for plant height, while Virmani *et al.* (1982) observed that the hybrids were almost equal to or slightly taller than the parents. However, most studies have reported higher mid-parent heterosis in plant height and some have reported heterobeltiosis and standard heterosis (Kim and Rutger, 1988). Because plant height is negatively correlated with lodging resistance, positive heterosis for plant height in hybrids would not be desirable, particularly with high nitrogen fertilization.

2.7.1.2 Days to flowering: Most data have indicated negative heterosis for days to flowering in rice (Chang *et al.*, 1973; Singh *et al.*, 1980; Fujimaki and Yoshida, 1984). However, some studies have reported both positive and negative heterosis for this character. Vijayakumar *et al.* (1997) found that hybrids outyielded their parents when their days to 50% flowering were similar or more than their respective restorers. They concluded that superior hybrids could be identified early by comparing their tiller number, plant height and days to 50% flowering with those of their respective restorers.

2.7.1.3 Days to maturity: Lin and Yuan (1980) observed that most hybrids had longer growth duration, however, Xu and Wang (1980) reported that days to maturity depended on the restorer. Conversely, Ponnuthurai *et al.* (1984) reported hybrid growth duration similar to that of the shorter growth duration parent. Alternatively, Virmani (1999) noted that growth duration did not correlate with expression of heterosis and hence heterotic hybrids could be developed with a range of desired growth duration.

2.7.1.4 Number of panicles: Virmani *et al.* (1981) reported heterobeltiosis to range from -45% to 505% for number of panicles per plant in rice. While, Kumar *et al.* (1994) reported heterobeltiosis for panicles per plant to range from 1% to 41% in their studies. Kim (1985) found no heterosis in panicles per sq. meter and stated that usually panicles per sq. meter did not contribute significantly to yield heterosis. Zhende (1988), however, reported a hybrid, Gang-Hua 2 having 20% more panicles per sq. meter than its parents.

2.7.1.5 Panicle characters: Hybrid rice has bigger panicles and more spikelets per panicle than conventional rice. Zhende (1988) reported that the hybrid Gang-Hua 2 had 20% more panicles per sq. meter, 12% more filled spikelets per panicle, 43% more total spikelets per sq. meter and 34% more filled spikelets than its better parent.

2.7.1.6 Grains per panicle: Virmani *et al.* (1981) reported heterobeltiosis for grains per panicle to range from -70% to 55%. Similarly, Virmani *et al.* (1982), Nijaguna and Mahadevappa (1983) and Kim (1985) reported that heterosis in yield was mainly due to more grains per panicle and heavier 1000-grain weight.

2.7.1.7 Total number of spikelets: Kim (1985) reported significant positive heterosis, heterobeltiosis and standard heterosis for number of spikelets per plant and 1000-grain weight. Blanco *et al.* (1986) observed high heterosis in spikelet number per sq. meter and slight positive heterosis in grain weight. Heterosis in other yield components such as panicles per plant, spikelets per panicle and spikelet fertility varied highly among crosses and cultivation conditions due to yield component compensation. They reported a higher harvest index in some hybrids, which was chiefly due to higher heterosis in spikelets per sq. meter and grain filling.

Additionally, the higher harvest index also resulted due to short duration of the hybrids (Akita, 1988). These results indicate that hybrids grow faster in vegetative stage and maintain this advantage till heading.

2.7.1.8 Spikelet fertility: Kim (1985) did not find significant heterosis in spikelet fertility and stated that spikelet fertility did not contribute significantly to heterosis. However, Kim and Rutger (1988) reported that in some studies, increased yield in most heterotic hybrids was due to heterosis in spikelet fertility and panicle number; heterosis in 1000-grain weight did not contribute much towards yield. Conversely, Ramesha *et al.* (1999) found negative heterosis for spikelet fertility. With respect to gene action in governing this character, Siddiq *et al.* (1994) reported non-additive gene action to be predominant.

Performance of any cross is normally estimated on the basis of the final grain yield, which in turn is affected by several characters contributing to yield. For example, Joshi (2001) observed high positive heterosis in several yield components; however, the grain yield was low. On further analysis, it was revealed that high negative heterosis for spikelet fertility masked the positive and significant performance of the other yield components, resulting in poor grain yield.

2.7.1.9 1000-grain weight: The yield advantage of hybrids is primarily due to higher grain weight and more number of spikelets. Virmani *et al.* (1981) reported heterobeltiosis to range from -31% to 14% for 1000-grain weight. Kim and Rutger (1988) observed positive heterosis predominantly in 1000-grain weight and number of spikelets per plant. They also observed high correlation between 1000-grain weight and grain yield. Kumar *et al.* (1994), however, found that heterobeltiosis for grain weight and filled grain ratio were not significant. They noted that grain weight was highly correlated to grain size, which is a product of grain length and width that are inherited independently and this independent inheritance lead to variation in F_1 grain weights. They also observed that heterosis in grain weight differed according to cross combination.

2.7.1.10 Biomass yield: Heterosis in grain yield is well demonstrated in rice (Virmani and Edwards, 1983). Grain yield is the product of dry matter accumulation and harvest index. High heterosis for biomass yield has been demonstrated in rice hybrids. However, heterosis for harvest index although reported (Blanco *et al.*, 1990), was less frequent than for biomass yield. Thus, heterosis for grain yield in rice is mainly due to increased dry matter accumulation (Yamauchi, 1994).

Hybrid superiority to conventional varieties in biomass yield has been reported widely. High yielding hybrids also showed significant heterosis and heterobeltiosis for total dry matter and harvest index (Ponnuthurai *et al.*, 1984; Kim, 1985). Kim and Rutger (1988) noted that hybrids that gave high grain yields also produced high biomass. However, too much vegetative growth of hybrid during early developmental stages resulted in excessive shading and produced no heterosis in yield. Hence, promoting high dry matter through excess vegetative vigor in the hybrids may not be useful in increasing yield. Certain hybrids that showed too much of vegetative growth had lower harvest index. In addition, biomass yield at different growth stages showed different patterns for hybrid rice and conventional rice. Hybrid rice has more dry matter accumulation in the early and middle growth stages whereas, conventional rice has more in late growth stages. Hybrid rice also accumulates more total dry matter than conventional rice (Zhende, 1988).

Ramesha *et al.* (1999) found that yield heterosis in hybrids results because of heterosis for total dry matter at different growth stages, coupled with heterosis for panicle dry weight, without much change in harvest index.

2.7.1.11 Harvest index: Sitaramaiah *et al.* (1998) observed that the high yielding hybrids also recorded higher biomass yield and harvest index. It was found that the hybrids showed a superior performance because of more grains per panicle, which was indicated by higher harvest index.

2.7.1.12 Grain yield: Several workers have reported presence of significant heterobeltiosis and standard heterosis for rice grain yield. Wei (1980) found that the best hybrids outyielded check varieties by 24-55%. Virmani *et al.* (1981) presented data on the large variation in heterosis and heterobeltiosis for yield and yield components. They reported heterobeltiosis to range from –91% to 369% for yield; however, most of the data showed the range of about 20-40%. Virmani *et al.* (1982) reported up to 73% heterosis, 57% heterobeltiosis and 34% standard heterosis in grain yield. Reddy *et al.* (1984) reported a hybrid with 68% heterosis, 33% heterobeltiosis and 24% standard heterosis in grain yield. Kim (1985) reported four hybrids, which showed up to 92% heterosis, up to 48% heterobeltiosis and up to 43% standard heterosis in grain yield under 3 different N levels (120, 180 and 240 Kg N/ha.). Moon *et al.* (1994) observed standard heterosis for grain yield ranging from 9-42%, with an average of 21%. They observed maximum positive heterosis in experimental plots ranging from 29-92% and standard heterosis ranging from 25-85%. Virmani *et al.* (1994) found that the yield advantage of hybrids over check varieties was higher in high yielding environments than in low yielding environments.

Phenotypic expression of growth and yield are the results of a series of genetically controlled biochemical and physiological reactions. Heterosis can increase the size of source as well as of sink in the rice plant. To understand sink and source relationship, study of physiological and biochemical characters such as photosynthetic area, photosynthetic efficiency, chlorophyll content, soluble proteins, enzyme activities, etc. is essential. For high yields in hybrid rice, sink is not the limiting factor that is in conventional rice. Thus, hybrid rice yields can be increased by breeding for enhanced relation between source and sink; improved canopy structure and by improving nutrient status of the soil at late growth stage (Zhende, 1988).

2.7.2 Physiological aspects

Heterosis in rice has been reported in several agronomic characters that influence yield. These include biomass yield, harvest index, leaf area index, crop growth rate, chlorophyll content, grains per panicle and per sq. meter and 1000-grain weight. It has also been reported for early maturity, root length, root weight and other characters. Hybrids generally produce more grain yield per day per hectare, indicating their higher physiological efficiency (Yuan and Virmani, 1988).

Qingquan *et al.* (1988) noted that hybrids had higher photosynthetic efficiency, lower respiration intensity, stronger root system and shorter growth duration than conventional varieties. They found that LAI in hybrids was 17-34% higher than that of conventional varieties at flowering and photosynthetic potential of 21-26% higher from tillering to flowering. Thus hybrids could absorb more solar energy because of higher LAI. Hybrid rootability was 21-34% higher than conventional varieties at seedling stage. Hence, hybrids have wider and deeper root distribution and more ability to absorb water and fertilizers. However, they pointed out that larger sink size and insufficient source in new hybrids resulted in more unfilled spikelets per panicle. They concluded that better crop management in later growth stages and higher photosynthetic activity maintained in functional leaves would correct the imbalance between sink and source.

Singh *et al.* (1996) studied ten physiological characters in thirteen hybrids, their parents and a local check. They observed that magnitude of heterosis differed from character to character depending on the hybrid combination. Majority of the hybrids exhibited significant positive heterosis, heterobeltiosis and standard heterosis for flag leaf area, chlorophyll content, stomatal conductance, peroxidase activity and seed protein. Some hybrids, which exhibited high heterosis for grain yield, also showed strong heterosis for above characters, suggesting a positive relationship of these characters and grain yield. However, most of the hybrids exhibited low heterosis for soluble protein and chlorophyll ratio. They did not observe a specific relationship between photosynthetic rate and grain yield.

2.7.2.1 Leaf area: Leaf area of hybrids is larger because there are more leaves at the seedling stage and individual leaves are longer and wider. Blanco *et al.* (1986) found heterosis in leaf area development and shoot dry weight and a high correlation between them at early vegetative growth stage. This indicates that heterosis in leaf area development during seedling stage would be the key to vigorous growth after transplanting. During vegetative growth, the LAI of hybrid rice increases rapidly and the leaf area duration is significantly longer than it is in conventional rice. The rapid increase in LAI of hybrid rice at early and middle growth stages favors production of more carbohydrates from photosynthesis in hybrid plants. Thus, photosynthetic rate per leaf does not increase significantly (Zhende, 1988). Hybrid rice has higher LAI and higher ratio of upper to middle layer leaf area, as well as better light intensity distribution in the canopy. The increase in upper to middle layer leaf area ratio favors photosynthesis (Zhende, 1988), resulting in yield heterosis at later stages.

The increase in leaf area is chiefly due to increase in leaf number, which may be associated with high tillering at the seedling stage. High tillering of the hybrids was shown by appearance of a primary tiller from the axil of the first leaf, which is normally dormant in pureline varieties (Yamauchi, 1994). Khanna-Chopra and Sinha (1995) found that leaf area at anthesis and the rate of leaf senescence during grain development are the important components influencing post-anthesis dry matter accumulation. Post-anthesis assimilation makes important contribution to grain yield. When the parents differed in leaf senescence rate, the hybrid either followed the slow senescence parent, or showed an intermediate behavior.

Kwak and Sohn (1996) observed significant positive heterosis and heterobeltiosis for leaf area index in their study on 15 crosses from a partial diallel of 6 japonica varieties. The GCA and SCA effects were highly significant for leaf area index, specific leaf weight, crop growth rate and net assimilation rate.

2.7.2.3 Growth parameters: Ponnuthurai *et al.* (1984) compared growth and yield of four hybrids and found that the hybrids significantly out-yielded their better parents, attributed to their greater plant weight and increased LAI. A significantly higher CGR was observed in the hybrids at late vegetative and reproductive stages. After heading however, little heterosis in CGR was observed. When hybrids showed higher heterosis in plant weight, CGR at the initial stage was constantly higher than the better parent, but this heterosis in CGR decreased with growth. A similar trend was observed for heterosis in LAI. However, NAR and RGR of the hybrids after transplanting did not differ significantly from those of the parents.

Sitaramaiah *et al.* (1998) observed that CGR increased up to 45 days after planting (DAP) and decreased later in all the six hybrids and two checks they studied. The LAI, however, consistently increased from 15 to 60 DAP and hybrids recorded a higher LAI from 30 DAP onward compared with the checks. However, the high initial CGR was not maintained in the later growth stages or translated into higher yields.

2.7.2.3.1 Vegetative growth phase: Heterosis for yield in hybrid rice comes mainly from vegetative growth. Hybrid rice accumulates more dry matter during vegetative growth, which results in more spikelets per panicle. Conventional rice however, does not have such heterosis and essentially depends on accumulation of assimilates after heading (Zhende, 1988).

Lin and Yuan (1980) noted that hybrids show higher vegetative growth rates than parents and larger green leaf area at earlier growth stages, which contributed to higher photosynthetic efficiency. High CGR at the vegetative stage originates from high LAI while the CGR at reproductive and ripening stages is controlled by NAR. Jennings (1967) reported that excess vegetative growth of some hybrids lowers light transmission rate, because of mutual shading of leaves, which reduces net photosynthetic rate and increases the consumption of stored carbohydrates by respiration, thus lowering NAR. Yamauchi and Yoshida (1985) reported high heterosis for leaf development and low heterosis for photosynthetic rate at the vegetative stage, while Murayama *et al.* (1982) reported heterosis for photosynthetic rate at the ripening stage. The recovery of heterosis during ripening stage could be due to increase in NAR.

2.7.2.3.3 Reproductive phase: Sinha and Khanna (1975) explained that heterosis in yield is the result of complementarity between growth and yield characteristics.

Heterotic hybrids have higher biomass production and yield as compared to their parents. They found that grain number per panicle makes major contribution towards heterotic yields. Using component analysis approach, Gibson and Schettz (1977) expressed grain yield as the product of grain filling duration, average CGR and conversion percentage (the percentage of dry matter produced during post-anthesis period, which is stored in the grain). The hybrid yielded higher by combining high CGR of one parent and high conversion percentage of the other. Khanna-Chopra *et al.* (1993) analyzed grain number per panicle in terms of its components; number of branches per panicle and number of grains per branch and revealed that hybrid followed the better parent in both the characters and exhibited higher grain number per panicle due to multiplicative interaction of the components.

Yamauchi (1994) reported that heterosis for dry matter accumulation was highest during vegetative and reproductive stages and lowest at flowering stage, increasing again during the ripening stage. Hence, the lower heterosis at heading decreased potential heterosis for grain yield. Because heterosis for grain yield is mostly determined by dry matter accumulation, high heterosis for grain yield could be obtained if the hybrids did not lose heterosis at flowering.

Understanding the mechanism by which heterosis for dry matter accumulation at heading is depressed is important. If the depression is eliminated and the heterosis for dry matter accumulation is maintained at the level of vegetative stage, heterosis for grain yield could be increased substantially (Yamauchi, 1994). It was observed that the decrease in heterosis in CGR before heading is due to decrease in heterosis in NAR. The decrease in NAR, in turn, might be caused by decrease in photosynthetic rate or by increase in respiration. Studies on plant nutritional status and plant canopy structure in terms of spacing might help to explain the decrease in NAR (Yamauchi, 1994).

2.7.3 Biochemical aspects

2.7.3.1 α-Amylase activity: Hybrid rice has higher initial growth rate than conventional varieties. This growth advantage is expressed as early as in seed germination. α-Amylase is an amylolytic enzyme synthesized *de novo* in rice. α-Amylase synthesis in germinating rice seeds parallels the disappearance of endosperm starch and the appearance of reducing sugars (Williams and Paterson, 1973). Thus, α-amylase is a primary enzyme in cereals in conversion of starch to simple sugars that provide energy for the growing seedlings. Germination studies show that, of the various genetic and environmental factors that contribute to seedling vigor, α-amylase enzyme activity is a primary factor (Karrer *et al.*, 1993).

Li *et al.* (1982) observed that germination speed of the hybrid, Nan-You 2 and its three parental lines was in the order of 'hybrid > R line > B line > A line'. A similar order was found in the activity of their α-amylases. The activity of the enzyme was found to be 20% higher in the hybrid than the mean value of the three parental lines. During initial germination (0-3 days), the hybrid showed 433% heterobeltiosis in α-amylase activity. The higher α-amylase reserve in seeds and its higher activity make it possible to rapidly hydrolyze starch in endosperm, providing energy and assimilates for rapid germination.

Karrer *et al.* (1993) investigated the relationship between seedling vigor, α-amylase activity and α-amylase mRNA accumulation in ten rice varieties. They found significant positive correlation among seedling vigor, α-amylase activity and accumulation of mRNA from a rice α-amylase gene (RAmy1A). Their study thus supports findings, which have correlated α-amylase enzyme activity with seedling vigor.

2.7.3.2 Nitrate reductase activity (NRA): Rao *et al.* (1979) observed that *in vivo* NRA was high during early growth, declined sharply after transplanting, then increased gradually and was highest at the pre-harvest stage. In contrast to this, Yuan and Shien (1980) reported, that NRA showed two peaks, one at tillering and the other at flowering, with a low at boot stage. Pal and Pal (1986) studied NRA in whole plants and leaves at 25-90 days after sowing. They found that *in vivo* NRA increased up to 50 days after sowing and decreased thereafter. Leaf nitrate content followed the similar pattern. Leaf and stem total N content decreased with age, whereas panicle N content increased.

Manonmani *et al.* (1993) measured NRA at 5 stages of growth (15, 30, 50, 70 and 90 days after sowing) for 4 early (105-120 days duration) and 5 very early (86-95 days duration) rice cultivars and their 20 hybrids. They found that NRA increased from seedling to flowering stage (up to 70 days after sowing) and declined thereafter. Most hybrids with very early parents also matured early and showed high NRA activity at flowering. They inter-correlated NRA at different times after sowing and found significant positive correlations, which indicated that estimation of NRA could be used for selecting early maturing types at the initial growth stages.

2.7.4 Genetic analysis of yield and yield components

Siddiq *et al.* (1994) noted that yield and yield components are predominantly controlled by non-additive gene action. Hence, heterosis breeding is the most appropriate approach for improving rice yields.

2.7.4.1 Plant height: Several workers reported positive correlation between plant height and grain yield (Chauhan *et al.*, 1986; Yang, 1986; Gomathinayagam *et al.*, 1988 and Vijayakumar *et al.*, 1997) while in contrast, negative association between plant height and grain yield has been reported by Amirthadevarathinam (1983) and Sukanya and Rathinum (1986). Krishnakumari (1983) found curvilinear association between plant height and yield in rice and suggested that a plant height of 84.20 cm was optimum for realizing high grain yield. Path analysis revealed high direct positive effect of plant height on grain yield (Sukanya and Rathinum, 1986; Gomathinayagam *et al.*, 1988 and Reuben and Katuli, 1989), while Kumar and Rangaswamy (1986) reported indirect effect of plant height on grain yield. Genetic analysis of plant height by Tripathy and Mishra (1986) and Siddiq *et al.* (1994) revealed that it was under the control of additive gene action.

2.7.4.2 Number of productive tillers: Significant positive correlation between tiller number and grain yield was reported by several workers (Amirthadevarathinam, 1983; Chauhan *et al.*, 1986; Sukanya and Rathinum, 1986; Ganesan and Subramaniam, 1990). Path analysis by a number of workers revealed a strong direct effect of tiller number on grain yield (Amirthadevarathinam, 1983; Yang, 1986; Hegde, 1987 and Sinha and Banerjee, 1987). Sivasubramaniam and Madhav Menon (1973) and Murai *et al.* (1987) reported preponderance of additive gene effects for tiller number, while preponderance of non-additive gene effects was suggested by Kalaimani and Sundaram (1987) and Siddiq *et al.* (1994).

2.7.4.3 Days to 50% flowering: Positive direct effect of days to 50% flowering on grain yield was observed by Amirthadevarathinam (1983). Richharia and Singh (1983) reported that heterosis in grain yield was due to heterosis for early flowering in hybrids; therefore selection for early flowering genotypes would be important.

Genetic analysis of days to 50% flowering by Tripathy and Mishra (1987) and Siddiq *et al.* (1994) indicated predominance of additive gene action, while, Kalaimani and Sundaram (1987) reported predominance of non-additive components. Alternatively, Sardana and Borthakur (1987) reported that both additive and non-additive gene effects are involved in controlling days to 50% flowering in rice. Whereas, Mao and Virmani (1994) observed significant dominance and epistatic effects on days to 50% flowering.

2.7.4.4 Days to maturity: Gomathinayagam *et al.* (1988) reported positive association of days to maturity with grain yield in rice and positive direct effect of this character on grain yield, while negative association between days to maturity and grain yield was reported by Amirthadevarathinam (1983).

2.7.4.5 Grain-filling duration: Kato (1989) found that the rate of grain-filling was positively correlated with characters related to grain size and was negatively correlated with those related to grain number. Senadhira and Li (1989) observed significant correlation between grain-filling duration and days to 50% flowering ($r = 0.70$), indicating that late flowering genotypes had, in general, longer grain-filling duration.

2.7.4.6 Panicle length: Sukanya and Rathinum (1986) reported negative association between panicle length and grain yield, while positive association of this character with grain yield was reported by Chauhan *et al.* (1986) and Rao and Jagdish (1987). Kaushik and Sharma (1988) found that additive gene effect was important for this character.

2.7.4.7 Number of spikelets per panicle: Positive correlation between grain number per panicle and grain yield was reported by several workers (Chauhan *et al.*, 1986;

Raj and Siddiq, 1986 and Kalaimani and Kadambavansundaram, 1988). Path analysis by Sinha and Banerjee (1987), Panwar *et al.* (1989) and Reuben and Katuli (1989) indicated positive direct effect of this character on grain yield. Genetic analysis of the character indicated predominance of additive component (Murai *et al.*, 1987), non-additive component (Kalaimani and Sundaram, 1987 and Siddiq *et al.*, 1994) and both additive and non-additive components.

Kim and Rutger (1988) observed high correlation between spikelets per plant and grain yield. They suggested that highest grain yield should result from hybrids of parents, which contribute increased spikelet numbers and higher grain weight respectively. Kumar *et al.* (1994) stated that heterosis in hybrid rice is mainly due to more spikelets per panicle and number of panicles per plant, rather than higher grain weight and filled grain ratio. They found that, in general, the number of spikelets per panicle showed the greatest expression of yield heterosis ranging from 20% to 81%. With respect to the genetic analysis, Mao and Virmani (1994) observed significant dominance and non-additive effects for spikelet number per panicle.

2.7.4.8 1000-grain weight: Positive direct effect of 1000-grain weight on grain yield was reported by Sukanya and Rathinam (1986) and Vijayakumar *et al.* (1997). Genetic analysis of the character revealed that it is predominantly under the control of non-additive gene effects (Murai *et al.*, 1987; Kaushik and Sharma, 1988 and Siddiq *et al.*, 1994). However, some workers have reported that 1000-grain weight is controlled by additive gene effects (Tripathy and Mishra, 1987) and by both additive and non-additive gene effects (Sardana and Borthakur, 1987; Mao and Virmani, 1994).

2.7.4.9 Biomass yield: Positive and significant correlation between biomass yield and grain yield has been reported by a number of workers (Sahu and Murty, 1976; Vinaya Rai and Murty, 1979; Siddiq and Reddy, 1984; Burondkar *et al.* 1988 and Ganesan and Subramaniam, 1990). Vinaya Rai and Murty (1979) reported that biomass yield was positively correlated with LAI and nitrogen uptake, while path analysis for biomass yield by Siddiq and Reddy (1984) indicated that nitrogen uptake ability and CGR for whole crop growth duration contributed maximum towards biomass yield both directly and indirectly through LAI. With respect to genetics of biomass yield, pronounced non-additive gene effect was reported by Yadav and Singh (1987) and Siddiq *et al.* (1994), while, Sharma *et al.* (1988) reported predominance of additive gene effects in governing this character. Murty (1994) found preponderance of dominance gene action for biomass yield, whereas, Mao and Virmani (1994) observed significant additive, dominance as well as epistatic effects on this character.

2.7.4.10 Grain yield: Genetic analysis of grain yield in rice and other crops by several workers (Mohapatra and Mohanty, 1985; Sinha *et al.*, 1985; Kuo and Liu, 1986 and Sharma *et al.*, 1988) revealed the importance of additive gene effects in controlling the character. On the contrary, several workers have reported predominance of non-additive gene effects for grain yield (Li, 1975; Sharma *et al.*, 1986; Bakshi Ram *et al.*, 1987; Kaushik and Sharma, 1988 and Siddiq *et al.*, 1994). While, Murty (1994) found preponderance of dominance gene action for grain yield. Alternatively, the role of both additive and non-additive components in controlling grain yield was reported by other workers (Nancharaiah *et al.*, 1974; Kim and Rutger, 1988; Sardana and Borthakur, 1987 and Kalaimani and Kadambavansundaram, 1988). Sasmal and Banerjee (1986) observed significance of both additive and non-additive components for grain yield and noted that crosses with high SCA generally involved high x low general combiners. Similarly, Mao and Virmani (1994) observed significant additive, dominance as well as epistatic effects for grain yield.

2.7.4.11 Harvest index (HI): Harvest index is the ratio of economic yield (grain yield) to biomass yield (total dry matter production). Significant positive correlation between HI and grain yield has been reported by several workers (Sahu and Murty, 1976; Vinaya Rai and Murty, 1979 and Sukanya and Rathinam, 1986). Lin and Wu (1981) also reported that HI has strong positive direct effect on grain yield. On the basis of path analysis, HI was found to be a major yield determinant contributing both directly and indirectly through characters like nitrogen uptake ability, CGR and LAI at flowering (Siddiq and Reddy, 1984).

With respect to genetics of HI, Donald and Hamblin (1976) suggested that HI is heritable to a considerable degree like grain yield; however, its genetic makeup is expected to be polygenic. Some workers have reported predominance of additive gene effects in controlling HI (Rosielle and Frey, 1977; Yadav and Singh, 1987 and Sharma *et al.*, 1988), while others have reported both additive and non-additive gene effects to be important in controlling HI (Sethi *et al.*, 1987 and Yadav *et al.*, 1987). Still, other workers (Mohapatra and Mohanty, 1985 and Sharma *et al.*, 1986) have reported predominance of dominance component in genetic control of HI.

2.7.5 Genetic analysis of physiological and biochemical characters

Although there are several reports on correlation, path analysis and genetics of yield and yield components, such reports are in scanty with respect to the physiological and biochemical parameters.

Nguyen and Bui (1993) studied combining ability and heterosis for some physiological characters in rice. They found highly significant mean squares for both GCA and SCA indicating the importance of additive and non-additive gene action. However, the non-additive gene action was more prevalent for all the characters except LAI.

2.7.5.1 Leaf area: Genetics of leaf area was studied by a number of workers in different crops. Phul *et al.* (1974) found that it was controlled by both additive and non-additive gene actions, in pearl millet, whereas, Sharma *et al.* (1977) reported that in barley, leaf area was predominantly controlled by additive gene action. Mason and Zuber (1976) reported that GCA effects were relatively more important than SCA effects for leaf area in maize. Murty (1994) found preponderance of dominant gene action for leaf area at 45 days after sowing, 60 days after sowing and at flowering in rice. For leaf area at harvest, leaf area duration, leaf photosynthetic rate and stomatal conductance, he reported both additive and dominance gene actions. However, dominant gene action appeared to have a greater role in inheritance of these characters. Narrow sense heritability was low for all the characters except leaf area at harvest. Positive correlation between LAI and grain yield in rice has been reported by Vinaya Rai and Murty (1979). LAI was positively associated with NAR.

2.7.5.2 Flag leaf area: Wan and Zhong (1981) found a highly significant correlation between flag leaf area and panicle weight. Daskalov *et al.* (1986) also found that flag leaf area was correlated with grain yield per panicle and grain number per panicle ($r = 0.33$ and 0.34). They suggested that flag leaf area would be a useful indirect character for use in selection for high grain yield. Regression analysis by Bashar *et al.* (1991) showed that flag leaf area has a significant effect on grain yield through grains per panicle and panicle length. Rao (1992) observed that flag leaf area was positively correlated with several yield components such as high-density grains, numbers of spikelets and grains per sq. meter and panicle length. He also suggested that flag leaf area might be considered as a selection criterion for further exploitation of potential yields in rice.

2.7.5.3 Growth parameters: Weng and Chen (1988) studied the relation between CGR and LAI in two seasons of rice crop and found a linear regression between CGR and LAI in the first season. However, in the second season, the slope of the regression line decreased at higher LAI and CGR reached a maximum at the LAI of 2.5-3.0. In the first season, the slope of the regression line was positively correlated with biomass yield at heading, while in the second season; CGR was partially correlated with biomass yield. In the first season, the slope of the regression line was highest in cultivars with higher photosynthetic rate, greater plant height and fewer panicles per plant. In the second season, CGR was greatest in taller cultivars with erect leaves and more panicles per plant.

Burondkar *et al.* (1988) found that NAR was positively correlated with yield and negatively associated with number of tillers, number of spikelets and LAI (Kim, 1985). Large variation in NAR and its positive correlation with RGR, total dry weight and negative association with leaf area ratio (LAR) was reported by Murty *et al.* (1986) and Murty and Sahu (1987).

2.7.5.4 Nitrate reductase activity (NRA): Yang and Sung (1980) found that the NRA was positively correlated with both grain weight and dry weight of 10-day-old seedlings. They concluded that NRA could be used as a measure of seedling vigor if nitrate N was provided.

2.7.5.5 Amylose content: Dwivedi and Nanda (1979) found that both additive and dominance effects conditioned high amylose content, while Chang *et al.* (1981) found that high amylose content was controlled by a single incompletely dominant gene. McKenzie and Rutger (1983) found high amylose content to be controlled by two dominant complementary genes. It was also influenced by modifying genes of minor effect. Similarly, Heda and Reddy (1986) also found that amylose content was controlled by two genes, with high content dominant over low. Shubash Kanti and Mosina (1984) noted that depending on the cross, the inheritance of amylose content was incompletely dominant, dominant or overdominant. For most crosses the coefficient of heritability was high, indicating the possibility of selection in those crosses.

Kuo *et al.* (1995) studied heterosis and combining ability for amylose content in 6 parents and their 30 hybrids. For amylose content, mid-parent heterosis was usually in the positive direction, while, heterobeltiosis was in the negative direction. Matsue and Ogata (1999) found that amylose content of spikelets was related to grain weight. They concluded that variations in amylose content in rice panicles were caused by differences in grain weight, which were closely related to earliness or lateness of flowering.

2.7.6 Molecular basis of heterosis

Kato *et al.* (1994) studied the relationship between heterosis for biomass yield and polymorphism of isozymes and RFLP markers using 14 rice cultivars and 90 hybrids. They found that dominance effects were larger than additive effects; supporting the findings by Xiao *et al.* (1995), that heterosis was due to accumulation of dominant genes. They reported that more than 10 genes were involved in heterosis for biomass yield and heterosis was greatest in hybrids of crosses between indica and japonica cultivars.

Zhang *et al.* (2001) identified several QTLs for yield and other characters. They found that overdominance was evident at six of the ten QTLs detected for yield, whereas partial dominance was prevalent among other QTLs detected for other characters. In addition, the additive effects of the QTLs indicated that, for all the characters, alleles from the parent of higher value contributed to the increase in trait scores at some QTLs, whereas, at other QTLs, alleles from the parent of lower value contributed to the increase in performance.

2.7.8 Effects of male sterility inducing cytoplasm on heterosis

In hybrid rice breeding program based on cytoplasmic male sterility, the effect of sterility inducing cytoplasm on agronomic characters is of much importance. Anonymous (1982) found that the male sterility inducing cytoplasm positively influenced number of spikelets per plant, negatively influenced seed-setting percentage and 1000-grain weight and did not influence height or growth period. Likewise, several studies in rice have demonstrated the positive and negative effects of the wild abortive (WA) cytoplasm on agronomic as well as physiological characters (Maruyama *et al.*, 1985; Sasahara *et al.*, 1986 and Chen *et al.*, 1987).

Rongqian (1988) studied cytoplasmic effects on agronomic characters by developing several CMS lines by nuclear substitution, with identical nuclei but different cytoplasms and crossed them with some restorers. He observed that cytoplasmic effects were manifested on several characters such as 1000-grain weight, days to heading, net photosynthetic rate and peroxidase zymograms. This indicates the potential of cytoplasmic effects on many characters at a time. He also found that nucleo-cytoplasmic interactions were exhibited in panicle length and percentage of filled spikelets, among other characters.

Xiaobang and Zebing (1988) studied the influence of 8 male sterility inducing cytoplasms on 12 agronomic characters of hybrid rice. They found that all the cytoplasms had negative effects on plant height, panicle neck length, panicles per plant, number of productive tillers, number of filled spikelets per panicle, spikelet fertility, 1000-grain weight and grain yield per plant. The decrease in yield of hybrid rice derived from the male sterile lines (AF_1) was due to degradation of all yield components; the number of productive tillers had the greatest direct negative effect on grain yield per plant, followed by total spikelets per panicle, filled spikelets per panicle, spikelet fertility and 1000-grain weight.

However, most AF_1 combinations showed heterobeltiosis in grain yield per plant, despite negative influence of the sterility inducing cytoplasm. They found that negative effects of the cytoplasm on heterosis were only relative; and if the restorers had high combining and restoring ability, the negative effects were not strong enough to change the direction and degree of heterosis. They concluded that genetic effects of sterility inducing cytoplasms vary with cytoplasmic sources and combinations. Therefore, it was necessary to evaluate the degree of influence and its direction with the cytoplasm in question. They suggested 'cytoplasmic effect' or 'cytoplasmic heterosis' and expressed it as follows:

$$\text{Cytoplasmic effect (\%)} = \frac{AF_1 - BF_1}{BF_1} \times 100$$

(Where, AF_1 = Mean value of AxR F_1 and BF_1 = Mean value of BxR F_1)

Ramesha *et al.* (1999) found that in all the CMS based hybrids, sink was the major limitation rather than the source because of high spikelet sterility, which may be related to restoration ability of the male parent.

2.7.9 Influence of reciprocal cross differences on heterosis

Heterosis in crops is the result of intra-nuclear interactions and nucleo-cytoplasmic interactions. The genetic mechanisms of cytoplasmic and nucleo-cytoplasmic gene action affecting heterosis are not yet clear. It is suggested that nucleo-cytoplasmic heterosis in crops is created by the mutual superiority of cytoplasmic and nuclear genes and that heterosis is the result of interactions of cytoplasmic and nuclear superior genes (Wang and Liang, 1995).

Ashby (1932) found significant difference between the embryo weights of the reciprocal crosses, though these had the same genotypic constitution. This difference was clearly due to maternal effect during development of the embryo. School in 1974 examined the inheritance of isocitrate lyase in germinating cottonseeds using reciprocal crosses and found that it was maternally inherited. He found this to be associated with seedling vigor.

Young and Virmani (1990) studied heterosis and combining ability for days to flowering, plant height and grain yield in 140 hybrids (70 'B x R' and 70 'R x B' crosses) and 17 parental lines (10 B + 7 R). Reciprocal cross effects ('B x R' vs. 'R x B') were highly significant for all the three traits. In addition, the interaction between reciprocal cross differences and the environment was highly significant for yield and days to flowering. Wang and Liang (1995) suggested that nucleo-cytoplasmic heterosis is created by the mutual superiority and interaction of cytoplasmic and nuclear genes.

Tsaftaris *et al.* (1999) studied DNA methylation pattern in maize inbreds and hybrids and found that the maize inbreds bred for high yield had decreased methylation, which indicated that selection could change the level of methylation. They noted that less favorable, stressful conditions result in more methylated (and, hence, less expressed) DNA and, in general, heterotic hybrids were more resistant to such density induced genomic DNA methylation. They proposed that this resistance of the hybrid genome to methylation and, consequently, suppression of many genes in inbreds under different stresses could be central to the high and stable yield in hybrids in different environmental conditions. They also noted that in response to different environmental conditions, the hybrids show superior performance over their parental homozygous lines. Thus DNA methylation could redefine the concept of genetic-phenotypic variation and the way the genotype and environment interact.

DNA methylation also results in genomic or parental imprinting (Gilbert, 1994), which causes the expression of only one of the two alleles of a gene depending on its parental origin. Some of the imprinted genes express only after paternal inheritance, while others are expressed only when maternally inherited. Haig and Westoby (1991) reported that, because of imprinting seed development comes to depend on the 2:1 ratio of maternal and paternal genomes in endosperm. In cereals, the endosperm's strength as a nutrient sink during grain filling is primarily determined by the number of endosperm cells. Therefore, paternally expressed genes might act to increase the final number of endosperm cells and maternally expressed genes might counteract this tendency. Thus, this phenomenon may also account for the reciprocal cross differences observed in reciprocal hybrids.

From the above, it can be concluded that dominance, overdominance due to allelic interaction and epistasis due to non-allelic interaction at cellular and enzymatic level, nucleo-cytoplasmic interactions and reciprocal cross effects, all contributed to heterosis in rice.

After a critical review of literature available on various aspects related to the study, following points become quite obvious: (i) The genetic basis of heterosis has been debated for more than 80 years and is still not resolved. (ii) Heterosis for growth and yield is the product of many physiological and biochemical processes, which are not yet fully understood. (iii) There is limited information available on genetic nature of physiological and biochemical characters influencing yield in rice. (iv) Enough work has been done on genetic nature of yield and its components, but reports are conflicting and vary from material to material. (v) Heterosis is affected by the nucleo-cytoplasmic interactions and also shows reciprocal differences.

MATERIALS AND METHODS

The experimental site, climate and materials and methods used in the present investigation on "Studies on heterosis and genetic analysis of morpho-physiological and biochemical characters in rice" are described as follows:

3.1 Experimental site

The field trials were conducted during kharif seasons of 1998, 1999 and 2000 on the research farm of Indian Agricultural Research Institute (IARI), New Delhi, which is situated at 28° 40' N latitude and 77° 12' E longitude and is 228.6 m above the mean sea level. The off-season crop was grown at 'Rice Breeding and Genetics Research Center' (RBGRC) of IARI at Aduthurai (Tamil Nadu) to affect crosses and advancing generations during the rabi seasons of 1998 and 1999.

3.2 Climate

The climate of New Delhi is semi-arid and sub-tropical with hot dry summer and cold winter. The mean annual precipitation is around 710 mm, most of which is received between July and September.

3.3 Materials

The present investigation consisted of two sets of experiments. The materials used for each of them are described as follows:

Experiment – I

This experiment was conducted in order to study (i) the nature and magnitude of heterosis, (ii) genetic analysis of various characters through correlation studies and F_2 segregation patterns, and (iii) effects of male sterility inducing cytoplasm and reciprocal cross differences on various characters influencing grain yield.

The material for this study was derived from 'Hybrid Observation Trial' conducted at IARI during kharif 1998. From the trial having 65 hybrids, three hybrids were selected based on their overall performance. The parents (A, B and R lines) of these hybrids were grown at RBGRC, Aduthurai during rabi season of 1998 and crosses were affected to produce three sets of hybrids, AF_1s (AxR), BF_1s (BxR) and RF_1s (RxB) by hand emasculation and pollination (Table 1). In kharif 1999, parts of seed of the three sets of hybrids were sown at IARI, New Delhi to produce respective F_2 populations. Rest of the F_1 seed was saved for the following year's experiment.

In kharif 2000, the parents (A, B and R lines), the nine F_1s (3 AF_1s, 3 BF_1s and 3 RF_1s) and their F_2 populations were grown at IARI, New Delhi. The parents and hybrids were grown in a randomized block design with two replications. Each genotype was represented by four rows of 3.5 m at a spacing of 20 x 15 cm^2 in both the replications. While the nine F_2 populations were grown separately in 10 rows of 3.5 m at a spacing of 20 x 15 cm^2. Standard and uniform agronomic practices were followed throughout the growing season to raise a healthy crop. Data were recorded on physiological and biochemical characters and yield components for parents and hybrids on five randomly selected plants from the middle two rows in each replication. Observations for yield and yield components were recorded at maturity while growth parameters and certain other characters were recorded at different stages of growth *viz.* seedling, tillering, flowering and maturity. For recording observations at different growth stages, five plants were taken from each genotype in each replication. Mean of observations of the five plants was used for further analysis. However, for the F_2 populations, data were recorded on 200 plants drawn from middle of the plot for yield components only.

Table 1: Hybrids along with their parentage involved in study of Expt. 1

Set	Sr. No.	Hybrid (Designation)	Parentage		
I	1	A F_1-1	PMS 2A	x	Pusa 1127
	2	B F_1-1	PMS 2B	x	Pusa 1127
	3	R F_1-1	Pusa 1127	x	PMS 2B
II	4	A F_1-2	Pusa 5A	x	Pusa 1124
	5	B F_1-2	Pusa 5B	x	Pusa 1124
	6	R F_1-2	Pusa 1124	x	Pusa 5B
III	7	A F_1-3	IR 58025A	x	PRR 78
	8	B F_1-3	IR 58025B	x	PRR 78
	9	R F_1-3	PRR 78	x	IR 58025B

Table 2: Hybrids involved in study of Expt. 2 and their parentage

Sr. No.	Hybrid	Parentage		
1	PRH 2	IR 58025A	x	PRR 22
2	PRH 3	Pusa 5A	x	PRR 72
3	PRH 5	Pusa 5A	x	PRR 24
4	PRH 6	Pusa 5A	x	PRR 80
5	PRH 7	Pusa 5A	x	PRR 22
6	PRH 15	Pusa 5A	x	PRR 75
7	PRH 16	Pusa 5A	x	PRR 76
8	PRH 17	Pusa 5A	x	PRR 77
9	PRH 21	PMS 2A	x	PRR 72
10	PRH 26	Pusa 5A	x	TCP 97-24
11	PRH 27	Pusa 5A	x	TCP 97-25
12	PRH 28	Pusa 5A	x	TCP 97-33
13	PRH 33	IR 58025A	x	PRR 72
14	(Pusa 44)	Check variety		

Experiment – II

This experiment was conducted in order to study the nature and magnitude of heterosis and association of various yield components with grain yield separately in parents and hybrids.

Thirteen hybrids (AxR) and their parents (Table 2) were grown in randomized block design with two replications in kharif 1999 at IARI, New Delhi. Four rows of 3.5 m length with a spacing of 20 x 15 cm^2 were grown and standard and uniform agronomic practices were followed to raise a healthy crop. Data on yield components were recorded from 10 randomly selected plants from the middle two rows.

3.4 Methods

The characters studied and the methods used for recording the data are described below.

Plant height (cm): Plant height was measured from ground level to the tip of the main panicle.

Number of productive tillers: The number of panicle bearing tillers in each plant was counted.

Days to 50% flowering: The period from the date of sowing to the date of 50% plants in panicle emergence stage was calculated.

Days to maturity: The period from the date of sowing to the date of maturity was recorded.

Grain filling duration (days): Grain filling duration was calculated as the difference between the number of days to 50% flowering and number of days to maturity.

Flag leaf area (cm^2): Flag leaf area of the main tiller was calculated as per the following formula given by Bhavan and Pande (1966).

Flag leaf area (cm^2) = length (cm) x breadth (cm) x 0.802

Length of main panicle (cm): Length of the main panicle in each plant was measured.

Weight of panicles (g): Weight of the main panicle as well as that of all panicles of the plant was recorded. Weight per panicle was also calculated by dividing the weight of all panicles with the number of panicles of the plant.

Number of filled and unfilled spikelets: Filled and unfilled spikelets of the main panicle of each plant were separated and counted separately. Total number of spikelets in the main panicle was calculated by adding up the two numbers.

Panicle density: It was calculated as the number of filled spikelets per unit length of main panicle.

Spikelet fertility (%): Proportion of filled spikelets to the total number of spikelets in the main panicle of each plant was expressed in percentage to calculate spikelet fertility.

1000-grain weight (g): One thousand filled grains were counted from the harvest of each plant and weighed to record the test weight.

Biomass yield (g): Five plants were uprooted at random at each growth stages *viz.*, seedling, tillering, flowering and maturity. They were oven-dried at 80 °C for 48 hours. Biomass yield per plant was recorded.

Grain yield (g): At maturity, each plant was threshed and cleaned separately and the grain yield was recorded.

Straw yield (g): Straw yield was calculated as the difference between biomass yield at maturity and grain yield.

Harvest index: Harvest index was calculated as the ratio of grain yield to the total biomass yield.

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biomass yield}} \times 100$$

Growth parameters like CGR, RGR, NAR and LAR: Crop growth rate (CGR, mg/plant/day), relative growth rate (RGR, mg/g/plant/day), net assimilation rate

(NAR, $mg/dm^2/day$) and leaf area ratio (LAR, cm^2/g) were calculated for following stages: a) seedling to tillering, b) tillering to flowering and c) flowering to maturity. CGR was also calculated for whole growth duration *i.e.* seedling to maturity. Following formulae were used to calculate these parameters (Radford, 1967).

$$CGR = \frac{W_2 - W_1}{t_2 - t_1}$$

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

$$NAR = \frac{(W_2 - W_1)(\log_e A_2 - \log_e A_1)}{(t_2 - t_1)(A_2 - A_1)}$$

$$LAR = \frac{(A_2 - A_1)(\log_e W_2 - \log_e W_1)}{(\log_e A_2 - \log_e A_1)(W_2 - W_1)}$$

where, W_1, W_2 and A_1, A_2 are the plant dry weight and leaf area at times t_1 and t_2 respectively.

Leaf area (cm^2): Three leaves were taken at random from each plant at different growth stages and their area was measured in an automatic leaf area meter (Model 3100, Li-cor). The average leaf area was multiplied with number of leaves of the plant to get leaf area per plant.

Leaf area index (LAI): The leaf area index was calculated using the following formula at different stages of crop growth *viz.* tillering, flowering and maturity:

$$LAI = \frac{\text{Leaf area } (dm^2)}{\text{Land area covered by plant } (dm^2)}$$

Leaf area duration (LAD): The leaf area duration was computed at two growth stages *viz.* from tillering to flowering and from flowering to maturity by multiplying the mean LAI with number of days under each growth period (Mandal and Chatterjee, 1973).

$$LAD = \frac{LAI_1 + LAI_2}{2} \times (t_2 - t_1)$$

where, LAI_1 and LAI_2 are the leaf area indices at time t_1 and t_2 respectively.

Estimation of α-amylase activity: Estimation of α-amylase was done in germinating seeds of rice. The extraction of α-amylase was done with 10 ml of 10 mM ice-cold calcium chloride solution using 1 g of sample overnight at 4 °C. The extract was centrifuged at 54000 g at 4 °C for 20 min. The supernatant was saved and 0.2 ml of it was diluted to 1.0 ml with water. To this 1.0 ml of starch solution was added and the test tubes were incubated at 27 °C for 15 min. 2.0 ml of DNS (dinitrosalicylic acid) was added to stop the reaction. The tubes were heated for 5 min on a boiling water bath and 1.0 ml of potassium sodium tartarate was added to them. After cooling, volume was made up to 10 ml and the absorbance was read at 560 nm. Standard graph was prepared using 0-100 μg maltose. The activity of the enzyme was expressed as mg of maltose produced per seed per minute.

Estimation of nitrate reductase activity: *In vivo* assay of NRA involves incubation of plant material into the incubation medium consisting of a buffer and substrate (nitrate) under dark and anaerobic conditions. Anaerobic conditions are necessary for making sufficient NADH available for NO_3^- reduction. Nitrate thus formed is estimated colorimetrically using sulphanilamide and N (1-naphthyl) ethylene diamine dihydrochloride (NEDD).

Fresh leaves of rice were sliced (8-10 mm in diameter) and after thorough mixing a representative sample of 0.5 g was transferred to 30 ml tubes containing ice-cold incubation medium consisting of 3 ml each of phosphate buffer (0.2M, pH

7.5) and 0.2M potassium nitrate solution. To this, 0.2 ml of 5% propanol and 2 drops of chloramphenicol (0.5 mg/ml) were added to facilitate penetration of the substrate into the plant tissue. The tubes were removed from the ice bath and evacuated with the help of a vacuum pump for 2-5 minutes, until all the cut materials sank below the surface of the incubation medium. After infiltration, the tubes were incubated in metabolic water-bath maintained at 30° C for 30 minutes in dark. The reaction was terminated by keeping the tubes in boiling water for 2 minutes. This helps in leaching out of the nitrite formed in the plant tissue into the incubation medium. The tubes were cooled at room temperature and the supernatant was collected in a separate tube. 1.0 ml of the aliquot was taken and to it 1.0 ml of sulphanilamide (1.0%) and 1.0 ml of NEDD (0.02%) and 2.0 ml water was added. The tubes were incubated at room temperature for 20 min and the absorbance of the pink color developed was read at 540 nm. The NRA was calculated from KNO_2 standard curve.

<u>Estimation of nitrogen</u>: Nitrogen content in the grains of rice was estimated by using an autoanalyzer (Technicon, USA). Rice grains of the parents and hybrids were crushed and samples of 100 mg were used for analysis. The samples and a check were transferred to digestion tubes and were digested on a 'Tecator' digestion unit. To each digestion tube, 4 ml of digestion solution, 1.5 g K_2SO_4 and 0.0075 g Se were added. Digestion solution was a mixture of conc. H_2SO_4 and phosphoric acid (100:5 v/v). To this 1.5 ml of 30% H_2O_5 was added and then the samples were digested at 350 °C. After digestion, the volume was made up to 75 ml. The nitrogen content was measured using the autoanalyzer. The color reaction is as follows: The ammonia liberated by the digested sample is reacted with alkaline hypochlorite to form chloromine, which is combined with phenol to give a blue indophenol dye. The intensity of the color was measured at 660 nm.

Nitrogen content was then read from a calibration curve of standard ammonium chloride solution. The percentage of nitrogen was calculated as follows:

$$\text{Nitrogen (\%)} = \frac{\text{N (mg)}}{\text{Sample weight (mg)}} \times 100$$

Crude protein content (%): The percent crude protein was calculated as follows:

$$\text{Protein (\%)} = \text{Nitrogen (\%)} \times 5.95$$

Estimation of amylose: The grains were ground to powder and 100 mg of it was taken for amylose estimation. 1 ml of distilled ethanol and 10 ml of 1N NaOH were added to the sample and it was heated for 10 min on a boiling water bath. The volume was made to 100 ml with water. 2.5 ml of this extract was taken and to it 20 ml of water and 3 drops of phenolphthalein was added. 0.1 N HCl was added drop-by-drop until the pink color just disappeared. 1 ml of iodine was added and the volume was made to 50 ml. The absorbance was read at 590 nm. The amount of amylose in the sample was calculated from a standard curve prepared from amylose (0.2 to 1.0 ml) against the blank.

Estimation of starch: Starch content was estimated by anthrone reagent. 0.5 g of grain sample was homogenized in hot 80% ethanol to remove sugars. It was centrifuged and the residue was retained. The procedure was repeated till the washings did not give color with anthrone reagent. The residue was dried over a water bath and to the residue, 5 ml of water and 6.5 ml of 52% perchloric acid was added. Extraction was done at 0 °C for 20 min. It was centrifuged and the supernatant was saved. Extraction was repeated and the supernatants were pooled and the final volume was made to 100 ml. 0.2 ml of the supernatant was pipetted out and volume was made up to 1.0 ml. Standards were prepared by taking 0.2, 0.4, 0.6, 0.8 and 1.0 ml of the working standard and making the volume to 1.0 ml with water. 4.0 ml of anthrone was added to each tube and heated for 8 min. in water bath. The samples were rapidly cooled and the intensity of the green color was read at 630 nm on Spectronic-20. Using the standard curve, glucose content in the samples was found out. The value was multiplied by 0.9 to get the starch content.

3.5 Statistical analysis

Means over replications for each genotype and character were calculated and used for statistical analysis. The statistical procedures are described experiment wise.

Estimation of heterosis: The magnitude of heterosis was expressed as heterosis over mid parent (MP) and better parent (BP). Heterosis was calculated as percentage increase or decrease of F_1's mean performance over the mean performance of MP or BP. Significance of heterosis was tested by the 't' test.

i) Heterosis (Ha) over mid parent (MP)

$$Ha\ (\%) = [(F_1 - MP) / MP] \times 100$$

$$SE_{(F_{1-MP})} = (3\ Me / 2r)^{1/2}$$

$$t = (F_1 - MP) / SE_{(F_{1-MP})}$$

ii) Heterosis (Hb) over better parent (BP) (Heterobeltiosis)

$$Hb\ (\%) = [(F_1 - BP) / BP] \times 100$$

$$SE_{(F_{1-BP})} = (2\ Me / r)^{1/2}$$

$$t = (F_1 - BP) / SE_{(F_{1-BP})}$$

iii) Heterosis (Hc) over standard check (SC) (Standard heterosis)

$$Hc\ (\%) = [(F_1 - SC) / SC] \times 100$$

$$SE_{(F_{1-SC})} = (2\ Me / r)^{1/2}$$

$$t = (F_1 - SC) / SE_{(F_{1-SC})}$$

where, Me = error mean square and,

r = replication

Analysis of variance: Differences between genotypes for the characters studied were tested for significance by the 'Analysis of Variance' technique. Analysis of variance was done on the basis of following model:

$$Y_{ij} = m + g_i + r_j + e_{ij}$$

where, Y_{ij} = phenotypic observation on i^{th} genotype in j^{th} replication

m = general mean

g_i = effect of i^{th} genotype

r_j = effect of j^{th} replication

e_{ij} = random error associated with i^{th} genotype and j^{th} replication

The structure of Analysis of Variance (ANOVA) table was as follows:

Source	df	MSS	Expected MSS	F value
Replication	(r - 1)	M_r	$\sigma_e^2 + g\sigma_r^2$	
Treatment (genotype)	(g - 1)	M_g	$\sigma_e^2 + r\sigma_g^2$	M_g/M_e
Error	(r - 1) (g - 1)	M_e	σ_e^2	
Total	(rg - 1)			

where, r = number of replications,

g = number of genotypes (treatments),

M_e, M_g and M_e = mean sum of squares due to replication, genotype and error, respectively,

σ_g^2 = Genotypic variance = $(M_g - M_e) / r$ and,

σ_p^2 = Phenotypic variance = $\sigma_g^2 + \sigma_e^2$

σ_e^2 = Error variance = M_e

MSS due to genotypes were tested against the error variance using 'F' test at P= 0.05 or P= 0.01 with V_1 and V_2 degrees of freedom, where V_1 is the degree of freedom for higher value of variance and V_2 is the degree of freedom for lower value of variance.

Coefficients of phenotypic and genotypic variation in parents and hybrids: Coefficients of phenotypic (PCV) and genotypic (GCV) variation in parents and hybrids were calculated by using formulae suggested by Burton and Devane (1952).

Coefficient of phenotypic variation (PCV) = (S.D.p / Mean) x 100, and

Coefficient of genotypic variation (GCV) = (S.D.g / Mean) x 100

where, S.D.p and S.D.g are the phenotypic and genotypic standard deviations respectively.

Estimation of mean, range, standard error and critical difference

Mean value for each character was worked out by dividing the total with corresponding number of observations, while the lowest and highest value for each character were taken as the range. Standard error of mean and critical difference were calculated as follows:

Standard error of mean (S.Em) = $(Me / r)^{1/2}$

Critical difference for mean (CD at 5%) = $[(2\ Me) / r]^{1/2}$ x t value at 5% level of significance

Heritability (h^2): Heritability in broad sense was calculated as follows:

$$h^2(\%) = (\sigma^2_g / \sigma^2_p) \times 100$$

where, σ^2_g = genotypic variance

σ^2_p = phenotypic variance

Estimation of correlation coefficients: Simple correlation coefficients between various character pairs were worked out separately for parents and the hybrids by using the following formula:

$r_{xy} = Cov._{xy} / (V_x.V_y)^{1/2}$

where, r_{xy} = Correlation coefficient between characters 'x' and 'y'

Var_x = Variance of character 'x'

Var_y = Variance of character 'y'

The significance of correlation coefficient was tested at 'n-2' degrees of freedom and at p = 0.05 or p = 0.01 from the 't' table, where 'n' is the number of pairs for which the correlation coefficients are calculated.

Effect of male sterility inducing cytoplasm: The nature and magnitude of the effects of male sterility inducing cytoplasm on various characters was worked out as percent deviations between the means of AF_1 (AxR) and BF_1 (BxR) as suggested by Xiaobang and Zebing (1988):

$$\text{Cytoplasmic effect (\%)} = [(\overline{AF_1} - \overline{BF_1}) / \overline{BF_1}] \times 100$$

Significance of the deviations was tested using the 't' test.

Effect of reciprocal cross differences: The nature and magnitude of the effects of reciprocal cross differences on various characters was worked out as percent deviations between the means of RF_1 (RxB) and BF_1 (BxR) as follows (Modified from Xiaobang and Zebing, 1988):

$$\text{Reciprocal cross effect (\%)} = [(\overline{RF_1} - \overline{BF_1}) / \overline{BF_1}] \times 100$$

Significance of the deviations was tested using the 't' test.

Coefficients of phenotypic, genotypic and environmental variation in F_2 populations: The coefficients of phenotypic (PCV), environmental (ECV) and genotypic (GCV) variation were calculated as follows:

Coefficient of phenotypic variation (PCV) = (S.D.p / Mean) x 100

Coefficient of environmental variation (ECV): It was calculated as the average of CVs of six non-segregating genotypes *viz.* the parental lines; A, B and R and the three F_1s; AF_1, BF_1 and RF_1. For panicle and grain yield related characters, however, the A line was excluded. The ECV was calculated separately for each cross combination.

Coefficient of genotypic variation (GCV): It was calculated as the difference in PCV and ECV. It indicated variation in F_2 population that was genetic in nature.

GCV = PCV – ECV

Kolmogorov-Smirnov test for normal distribution: The Kolmogorov-Smirnov statistic was performed to test the goodness of fit of the distributions obtained for various characters in the nine F_2 populations for normal distribution. It was performed using the software package SPSS v. 10.0.

RESULTS

The experimental results obtained from the present investigation on heterosis and genetic analysis of morpho-physiological and biochemical characters affecting grain yield are presented here under the following heads.

4.1 Nature and magnitude of heterosis

4.2 Genetic analysis of yield components and physiological and biochemical characters

4.3 Effect of male sterility inducing cytoplasm on various characters

4.4 Effect of reciprocal cross differences on various characters

4.1 Nature and magnitude of heterosis

4.1.1 Experiment – I

In Experiment I, a total of 9 hybrids from three cross combinations and their parents were evaluated for yield and its components and physiological and biochemical characters. The results are presented under the following sub-heads:

i) Analysis of variance,

ii) Variability and heritability,

iii) Mean performance of parents and hybrids and estimation of mid-parent, better-parent and standard heterosis

4.1.1.1 Analysis of variance

Analysis of variance was carried out and the mean sums of squares for various characters are presented in Table 3. 'F' test revealed highly significant variation among the 18 genotypes (including 9 parents and 9 hybrids) for all the characters studied.

Table 3: Analysis of variance for various characters in parents and hybrids of Expt. 1

Characters	Mean Sum of Squares		
	Replication	Genotype	Error
d.f.	1	18	18
Plant height (cm)	1.6842	368.7379 **	6.8820
Number of productive tillers	0.1053	4.5807 **	0.7742
Days to 50% flowering	0.6579	55.4386 **	2.0468
Days to maturity	0.4211	78.0673 **	1.0322
Grain filling duration	0.0263	5.7982 **	0.4708
Flag leaf area (cm^2)	7.1257	234.7243 **	5.8324
Length of main panicle (cm)	0.0516	12.0744 **	0.7749
Weight of main panicle (g)	0.1006	3.3233 **	0.1027
Weight of all panicles (g)	0.0531	107.5671 **	2.4851
Weight per panicle (g)	0.0131	0.9788 **	0.0346
Number of filled spikelets	100.1579	5,793.4398 **	196.3557
Number of unfilled spikelets	110.7379	4,814.1473 **	169.2623
Total number of spikelets	31.0116	1,112.8255 **	16.1160
Panicle density	0.0412	8.5744 **	0.2539
Spikelet fertility (%)	53.9520 *	1,186.9511 **	18.8028
1000-grain weight (g)	0.6029	21.7822 **	0.6935
Biomass yield (g)	11.6390	193.6118 **	5.3989
Grain yield (g)	9.4300	99.2205 **	2.5334
Straw yield (g)	6.6924	23.3408 **	4.9554
Harvest index	0.0003	0.0435 **	0.0009
CGR (mg/day/plant)			
Seedling - tillering	5,464.7468 *	17,356.5706 **	1,078.2392
Tillering - flowering	4,800.4934 *	16,108.4400 **	984.4313
Flowering - maturity	5,520.5462 *	59,471.3134 **	1,228.5925
Whole duration	3,069.3964 *	14,551.3272 **	486.3275
RGR (mg/g/plant/day)			
Seedling - tillering	2.8577	58.0046 **	1.1673
Tillering - flowering	0.0612	10.8950 **	0.2772
Flowering - maturity	1.6891	27.1106 **	0.8317
NAR ($mg/dm^2/day$)			
Seedling - tillering	85.6848	2,013.6069 **	24.6033
Tillering - flowering	3.4012	63.0647 **	0.9643
Flowering - maturity	18.8857	482.8939 **	4.3323

Table 3 (Cont...)

Characters	Mean Sum of Squares		
	Replication	Genotype	Error
Leaf area (cm^2/plant)			
Seedling	0.1106	2.4824 **	0.0303
Tillering	6,214.4566 *	71,377.9957 **	1,274.3383
Flowering	4,818.6641 *	67,486.2286 **	1,039.3958
Maturity	2,201.8806	20,783.4730 **	560.1164
LAR (cm^2/g)			
Seedling - tillering	0.3773	20.3689 **	0.1274
Tillering - flowering	4.2780	217.4940 **	3.8241
Flowering - maturity	2.3730	196.9100 **	4.2682
LAI			
Tillering	0.1135	0.7749 **	0.0299
Flowering	0.1258	0.7261 **	0.0313
Maturity	0.0078	0.2315 **	0.0065
LAD			
Tillering - flowering	80.0505	560.7337 **	18.6429
Flowering - maturity	25.6025	323.7013 **	8.2187
α-Amylase activity (mg/seed/min)			
at 24 hrs	0.2007	26.0307 **	0.4464
at 48 hrs	0.2023	49.7349 **	0.7941
at 72 hrs	0.3042	49.1965 **	0.7238
NRA (μ moles NO_2/g fr.wt./hr)			
Seedling	1,203.3695	10,708.1917 **	326.5028
Tillering	1,013.2895	18,659.5455 **	333.4828
Flowering	656.6568	19,169.8000 **	305.1768
25 days after flowering	593.6800	11,355.6495 **	151.4644
Nitrogen (%) in grain	0.0001	0.0246 **	0.0004
Protein (%) in grain	0.0038	0.8709 **	0.0128
Amylose (%) in grain	0.5293	25.6472 **	0.3816
Starch (%) in grain	0.2529	30.2537 **	0.8720

* , ** = Significant at 5% and 1% levels, respectively

4.1.1.2 Variability and heritability

The estimates of general mean (GM), range, coefficient of genotypic variation (GCV), coefficient of phenotypic variation (PCV) and broad sense heritability (h^2) for the characters studied are presented in Table 4. A perusal of the table revealed that grain yield exhibited maximum PCV (56.00%), followed by number of unfilled spikelets on the main panicle (53.95%), harvest index (48.65%), panicle density (48.55%), number of filled spikelets on the main panicle (47.31%) and weight of main panicle (45.27%). Considerably higher PCV values were also obtained for following characters: spikelet fertility (44.48%), weight of all panicles of a plant (43.34%), weight per panicle (43.04%), CGR at flowering-maturity (39.79%) and NAR at flowering-maturity (37.87%). On the other hand, days to maturity recorded the lowest PCV of 5.14% followed by starch content in grain (5.38%), days to 50% flowering (5.79%), grain filling duration (5.95%), grain nitrogen content (7.50%), grain protein content (7.50%), NRA at flowering (9.60%) and NRA at tillering (9.74%).

The estimates of coefficient of genotypic variation (GCV) for all these characters followed a similar trend as that of PCV values for the respective characters.

Existence of wide spectrum of variability for yield and yield components in the experimental material was also evident from wider range values for plant height (68.30-107.20), number of productive tillers (7.90-12.50), flag leaf area (31.82-66.28), weight per panicle (0.31-2.60), total number of spikelets in the main panicle (149.80-243.40), 1000-grain weight (14.33-24.90), biomass yield (19.36-52.90), grain yield (0.00-22.17), straw yield (19.36-32.35) and harvest index (0.00-0.46). The maximum variation was found in weight per panicle (0.31-2.60 g, 88.02% variation), whereas days to maturity showed the least variation (114.50-138.50 days, 17.33% variation).

Table 4: Estimates of range, general mean, genotypic and phenotypic coefficients of variation and heritability (broad sense) for various characters in parents and hybrids of Expt. 1

Character	Range			GM	GCV (%)	PCV (%)	h^2 (%) (bs)
Plant height (cm)	68.30	-	107.20	90.01	14.87	15.15	96.34
Number of productive tillers	7.90	-	12.50	10.72	13.07	15.50	71.09
Days to 50% flowering	85.50	-	104.00	92.55	5.58	5.79	92.88
Days to maturity	114.50	-	138.50	122.32	5.07	5.14	97.39
Grain filling duration	27.00	-	34.50	29.76	5.48	5.95	84.98
Flag leaf area (cm^2)	31.82	-	66.28	54.82	19.52	20.01	95.15
Length of main panicle (cm)	20.90	-	28.95	25.50	9.32	9.94	87.94
Weight of main panicle (g)	0.53	-	4.39	3.03	43.89	45.27	94.00
Weight of all panicles (g)	3.40	-	27.50	18.02	42.35	43.34	95.48
Weight per panicle (g)	0.31	-	2.60	1.71	41.54	43.04	93.17
Number of filled spikelets	0.00	-	173.90	114.62	45.73	47.31	93.44
Number of unfilled spikelets	54.20	-	218.50	92.53	52.08	53.95	93.21
Total number of spikelets	149.80	-	243.40	207.15	11.25	11.41	97.14
Panicle density	0.00	-	6.94	4.42	47.14	48.55	94.25
Spikelet fertility (%)	0.00	-	75.98	55.05	43.79	44.48	96.88
1000-grain weight (g)	14.33	-	24.90	19.76	16.47	17.01	93.83
Biomass yield (g)	19.36	-	52.90	39.59	25.35	26.07	94.57
Grain yield (g)	0.00	-	22.17	13.40	54.59	56.00	95.02
Straw yield (g)	19.36	-	32.35	26.19	11.88	14.74	64.97
Harvest index	0.00	-	0.46	0.31	47.66	48.65	95.95
CGR (mg/day/plant)							
Seedling - tillering	204.73	-	539.25	365.11	24.71	26.30	88.30
Tillering - flowering	161.58	-	470.97	330.01	26.14	27.79	88.48
Flowering - maturity	97.26	-	673.15	453.26	38.97	39.79	95.95
Whole duration	141.83	-	418.32	319.17	26.57	27.48	93.53
RGR (mg/g/plant/day)							
Seedling - tillering	38.29	-	57.88	47.63	11.19	11.42	96.05
Tillering - flowering	11.47	-	20.46	14.98	15.33	15.72	95.04
Flowering - maturity	5.29	-	18.76	13.78	26.99	27.83	94.05
NAR (mg/dm^2/day)							
Seedling - tillering	117.36	-	247.68	167.73	18.87	19.10	97.59
Tillering - flowering	14.93	-	35.36	24.03	23.14	23.50	96.99
Flowering - maturity	8.91	-	63.84	42.70	37.53	37.87	98.22

Table 4 (Cont...)

Character	Range			GM	GCV (%)	PCV (%)	h^2 (%) (bs)
Leaf area (cm^2/plant)							
Seedling	2.55	-	6.03	4.45	24.90	25.21	97.59
Tillering	826.24	-	1456.32	1,223.11	15.24	15.52	96.49
Flowering	1222.62	-	1770.75	1,538.66	11.85	12.03	96.97
Maturity	521.64	-	859.64	704.28	14.25	14.64	94.75
LAR (cm^2/g)							
Seedling - tillering	22.46	-	35.62	28.92	10.97	11.03	98.76
Tillering - flowering	47.01	-	87.41	64.13	16.09	16.38	96.54
Flowering - maturity	27.24	-	59.47	35.78	27.29	27.89	95.76
LAI							
Tillering	2.75	-	4.85	4.08	14.91	15.49	92.57
Flowering	4.08	-	5.90	5.13	11.49	12.00	91.73
Maturity	1.74	-	2.87	2.35	14.26	14.66	94.51
LAD							
Tillering - flowering	53.20	-	109.46	88.80	18.50	19.13	93.56
Flowering - maturity	86.28	-	124.83	110.66	11.33	11.62	95.05
α-Amylase activity (mg/seed/min)							
at 24 hrs	5.00	-	15.00	10.60	33.74	34.32	96.63
at 48 hrs	8.00	-	21.67	15.59	31.72	32.24	96.86
at 72 hrs	15.00	-	31.50	23.42	21.02	21.33	97.10
NRA (μ moles NO_2/g fr.wt./hr)							
Seedling	575.40	-	814.80	675.58	10.66	10.99	94.08
Tillering	836.30	-	1152.50	999.67	9.57	9.74	96.49
Flowering	871.50	-	1188.00	1,030.72	9.45	9.60	96.87
25 days after flowering	147.70	-	444.00	285.32	26.23	26.59	97.37
Nitrogen (%) in grain	1.33	-	1.76	1.49	7.39	7.50	97.10
Protein (%) in grain	7.91	-	10.47	8.87	7.39	7.50	97.10
Amylose (%) in grain	19.00	-	29.50	23.89	14.88	15.10	97.07
Starch (%) in grain	66.50	-	78.80	73.36	5.22	5.38	94.40

GM = General mean

GCV = Coefficient of genotypic variation

PCV = Coefficient of phenotypic variation

h^2 (bs) = Heritability (broad sense)

Growth parameters like CGR, RGR, NAR, LAI, LAD and biochemical parameters like nitrate reductase activity, α-amylase activity and amylose content in grain also showed wide variation, while starch content in grain showed the lowest range (66.50%-78.80%, 15.61% variation).

High coefficients of variation (GCV and PCV) were coupled with high heritability (broad sense) estimates for some of the characters studied. Broad sense heritability ranged from 64.97% for straw yield to 98.76% for LAR at seedling to tillering stage. Characters like NAR at flowering to maturity (98.22%), NAR at seedling to tillering (97.59%), leaf area at seedling stage (97.59%) and days to maturity (97.39%) also showed high estimates of broad sense heritability, whereas other characters like number of productive tillers (71.09%), grain filling duration (84.98%), length of main panicle (87.94%) and CGR at seedling to tillering stage (88.30%) showed comparatively low estimates of broad sense heritability.

4.1.1.3 Mean performance of parents and hybrids and the extent of heterosis

Mean values of parental lines and hybrids of the three cross combinations are presented in Table 5. Heterosis as percent increase or decrease over the mid-parent (Ha), better parent (Hb) and standard check (Hc) is presented crosswise in Tables 6, 7 and 8, respectively. Mid-parent heterosis and heterobeltiosis (%) has also been depicted in figures 1a through 3d separately for yield components and physiological and biochemical characters, crosswise. The nature and magnitude of heterosis is presented character wise hereunder.

4.1.1.3.1 Yield and Yield components

Plant height (cm): Plant height of the parental lines ranged from 68.30 cm in PMS 2A to 103.70 cm in PRR 78, with a mean value of 82.52 cm. While in case of hybrids it

Table 5: Mean performance of parents and hybrids of Expt. 1 for various characters

Characters	PARENTS									Pusa 834 (Check)
	PMS 2A	Pusa 5A	IR 58025A	PMS 2B	Pusa 5B	IR 58025B	Pusa 1127	Pusa 1124	PRR 78	
Plant height (cm)	68.30	70.10	77.60	74.60	74.40	80.80	91.70	101.50	103.70	90.10
Number of productive tillers	11.50	8.40	11.50	11.00	8.00	10.70	8.80	12.40	7.90	11.30
Days to 50% flowering	104.00	93.00	94.00	103.00	92.00	91.50	95.50	100.50	91.00	85.50
Days to maturity	138.50	123.50	123.50	134.00	122.50	120.00	125.50	130.00	119.50	115.00
Grain filling duration	34.50	30.50	29.50	31.00	30.50	28.50	30.00	29.50	28.50	29.50
Flag leaf area (cm^2)	39.53	43.30	46.05	39.50	43.49	49.68	60.53	59.74	63.03	31.82
Length of main panicle (cm)	20.90	24.30	23.80	21.90	24.80	24.50	26.65	26.50	28.95	23.95
Weight of main panicle (g)	0.53	0.56	0.82	1.77	1.82	2.49	3.78	4.15	3.90	2.19
Weight of all panicles (g)	3.90	3.40	3.55	12.10	12.63	14.60	16.59	22.82	19.84	16.14
Weight per panicle (g)	0.34	0.41	0.31	1.10	1.63	1.37	1.91	1.88	2.60	1.43
Number of filled spikelets	0.00	0.00	3.40	113.90	102.40	108.10	117.60	127.90	132.10	80.20
Number of unfilled spikelets	218.50	188.80	204.30	97.60	80.60	93.20	64.90	55.90	69.50	69.60
Total spikelets in main panicle	218.50	188.80	207.70	211.50	183.00	201.30	182.50	183.80	201.60	149.80
Panicle density	0.00	0.00	0.14	5.22	4.14	4.43	4.43	4.84	4.57	3.35
Spikelet fertility (%)	0.00	0.00	1.48	54.48	56.54	54.95	64.52	69.93	65.80	53.89
1000-grain weight (g)	14.33	17.57	15.83	14.53	17.87	15.95	20.61	22.79	24.90	20.06
Biomass yield (g)	19.36	23.23	22.10	28.61	34.61	28.23	36.61	49.91	42.36	39.15
Grain yield (g)	0.00	0.00	0.06	7.65	8.50	8.51	12.17	17.71	14.71	11.07
Straw yield (g)	19.36	23.23	22.03	20.95	26.11	19.72	24.45	32.20	27.64	28.07
Harvest index	0.00	0.00	0.00	0.27	0.25	0.30	0.34	0.36	0.35	0.29

Table 5 (Cont...)

Characters	HYBRIDS											
	AF_1-1	AF_1-2	AF_1-3	BF_1-1	BF_1-2	BF_1-3	RF_1-1	RF_1-2	RF_1-3	GM	S.Em	CD at 5%
Plant height (cm)	82.60	95.50	102.00	87.70	101.80	107.20	90.60	105.70	104.30	90.01	4.10	14.46
Number of productive tillers	12.20	12.50	11.90	11.10	10.90	11.60	10.10	11.60	10.20	10.72	0.46	1.63
Days to 50% flowering	94.50	93.00	91.00	89.50	91.00	86.00	86.50	88.00	89.00	92.55	1.66	4.30
Days to maturity	122.00	124.00	118.00	120.50	120.50	114.50	116.00	119.50	117.00	122.32	1.98	2.17
Grain filling duration	27.50	31.00	27.00	31.00	29.50	28.50	29.50	31.50	28.00	29.76	0.54	0.99
Flag leaf area (cm^2)	57.97	62.07	64.76	58.73	63.06	64.25	63.33	66.28	64.43	54.82	3.43	12.25
Length of main panicle (cm)	22.25	25.15	28.60	24.55	27.90	28.70	24.75	28.05	28.30	25.50	0.78	1.63
Weight of main panicle (g)	3.21	4.18	4.08	3.49	4.21	4.19	3.62	4.39	4.11	3.03	0.43	0.22
Weight of all panicles (g)	19.85	23.48	24.93	20.99	25.38	26.77	22.51	27.50	25.49	18.02	2.49	5.22
Weight per panicle (g)	1.67	1.91	2.16	1.94	2.36	2.32	2.23	2.32	2.53	1.71	0.23	0.07
Number of filled spikelets	130.80	141.70	150.60	156.00	153.60	173.90	171.60	157.80	156.20	114.62	17.70	197.77
Number of unfilled spikelets	79.50	66.90	77.90	64.90	68.30	69.50	54.20	64.70	69.30	92.53	16.10	133.85
Total spikelets in main panicle	210.30	208.60	228.50	220.90	221.90	243.40	225.80	222.50	225.50	207.15	6.95	92.22
Panicle density	5.90	5.65	5.27	6.36	5.51	6.11	6.94	5.63	5.55	4.42	0.67	0.53
Spikelet fertility (%)	61.75	68.03	66.97	70.79	69.30	71.40	75.98	70.91	69.23	55.05	7.93	25.50
1000-grain weight (g)	17.65	23.09	21.54	18.13	24.05	22.25	18.31	24.36	21.68	19.76	1.07	1.46
Biomass yield (g)	38.35	45.45	52.73	42.28	48.26	52.90	46.72	49.23	52.19	39.59	3.46	11.34
Grain yield (g)	14.16	19.04	20.38	16.33	21.06	21.72	18.26	22.17	21.10	13.40	2.38	5.32
Straw yield (g)	24.20	26.40	32.35	25.95	27.20	31.18	28.46	27.06	31.09	26.19	1.26	10.41
Harvest index	0.38	0.43	0.39	0.39	0.45	0.41	0.39	0.46	0.41	0.31	0.05	0.00

Table 5 (Cont...)

Characters	PARENTS									Pusa 834 (Check)
	PMS 2A	Pusa 5A	IR 58025A	PMS 2B	Pusa 5B	IR 58025B	Pusa 1127	Pusa 1124	PRR 78	
CGR (mg/day/plant)										
Seedling - tillering	204.73	254.21	243.37	212.84	332.73	287.50	304.03	400.54	411.32	394.15
Tillering - flowering	161.58	228.81	274.29	244.90	244.19	250.82	267.74	427.63	281.75	358.71
Flowering - maturity	97.26	175.90	108.27	318.29	413.48	280.40	443.13	592.03	566.18	426.95
Whole duration	141.83	188.04	178.94	213.49	282.55	235.22	283.77	383.86	354.44	323.03
RGR (mg/g/plant/day)										
Seedling - tillering	42.05	49.19	40.56	39.90	48.56	42.62	43.83	46.12	50.78	55.43
Tillering - flowering	11.47	15.06	16.74	15.75	12.61	13.89	13.61	15.50	12.13	16.57
Flowering - maturity	5.48	8.61	5.29	13.64	14.86	11.68	15.58	14.60	16.83	14.04
NAR ($mg/dm^2/day$)										
Seedling - tillering	127.45	138.31	117.36	127.62	175.69	143.93	166.83	162.87	187.96	247.68
Tillering - flowering	14.93	17.47	19.17	22.18	18.30	19.35	23.67	28.26	19.88	35.36
Flowering - maturity	9.85	15.32	8.91	35.92	41.72	28.53	49.66	50.94	53.60	51.71
Leaf area (cm^2/plant)										
Seedling	2.55	3.05	3.68	2.67	3.00	3.50	3.75	5.00	4.00	4.78
Tillering	955.62	1,083.62	1,205.15	990.50	1,127.15	1,163.88	1,028.00	1,390.48	1,264.74	826.24
Flowering	1,222.62	1,569.25	1,684.30	1,228.07	1,570.75	1,440.00	1,244.00	1,647.08	1,583.12	1,233.19
Maturity	785.26	811.30	843.30	615.59	576.71	640.40	615.70	786.00	663.00	521.64
LAR (cm^2/g)										
Seedling - tillering	33.06	35.62	34.60	31.33	27.70	29.64	26.33	28.36	27.07	22.46
Tillering - flowering	77.05	86.37	87.41	71.14	69.10	71.88	57.61	54.98	61.05	47.01
Flowering - maturity	55.76	56.30	59.47	38.05	35.69	41.13	31.43	28.74	31.44	27.24

Table 5 (Cont...)

Characters	HYBRIDS									GM	S.Em	CD at 5%
	AF_1-1	AF_1-2	AF_1-3	BF_1-1	BF_1-2	BF_1-3	RF_1-1	RF_1-2	RF_1-3			
CGR (mg/day/plant)												
Seedling - tillering	320.98	419.98	484.38	361.77	438.10	539.25	386.68	469.23	471.33	365.11	30.60	2,265.38
Tillering - flowering	386.36	375.56	311.60	335.42	392.23	443.83	470.97	454.12	359.75	330.01	27.66	2,068.29
Flowering - maturity	468.87	509.84	608.59	568.45	631.49	529.68	673.15	628.86	571.14	453.26	56.60	2,581.27
Whole duration	315.19	366.50	396.05	350.86	400.57	418.32	402.77	411.95	416.95	319.17	28.42	1,021.77
RGR (mg/g/plant/day)												
Seedling - tillering	38.29	46.83	51.60	46.05	52.28	57.88	48.90	51.02	53.03	47.63	1.72	2.45
Tillering - flowering	17.21	14.38	11.62	15.13	15.46	15.72	20.46	18.71	12.65	14.98	0.75	0.58
Flowering - maturity	14.85	13.79	16.05	17.39	16.54	13.29	18.76	16.34	14.19	13.78	1.17	1.75
NAR ($mg/dm^2/day$)												
Seedling - tillering	146.60	166.82	200.25	156.67	170.73	213.46	159.58	184.20	192.80	167.73	10.22	51.69
Tillering - flowering	29.24	24.53	20.46	24.32	25.15	28.02	33.00	28.56	24.78	24.03	1.72	2.03
Flowering - maturity	46.76	47.58	49.88	54.64	57.72	42.23	63.84	56.62	45.83	42.70	5.08	9.10
Leaf area ($cm^2/plant$)												
Seedling	5.75	5.03	5.28	5.66	5.15	5.18	6.03	5.05	5.37	4.45	0.35	0.06
Tillering	1,171.00	1,429.30	1,346.00	1,255.00	1,456.32	1,426.00	1,311.27	1,448.47	1,360.27	1,223.11	58.58	2,677.38
Flowering	1,485.00	1,640.70	1,720.46	1,515.00	1,669.79	1,756.55	1,553.00	1,701.00	1,770.75	1,538.66	58.46	2,183.77
Maturity	638.60	653.50	829.00	679.20	669.46	859.64	677.61	676.70	838.77	704.28	31.90	1,176.80
LAR (cm^2/g)												
Seedling - tillering	26.16	28.13	25.78	29.46	30.71	27.17	30.70	27.76	27.54	28.92	1.01	0.27
Tillering - flowering	58.90	58.74	56.91	62.41	61.56	56.22	62.14	60.90	57.01	64.13	3.34	8.03
Flowering - maturity	31.79	29.03	32.21	31.92	28.68	31.50	29.45	28.90	31.00	35.78	3.20	8.97

Table 5 (Cont...)

Characters	PARENTS									Pusa 834 (Check)
	PMS 2A	Pusa 5A	IR 58025A	PMS 2B	Pusa 5B	IR 58025B	Pusa 1127	Pusa 1124	PRR 78	
LAI										
Tillering	3.19	3.61	4.02	3.30	3.76	3.88	3.43	4.63	4.22	2.75
Flowering	4.08	5.23	5.61	4.09	5.24	4.80	4.15	5.49	5.28	4.11
Maturity	2.62	2.70	2.81	2.05	1.92	2.13	2.05	2.62	2.21	1.74
LAD										
Tillering - flowering	90.74	97.73	84.28	90.59	93.13	72.05	71.58	108.85	96.35	53.20
Flowering - maturity	108.76	121.01	124.27	95.26	109.16	98.90	92.99	119.63	106.69	86.28
α-Amylase activity (mg/seed/min)										
at 24 hrs	5.00	5.00	7.50	6.00	6.50	8.25	10.00	11.25	10.50	6.25
at 48 hrs	8.00	8.25	10.25	9.25	9.25	11.00	15.00	16.25	16.00	11.50
at 72 hrs	15.00	15.75	20.25	17.75	16.00	20.50	22.75	25.25	24.25	20.65
NRA (μ moles NO_2/g fr.wt./hr)										
Seedling	575.40	604.30	628.50	588.50	617.80	625.10	638.90	814.80	750.30	592.60
Tillering	876.00	920.00	960.00	836.30	912.00	979.50	935.00	1,144.20	1,056.00	840.30
Flowering	924.00	966.40	1,008.00	886.70	1,028.50	1,071.70	872.00	1,125.60	1,053.50	871.50
25 days after flowering	222.00	444.00	324.00	228.00	354.00	210.10	287.00	373.00	235.00	147.70
Nitrogen (%) in grain	1.46	1.38	1.34	1.45	1.40	1.36	1.45	1.56	1.76	1.33
Protein (%) in grain	8.69	8.21	7.97	8.63	8.33	8.09	8.63	9.28	10.47	7.91
Amylose (%) in grain	20.50	19.00	22.30	20.70	19.60	22.60	25.50	20.50	27.40	23.40
Starch (%) in grain	66.50	68.80	70.60	70.50	70.80	70.00	68.70	73.90	78.50	73.60

Table 5 (Cont...)

Characters	HYBRIDS									GM	S.Em	CD at 5%
	AF_1-1	AF_1-2	AF_1-3	BF_1-1	BF_1-2	BF_1-3	RF_1-1	RF_1-2	RF_1-3			
LAI												
Tillering	3.90	4.76	4.49	4.18	4.85	4.75	4.37	4.83	4.53	4.08	0.20	0.06
Flowering	4.95	5.47	5.73	5.05	5.57	5.86	5.18	5.67	5.90	5.13	0.19	0.07
Maturity	2.13	2.18	2.76	2.26	2.23	2.87	2.26	2.26	2.80	2.35	0.11	0.01
LAD												
Tillering - flowering	68.17	92.10	109.46	66.48	107.33	103.96	73.99	101.83	105.41	88.80	5.29	39.17
Flowering - maturity	97.33	118.53	114.73	113.37	115.01	124.27	109.67	124.83	121.78	110.66	3.70	17.27
α-Amylase activity (mg/seed/min)												
at 24 hrs	12.83	14.00	13.33	13.33	14.50	14.17	13.33	14.67	15.00	10.60	1.15	0.94
at 48 hrs	18.33	20.00	19.50	20.00	20.17	20.17	20.83	21.67	20.83	15.59	1.59	1.67
at 72 hrs	23.50	29.50	26.83	24.83	30.00	27.33	25.00	31.50	28.33	23.42	1.58	1.52
NRA (μ moles NO_2/g fr.wt./hr)												
Seedling	625.10	733.50	769.00	740.00	714.00	677.00	633.60	776.00	731.70	675.58	23.48	685.98
Tillering	979.50	1,004.00	1,098.50	1,077.00	1,081.00	1,067.00	1,021.00	1,152.50	1,053.90	999.67	30.34	700.65
Flowering	1,033.00	1,188.00	1,107.00	984.00	1,134.00	1,131.30	975.10	1,140.30	1,083.00	1,030.72	30.72	641.18
25 days after flowering	265.30	233.90	370.50	260.40	245.00	369.00	259.80	226.30	366.00	285.32	24.00	318.23
Nitrogen (%) in grain	1.46	1.51	1.59	1.49	1.55	1.64	1.45	1.52	1.61	1.49	0.04	0.00
Protein (%) in grain	8.69	8.98	9.46	8.87	9.22	9.76	8.63	9.04	9.58	8.87	0.21	0.03
Amylose (%) in grain	26.50	21.50	29.30	27.00	21.00	29.50	26.80	21.20	29.50	23.89	1.14	0.80
Starch (%) in grain	70.60	76.60	78.00	72.50	77.00	78.80	73.00	76.90	78.50	73.36	1.23	1.83

Table 6: Mid-parent, better-parent and standard heterosis (%) for various characters in crosses involving PMS 2A, PMS 2B and Pusa 1127

Characters	Mid-parent heterosis			Better-parent heterosis			Standard heterosis		
	AF_1-1	BF_1-1	RF_1-1	AF_1-1	BF_1-1	RF_1-1	AF_1-1	BF_1-1	RF_1-1
Plant height (cm)	3.25	5.47	8.96 **	-9.92 **	-4.36	-1.20	-8.32 *	-2.66	0.55
Number of productive tillers	20.20 *	12.12	2.02	6.09	0.91	-8.18	7.96	-1.77	-10.62
Days to 50% flowering	-5.26 **	-9.82 **	-12.85 **	-9.13 **	-13.11 **	-16.02 **	10.53 **	4.68 *	1.17
Days to maturity	-7.58 **	-7.13 **	-10.60 **	-11.91 **	-10.07 **	-13.43 **	6.09 **	4.78 **	0.87
Grain filling duration	-14.73 **	1.64	-3.28	-20.29 **	0.00	-4.84 *	-6.78 **	5.08 *	0.00
Flag leaf area (cm^2)	15.86 **	17.42 **	26.61 **	-4.24	-2.98	4.61	82.20 **	84.60 **	99.04 **
Length of main panicle (cm)	-6.41	1.13	1.96	-16.51 **	-7.88 *	-7.13 *	-7.10	2.51	3.34
Weight of main panicle (g)	15.51	25.84 *	30.24 **	-15.23	-7.64	-4.41	46.37 **	59.47 **	65.04 **
Weight of all panicles (g)	38.38 **	46.33 **	56.93 **	19.62	26.49 *	35.66 **	22.99 *	30.06 **	39.48 **
Weight per panicle (g)	10.78	28.36 *	48.16 **	-12.59	1.28	16.90	16.53	35.02 *	55.84 **
Number of filled spikelets	13.00	34.77 **	48.25 **	11.22	32.65 **	45.92 **	63.09 **	94.51 **	113.97 **
Number of unfilled spikelets	-2.15	-20.12 *	-33.29 **	-63.62 **	-33.50 **	-44.47 **	14.22	-6.75	-22.13
Total number of spikelets	4.89	12.13 **	14.62 **	-3.75	4.44	6.76 *	40.39 **	47.46 **	50.73 **
Panicle density	22.30 *	32.01 **	43.99 **	33.20 **	22.02 *	33.10 **	75.77 **	89.73 **	106.96 **
Spikelet fertility (%)	3.79	18.97 **	27.71 **	-4.28	9.72	17.77 **	14.58 *	31.34 **	40.98 **
1000-grain weight (g)	0.47	3.16	4.23	-14.36 **	-12.06 **	-11.15 *	-11.99 **	-9.64 *	-8.70
Biomass yield (g)	37.04 **	29.65 **	43.26 **	4.75	15.48 *	27.60 **	-2.02	8.01	19.35 **
Grain yield (g)	42.85 **	64.84 **	84.27 **	16.37	34.27 *	50.11 **	27.86	47.53 **	64.93 **
Straw yield (g)	10.47	14.30	25.36 **	-1.03	6.13	16.40	-13.80	-7.58	1.37
Harvest index	23.76 *	28.37 **	28.89 **	10.70	14.82	15.29	31.79 **	36.69 **	37.24 **

Table 6 (Cont...)

Characters	Mid-parent heterosis			Better-parent heterosis			Standard heterosis		
	AF_1-1	BF_1-1	RF_1-1	AF_1-1	BF_1-1	RF_1-1	AF_1-1	BF_1-1	RF_1-1
CGR (mg/day/plant)									
Seedling - tillering	24.20 *	39.98 **	49.62 **	5.58	18.99	27.19 *	-18.56 *	-8.22	-1.90
Tillering - flowering	50.73 **	30.86 **	83.74 **	44.30 **	25.28 *	75.90 **	7.71	-6.49	31.30 **
Flowering - maturity	23.16 **	49.31 **	76.81 **	5.81	28.28 **	51.91 **	9.82	33.14 **	57.67 **
Whole duration	26.77 **	41.12 **	61.99 **	11.07	23.64 **	41.93 **	-2.43	8.62	24.68 **
RGR (mg/g/plant/day)									
Seedling - tillering	-8.55 **	9.98 **	16.79 **	-12.65 **	5.05	11.56 **	-30.93 **	-16.93 **	-11.79 **
Tillering - flowering	17.21 **	3.10	39.36 **	26.43 **	-3.92	29.88 **	3.85	-8.65 *	23.48 **
Flowering - maturity	1.65	19.06 **	28.43 **	-4.65	11.68	20.47 **	5.79	23.91 **	33.66 **
NAR (mg/dm^2/day)									
Seedling - tillering	-0.42	6.42 *	8.39 *	-12.13 **	-6.09	-4.35	-40.81 **	-36.74 **	-35.57 **
Tillering - flowering	27.54 **	6.10	43.92 **	23.53 **	2.76	39.40 **	-17.31 **	-31.21 **	-6.68 *
Flowering - maturity	9.29 *	27.70 **	49.20 **	-5.84	10.02 *	28.55 **	-9.57 *	5.66	23.46 **
Leaf area (cm^2/plant)									
Seedling	79.13 **	76.30 **	87.82 **	53.32 **	50.89 **	60.76 **	20.31 **	18.41 **	26.15 **
Tillering	16.03 **	24.35 **	29.92 **	13.91 **	22.08 **	27.56 **	41.73 **	51.89 **	58.70 **
Flowering	20.14 **	22.57 **	25.64 **	19.37 **	21.78 **	24.84 **	20.42 **	22.85 **	25.93 **
Maturity	3.73	10.32 **	10.06 **	-18.68 **	10.31 *	10.06 *	22.42 **	30.20 **	29.90 **
LAR (cm^2/g)									
Seedling - tillering	-9.27 **	2.18	6.47 **	-20.87 **	-5.96 **	-2.01	16.48 **	31.17 **	36.68 **
Tillering - flowering	-8.50 **	-3.05	-3.48	-23.55 **	-12.27 **	-12.66 **	25.29 **	32.77 **	32.18 **
Flowering - maturity	-8.49	-8.11	-15.23 **	-42.99 **	-16.10 **	-22.60 **	16.72 *	17.21 *	8.13

Table 6 (Cont...)

Characters	Mid-parent heterosis			Better-parent heterosis			Standard heterosis		
	AF_1-1	BF_1-1	RF_1-1	AF_1-1	BF_1-1	RF_1-1	AF_1-1	BF_1-1	RF_1-1
LAI									
Tillering	16.03 **	24.35 **	29.92 **	13.91 *	22.08 **	27.56 **	41.73 **	51.89 **	58.70 **
Flowering	20.14 **	22.57 **	25.64 **	19.37 **	21.78 **	24.84 **	20.42 **	22.85 **	25.93 **
Maturity	3.73	10.32 **	10.06 **	-18.68 **	10.31 *	10.06 *	22.42 **	30.20 **	29.90 **
LAD									
Tillering - flowering	-15.93 **	-18.01 **	-8.74	-24.88 **	-26.62 **	-18.32 **	28.13 **	24.95 **	39.08 **
Flowering - maturity	3.41	20.45 **	16.52 **	-10.51 **	19.01 **	15.13 **	12.81 **	31.40 **	27.11 **
α-Amylase activity (mg/seed/min)									
at 24 hrs	60.38 **	66.63 **	66.63 **	28.30 **	33.30 **	33.30 **	105.25 **	113.25 **	113.25 **
at 48 hrs	51.17 **	64.94 **	71.79 **	22.20 **	33.33 **	38.87 **	59.35 **	73.87 **	81.08 **
at 72 hrs	16.06 **	22.61 **	23.45 **	3.31	9.14 *	9.89 *	13.82 **	20.24 **	21.07 **
NRA (μ moles NO_2/g fr.wt./hr)									
Seedling	1.86	20.58 **	3.24	-2.16	15.82 **	-0.83	5.48 **	24.87 **	6.92 **
Tillering	10.60 **	21.61 **	15.28 **	4.76 *	15.19 **	9.20 **	16.57 **	28.17 **	21.50 **
Flowering	17.47 **	11.90 **	10.89 **	11.80 **	10.97 **	9.97 **	18.53 **	12.91 **	11.89 **
25 days after flowering	3.03	1.13	0.89	-7.56	-9.27 *	-9.48 *	79.62 **	76.30 **	75.90 **
Nitrogen (%) in grain	0.69	2.76 *	0.00	0.00	2.76 *	0.00	9.77	12.03	9.02
Protein (%) in grain	0.69	2.76 *	0.00	0.00	2.76 *	0.00	9.77	12.03	9.02
Amylose (%) in grain	14.72 **	16.87 **	16.01 **	3.92	5.87 *	5.09	13.26	15.38	14.53
Starch (%) in grain	1.43	4.17 **	4.88 **	2.76	2.84 *	3.54 *	-4.08	-1.49	-0.82

* , ** = Significant at 5% and 1% levels, respectively

varied from 82.60 cm (AF_1-1) to 107.20 cm (BF_1-3), with a mean of 97.49 cm. The ranges for Ha, Hb and Hc were, 3.25% (AF_1-1) to 20.18% (RF_1-2), -9.92% (AF_1-1) to 4.14% (RF_1-2) and -8.32% (AF_1-1) to 18.98% (BF_1-3) respectively. For this character, seven hybrids showed significantly positive Ha and two showed significantly negative Hb. When compared with the check, five hybrids showed significant positive heterosis and one showed significant negative heterosis.

Number of productive tillers: On an average PRR 78 had only 7.90 productive tillers and Pusa 1124 had 12.40 tillers among the parental lines, with a parental mean of 10.02. While the average number of productive tillers in hybrids ranged from 10.10 (RF_1-1) to 12.50 (AF_1-2), with a mean of 11.34. The Ha was the lowest in RF_1-1 (2.02%) and highest in BF_1-3 (24.73%), while Hb ranged from -12.10% for BF_1-2 to 8.41% for BF_1-3. Similarly, Hc ranged from -10.62% in RF_1-1 to 10.62% in AF_1-2. For this character, four hybrids showed significant increase over the mid-parent value, however the rest did not significantly differ from their mid-parental value. None of the hybrids manifested significant heterobeltiosis or standard heterosis.

Days to 50% flowering: In terms of number of days to 50% flowering, PRR 78 was the earliest (91.00 days) and PMS 2A was the latest (104.00 days) among the parents, with the parental mean being 96.06 days. In case of hybrids, BF_1-3 flowered earliest in 86.00 days and AF_1-1 was the latest to flower in 94.50 days. The mean of hybrids for this character was 89.83 days. The Ha ranged from -12.85% for RF_1-1 to -1.62% for AF_1-3, while the range for Hb was from -16.02% in RF_1-1 to -2.73% in RF_1-3. In case of Hc, all the hybrids showed positive values, the range being 0.58% in BF_1-3 to 10.53% in AF_1-1. Seven hybrids in each case exhibited significantly negative Ha and Hb, while six hybrids exhibited significantly positive Hc indicating their lateness over the check variety.

Table 7: Mid-parent, better-parent and standard heterosis (%) for various characters in crosses involving Pusa 5A, Pusa 5B and Pusa 1124

Characters	Mid-parent heterosis			Better-parent heterosis			Standard heterosis		
	AF_1-2	BF_1-2	RF_1-2	AF_1-2	BF_1-2	RF_1-2	AF_1-2	BF_1-2	RF_1-2
Plant height (cm)	11.31 **	15.75 **	20.18 **	-5.91 *	0.30	4.14	5.99	12.99 **	17.31 **
Number of productive tillers	20.19 *	6.86	13.73	0.81	-12.10	-6.45	10.62	-3.54	2.65
Days to 50% flowering	-3.88 **	-5.45 **	-8.57 **	-7.46 **	-9.45 **	-12.44 **	8.77 **	6.43 **	2.92
Days to maturity	-2.17 **	-4.55 **	-5.35 **	-4.62 **	-7.31 **	-8.08 **	7.83 **	4.78 **	3.91 **
Grain filling duration	3.33	-1.67	5.00 *	1.64	-3.28	3.28	5.08 *	0.00	6.78 **
Flag leaf area (cm^2)	20.47 **	22.17 **	28.40 **	3.89	5.56	10.94 *	95.08 **	98.21 **	108.32 **
Length of main panicle (cm)	-0.98	8.77 **	9.36 **	-5.09	5.28	5.85	5.01	16.49 **	17.12 **
Weight of main panicle (g)	39.92 **	40.93 **	47.06 **	0.75	1.47	5.89	90.60 **	91.97 **	100.32 **
Weight of all panicles (g)	32.49 **	43.22 **	55.18 **	2.91	11.25	20.53 **	45.49 **	57.28 **	70.41 **
Weight per panicle (g)	8.61	34.47 **	32.06 **	1.26	25.37 *	23.12 *	32.98 *	64.64 **	61.69 **
Number of filled spikelets	23.06 **	33.39 **	37.04 **	10.79	20.09 *	23.38 **	76.68 **	91.52 **	96.76 **
Number of unfilled spikelets	-1.98	0.07	-5.20	-64.57 **	-15.26	-19.73	-3.88	-1.87	-7.04
Total number of spikelets	11.97 **	20.99 **	21.32 **	10.49 **	20.73 **	21.06 **	39.25 **	48.13 **	48.53 **
Panicle density	25.72 *	22.73 *	25.31 *	16.69	13.92	16.31	68.34 **	64.35 **	67.80 **
Spikelet fertility (%)	7.59	9.60	12.14 *	-2.71	-0.90	1.40	26.23 **	28.59 **	31.57 **
1000-grain weight (g)	13.59 **	18.30 **	19.84 **	1.33	5.53	6.90	15.11 **	19.88 **	21.44 **
Biomass yield (g)	24.28 **	14.19 **	16.49 **	-8.95	-3.31	-1.36	16.09 *	23.28 **	25.76 **
Grain yield (g)	45.29 **	60.67 **	69.15 **	7.53	18.92 *	25.19 *	71.98 **	90.19 **	100.23 **
Straw yield (g)	-4.73	-6.70	-7.19	-18.01 *	-15.53 *	-15.97 *	-5.95	-3.11	-3.61
Harvest index	41.73 **	48.19 **	53.27 **	20.27 *	25.75 **	30.06 **	49.75 **	56.57 **	61.94 **

Table 7 (Cont...)

Characters	Mid-parent heterosis			Better-parent heterosis			Standard heterosis		
	AF_1-2	BF_1-2	RF_1-2	AF_1-2	BF_1-2	RF_1-2	AF_1-2	BF_1-2	RF_1-2
CGR (mg/day/plant)									
Seedling - tillering	14.55	19.49 *	27.98 **	4.85	9.38	17.15	6.55	11.15	19.05 *
Tillering - flowering	11.80	16.77	35.19 **	-12.18	-8.28	6.20	4.70	9.35	26.60 **
Flowering - maturity	1.41	25.61 **	25.08 **	-13.88 *	6.66	6.22	19.41 *	47.91 **	47.29 **
Whole duration	9.99	20.22 **	23.63 **	-4.52	4.35	7.32	13.46	24.01 **	27.53 **
RGR (mg/g/plant/day)									
Seedling - tillering	-1.08	10.44 **	7.78 **	-4.81 *	7.67 **	5.08 *	-15.52 **	-5.68 **	-7.95 **
Tillering - flowering	2.30	9.97 **	33.11 **	-7.22 *	-0.26	20.72 **	-13.22 **	-6.71 *	12.92 **
Flowering - maturity	-6.40	12.27 *	10.97	-5.57	11.30	10.01	-1.80	17.79 *	16.42 *
NAR (mg/dm^2/day)									
Seedling - tillering	-1.45	0.86	8.81 **	2.43	-2.82	4.84	-32.64 **	-31.07 **	-25.63 **
Tillering - flowering	5.36	8.04 *	22.69 **	-13.21 **	-11.00 **	1.06	-30.63 **	-28.87 **	-19.22 **
Flowering - maturity	2.70	24.59 **	22.20 **	-6.59	13.33 **	11.15 *	-7.99	11.63 **	9.49 *
Leaf area (cm^2/plant)									
Seedling	25.75 **	28.75 **	26.28 **	0.60	3.00	1.02	5.23	7.74 *	5.67
Tillering	13.54 **	15.69 **	15.07 **	2.79	4.74	4.17	72.99 **	76.26 **	75.31 **
Flowering	1.98	3.78 *	5.72 **	-0.39	1.38	3.27	33.05 **	35.40 **	37.93 **
Maturity	-4.09	-1.75	-0.68	-19.45 **	-14.83 **	-13.91 **	25.28 **	28.34 **	29.73 **
LAR (cm^2/g)									
Seedling - tillering	0.35	9.55 **	-0.95	-21.04 **	8.27 **	-2.12	25.25 **	36.74 **	23.62 **
Tillering - flowering	-5.33	-0.78	-1.84	-31.99 **	-10.91 **	-11.87 **	24.94 **	30.95 **	29.55 **
Flowering - maturity	-9.90	-10.97	-10.29	-48.44 **	-19.64 **	-19.02 **	6.57	5.30	6.11

Table 7 (Cont...)

Characters	Mid-parent heterosis			Better-parent heterosis			Standard heterosis		
	AF_1-2	BF_1-2	RF_1-2	AF_1-2	BF_1-2	RF_1-2	AF_1-2	BF_1-2	RF_1-2
LAI									
Tillering	13.54 **	15.69 **	15.07 **	2.79	4.74	4.17	72.99 **	76.26 **	75.31 **
Flowering	1.98	3.78	5.72	-0.39	1.38	3.27	33.05 **	35.40 **	37.93 **
Maturity	-4.09	-1.75	-0.68	-19.45 **	-14.83 **	-13.91 **	25.28 **	28.34 **	29.73 **
LAD									
Tillering - flowering	-8.80 *	6.28	0.83	-15.38 **	-1.39	-6.44	73.11 **	101.73 **	91.40 **
Flowering - maturity	3.62	0.54	9.12 **	-2.05	-3.86	4.35	37.38 **	33.30 **	44.68 **
α-Amylase activity (mg/seed/min)									
at 24 hrs	57.71 **	63.38 **	65.26 **	24.43 **	28.90 **	30.39 **	123.96 **	132.01 **	134.68 **
at 48 hrs	56.85 **	58.18 **	69.95 **	23.07 **	24.12 **	33.35 **	73.87 **	75.35 **	88.39 **
at 72 hrs	43.04 **	45.45 **	52.74 **	16.84 **	18.81 **	24.76 **	42.87 **	45.28 **	52.56 **
NRA (μ moles NO_2/g fr.wt./hr)									
Seedling	2.40	-0.32	8.33 **	-9.98 **	-12.37 **	-4.76 *	23.78 **	20.49 **	30.95 **
Tillering	-2.34	5.15 **	12.10 **	-12.25 **	-5.52 **	0.73	19.48 **	28.64 **	37.15 **
Flowering	10.30 **	5.29 **	5.87 **	5.54 **	0.75	1.31	36.32 **	30.12 **	30.84 **
25 days after flowering	-35.65 **	-32.60 **	-37.74 **	-47.32 **	-34.32 **	-39.33 **	58.36 **	65.88 **	53.22 **
Nitrogen (%) in grain	2.03	4.73 **	2.70 *	-3.21 *	-0.64	-2.56 *	13.53	16.54	14.29
Protein (%) in grain	2.03	4.73 **	2.70 *	-3.21 *	-0.64	-2.56 *	13.53	16.54	14.29
Amylose (%) in grain	7.24 *	4.73	5.73 *	4.88	2.42	3.40	-8.11	-10.26	-9.40
Starch (%) in grain	5.87 **	6.43 **	6.29 **	3.65 **	4.19 **	4.06 **	4.08	4.62	4.49

* , ** = Significant at 5% and 1% levels, respectively

Days to maturity: Among parents, the value for this character ranged from 119.50 days in PRR 78 to 138.50 days in PMS 2A, with a mean of 126.33 days. While the range for this character in hybrids was from 114.50 for BF_1-3 to 124.00 for AF_1-2, with a mean of 119.11. The Ha varied from -10.60% for RF_1-1 to -2.17% for AF_1-2, while Hb ranged from -13.43% for RF_1-1 to -2.50% for RF_1-3. The standard heterosis was found to vary between -0.43% for BF_1-3 and 7.83% for AF_1-2. All the hybrids showed significantly negative Ha and Hb for this character indicating earliness. On the other hand, six hybrids showed significant positive Hc values, indicating their lateness compared to the check.

Grain filling duration (days): In general, it was observed that late maturing genotypes also had longer grain filling duration. In parental genotypes, the grain filling duration varied from 28.50 days in IR 58025B to 34.50 days in PMS 2A, with a mean of 30.28 days. The character ranged from 27.00 days (AF_1-3) to 31.50 days (RF_1-2) in hybrids, with a mean of 29.28 days. The Ha for grain filling duration ranged from -14.73% for AF_1-1 to 5.00% for RF_1-2, with two of the hybrids showing significant negative values and only one showing a significant positive value. While Hb ranged from -20.29% for AF_1-1 to 3.28% for RF_1-2, with three hybrids manifesting significant negative Hb. Compared with the check, heterosis ranged from -8.47% (AF_1-3) to 6.78% (RF_1-2), with three hybrids showing significantly negative values and an equal number of them demonstrating positive significant values.

Flag leaf area (cm^2): PMS 2B scored the lowest (39.50 cm^2) for this character among parents, while PRR 78, with 63.03 cm^2 flag leaf area, scored the highest. The parental mean for flag leaf area was 49.43 cm^2. In case of hybrids, the flag leaf area was minimum in AF_1-1 (57.97 cm^2) and maximum in RF_1-2 (66.28 cm^2), with a mean of 62.76 cm^2. The range of Ha was from 14.01% in BF_1-3 to 28.40% in RF_1-2, while Hb ranged between -4.24% in AF_1-1 and 10.94% in RF_1-2. All hybrids showed highly significant positive Hc values ranging from 82.20% in AF_1-1 to 108.32% in RF_1-2.

Table 8: Mid-parent, better-parent and standard heterosis (%) for various characters in crosses involving IR 58025A, IR 58025B and PRR 78

Characters	Mid-parent heterosis			Better-parent heterosis			Standard heterosis		
	AF_1-3	BF_1-3	RF_1-3	AF_1-3	BF_1-3	RF_1-3	AF_1-3	BF_1-3	RF_1-3
Plant height (cm)	12.52 **	16.21 **	13.06 **	-1.64	3.38	0.58	13.21 **	18.98 **	15.76 **
Number of productive tillers	22.68 **	24.73 **	9.68	3.48	8.41	-4.67	5.31	2.65	-9.73
Days to 50% flowering	-1.62	-5.75 **	-2.47	-3.19	-6.01 **	-2.73	6.43 **	0.58	4.09 *
Days to maturity	-2.88 **	-4.38 **	-2.30 **	-4.45 **	-4.58 **	-2.50 **	2.61 **	-0.43	1.74
Grain filling duration	-6.90 **	0.00	-1.75	-8.47 **	0.00	-1.75	-8.47 **	-3.39	-5.08 *
Flag leaf area (cm^2)	18.74 **	14.01 **	14.34 **	2.75	1.93	2.23	103.55 **	101.94 **	102.52 **
Length of main panicle (cm)	8.44 **	7.39 *	5.89	-1.21	-0.86	-2.25	19.42 **	19.83 **	18.16 **
Weight of main panicle (g)	27.77 **	31.15 **	28.80 **	4.72	7.49	5.57	86.26 **	91.19 **	87.77 **
Weight of all panicles (g)	44.80 **	55.46 **	48.03 **	25.69 **	34.95 **	28.50 **	54.48 **	65.85 **	57.92 **
Weight per panicle (g)	8.73	16.85	27.19 **	-16.91 *	-10.70	-2.80	50.55 **	61.81 **	76.13 **
Number of filled spikelets	25.40 **	44.80 **	30.06 **	14.00	31.64 **	18.24 *	87.78 **	116.83 **	94.76 **
Number of unfilled spikelets	-4.24	-14.57	-14.81	-61.87 **	-25.43 **	-25.64 **	11.93	-0.14	-0.43
Total number of spikelets	11.65 **	20.82 **	11.94 **	11.65 **	20.82 **	11.94 **	52.54 **	62.48 **	50.53 **
Panicle density	17.05	35.84 **	23.25 *	15.35	33.86 **	21.45	57.00 **	82.20 **	65.31 **
Spikelet fertility (%)	10.92 *	18.26 **	14.66 **	1.77	8.51	5.20	24.26 **	32.48 **	28.45 **
1000-grain weight (g)	5.47	8.94 *	6.15	-13.48 **	-10.63 **	-12.92 **	7.39	10.93 *	8.09
Biomass yield (g)	63.63 **	49.89 **	47.89 **	24.50 **	24.88 **	23.22 **	34.71 **	35.13 **	33.33 **
Grain yield (g)	75.52 **	87.08 **	81.75 **	38.52 **	47.64 **	43.43 **	84.06 **	96.17 **	90.58 **
Straw yield (g)	30.26 **	31.65 **	31.29 **	17.04 *	12.77	12.46	15.25	11.05	10.75
Harvest index	19.56 *	27.56 **	25.34 **	11.90	19.39 *	17.31	36.04 **	45.15 **	42.62 **

Table 8 (Cont…)

Characters	Mid-parent heterosis			Better-parent heterosis			Standard heterosis		
	AF_1-3	BF_1-3	RF_1-3	AF_1-3	BF_1-3	RF_1-3	AF_1-3	BF_1-3	RF_1-3
CGR (mg/day/plant)									
Seedling - tillering	38.63 **	54.33 **	34.89 **	17.76 *	31.10 **	14.59	22.89 *	36.81 **	19.58 *
Tillering - flowering	17.02	66.67 **	35.10 **	10.59	57.53 **	27.69 *	-13.13	23.73 *	0.29
Flowering - maturity	43.78 **	25.14 **	34.93 **	7.49	-6.45	0.88	42.54 **	24.06 **	33.77 **
Whole duration	34.33 **	41.88 **	41.42 **	11.74	18.02 **	17.63 *	22.60 **	29.50 **	29.07 **
RGR (mg/g/plant/day)									
Seedling - tillering	10.50 **	23.95 **	13.56 **	1.62	13.99 **	4.42	-6.91 **	4.43 *	-4.33 *
Tillering - flowering	-10.65 **	20.89 **	-2.76	-30.58 **	13.23 **	-8.93 *	-29.86 **	-5.10	-23.67 **
Flowering - maturity	12.60 *	-6.80	-0.48	-4.61	-21.05 **	-15.69 **	14.35 *	-5.36	1.07
NAR (mg/dm^2/day)									
Seedling - tillering	20.67 **	28.63 **	16.18 **	6.54 *	13.57 **	2.57	-19.15 **	-13.81 **	-22.16 **
Tillering - flowering	4.27	42.81 **	26.30 **	2.89	40.92 **	24.62 **	-42.15 **	-20.77 **	-29.93 **
Flowering - maturity	21.46 **	2.84	11.62 *	-6.94	-21.21 **	-14.49 **	-3.55	-18.34 **	-11.37 *
Leaf area (cm^2/plant)									
Seedling	40.74 **	38.08 **	43.14 **	32.00 **	29.50 **	34.25 **	10.46 *	8.37 *	12.34 **
Tillering	10.84 **	17.43 **	12.02 **	6.43 *	12.75 **	7.55 *	62.91 **	72.59 **	64.63 **
Flowering	13.82 **	16.21 **	17.15 **	2.15	10.95 **	11.85 **	39.51 **	42.44 **	43.59 **
Maturity	27.21 **	31.91 **	28.70 **	-1.70	29.66 **	26.51 **	58.92 **	64.80 **	60.79 **
LAR (cm^2/g)									
Seedling - tillering	-9.07 **	-4.19 **	-2.86 *	-25.48 **	-8.34 **	-7.06 **	14.81 **	20.97 **	22.65 **
Tillering - flowering	-14.37 **	-15.42 **	-14.23 **	-34.89 **	-21.78 **	-20.69 **	21.06 **	19.59 **	21.27 **
Flowering - maturity	-11.24 *	-13.19 *	-14.57 **	-45.83 **	-23.41 **	-24.63 **	18.27 *	15.66	13.83

Table 8 (Cont...)

Characters	Mid-parent heterosis			Better-parent heterosis			Standard heterosis		
	AF_1-3	BF_1-3	RF_1-3	AF_1-3	BF_1-3	RF_1-3	AF_1-3	BF_1-3	RF_1-3
LAI									
Tillering	10.84 **	17.43 **	12.02 **	6.43	12.75 **	7.55	62.91 **	72.59 **	64.63 **
Flowering	13.82 **	16.21 **	17.15 **	2.15	10.95 **	11.85 **	39.51 **	42.44 **	43.59 **
Maturity	27.21 **	31.91 **	28.70 **	-1.70	29.66 **	26.51 **	58.92 **	64.80 **	60.79 **
LAD									
Tillering - flowering	30.00 **	23.47 **	25.19 **	13.61 **	7.90	9.40	105.74 **	95.41 **	98.13 **
Flowering - maturity	11.61 **	20.89 **	18.47 **	-7.68 **	16.48 **	14.14 **	32.97 **	44.03 **	41.14 **
α-Amylase activity (mg/seed/min)									
at 24 hrs	42.16 **	51.11 **	59.97 **	26.92 **	34.91 **	42.82 **	113.25 **	126.68 **	139.96 **
at 48 hrs	44.47 **	49.41 **	54.30 **	21.89 **	26.06 **	30.19 **	69.55 **	75.35 **	81.08 **
at 72 hrs	19.90 **	22.13 **	26.60 **	10.63 **	12.70 **	16.82 **	29.93 **	32.35 **	37.19 **
NRA (μ moles NO_2/g fr.wt./hr)									
Seedling	11.82 **	-1.56	6.40 *	2.49	-9.77 **	-2.48	29.77 **	14.24 **	23.47 **
Tillering	7.93 **	4.84 **	3.55 *	4.02 *	1.04	-0.20	30.73 **	26.98 **	25.42 **
Flowering	4.18 **	6.47 **	1.92	5.08 **	5.56 **	1.05	27.02 **	29.81 **	24.27 **
25 days after flowering	66.48 **	65.81 **	64.46 **	14.35 **	57.02 **	55.74 **	150.85 **	149.83 **	147.80 **
Nitrogen (%) in grain	1.92	5.13 **	3.21 **	-9.66 **	-6.82 **	-8.52 **	19.55	23.31	21.05
Protein (%) in grain	1.92	5.13 **	3.21 **	-9.66 **	-6.82 **	-8.52 **	19.55	23.31	21.05
Amylose (%) in grain	17.20 **	18.01 **	18.01 **	6.94 **	7.68 **	7.68 **	25.22	26.08	26.08
Starch (%) in grain	5.05 **	6.13 **	5.73 **	-0.64	0.38	0.00	5.98	7.07	6.66

* , ** = Significant at 5% and 1% levels, respectively

Similarly all the hybrids exhibited highly significant positive Ha and only one hybrid (RF_1-2) showed significant positive Hb for this character, while none manifested significant negative Hb.

Length of main panicle (cm): Among parents, the length of main panicle ranged from 20.90 cm in PMS 2A to 28.95 cm in PRR 78, with a mean of 24.70 cm. In case of hybrids, the main panicle was shortest in AF_1-1 (22.25 cm) and longest in BF_1-3 (28.70 cm), with a mean of 26.47 cm. Ha ranged from -6.41% (AF_1-1) to 9.36% (RF_1-2), while Hb ranged from -16.51% (AF_1-1) to 5.85% (RF_1-2). When compared with the check, heterosis ranged between -7.10% (AF_1-1) and 19.83% (BF_1-3). Four hybrids showed significant positive Ha for this character. However in case of Hb, an opposite pattern was found, where three hybrids exhibited significant negative Hb and none showed significant positive value. While, in case of Hc, five hybrids were significantly superior to the check and none was significantly inferior.

Weight of main panicle (g): Among the fertile parental lines, the main panicle weighed least in PMS 2B (1.77 g) and heaviest in Pusa 1124 (4.15 g), with the mean being 2.99 g. AF_1-1 produced the lowest weighing main panicle of 3.21 g, while RF_1-2 produced the heaviest main panicle of 4.39 g. The mean for this character was 3.94 g among the hybrids. The mid-parent heterosis was significantly positive in eight of the nine hybrids, with its range being 15.51% (AF_1-1) to 47.06% (RF_1-2). None of the hybrids significantly differed from its better parent and the range of Hb was from -15.23% (AF_1-1) to 7.49% (BF_1-3). On the other hand, compared with the check, all the hybrids scored highly significant positive superiority for this character; the range of Hc being 46.37% (AF_1-1) to 100.32% (RF_1-2).

Weight of all panicles (g): Among parents, the character ranged from 12.10 g in PMS 2B to 22.82 g in Pusa 1124, with the mean being 16.43 g. While, among hybrids, the range for this character was from 19.85 g (AF_1-1) to 27.50 g (RF_1-2); with a mean of 24.10 g. Highly significant positive values for Ha were obtained in case of all the hybrids, the range being 32.49% (AF_1-2) to 56.93% (RF_1-1). Hb ranged from 2.91% (AF_1-2) to 35.66% (RF_1-1) and six hybrids were significantly superior to their better parents. Compared with the check, all hybrids showed significant positive heterosis and the range of Hc was from 22.99% (AF_1-1) to 70.41% (RF_1-2).

The figures 1a, 2a and 3a clearly indicate that the hybrids scored the highest for this character among the yield components over the mid-parent value, resulting in high mid-parent heterosis in grain yield.

Weight per panicle (g): Among the fertile parental lines, the weight per panicle ranged from 1.10 g in PMS 2B to 2.60 g in PRR 78, with the mean being 1.75 g. While among the hybrids, the weight was minimum in AF_1-1 (1.67 g) and maximum in RF_1-3 (2.53 g) with an average of 2.16 g. Mid-parent heterosis for weight per panicle ranged from 8.61% in AF_1-2 to 48.16% in RF_1-1, while Hb ranged from -16.91% (AF_1-3) to 25.37% (BF_1-2). The Hc ranged between 16.53% (AF_1-1) and 76.13% (RF_1-3). Five hybrids were significantly superior to their mid-parents and only two were significantly superior to their better parents, while AF_1-3 exhibited negative Hb. Compared to the check, eight hybrids, with the exception of AF_1-1, showed significant superiority.

Number of filled spikelets in main panicle: Among the fertile parents the character ranged from 102.40 in Pusa 5B to 132.10 in PRR 78, with the mean of 117.00. In hybrids, the range as well as the mean value were much higher than those found in case of the parental lines. The mean of hybrids for this character was 154.69, with the range being 130.80 (AF_1-1) to 173.90 (BF_1-3). The Ha ranged from 13.00% for AF_1-1 to 48.25% for RF_1-1, while Hb ranged from 10.79% for AF_1-2 to 45.92% for RF_1-1. Similarly, the range for Hc was from 63.09% in AF_1-1 to 116.83% in BF_1-3. Eight hybrids showed significantly positive Ha and six manifested significantly

Fig 1a: Mid-parent heterosis (%) for yield components in cross combination involving PMS 2A, PMS 2B and Pusa 1127

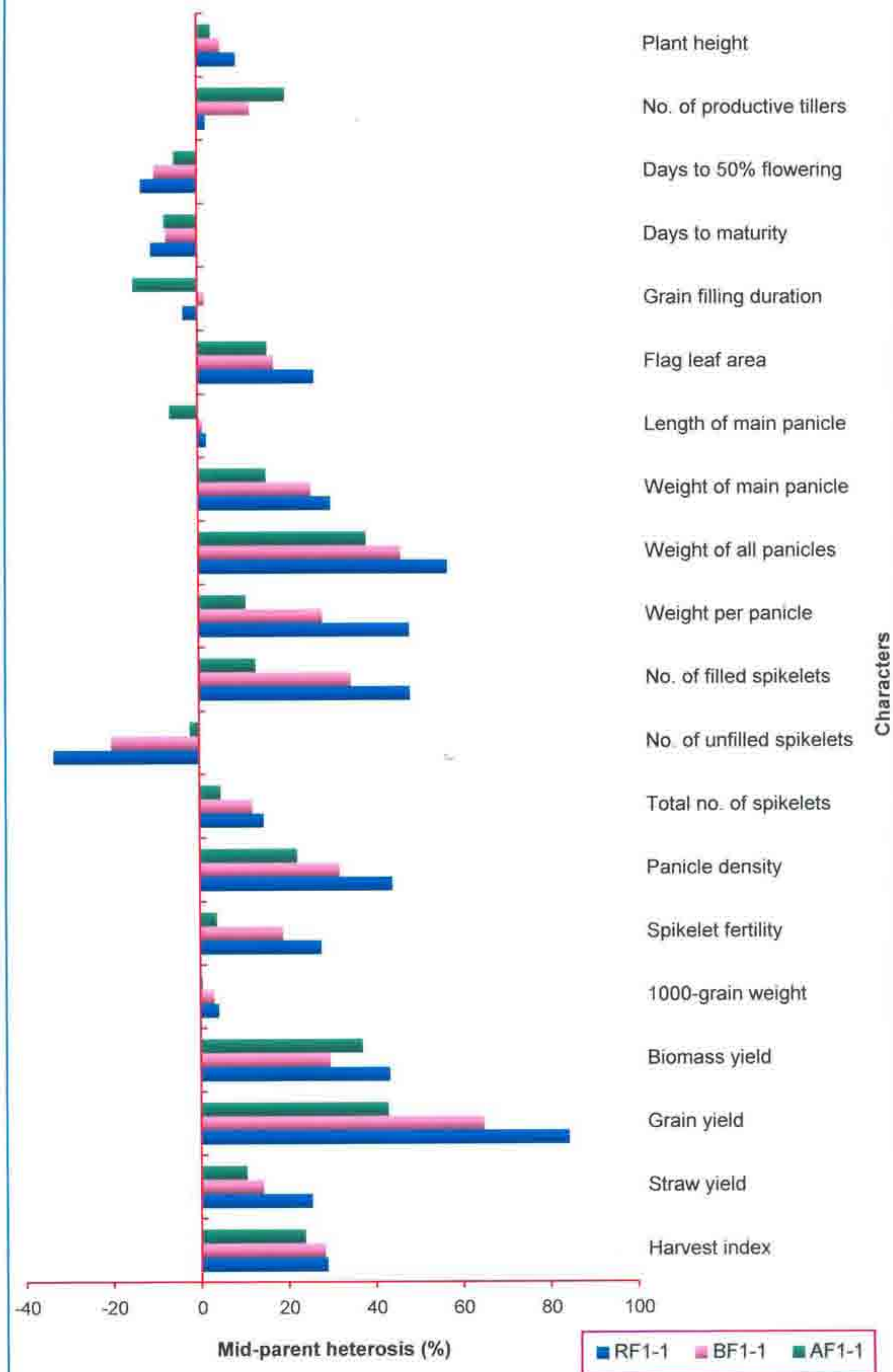
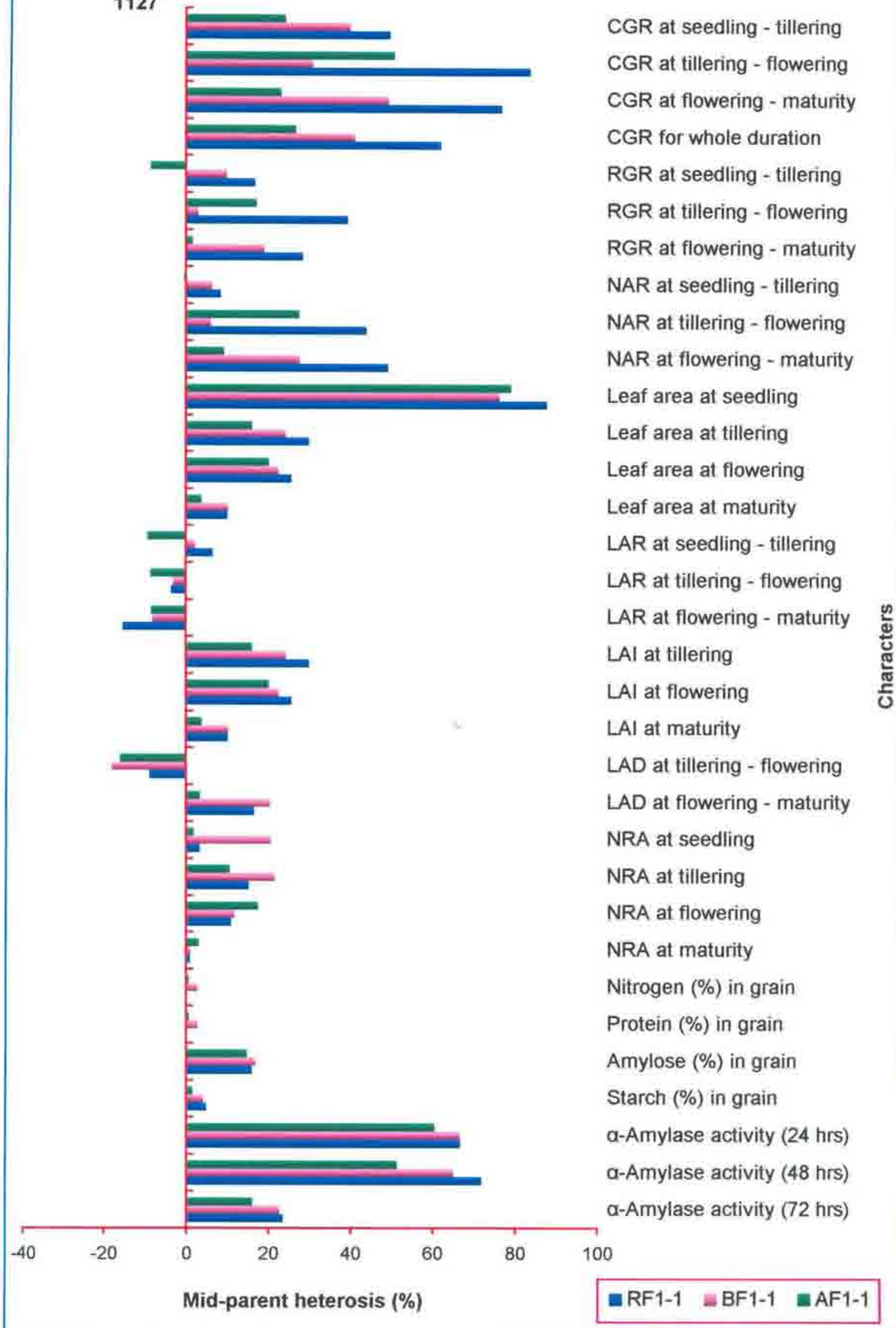


Fig 1b: Mid-parent heterosis (%) for physiological and biochemical characters in cross combination involving PMS 2A, PMS 2B and Pusa 1127



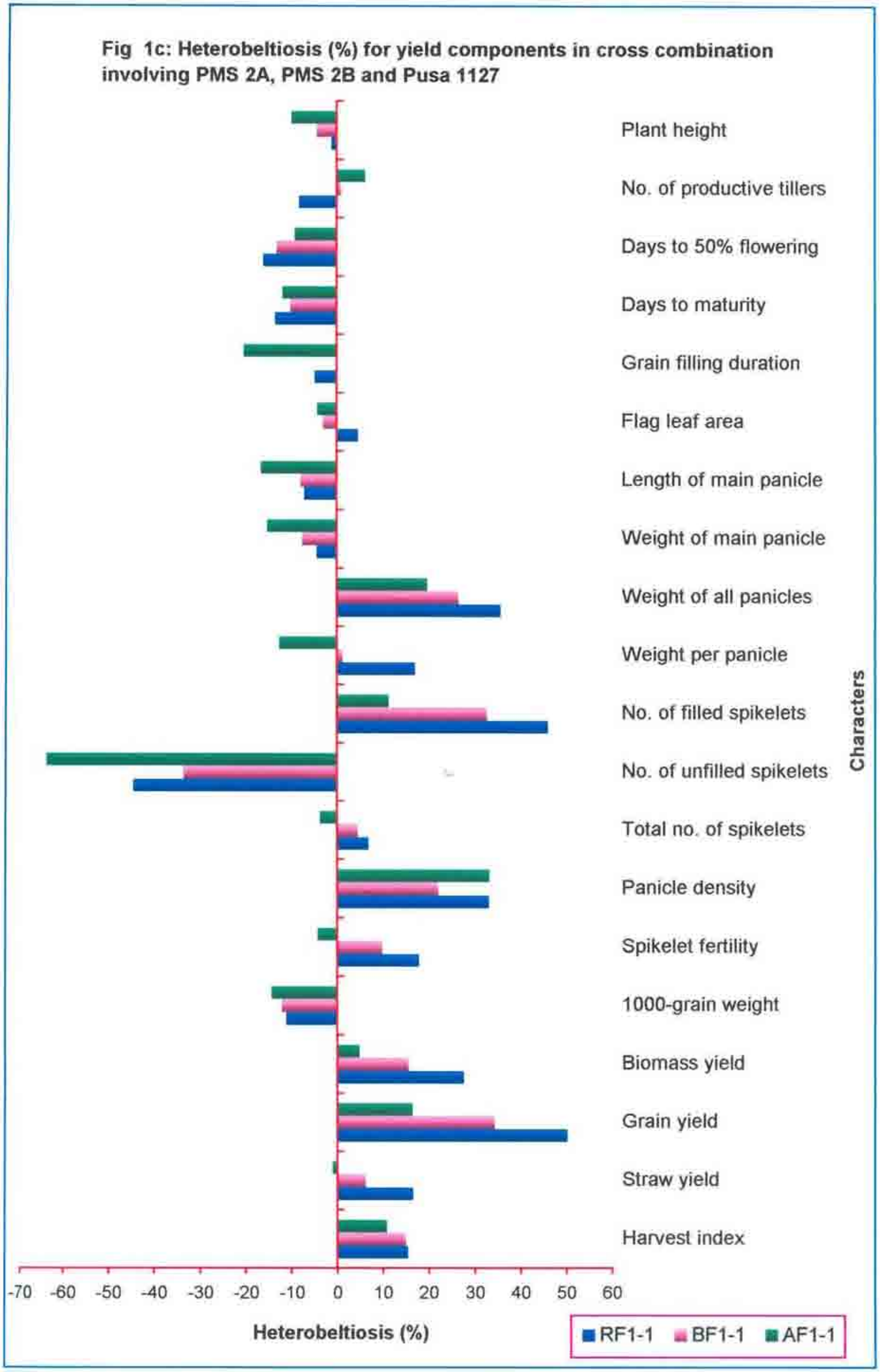
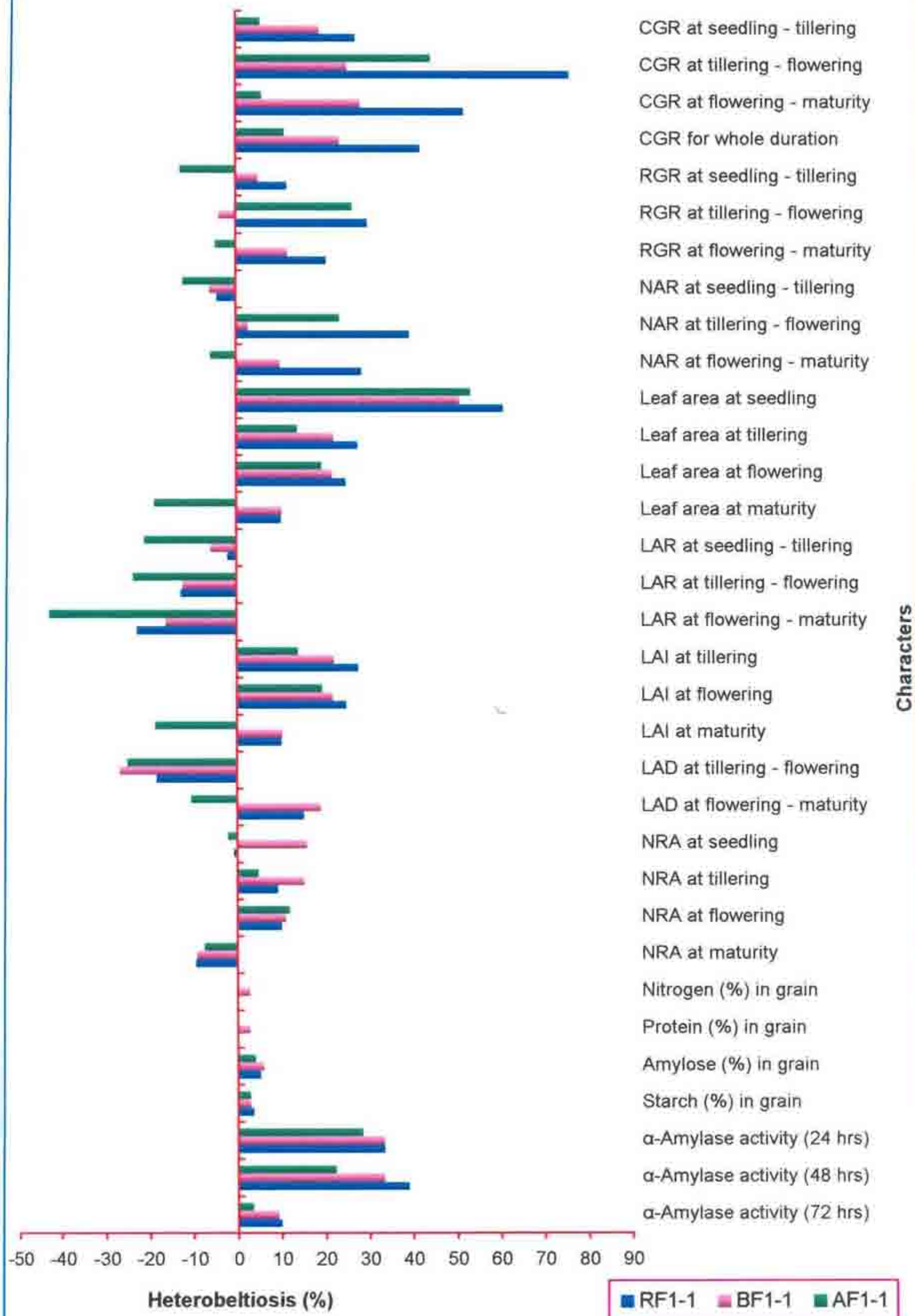


Fig 1c: Heterobeltiosis (%) for yield components in cross combination involving PMS 2A, PMS 2B and Pusa 1127
Plant height
No. of productive tillers
Days to 50% flowering
Days to maturity
Grain filling duration
Flag leaf area
Length of main panicle
Weight of main panicle
Weight of all panicles
Weight per panicle
No. of filled spikelets
No. of unfilled spikelets
Total no. of spikelets
Panicle density
Spikelet fertility
1000-grain weight
Biomass yield
Grain yield
Straw yield
Harvest index
Characters
-70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60
Heterobeltiosis (%)
RF1-1
BF1-1
AF1-1

Fig 1d: Heterobeltiosis (%) for physiological and biochemical characters in cross combination involving PMS 2A, PMS 2B and Pusa 1127



positive Hb. All the hybrids were significantly superior to the check variety for this character.

Number of unfilled spikelets in main panicle: Among the fertile parental lines, this character ranged from 55.90 in Pusa 1124 to 97.60 in PMS 2B, with the mean of 76.95. While in hybrids, the character ranged from 54.20 (RF_1-1) to 79.50 (AF_1-1), with a mean of 68.36. The Ha ranged from -33.29% (RF_1-1) to 0.07% (BF_1-2). However, for Hb, high negative values were obtained ranging from -64.57% (AF_1-2) to -15.26% (BF_1-2), indicating that the hybrids had less numbers of unfilled spikelets. Similarly, Hc ranged between -22.13% (RF_1-1) and 14.22% (AF_1-1). Only two hybrids showed significant negative Ha for this character and seven hybrids showed significant negative Hb, indicating their superiority over their mid-parents and better-parents respectively. However, none of the hybrids differed significantly from the check variety for this character.

The figures 1c, 2c and 3c clearly indicate very high negative heterobeltiosis for this character in all the three cross combinations, indicating superiority of the hybrids. The magnitude of mid-parent heterosis, however, was much less, although it was in negative direction in all the three cross combinations.

Total number of spikelets in main panicle: Among all the parental lines, Pusa 1127 had the lowest number of spikelets in the main panicle (182.50) and PMS 2B, the highest (211.50). The parental mean was 197.63. For hybrids, the range for this character was from 208.60 (AF_1-2) to 243.40 (BF_1-3), with a mean value of 223.04. Ha ranged from 4.89% (AF_1-1) to 21.32% (RF_1-2) with eight of the nine hybrids manifesting significant positive Ha. Heterobeltiosis ranged between -3.75% (AF_1-1) and 21.06% (RF_1-2) with seven hybrids manifesting significant superiority for this character. Similarly, Hc ranged from 39.25% (AF_1-2) to 62.48% (BF_1-3) and all hybrids were significantly superior to the check variety for this character.

Panicle density: Among the fertile parental lines, panicle density ranged from 4.14 in Pusa 5B to 5.22 in PMS 2B, with the mean density being 4.60. While in case of hybrids, both the range and mean value of the character were much higher. The range was 5.27 (AF_1-3) to 6.94 (RF_1-1) and the mean was 5.88. Ha was lowest in AF_1-3 (17.05%) and highest in RF_1-1 (43.99%) and Hb ranged from 13.92% in BF_1-2 to 33.86% in BF_1-3. Similarly, the range of Hc was from 57.00% in AF_1-3 to 106.96% in RF_1-1. Eight hybrids exhibited significant positive Ha and four manifested significant positive Hb. While, all of the hybrids showed significant positive Hc for this character.

Spikelet fertility (%): The character ranged from 54.48% in PMS 2B to 69.93% in Pusa 1124 among the fertile parents, with the mean spikelet fertility of 61.04%. Whereas, the range of spikelet fertility in hybrids was from 61.75% (AF_1-1) to 75.98% (RF_1-1), with the mean value of 69.37%. Ha ranged from 3.79% in AF_1-1 to 27.71% in RF_1-1 with six hybrids showing significant positive values. While the range of heterobeltiosis for this character was -4.28% (AF_1-1) to 17.77% (RF_1-1) with only RF_1-1 showing significant positive value. Similarly, Hc ranged between 14.58% in AF_1-1 and 40.98% in RF_1-1 and all hybrids showed significant positive values indicating their superiority over the check variety.

1000-grain weight (g): Among the parental lines, PMS 2A had the lowest 1000-grain weight (14.33 g) and PRR 78 had the highest (24.90 g), with a mean of 18.26 g. Whereas in hybrids, the character ranged from 17.65 g (AF_1-1) to 24.36 g (RF_1-2) with a mean of 21.23 g. The range for mid-parent heterosis for 1000-grain weight was between 0.47% (AF_1-1) and 19.84% (RF_1-2), with four hybrids showing significant positive heterosis. With respect to Hb, six hybrids showed significant negative values and none showed significant positive value, with the range being -14.36% (AF_1-1) to 6.90% (RF_1-2). Similarly, Hc ranged from -11.99% (AF_1-1) to

21.44% (RF_1-2), with four hybrids manifesting significant positive values and two showing significant negative values.

Biomass yield (g): Among the fertile parental lines, biomass yield ranged widely from 28.23 g (IR 58025B) to 49.91 g (Pusa 1124), with a mean value of 36.72 g. However, among hybrids the range was higher and comparatively narrower, from 38.35 g (AF_1-1) to 52.90 g (BF_1-3), with a mean value of 47.57 g. The Ha varied from 14.19% in BF_1-2 to 63.63% in AF_1-3, with all the hybrids showing significantly positive values. With respect to heterobeltiosis, five hybrids showed significant positive values and the range was -8.95% (AF_1-2) to 27.60% (RF_1-1). Compared with the check, seven hybrids were significantly superior; the range for Hc being -2.02% in AF_1-1 to 35.13% in BF_1-3.

Grain yield (g): The range for grain yield in fertile parental lines was from 7.65 g (PMS 2B) to 17.71 g (Pusa 1124), the mean being 11.54 g. While it ranged from 14.16 g (AF_1-1) to 22.17 g (RF_1-2), with a mean grain yield of 19.36 g in hybrids. The Ha ranged between 42.85% in AF_1-1 and 87.08% in BF_1-3, with all the hybrids showing highly significant positive heterosis. The Hb varied from 7.53% for AF_1-2 to 50.11% for RF_1-1 and seven hybrids exhibited significantly positive values. Over the check, eight hybrids demonstrated highly significant positive heterosis; Hc ranging from 27.86% in AF_1-1 to 100.23% in RF_1-2.

Straw yield (g): Among the fertile parental lines, straw yield varied widely and ranged between 19.72 g (IR 58025B) and 32.20 g (Pusa 1124), with a mean of 25.18 g. However in hybrids, the range for straw yield was narrower and was from 24.20 g (AF_1-1) to 32.35 g (AF_1-3) with the average being 28.21 g. The Ha ranged from -7.19% (RF_1-2) to 31.65% (BF_1-3), with four hybrids manifesting significantly positive values. Hb ranged from -18.01% (AF_1-2) to 17.04% (AF_1-3) with only AF_1-3 manifesting significant positive value and three showing significant negative values.

Compared to the check, none of the hybrids manifested either positive or negative significant heterosis. The range for Hc was from -13.80% (AF_1-1) to 15.25% (AF_1-3).

Harvest index: Harvest index ranged between 0.25 in Pusa 5B and 0.36 in Pusa 1124, with a mean value of 0.31 for the fertile parental lines. However, it ranged from 0.38 (AF_1-1) to 0.46 (RF_1-2) in hybrids, with the mean being 0.41. The Ha varied from 19.56% in AF_1-3 to 53.27% in RF_1-2 with all hybrids showing significant superiority over the mid-parent. Hb ranged between 10.10% in AF_1-1 and 30.06% in RF_1-2 with four hybrids being significantly superior over the better parent. Compared with the check, all hybrids showed significant superiority; the Hc ranged from 31.79% in AF_1-1 to 61.94% in RF_1-2.

4.1.1.3.2 Physiological and biochemical characters

a) Crop growth rate (CGR, mg/day/plant)

CGR was recorded at four growth phases *viz.* seedling to tillering, tillering to flowering, flowering to maturity and for the whole crop duration. The results are presented separately for each growth phase.

i) Seedling to tillering: Among the parental lines, PMS 2A had the lowest CGR (204.73) during seedling to tillering phase, while PRR 78 had the highest of 411.32 during the same phase. The mean value for CGR during this stage for the parental lines was 294.58. The hybrids in general expressed better crop growth rate varying from 320.98 (AF_1-1) to 539.25 (BF_1-3), with the mean being 432.41 in this phase. Ha ranged from 14.55% (AF_1-2) to 54.33% (BF_1-3), with eight hybrids exhibiting significant values, while Hb ranged from 4.85% (AF_1-2) to 31.10% (BF_1-3) and only three hybrids manifested significant values. Whereas in case of Hc, four hybrids exhibited significant positive heterosis and one manifested significant negative value, the range of Hc being -18.56% in AF_1-1 to 36.81% in BF_1-3.

ii) Tillering to flowering: For CGR in this phase, the parental range was from 161.58 in PMS 2A to 427.63 in Pusa 1124, with the mean CGR being 264.63. However in case of hybrids, the range as well as the mean were much higher compared to the parents and were 311.60 (AF_1-3) to 470.97 (RF_1-1) and 392.20 respectively. Ha varied from 11.80% in AF_1-2 to 83.74% in RF_1-1, with six hybrids showing highly significant values. In case of heterobeltiosis, five hybrids showed significantly positive values and none showed significant negative value, the range being -12.18% in AF_1-2 to 75.90% in RF_1-1. For Hc, the range was from -13.13% in AF_1-3 to 31.30% in RF_1-1, with only three hybrids showing significant positive values.

From figures 1b, 1d, 3b and 3d it is clear that hybrids of the first and third cross combinations exploited maximum advantage in this growth phage. However, in the second cross combination (figures 2b and 2d), involving Pusa 5A, Pusa 5B and Pusa 1124, the hybrids AF_1-2 and BF_1-2 showed positive Ha and negative Hb. This was because of higher growth rate of the restorer Pusa 1124 during this growth phage than its hybrids.

iii) Flowering to maturity: The CGR at flowering to maturity was low in PMS 2A (97.26) and was much higher in Pusa 1124 (592.03), among the parental lines, with the mean CGR being 332.77. However for hybrids, the range for this character was much higher, from 468.87 in AF_1-1 to 673.15 in RF_1-1, with the average being 576.68. Ha for this character ranged from 1.41% for AF_1-2 to 76.81% in RF_1-1, with eight hybrids showing highly significant values. Whereas, Hb ranged from -13.88% in AF_1-2 to 51.91% in RF_1-1, with two hybrids showing highly significant values and only one (AF_1-2) showing significantly negative Hb value. In case of Hc, eight hybrids except AF_1-1 showed significantly positive heterosis, with the range being 9.82% in AF_1-1 to 57.67% in RF_1-1.

iv) Whole growth duration: The mean value for parental lines for CGR for whole growth duration was 251.35 with the range being 141.83 for PMS 2A to 383.86 for Pusa 1124. Whereas the hybrids were much superior to the parental lines for this character and the range was from 315.19 for AF_1-1 to 418.32 in BF_1-3, with the average CGR of 386.57. Mid-parent heterosis varied from 9.99% in AF_1-2 to 61.99% in RF_1-1, with eight hybrids manifesting highly significant values. However, over the better parent, only four hybrids showed significant positive values and none showed significant negative value. The range of Hb was from -4.52% in AF_1-2 to 41.93% in RF_1-1. Hc ranged from -2.43% in AF_1-1 to 29.50 in BF_1-3, with six hybrids showing significant superiority over the check variety.

b) Relative growth rate (RGR, mg/g/plant/day)

RGR was studied during three growth phases, *viz.* seedling to tillering, tillering to flowering and flowering to maturity. As the CGR and RGR are related, the same pattern that was found in case of CGR was found for RGR as well. The results are described separately for the different growth phases.

i) Seedling to tillering: Among the parents, RGR varied from 39.90 for PMS 2B to 50.78 for PRR 78 with a mean of 44.85 for this phase. The range for the same growth phase in hybrids was from 38.29 in AF_1-1 to 57.88 in BF_1-3, with the mean being 49.54. Heterosis over mid-parent ranged from -8.55% in AF_1-1 to 23.95% in BF_1-3, with seven hybrids manifesting highly significant positive Ha values and only one showing highly significant negative value. While compared to their respective better parents, four hybrids demonstrated significant superiority and two showed significant inferiority; the range of Hb being -12.65% in AF_1-1 to 13.99% in BF_1-3. Compared to the check, all hybrids, except BF_1-3, showed significant negative heterosis and the range of Hc was from -30.93% in AF_1-1 to 4.43% in BF_1-3.

Fig 2a: Mid-parent heterosis (%) for yield components in cross combination involving Pusa 5A, Pusa 5B and Pusa 1124

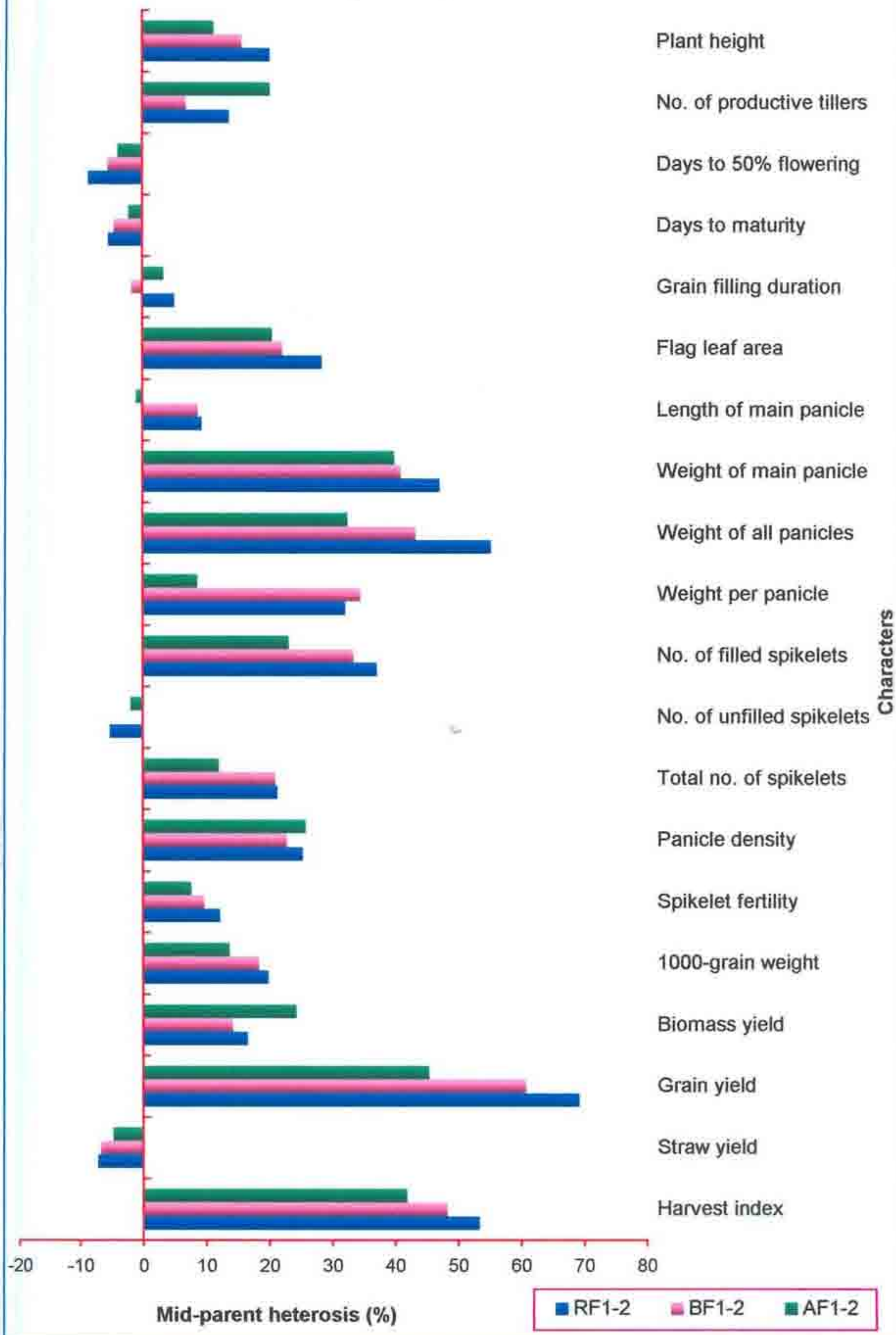


Fig 2b: Mid-parent heterosis (%) for physiological and biochemical characters in cross combination involving Pusa 5A, Pusa 5B and Pusa 1124

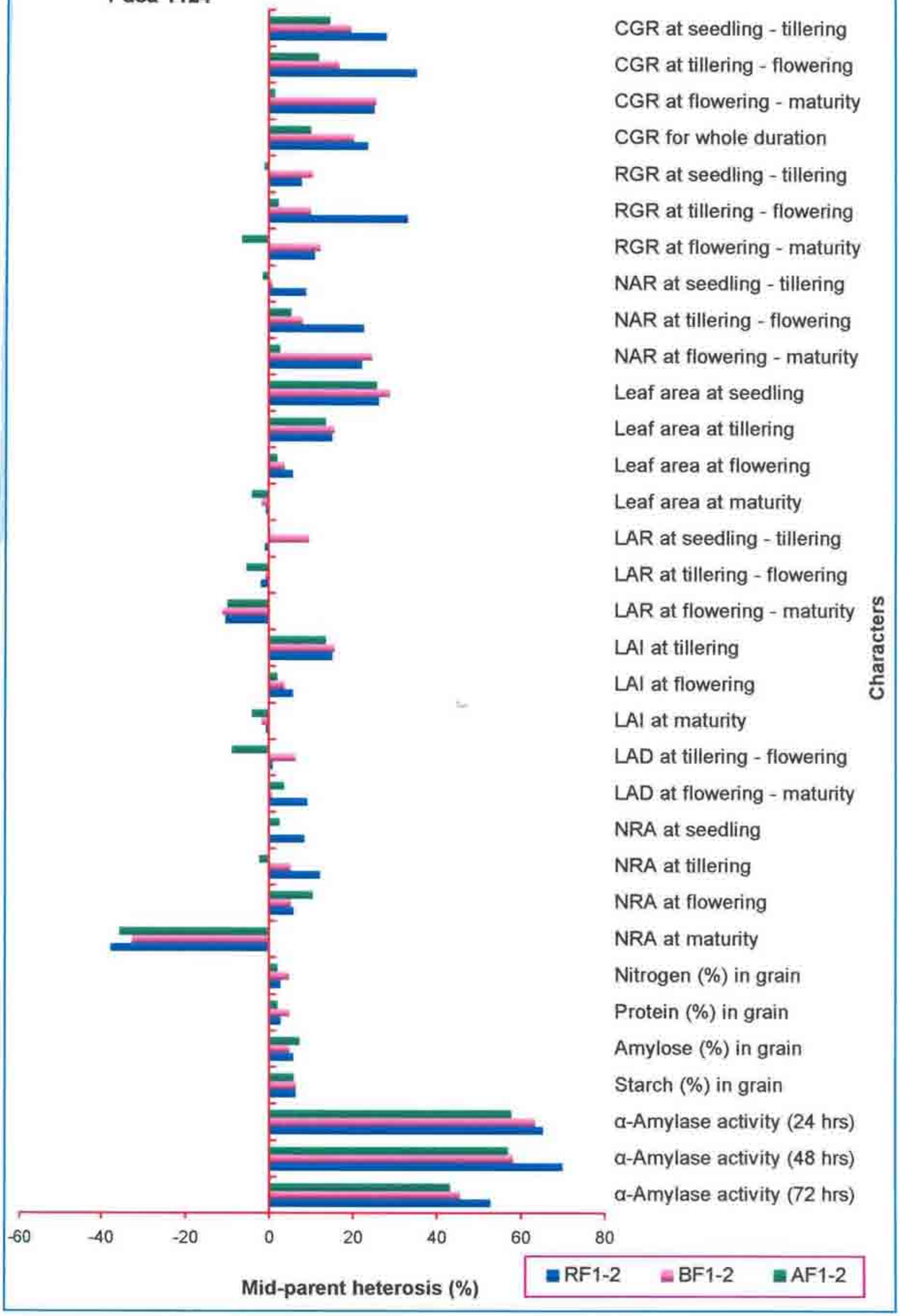


Fig 2c: Heterobeltiosis (%) for yield components in cross combination involving Pusa 5A, Pusa 5B and Pusa 1124

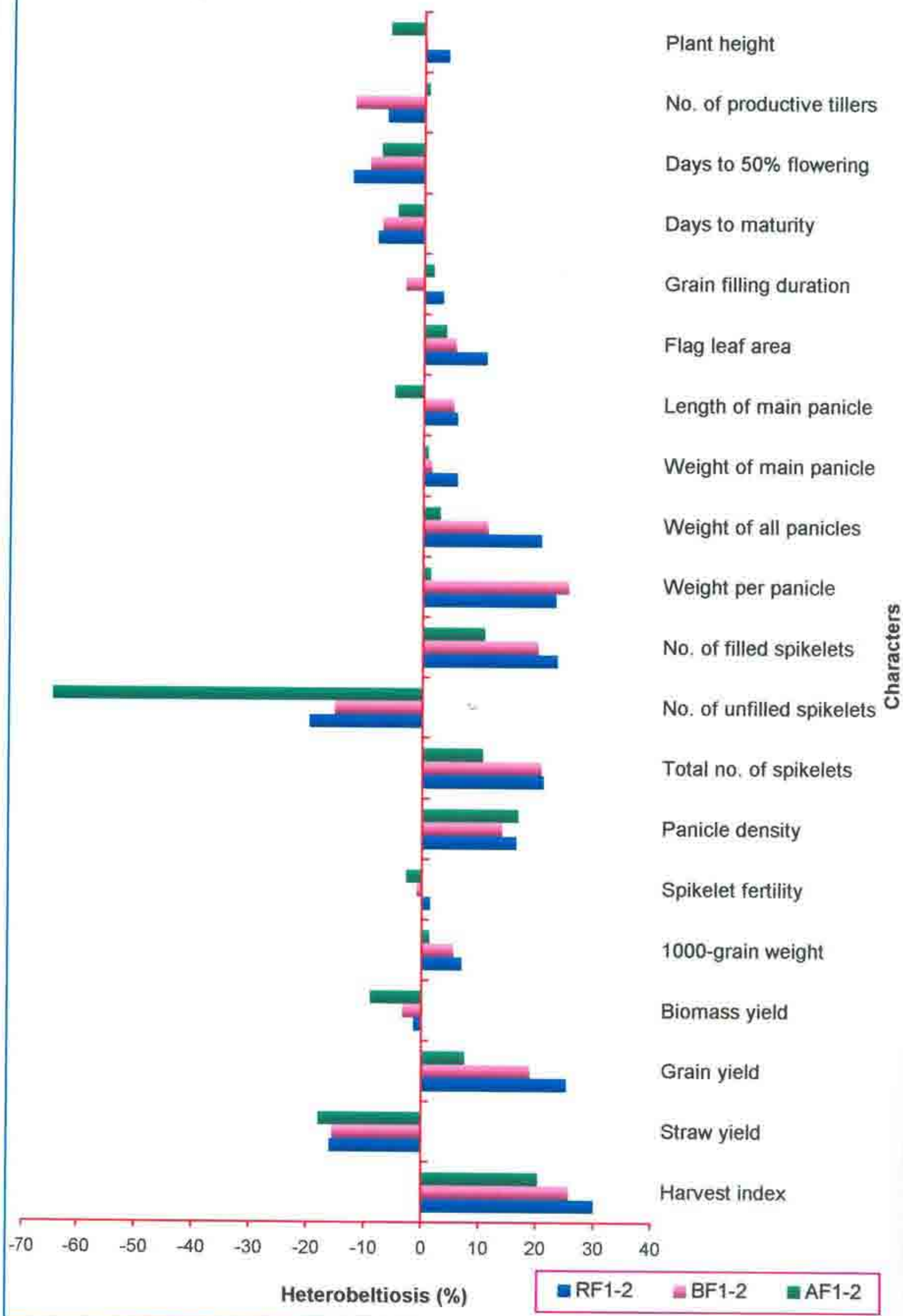
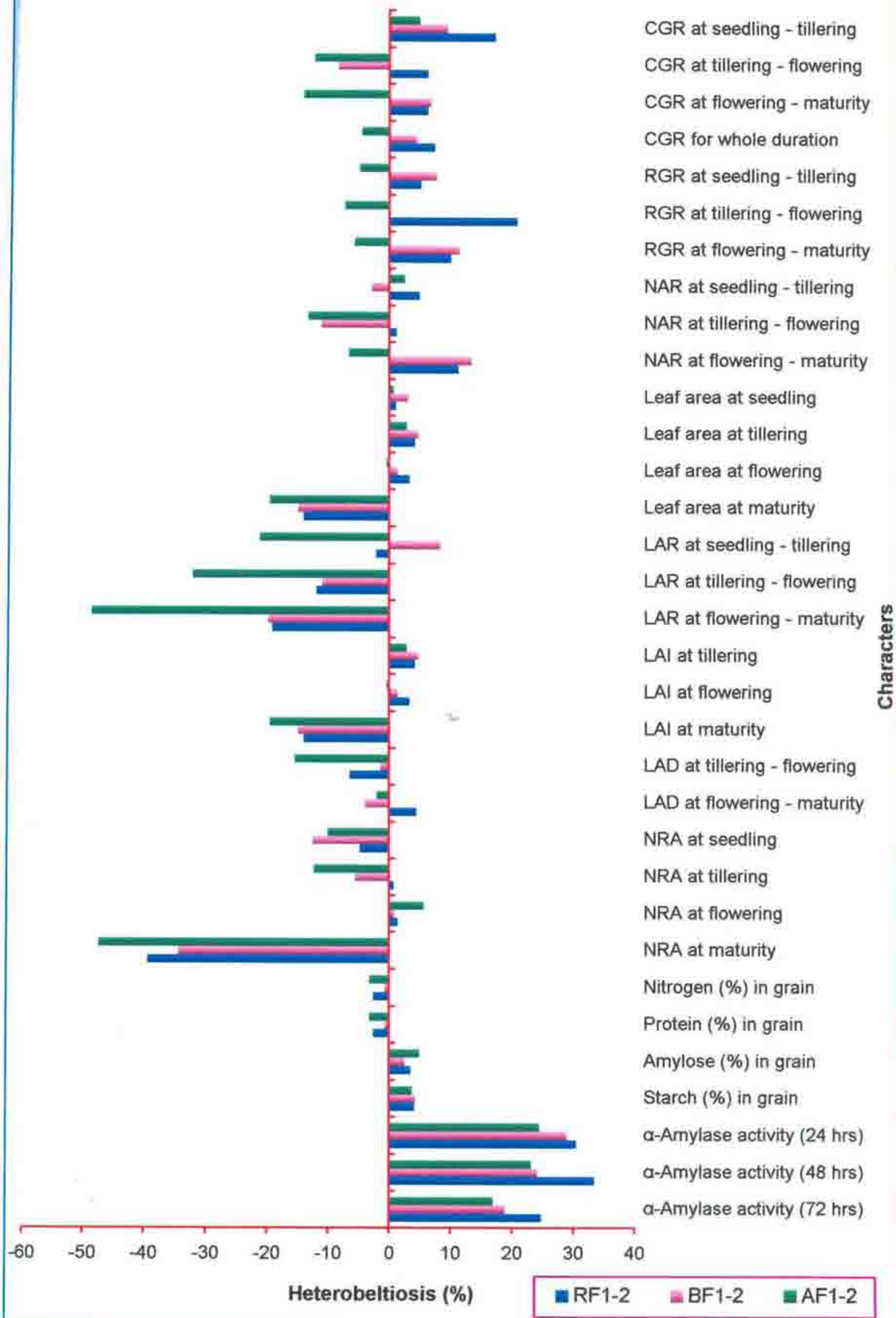


Fig 2d: Heterobeltiosis (%) for physiological and biochemical characters in cross combination involving Pusa 5A, Pusa 5B and Pusa 1124



ii) Tillering to flowering: At this phase, RGR varied from 11.47 in PMS 2A to 16.74 in IR 58025A among the parental lines with a mean of 14.08. While among hybrids, it ranged from 11.62 in AF_1-3 to 20.46 in RF_1-1, with the mean being 15.70. Five hybrids demonstrated significant positive Ha and only one showed significant negative Ha, the range being -10.65% in AF_1-3 to 39.36% in RF_1-1. Hb varied from -30.58% in AF_1-3 to 29.88% in RF_1-1 and four hybrids manifested significant positive Hb while three showed significant negative Hb values. Whereas, compared to the check, only two hybrids were significantly superior and five of them were significantly poor for this character; the range of Hc being -29.86% in AF_1-3 to 23.48% in RF_1-1.

iii) Flowering to maturity: For this phase, RGR varied from 5.29 in IR 58025A to 16.83 in PRR 78 among the parents, with the average of 11.84. While, among the hybrids, it ranged between 13.29 in BF_1-3 and 18.76 in RF_1-1, with a mean of 15.69. Four hybrids exhibited significant positive Ha, the range being -6.80% in BF_1-3 to 28.43% in RF_1-1. Hb varied from -21.05% in BF_1-3 to 20.47% in RF_1-1, with only one hybrid showing significant positive Hb and two showing significant negative values. Whereas, compared to the check, five hybrids exhibited significantly positive heterosis for this character, the range of Hc being -5.36% in BF_1-3 to 33.66% in RF_1-1.

c) Net assimilation rate (NAR, mg/dm^2/day)

NAR was studied during three growth phases, *viz.* seedling to tillering, tillering to flowering and flowering to maturity. The results are presented separately for each growth phase.

i) Seedling to tillering: Among the parental lines, IR 58025A had the lowest NAR (117.36) during this phase, while PRR 78 had the highest NAR of 187.96. The mean value for NAR during this phase for the parental lines was 149.78. The hybrids had better net assimilation rate varying from 146.60 in AF_1-1 to 213.46 in BF_1-3, with the mean value of 176.79. The Ha varied between -1.45% (AF_1-2) and 28.63% (BF_1-3), with six hybrids showing significant positive values and none showing significant negative value. Whereas Hb ranged from -12.13% in AF_1-1 to 13.57% in BF_1-3, with two hybrids showing significant positive values and one hybrid (AF_1-1) showing significant negative value. On the other hand, compared with the check, all the hybrids were significantly poorer for this character, the range of Hc being -40.81% in AF_1-1 to -13.81% in BF_1-3.

ii) Tillering to flowering: For this character, the parental range was from 14.93 in PMS 2A to 28.26 in Pusa 1124, with the mean value of 20.36. However in case of hybrids, the range as well as the mean were higher compared to the parents and found to be 20.46 (AF_1-3) to 33.00 (RF_1-1) and 26.45 respectively. Ha varied from 4.27% in AF_1-3 to 43.92% in RF_1-1, with six hybrids showing significant positive values. In case of heterobeltiosis, four hybrids exhibited significantly positive values and two showed significant negative values; the range being from -13.21% in AF_1-2 to 40.92% in BF_1-3. Hc varied from -42.15% in AF_1-3 to -6.68% in RF_1-1, with all hybrids showing significantly poor performance for this character compared to the check variety.

iii) Flowering to maturity: The NAR at flowering to maturity varied from 8.91 in IR 58025A to 53.60 in PRR 78, among the parents, with a mean of 32.72. For hybrids, the range for this character was from 42.23 in BF_1-3 to 63.84 in RF_1-1, with the average NAR being 51.68. Ha for this character ranged from 2.70% for AF_1-2 to 49.20% in RF_1-1, with seven hybrids showing highly significant values. Whereas, Hb ranged from -21.21% in BF_1-3 to 28.55% in RF_1-1, with four hybrids showing significant positive values and two hybrids showing significant negative values. Three hybrids exhibited significantly positive standard heterosis and an equal number showed significant negative Hc, with the range being -18.34% in BF_1-3 to 23.46% in RF_1-1.

d) Leaf area (cm^2)

The leaf area per plant was recorded at four growth stages *viz.* seedling, tillering, flowering and maturity. The results are presented separately for each stage.

i) Seedling: Among parents, the leaf area per plant at seedling stage varied from 2.55 cm^2 in PMS 2A to 5.00 cm^2 in Pusa 1124, with the mean being 3.47 cm^2. The range for the same period in hybrids was from 5.03 cm^2 in AF_1-2 to 6.03 cm^2 in RF_1-1, with the mean being 5.39 cm^2. Heterosis over mid-parent ranged from 25.75% in AF_1-2 to 87.82% in RF_1-1, with all hybrids showing highly significant values. While, compared to their respective better parents, six hybrids demonstrated significant superiority, although all the hybrids exhibited positive Hb values; the range being 0.60% in AF_1-2 to 60.76% in RF_1-1. Even when compared with the check, all hybrids showed significant positive heterosis and the range of Hc was from 5.23% in AF_1-2 to 26.15% in RF_1-1.

ii) Tillering: At tillering stage, leaf area per plant in parental lines varied from 955.62 cm^2 in PMS 2A to 1390.48 cm^2 in Pusa 1124 with the mean being 1134.35 cm^2. While among hybrids, it ranged from 1171.00 cm^2 in AF_1-1 to 1456.32 cm^2 in BF_1-2, with a mean of 1355.96 cm^2. All the hybrids demonstrated highly significant mid-parent and standard heterosis for this character, with the ranges being 10.84% in AF_1-3 to 29.92% in RF_1-1 (for Ha) and 41.73% in AF_1-1 to 76.26% in BF_1-2 (for Hc). While, in case of heterobeltiosis, although all hybrids showed positive heterosis, ranging from 2.79% (AF_1-2) to 27.56% (RF_1-1), only six were significantly superior to their respective better parents.

iii) Flowering: At this stage, leaf area per plant varied from 1222.62 cm^2 in PMS 2A to 1684.30 cm^2 in IR 58025A among the parents, with an average of 1465.47 cm^2. While, among the hybrids, it ranged from 1485.00 cm^2 in AF_1-1 to 1770.75 cm^2 in RF_1-3, with a mean of 1645.81 cm^2. Eight hybrids exhibited significant positive Ha values, the range being 1.98% (AF_1-2) to 25.64% (RF_1-1). Hb varied from -0.39% in AF_1-2 to 24.84% in RF_1-1, with five hybrids showing significant positive Hb and none showing significant negative value. Whereas, compared to the check, all hybrids showed significant positive heterosis for this character, Hc ranging form 20.42% in AF_1-1 to 43.59% in RF_1-3.

iv) Maturity: Among parents, leaf area per plant at this stage varied from 576.71 cm^2 in Pusa 5B to 843.30 cm^2 for IR 58025A with the mean being 704.14 cm^2. The range for the same period in hybrids was from 638.60 cm^2 in AF_1-1 to 859.64 cm^2 in BF_1-3, with the mean leaf area being 724.72 cm^2. Heterosis over mid-parent ranged from -4.09% in AF_1-2 to 31.91% in BF_1-3, with five hybrids demonstrating highly significant positive Ha values. While, compared to their respective better parents, four hybrids demonstrated significant superiority and an equal number of them exhibited significant inferiority, the range of Hb being -19.45% (AF_1-2) to 29.66% (BF_1-3). When compared to the check, all hybrids showed highly significant positive heterosis, with the range of Hc being 22.42% in AF_1-1 to 64.80% in BF_1-3.

e) Leaf area ratio (LAR, cm^2/g)

LAR was studied during three growth phases, *viz.* seedling to tillering, tillering to flowering and flowering to maturity. The results are presented separately for each growth phase.

i) Seedling to tillering: The mean value for LAR during this phase for the parental lines was 30.41. Pusa 1127 had the lowest LAR (26.33), while Pusa 5A had the highest LAR of 35.62. The hybrids however, displayed negative trend with respect to this character when compared with the parental lines and the range for LAR was from 25.78 in AF_1-3 to 30.71 in BF_1-2, with the mean being 28.16. The Ha ranged from -9.27% in AF_1-1 to 9.55% in BF_1-2, with three hybrids each showing significant positive and negative values. While, Hb ranged from -25.48% in AF_1-3 to 8.27% in

BF_1-2, with only one hybrid, BF_1-2, showing significant positive value and five hybrids showing significant negative values. On the other hand, compared with the check, all the hybrids were significantly superior for this character, the range of Hc being 14.81% in AF_1-3 to 36.74% in BF_1-2.

ii) Tillering to flowering: For this character, the parental range was from 54.98 in Pusa 1124 to 87.41 in IR 58025A and the mean was 70.73. However, in case of hybrids, the range was found to be from 56.22 (BF_1-3) to 62.41 (BF_1-1) and the average LAR was 59.42. All the hybrids performed poorly when compared with the mid- and better-parent values. The range for Ha was from -15.42% in BF_1-3 to -0.78% in BF_1-2, with four hybrids showing highly significant values. In case of heterobeltiosis, all the hybrids displayed highly significant negative values and the range was from -34.89% in (AF_1-3) to -10.91% in BF_1-2. Compared to the check, however, all hybrids exhibited highly significant positive values for this character and the range for Hc was from 19.59% in BF_1-3 to 32.77% in BF_1-1.

iii) Flowering to maturity: The LAR at flowering to maturity ranged from 28.74 in Pusa 1124 to 59.47 in IR 58025A, among the parents, with the average being 42.00. For hybrids, the range for this character was from 28.68 in BF_1-2 to 32.21 in AF_1-3, with a mean value of 30.50. The range of Ha for this character was from -15.23% for RF_1-1 to -8.11% in BF_1-1, with four hybrids showing significant negative values. Whereas Hb ranged from -48.44% in AF_1-2 to -16.10% in BF_1-1, with all hybrids manifesting significantly negative values than their better parents. In case of Hc, however, all hybrids showed positive values; however, only three of them were significant, with the range being 5.30% in BF_1-2 to 18.27% in AF_1-3.

Fig 3a: Mid-parent heterosis (%) for yield components in cross combination involving IR 58025A, IR 58025B and PRR 78

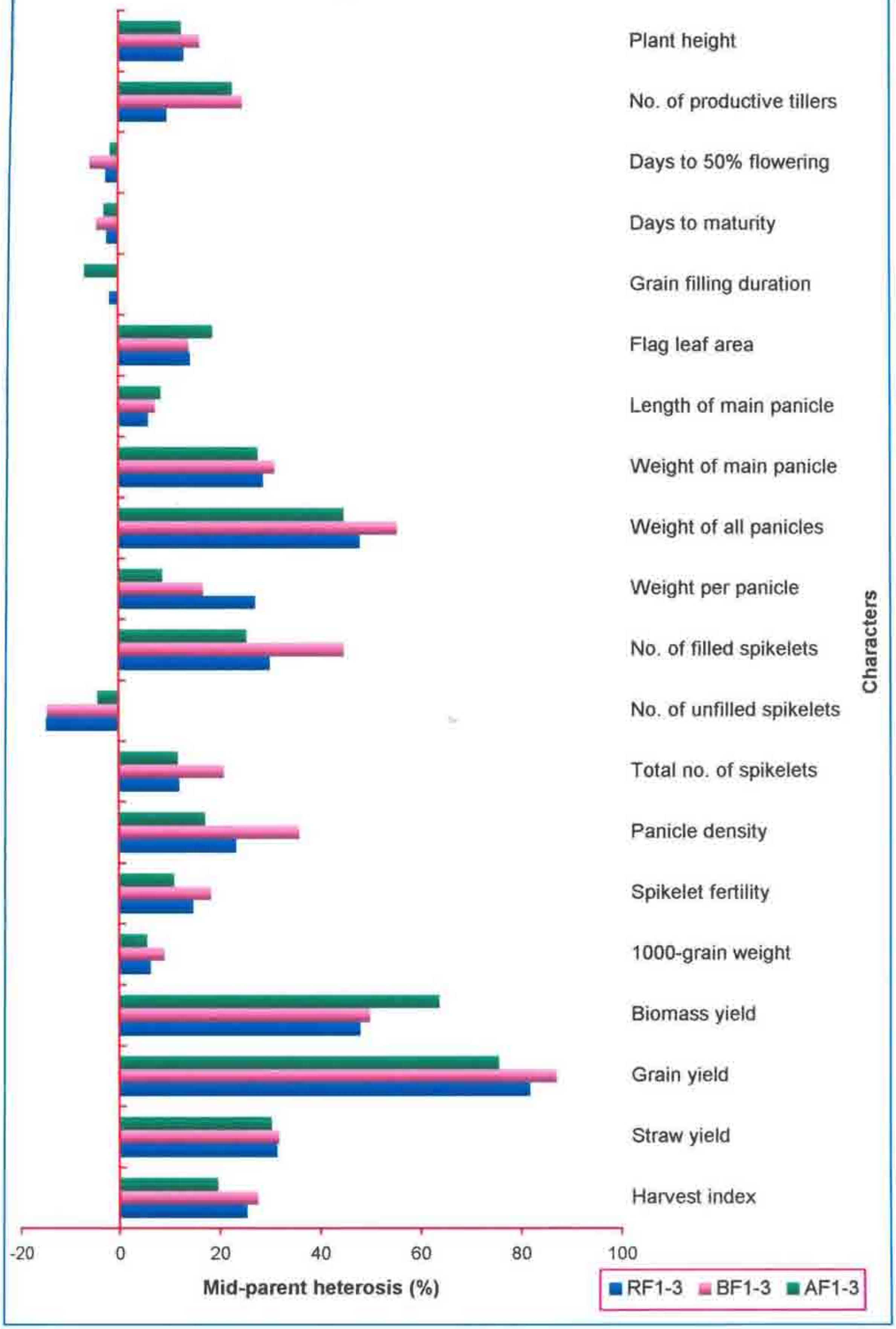


Fig 3b: Mid-parent heterosis (%) for physiological and biochemical characters in cross combination involving IR 58025A, IR 58025B and PRR 78

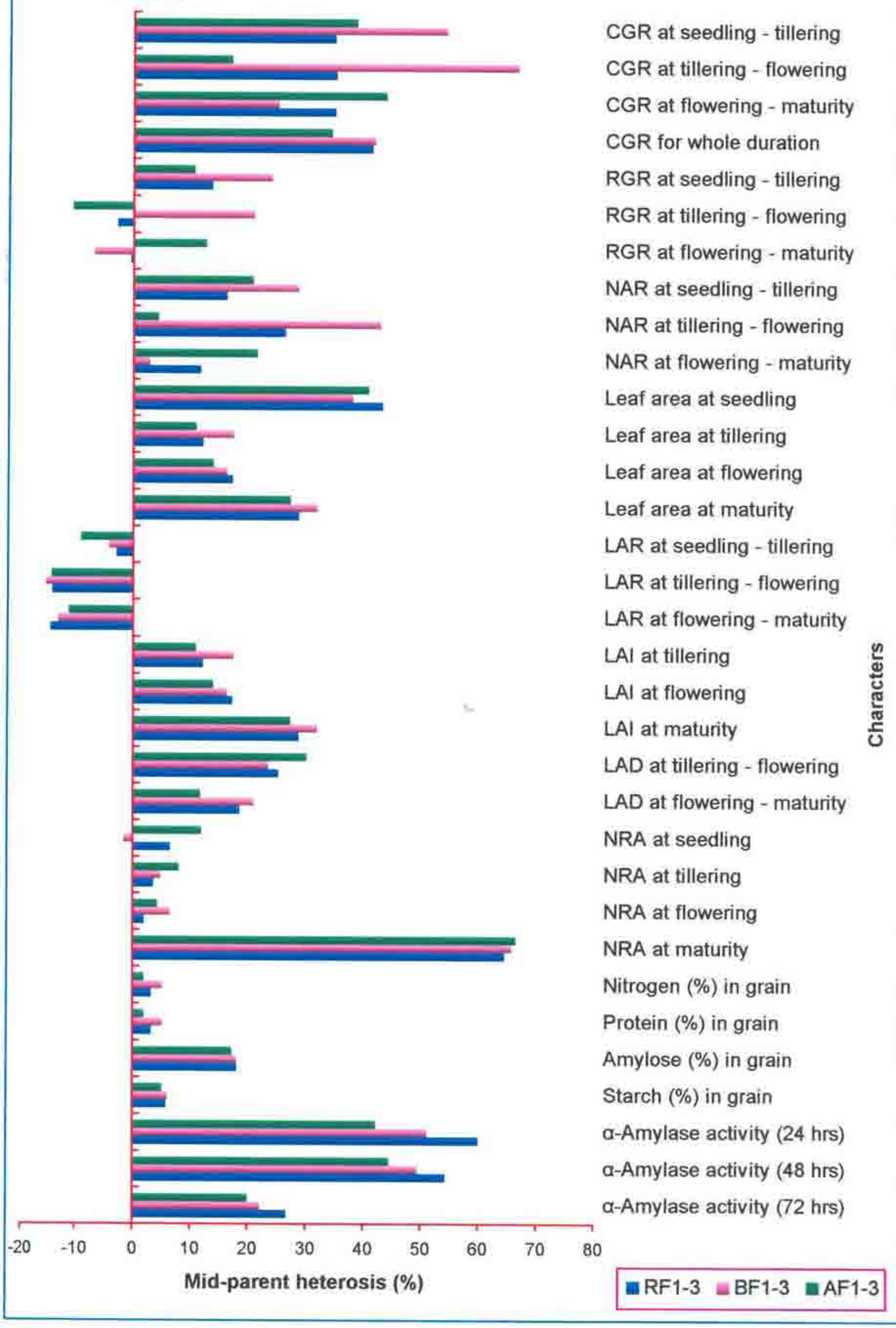


Fig 3c: Heterobeltiosis (%) for yield components in cross involving IR 58025A, IR 58025B and PRR 78

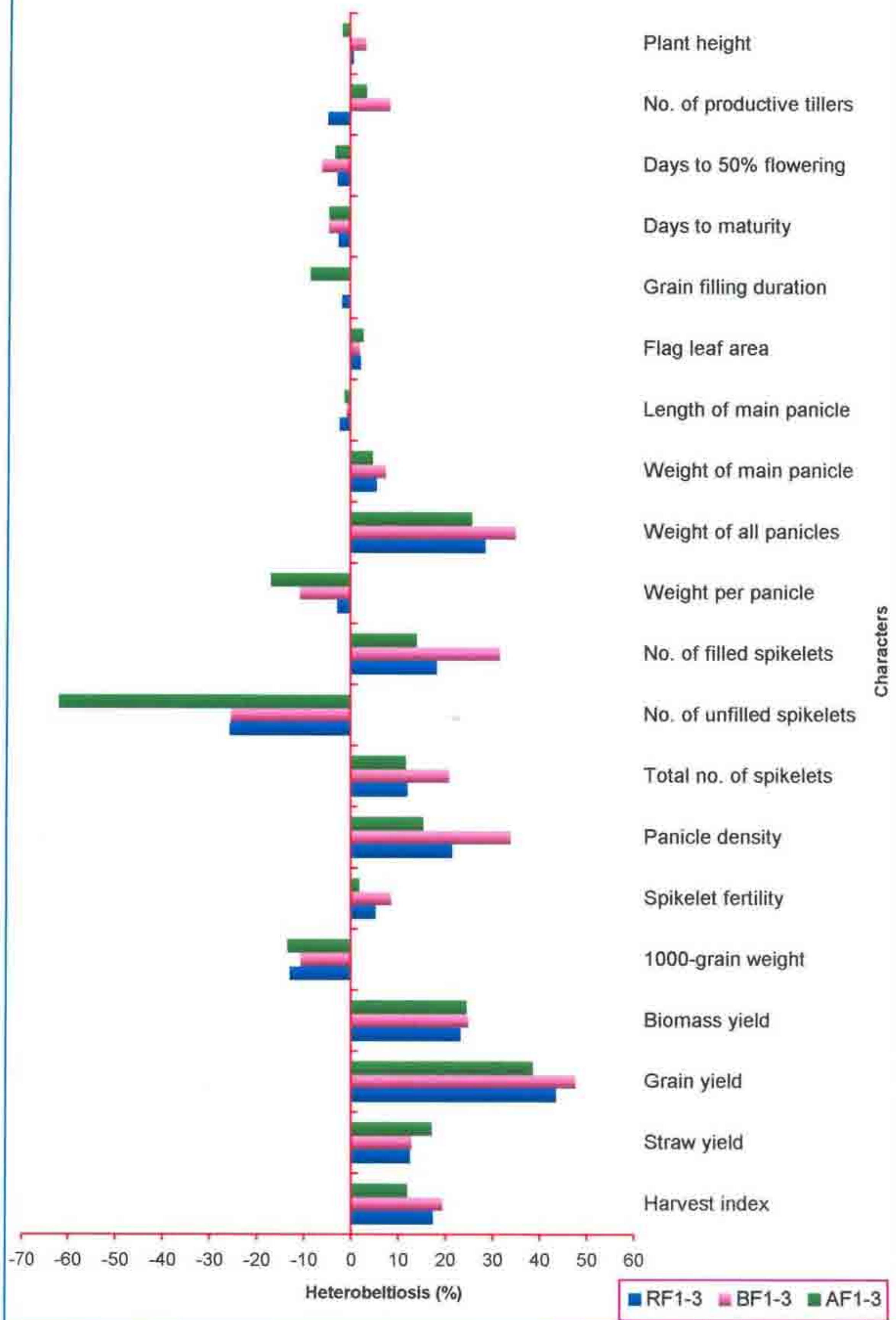
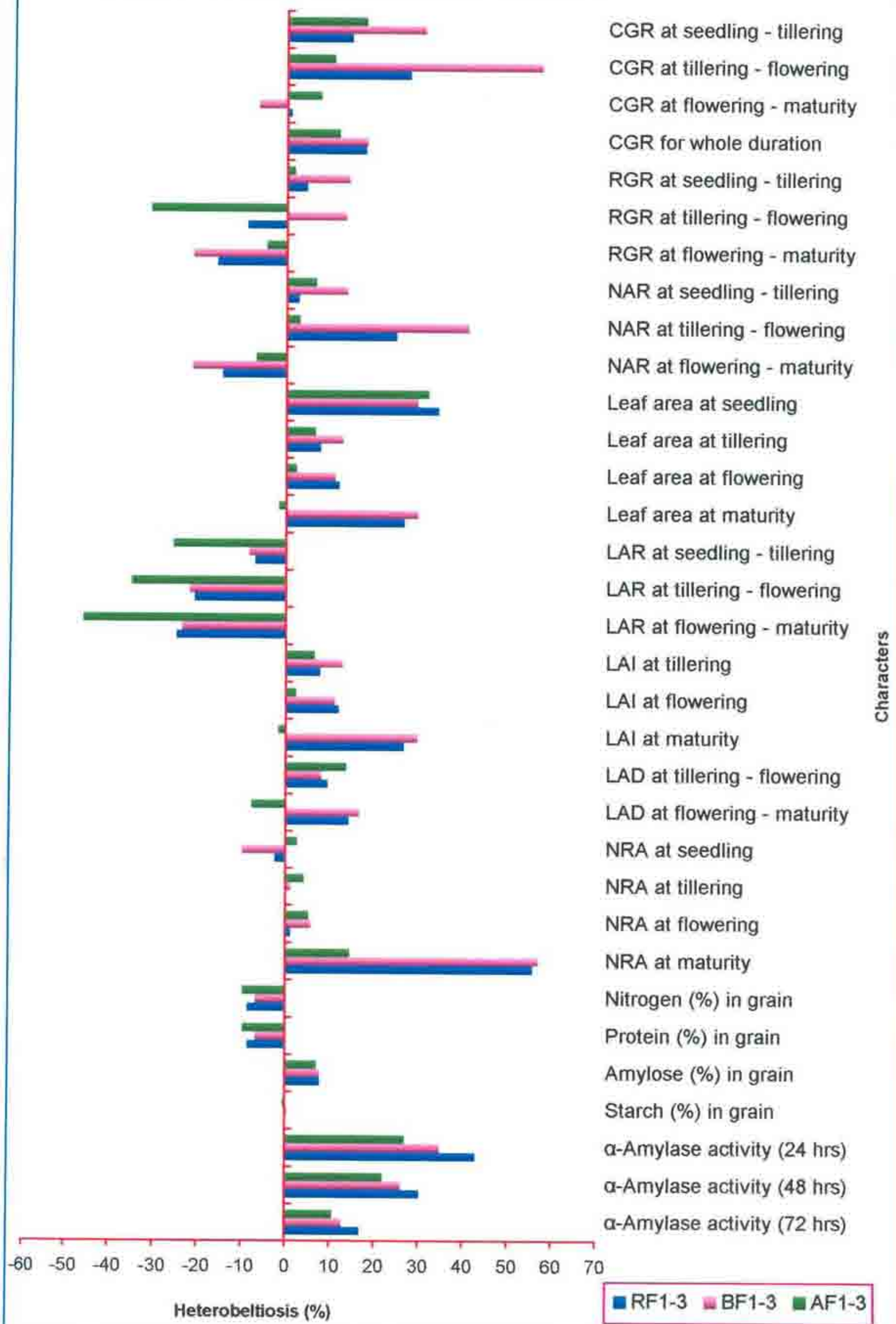


Fig 3d: Heterobeltiosis (%) for physiological and biochemical characters in cross involving IR 58025A, IR 58025B and PRR 78



f) Leaf area index (LAI)

The LAI was studied among the parents and hybrids at tillering, flowering and maturity stages. The results are presented hereunder the separately for each growth stage.

i) Tillering: At tillering stage, the LAI in parental lines varied from 3.19 in PMS 2A to 4.63 in Pusa 1124 with the mean being 3.78. While, among the hybrids, it ranged from 3.90 in AF_1-1 to 4.85 in BF_1-2, with the mean LAI being 4.52. All the hybrids exhibited highly significant mid-parent and standard heterosis for this character, with the ranges of 10.84% in AF_1-3 to 29.92% in RF_1-1 (for Ha) and 41.73% in AF_1-1 to 76.26% in BF_1-2 (for Hc). While in case of heterobeltiosis, although all hybrids showed positive heterosis, ranging from 2.79% in AF_1-2 to 27.56% in RF_1-1, only five were significantly superior to their respective better parents for this character.

ii) Flowering: At this stage, the LAI varied from 4.08 in PMS 2A to 5.61 in IR 58025A among the parental lines, with an average of 4.88. While, among hybrids, it ranged from 4.95 in AF_1-1 to 5.90 in RF_1-3, with a mean of 5.49. Six hybrids showed significant positive Ha values, the range being 1.98% in AF_1-2 to 25.64% in RF_1-1. Hb varied from -0.39% in AF_1-2 to 24.84% in RF_1-1, with five hybrids showing significant positive values and none showing a significant negative value. Whereas, compared with the check, all hybrids exhibited significantly positive heterosis for this character, the range of Hc being 20.42% in AF_1-1 to 43.59% in RF_1-3.

iii) Maturity: Among the parents, the LAI at this stage varied from 1.92 in Pusa 5B to 2.81 for IR 58025A with the mean being 2.35. The range for the same period in hybrids was from 2.13 in AF_1-1 to 2.87 in BF_1-3, with the mean LAI being 2.42. Heterosis over mid-parent ranged from -4.09% in AF_1-2 to 31.91% in BF_1-3, with five hybrids showing highly significant positive Ha values. When compared to their respective better parents, four hybrids demonstrated significant superiority and an equal number of them exhibited significant inferiority, the range of Hb being -19.45% in AF_1-2 to 29.66% in BF_1-3. Compared to the check, all hybrids showed highly significant positive heterosis, with the range of Hc being 22.42% in AF_1-1 to 64.80% in BF_1-3.

g) Leaf area duration (LAD)

The leaf area duration was calculated for two growth phases: tillering to flowering and flowering to maturity. The results are presented below:

i) Tillering to flowering: For LAD at this phase, the parental range was from 71.58 (Pusa 1127) to 108.85 (Pusa 1124), with a mean value of 89.48. However, in case of hybrids the range was found to be from 66.48 (BF_1-1) to 109.46 (AF_1-3) and the average value was 92.08. Three hybrids performed poorly when compared with the mid-parent and an equal number of them were significantly superior to the mid-parent value. The range for Ha was from -18.01% in BF_1-1 to 30.00% in AF_1-3; while Hb ranged from -26.62% in BF_1-1 to 13.61% in AF_1-3, with four hybrids showing highly significant negative values and two hybrids showing significant positive values. Compared to the check, however, all hybrids showed highly significant positive heterosis indicating poor performance of the check for this character. For Hc, the range was from 24.95% in BF_1-1 to 105.74% in AF_1-3.

ii) Flowering to maturity: The LAD at flowering to maturity varied from 92.99 in Pusa 1127 to 124.27 in IR 58025A, among the parents, with the average of 108.52. For hybrids, the range for this character was from 97.33 in AF_1-1 to 124.83 in RF_1-2, with a mean LAD of 115.50. The range of Ha for this character was from 0.54% for BF_1-2 to 20.89% in BF_1-3, with six hybrids showing significant positive values. Whereas Hb ranged from -10.51% in AF_1-1 to 19.01% in BF_1-1, with two hybrids performing significantly poorer than their better parents and four hybrids showing significant superiority. In case of Hc, however, all hybrids showed highly significant positive values, with a range of 12.81% in AF_1-1 to 44.68% in RF_1-2.

I) α-Amylase activity (mg maltose/seed/min)

The α-amylase activity was measured at three different intervals during seed germination, at 24 hours, at 48 hours and at 72 hours after seed soaking.

i) <u>24 hours</u>: Among the parents, the α-amylase activity at this stage varied from 5.00 units in PMS 2A to 11.25 units for Pusa 1124 with the mean value of 7.78. While, the hybrids displayed much higher activity than the parents, ranging from 12.83 in AF_1-1 to 15.00 in RF_1-3, with the mean of 13.91. Heterosis over mid-parent ranged from 42.16% in AF_1-3 to 66.63% in RF_1-1, with all hybrids showing significant superiority. Similar pattern was found in case of heterobeltiosis as well, with all hybrids exhibiting highly significant Hb values, ranging from 24.43% in AF_1-2 to 42.82% in RF_1-3. The range of Hc was very high, from 105.25% in AF_1-1 to 139.96% in RF_1-3, indicating that the hybrids had a very high α-amylase activity compared to the check variety during the early germination stage.

ii) <u>48 hours:</u> At this stage, the α-amylase activity in parental lines varied from 8.00 in PMS 2A to 16.25 in Pusa 1124 with the mean being 11.47. While, among hybrids, it ranged from 18.33 in AF_1-1 to 21.67 in RF_1-2, with the mean activity of 20.17. All of the hybrids exhibited highly significant mid-parent, better-parent as well as standard heterosis, with the ranges of 44.47% in AF_1-3 to 71.79% in RF_1-1 (for Ha); 21.89% in AF_1-3 to 38.87% in RF_1-1 (for Hb) and 59.35% in AF_1-1 to 88.39% in RF_1-2, indicating that the hybrids exploited the advantage in early growth stage compared to the parents or pureline varieties.

iii) <u>72 hours</u>: At this stage, the α-amylase activity varied from 15.00 in PMS 2A to 25.25 in Pusa 1124 among the parents, with an average of 19.72. Among the hybrids, the activity ranged from 23.50 (AF_1-1) to 31.50 (RF_1-2), with a mean of 27.43. All hybrids demonstrated highly significant positive mid-parent and standard heterosis. The range for Ha was 16.06% in AF_1-1 to 52.74% in RF_1-2, while Hc varied from 13.82% in AF_1-1 to 52.56% in RF_1-2. Although, the Hb values were also positive in all hybrids, ranging from 3.31% in AF_1-1 to 24.76% in RF_1-2, only eight hybrids, except AF_1-1 demonstrated significant superiority over their respective better parents.

h) Nitrate reductase activity (NRA, µ moles KNO_2/g fr.wt./hr)

The NRA was recorded at following growth stages: seedling, tillering, flowering and 25 days after flowering. The results are presented below separately for each growth stage.

i) Seedling: Among the parents, the NRA at seedling stage varied from 575.40 in PMS 2A to 814.80 for Pusa 1124 with the mean being 649.29. The range for the same period in hybrids was from 625.10 in AF_1-1 to 776.00 in RF_1-2, with the mean NRA of 711.10. Heterosis over mid-parent ranged from -1.56% in BF_1-3 to 20.58% in BF_1-1 and four hybrids showed significant positive Ha values. While compared to their respective better parents, only one hybrid showed positive Hb value and three exhibited highly significant negative heterobeltiosis, the range of Hc being -12.37% in BF_1-2 to 15.82% in BF_1-1. Compared to the check, all hybrids exhibited significant positive heterosis, with a range of 5.48% in AF_1-1 to 30.95% in RF_1-2.

ii) Tillering: At tillering stage, the NRA in parental lines varied from 836.30 in PMS 2B to 1144.20 in Pusa 1124 with a mean of 957.67. Among hybrids the activity ranged from 979.50 in AF_1-1 to 1152.50 in RF_1-2, with the mean value of 1059.38. Eight hybrids demonstrated highly significant mid-parent heterosis for this character, with a range of -2.34% (AF_1-2) to 21.61% (BF_1-1). With regards to Hb, the range was from -12.25% in AF_1-2 to 15.19% in BF_1-1, with four hybrids showing significant positive values and two showing significant negative heterobeltiosis. While in case of standard heterosis, all the hybrids were significantly superior to the check variety. The Hc for NRA at tillering stage ranged from 16.57% to 37.15% in AF_1-1 and RF_1-2 respectively.

iii) <u>Flowering</u>: For this stage, the NRA varied from 872.00 in Pusa 1127 to 1125.60 in Pusa 1124 among the parents, with the average activity of 992.93. While, among the hybrids, it ranged from 975.10 in RF_1-1 to 1188.00 in RF_1-3, with the mean of 1086.19. All the nine hybrids manifested significant positive Ha values, which ranged from 1.92% in RF_1-3 to 17.47% in AF_1-1. Hb varied from 0.75% in BF_1-2 to 11.80% in AF_1-1, with six hybrids demonstrating significant positive Hb. When compared to the check, all hybrids revealed significantly positive heterosis for this character, the range of Hc being 11.89% in RF_1-1 to 36.32% in AF_1-2.

iv) <u>25 days after flowering</u>: Among the parents, the NRA at this stage varied from 210.10 in IR 58025B to 444.00 for Pusa 5A with the mean being 297.46. The range for the same period in hybrids was from 226.30 in RF_1-2 to 370.50 in AF_1-3, with the mean NRA being 288.47. Heterosis over mid-parent ranged from -37.74% in RF_1-2 to 66.48% in AF_1-3, with three hybrids showing highly significant positive Ha values and an equal number showing highly significant negative values. When compared to their respective better parents, five hybrids showed significantly negative values and three exhibited significant superiority, the range of Hb being -47.32% in AF_1-2 to 57.02% in BF_1-3. As compared to the check, all hybrids exhibited highly significant positive heterosis, with Hc ranging from 53.22% in RF_1-2 to 150.85% in AF_1-3.

i) Grain nitrogen content (%) and grain protein content (%)

The nitrogen and crude protein contents in grain ranged from 1.34% and 7.97% in IR 58025A to 1.76% and 10.47% in PRR 78, with the mean values of 1.46% and 8.70% respectively. However, in hybrids the values ranged from 1.45% and

8.63% in RF_1-1 to 1.64% and 9.76% in BF_1-3, with the means of 1.54% and 9.14% respectively. For both the characters, mid-parent heterosis ranged from 0.00% in RF_1-1 to 5.13% in BF_1-3 with five hybrids exhibiting significant superiority over the mid-parent. While Hb for the characters ranged between -9.66% in AF_1-3 and 2.76% in BF_1-1 with only one hybrid exhibiting significant superiority and five having poor performance compared to their better parents. When compared with the check, all hybrids showed positive values, although none of them was significant. The range of Hc for these characters was found to be from 9.02% in RF_1-1 to 23.31% in BF_1-3.

j) Amylose content in grain (%)

The amylose content in grain ranged from 19.00% in Pusa 5A to 27.40% in PRR 78, with the average being 22.01%. However, in hybrids the character ranged from 21.00% in BF_1-1 to 29.50% in BF_1-3, with the mean being 25.81%. Mid-parent heterosis ranged from 4.73% in BF_1-2 to 18.01% in BF_1-3 with eight hybrids, except BF_1-2, demonstrating significant superiority over the mid-parent. While Hb for amylose content ranged between 2.42% in BF_1-2 and 7.68% in BF_1-3 with four hybrids exhibiting significant positive values. The standard heterosis ranged between -10.26% in BF_1-2 and 26.08% in BF_1-3, however, none of the hybrids showed either significant superiority or inferiority over the check.

k) Starch content in grain (%)

Starch content in grain ranged from 66.50% in PMS 2A to 78.50% in PRR 78, with an average of 70.92%. Whereas, in hybrids it ranged from 70.60% in AF_1-1 to 78.80% in BF_1-3, with the mean of 75.77%. Mid-parent heterosis ranged from 1.43% in AF_1-1 to 6.43% in BF_1-2 with eight hybrids, except AF_1-1, showing significant superiority. While Hb for the character ranged between -0.64% in AF_1-3 and 4.19% in BF_1-2 with five hybrids showing significant superiority. Standard heterosis ranged between -4.08% in AF_1-1 and 7.07% in BF_1-3 with none of the hybrids showing significant superiority or inferiority over the check.

4.1.2 Experiment – II

The second experiment on the nature and magnitude of heterosis involved 13 hybrids and their parents. These were evaluated for 19 yield component characters and yield. The results obtained are presented hereunder the following heads:

i) Analysis of variance,

ii) Variability and heritability,

iii) Mean performance of parents and hybrids and estimation of mid-parent, better-parent and standard heterosis

4.1.2.1 Analysis of variance

Analysis of variance was done for the characters under study and the mean sums of squares are presented in Table 9. 'F' test revealed highly significant variation among the 27 genotypes for all the characters.

4.1.2.2 Variability and heritability

The estimates of general mean (GM), range, coefficient of genotypic variation (GCV), coefficient of phenotypic variation (PCV) and broad sense heritability (h^2) for various characters are presented in Table 10. The table revealed that number of unfilled spikelets in main panicle exhibited maximum PCV of 61.42%, followed by number of filled spikelets in main panicle (44.09%), panicle density (43.78%), grain yield (41.26%) and weight per panicle (40.55%). On the other hand, days to maturity recorded the lowest PCV of 5.74% followed by days to 50% flowering (6.02%), grain-filling duration (6.20%), length of main panicle (9.30%) and 1000-grain weight (12.29%). The estimates of coefficient of genotypic variation (GCV) for all

Table 9: Analysis of variance for different characters in parents and hybrids of Expt. 2

Characters	Mean Sum of Squares		
	Replication	Genotype	Error
d.f.	1	26	26
Plant height (cm)	1.5674	343.7144 **	4.0705
Number of productive tillers	0.1452	2.9423 **	0.1713
Days to 50% flowering	2.2407 *	72.4929 **	0.9715
Days to maturity	0.9074	110.0185 **	1.3689
Grain filling duration	0.2963	5.9843 **	0.6425
Flag leaf area (cm^2)	2.1139	169.3118 **	3.3599
Length of main panicle (cm)	0.1024	12.0585 **	0.1601
Weight of main panicle (g)	0.0796	3.2297 **	0.0835
Weight of all panicles (g)	1.1412	69.7498 **	2.6093
Weight per panicle (g)	0.1004 *	1.2312 **	0.0427
Number of filled spikelets	38.8007	4,400.5411 **	91.5530
Number of unfilled spikelets	103.7341	4,506.7436 **	105.1572
Total spikelets in main panicle	24.0000	1529.1132 **	23.5338
Panicle density	0.0086	6.0715 **	0.0336
Spikelet fertility (%)	0.0354	1,092.4426 **	5.8951
1000-grain weight (g)	0.0989	13.8854 **	0.1269
Biomass yield (g)	3.4656	61.4213 **	4.0039
Grain yield (g)	0.1483	37.4731 **	0.4031
Straw yield (g)	2.1800	28.8539 *	2.8521
Harvest index	0.0004	0.0356 **	0.0010

* , ** = Significant at 5% and 1% levels, respectively

Table 10: Estimates of range, general mean, genotypic and phenotypic coefficients of variation and heritability (broad sense) for different characters in parents and hybrids of Expt. 2

Character	Range			GM	GCV (%)	PCV (%)	h^2 (%) (bs)
Plant height (cm)	66.30	-	113.70	97.50	13.37	13.52	97.66
Number of productive tillers	6.60	-	11.50	8.61	13.66	14.48	88.99
Days to 50% flowering	90.00	-	113.50	100.65	5.94	6.02	97.36
Days to maturity	118.50	-	145.50	130.02	5.67	5.74	97.54
Grain filling duration	25.50	-	32.00	29.37	5.56	6.20	80.61
Flag leaf area (cm^2)	40.14	-	67.10	53.54	17.01	17.35	96.11
Length of main panicle (cm)	20.65	-	31.70	26.57	9.18	9.30	97.38
Weight of main panicle (g)	0.53	-	5.27	3.80	32.97	33.84	94.96
Weight of all panicles (g)	3.40	-	27.61	16.41	35.30	36.65	92.79
Weight per panicle (g)	0.33	-	3.33	1.97	39.17	40.55	93.29
Number of filled spikelets	0.00	-	196.90	107.49	43.18	44.09	95.92
Number of unfilled spikelets	30.50	-	219.20	78.19	60.00	61.42	95.44
Total spikelets in main panicle	126.40	-	244.70	185.68	14.78	15.01	96.97
Panicle density	0.00	-	6.81	3.99	43.54	43.78	98.90
Spikelet fertility (%)	0.00	-	80.47	58.22	40.04	40.25	98.93
1000-grain weight (g)	14.48	-	24.25	21.54	12.17	12.29	98.19
Biomass yield (g)	19.84	-	41.97	30.34	17.66	18.85	87.76
Grain yield (g)	0.00	-	15.32	10.55	40.82	41.26	97.87
Straw yield (g)	13.00	-	27.86	19.79	18.22	20.12	82.01
Harvest index	0.00	-	0.48	0.34	39.15	40.21	94.77

GM = General mean

GCV = Coefficient of genotypic variation

PCV = Coefficient of phenotypic variation

h^2 (bs) = Heritability (broad sense)

these characters followed a similar trend as that of PCV values for respective characters.

Existence of wide spectrum of variability for yield and its components in the experimental material was also evident from wider range of values for plant height (66.30 cm-113.70 cm), flag leaf area (40.14 cm^2-67.10 cm^2), weight per panicle (0.33 g-3.33 g), total number of spikelets in the main panicle (126.40-244.70), 1000-grain weight (14.48 g-24.25 g), biological yield (19.84 g-41.97 g), grain yield (0.00 g-15.32 g), straw yield (13.00 g-27.86 g) and harvest index (0.00-0.48). Maximum variation was found in weight per panicle (0.33 g-3.33 g, 90.07% variation), followed by weight of main panicle (0.53 g-5.27 g, 89.94% variation). While, days to maturity exhibited the lowest variation (118.50-145.50 days, 18.56% variation) followed by grain-filling duration (25.50-32.00 days, 20.31% variation).

High coefficients of variation (GCV and PCV) were coupled with high heritability (broad sense) estimates for majority of the characters studied. Broad sense heritability ranged from 80.61% for grain-filling duration to 98.93% for spikelet fertility. Characters like panicle density (98.90%), 1000-grain weight (98.19%), grain yield (97.87%) and plant height (97.66%) also showed high estimates of broad sense heritability, whereas other characters like straw yield (82.01%), biomass production (87.76%), number of productive tillers (88.99%) and weight of all panicles of a plant (92.79%) showed comparatively low estimates of broad sense heritability.

4.1.2.3 Mean performance of parents and hybrids and the extent of heterosis

Mean values of the characters studied in the parental lines and hybrids are presented in Table 11. Heterosis as percent increase or decrease over the mid-parent (Ha), better parent (Hb) and standard check (Hc) is presented in Table 12. The nature and magnitude of heterosis is presented character wise hereunder.

Table 11: Mean performance of parents and hybrids of Expt. 2 for various characters

Characters	PARENTS									
	PMS 2A	Pusa 5A	IR 58025A	PRR 22	PRR 24	PRR 72	PRR 75	PRR 76	PRR 77	PRR 80
Plant height (cm)	66.30	68.40	74.70	98.40	89.50	93.20	95.00	88.10	103.20	79.70
Number of productive tillers	11.50	8.10	10.90	9.90	7.60	8.00	7.40	9.30	9.70	8.60
Days to 50% flowering	104.50	93.50	94.00	95.50	101.00	106.00	103.00	97.50	94.00	96.00
Days to maturity	136.00	124.00	122.50	124.00	130.50	137.00	131.00	126.00	121.00	125.00
Grain filling duration	31.50	30.50	28.50	28.50	29.50	31.00	28.00	28.50	27.00	29.00
Flag leaf area (cm^2)	41.78	40.55	45.17	56.06	59.37	64.68	58.69	50.90	65.72	46.46
Length of main panicle (cm)	20.65	24.95	23.80	28.90	25.40	26.30	24.30	25.40	29.45	24.75
Weight of main panicle (g)	0.53	0.61	0.79	5.27	3.33	4.24	4.12	2.84	4.65	3.91
Weight of all panicles (g)	3.90	3.40	3.60	21.70	11.75	16.09	14.86	14.90	19.32	14.18
Weight per panicle (g)	0.34	0.42	0.33	2.19	1.55	2.01	2.01	1.60	1.99	1.65
Number of filled spikelets	0.00	0.00	1.60	196.90	157.60	148.30	136.90	98.10	129.20	95.90
Number of unfilled spikelets	219.20	177.90	191.80	47.80	38.50	38.10	53.00	36.30	51.50	30.50
Total spikelets in main panicle	219.20	177.90	193.40	244.70	196.10	186.40	189.90	134.40	180.70	126.40
Panicle density	0.00	0.00	0.07	6.81	6.20	5.64	5.63	3.86	4.39	3.87
Spikelet fertility (%)	0.00	0.00	0.83	80.47	80.37	79.56	72.09	72.99	71.50	75.87
1000-grain weight (g)	14.48	17.55	15.78	21.92	20.98	24.17	23.56	23.71	22.35	22.67
Biomass yield (g)	19.84	22.06	22.06	36.82	21.31	25.24	24.32	29.79	28.22	27.16
Grain yield (g)	0.00	0.00	0.03	13.10	8.31	9.85	9.99	9.97	11.40	9.32
Straw yield (g)	19.84	22.06	22.04	23.73	13.00	15.40	14.33	19.82	16.83	17.85
Harvest index	0.00	0.00	0.00	0.36	0.39	0.39	0.41	0.33	0.40	0.34

Table 11 (Cont...)

Characters	PARENTS			Pusa 44	HYBRIDS					
	TCP 97-24	TCP 97-25	TCP 97-33	(Check)	PRH-2	PRH-3	PRH-5	PRH-6	PRH-7	PRH-15
Plant height (cm)	98.30	96.30	97.00	89.80	103.30	113.70	110.40	113.30	107.00	103.30
Number of productive tillers	9.40	9.10	9.70	9.50	8.30	8.30	7.00	8.20	7.30	9.10
Days to 50% flowering	113.50	109.00	112.50	104.50	95.00	104.00	94.50	100.50	90.00	97.00
Days to maturity	145.50	140.50	144.00	135.50	120.50	134.50	121.50	128.50	118.50	124.50
Grain filling duration	32.00	31.50	31.50	31.00	25.50	30.50	27.00	28.00	28.50	27.50
Flag leaf area (cm^2)	48.61	49.92	45.92	53.68	61.14	63.20	43.26	42.69	53.65	40.14
Length of main panicle (cm)	26.40	25.50	24.90	25.30	27.95	29.15	27.20	28.75	27.05	25.35
Weight of main panicle (g)	4.12	4.11	4.17	3.01	4.45	4.72	5.21	4.07	4.20	4.33
Weight of all panicles (g)	16.09	16.81	18.18	14.45	27.61	16.02	22.41	14.25	21.68	16.51
Weight per panicle (g)	1.71	1.85	1.87	1.52	3.33	1.93	3.20	1.74	2.97	1.81
Number of filled spikelets	133.20	129.20	134.80	111.80	161.10	110.80	121.20	108.80	127.40	84.10
Number of unfilled spikelets	39.90	52.00	52.00	68.40	69.00	72.70	76.40	62.40	56.20	114.00
Total spikelets in main panicle	173.10	181.20	186.80	180.20	230.10	183.50	197.60	171.20	183.60	198.10
Panicle density	5.05	5.07	5.41	4.42	5.76	3.80	4.46	3.78	4.71	3.32
Spikelet fertility (%)	76.95	71.30	72.16	62.04	70.01	60.38	61.34	63.55	69.39	42.45
1000-grain weight (g)	22.23	23.39	22.35	21.06	18.08	23.14	24.25	23.19	22.03	23.81
Biomass yield (g)	32.88	31.47	36.95	30.32	41.97	34.47	30.16	29.95	31.31	31.33
Grain yield (g)	10.82	10.77	11.67	8.96	14.12	13.51	14.54	10.51	14.29	13.61
Straw yield (g)	22.06	20.70	25.28	21.36	27.86	20.97	15.62	19.45	17.02	17.73
Harvest index	0.33	0.34	0.32	0.30	0.34	0.39	0.48	0.35	0.46	0.43

Table 11 (Cont...)

Characters	HYBRIDS							Mean	S.Em	CD at 5%
	PRH-16	PRH-17	PRH-21	PRH-26	PRH-27	PRH-28	PRH-33			
Plant height (cm)	109.80	108.70	96.60	103.60	106.80	105.50	112.70	97.50	5.86	8.37
Number of productive tillers	8.80	7.70	9.20	7.60	7.80	6.60	8.00	8.61	0.52	0.35
Days to 50% flowering	99.50	99.50	106.50	101.50	104.50	95.50	105.00	100.65	2.69	2.00
Days to maturity	127.50	127.50	138.00	131.50	135.50	124.50	135.50	130.02	3.32	2.81
Grain filling duration	28.00	28.00	31.50	30.00	31.00	29.00	30.50	29.37	0.77	1.32
Flag leaf area (cm^2)	58.57	63.37	67.10	62.84	66.24	42.32	53.69	53.54	4.02	6.91
Length of main panicle (cm)	31.70	26.15	27.30	29.35	31.15	24.10	26.25	26.57	1.09	0.33
Weight of main panicle (g)	4.99	4.56	3.69	4.26	4.30	4.24	4.03	3.80	0.57	0.17
Weight of all panicles (g)	23.31	18.28	18.11	20.53	19.15	17.47	18.61	16.41	2.55	5.36
Weight per panicle (g)	2.65	2.37	1.97	2.70	2.46	2.65	2.33	1.97	0.34	0.09
Number of filled spikelets	144.70	96.50	60.20	123.40	99.80	104.20	86.50	107.49	21.21	188.23
Number of unfilled spikelets	63.90	59.00	78.30	79.80	87.80	77.30	117.40	78.19	21.39	216.20
Total spikelets in main panicle	208.60	155.50	138.50	203.20	187.60	181.50	203.90	185.68	11.78	48.39
Panicle density	4.56	3.69	2.21	4.20	3.20	4.32	3.30	3.99	0.78	0.07
Spikelet fertility (%)	69.37	62.06	43.47	60.73	53.20	57.41	42.42	58.22	10.50	12.12
1000-grain weight (g)	23.63	22.67	19.48	22.36	23.72	20.87	18.31	21.54	1.17	0.26
Biomass yield (g)	35.22	32.55	36.79	33.79	30.47	31.05	31.68	30.34	2.38	8.23
Grain yield (g)	15.32	12.72	13.40	13.87	10.14	11.86	12.76	10.55	1.89	0.83
Straw yield (g)	19.90	19.83	23.40	19.92	20.34	19.19	18.93	19.79	1.47	5.86
Harvest index	0.44	0.39	0.36	0.41	0.33	0.38	0.40	0.34	0.06	0.00

Table 12: Mid-parent, better-parent and standard heterosis (%) for various characters in hybrids of Expt. 2

Characters	PRH-2			PRH-3			PRH-5		
	MP	BP	SH	MP	BP	SH	MP	BP	SH
Plant height (cm)	19.35 **	4.98 *	15.03 **	40.72 **	22.00 **	26.61 **	39.84 **	23.35 **	22.94 **
Number of productive tillers	-20.19 **	-23.85 **	-12.63	3.11	2.47	-12.63	-10.83	-13.58	-26.32 **
Days to 50% flowering	0.26	-0.52	-9.09 **	4.26 **	-1.89	-0.48	-2.83 **	-6.44 **	-9.57 **
Days to maturity	-2.23 *	-2.82 **	-11.07 **	3.07 **	-1.82 *	-0.74	-4.52 **	-6.90 **	-10.33 **
Grain filling duration	-10.53 **	-10.53 **	-17.74 **	-0.81	-1.61	-1.61	-10.00 **	-11.48 **	-12.90 **
Flag leaf area (cm^2)	20.80 **	9.06 *	13.89 **	20.12 **	-2.29	17.73 **	-13.42 **	-27.14 **	-19.42 **
Length of main panicle (cm)	6.07 **	-3.29	10.47 **	13.76 **	10.84 **	15.22 **	8.04 **	7.09 **	7.51 **
Weight of main panicle (g)	14.55 **	-15.65 **	47.67 **	55.67 **	11.32 *	56.81 **	102.37 **	56.69 **	73.09 **
Weight of all panicles (g)	52.12 **	27.24 **	91.07 **	11.53	-0.47	10.83	83.88 **	77.45 **	55.09 **
Weight per panicle (g)	86.64 **	51.76 **	118.70 **	6.04	-4.06	26.85	101.77 **	107.16 **	110.47 **
Number of filled spikelets	5.64 *	-18.18 **	44.10 **	-11.61 **	-25.29 **	-0.89	-6.77 *	-23.10 **	8.41 *
Number of unfilled spikelets	-2.13	-64.03 **	0.88	22.49 *	-59.13 **	6.29	28.30 **	-57.05 **	11.70
Total spikelets in main panicle	5.04	-5.97 *	27.69 **	0.74	-1.56	1.83	5.67	0.76	9.66 *
Panicle density	2.50	-15.40 **	30.43 **	-22.30 **	-32.59 **	-13.98 **	-13.89 **	-28.19 **	0.84
Spikelet fertility (%)	3.41	-12.99 **	12.85 **	-11.27 **	-24.11 **	-2.68	-10.39 **	-23.68 **	-1.14
1000-grain weight (g)	-4.09 **	-17.52 **	-14.13 **	10.93 **	-4.26 **	9.90 **	25.88 **	15.59 **	15.17 **
Biomass yield (g)	42.56 **	13.99	38.45 **	45.77 **	36.57 **	13.71	39.08 **	36.73 *	-0.53
Grain yield (g)	30.67 **	7.79	57.53 **	47.20 **	37.18 **	50.73 **	72.89 **	74.91 **	62.22 **
Straw yield (g)	21.74	17.41	30.44 *	11.96	-4.94	-1.83	-10.88	-29.18 *	-26.86
Harvest index	2.21	-5.44	13.79	22.87	0.44	32.56 *	51.19 **	23.61 *	63.08 **

* , ** = Significant at 5% and 1% levels respectively

Table 12 (Cont...)

Characters	PRH-6			PRH-7			PRH-15		
	MP	BP	SH	MP	BP	SH	MP	BP	SH
Plant height (cm)	53.00 **	42.16 **	26.17 **	28.30 **	8.74 **	19.15 **	26.44 **	8.74 **	15.03 **
Number of productive tillers	-1.80	-4.65	-13.68	-18.89 **	-26.26 **	-23.16 **	17.42 *	12.35	-4.21
Days to 50% flowering	6.07 **	4.69 **	-3.83 **	-4.76 **	-5.76 **	-13.88 **	-1.27	-5.83 **	-7.18 **
Days to maturity	3.21 **	2.80 **	-5.17 **	-4.44 **	-4.44 **	-12.55 **	-2.35 **	-4.96 **	-8.12 **
Grain filling duration	-5.88 *	-8.20 **	-9.68 **	-3.39	-6.56 *	-8.06 **	-5.98 *	-9.84 **	-11.29 **
Flag leaf area (cm^2)	-1.88	-8.13	-20.48 **	11.06 *	-4.30	-0.07	-19.12 **	-31.62 **	-25.23 **
Length of main panicle (cm)	15.69 **	15.23 **	13.64 **	0.46	-6.40 **	6.92 **	2.94	1.60	0.20
Weight of main panicle (g)	41.96 **	4.09	35.22 **	18.41 **	-20.30 **	39.53 **	45.52 **	4.98	43.69 **
Weight of all panicles (g)	6.31	0.49	-1.38	26.28 **	-0.12	50.00 **	20.11 *	11.11	14.22
Weight per panicle (g)	6.07	5.40	14.25	55.46 **	35.46 **	95.21 **	-0.22	-9.65	19.24
Number of filled spikelets	9.73 *	13.45 **	-2.68	-14.87 **	-35.30 **	13.95 **	-29.71 **	-38.57 **	-24.78 **
Number of unfilled spikelets	12.33	-64.92 **	-8.77	-12.46	-68.41 **	-17.84	70.66 **	-35.92 **	66.67 **
Total spikelets in main panicle	12.52 **	-3.77	-4.99	-13.11 **	-24.97 **	1.89	7.72 *	4.32	9.93 *
Panicle density	-5.62	-2.33	-14.36 **	-14.04 **	-30.87 **	6.58	-32.15 **	-41.11 **	-24.92 **
Spikelet fertility (%)	-4.00	-16.24 **	2.43	1.30	-13.76 **	11.84 **	-33.99 **	-41.11 **	-31.57 **
1000-grain weight (g)	15.33 **	2.32 **	10.14 **	11.63 **	0.50 **	4.63 **	15.83 **	1.06 **	13.06 **
Biomass yield (g)	21.71 *	10.27	-1.20	6.36	-14.96	3.28	35.12 **	28.82 *	3.35
Grain yield (g)	17.91 **	12.78	17.24 *	32.32 **	9.13	59.49 **	47.13 **	36.19 **	51.84 **
Straw yield (g)	-2.53	-11.83	-8.94	-25.64 *	-28.26 *	-20.30	-2.57	-19.63	-17.00
Harvest index	18.77	2.27	18.67	51.30 **	28.33 *	54.42 **	31.90 **	5.71	46.92 **

* , ** = Significant at 5% and 1% levels respectively

Table 12 (Cont...)

Characters	PRH-16			PRH-17			PRH-21		
	MP	BP	SH	MP	BP	SH	MP	BP	SH
Plant height (cm)	40.32 **	24.63 **	22.27 **	26.69 **	5.33 *	21.05 **	21.13 **	3.65	7.57 **
Number of productive tillers	1.15	-5.38	-7.37	-13.48 *	-20.62 **	-18.95 *	-5.64	-20.00 **	-3.16
Days to 50% flowering	4.19 **	2.05	-4.78 **	6.13 **	5.85 **	-4.78 **	1.19	0.47	1.91
Days to maturity	2.00 *	1.19	-5.90 **	4.08 **	2.82 **	-5.90 **	1.10	0.73	1.85 *
Grain filling duration	-5.08 *	-8.20 **	-9.68 **	-2.61	-8.20 **	-9.68 **	0.80	0.00	1.61
Flag leaf area (cm^2)	28.09 **	15.07 **	9.10 *	19.26 **	-3.58	18.05 **	26.05 **	3.73	24.99 **
Length of main panicle (cm)	25.92 **	24.80 **	25.30 **	-3.86	-11.21 **	3.36	16.29 **	3.80	7.91 **
Weight of main panicle (g)	113.99 **	75.84 **	65.61 **	40.87 **	-1.94	51.50 **	22.63 **	-13.09 **	22.43 **
Weight of all panicles (g)	69.34 **	56.46 **	61.28 **	14.42	-5.38	26.47 *	28.51 **	12.55	25.33 *
Weight per panicle (g)	64.00 **	65.35 **	74.11 **	31.15 *	19.19	56.04 **	26.35	-2.13	29.42
Number of filled spikelets	44.34 **	47.50 **	29.43 **	-16.67 **	-25.31 **	-13.69 **	-54.08 **	-59.41 **	-46.15 **
Number of unfilled spikelets	9.32	-64.08 **	-6.58	-10.67	-66.84 **	-13.74	15.40	-64.28 **	14.47
Total spikelets in main panicle	33.59 **	17.26 **	15.76 **	-13.27 **	-13.95 **	-13.71 **	-31.71 **	-36.82 **	-23.14 **
Panicle density	14.02 **	18.19 **	3.30	-13.49 **	-15.88 **	-16.49 **	-59.37 **	-60.89 **	-50.10 **
Spikelet fertility (%)	7.11 *	-4.96	11.81 **	-3.06	-13.21 **	0.03	-35.14 **	-45.37 **	-29.94 **
1000-grain weight (g)	14.56 **	-0.32 *	12.23 **	13.61 **	1.41 **	7.65 **	0.79 **	-19.42 **	-7.50 **
Biomass yield (g)	35.85 **	18.21	16.16	29.47 **	15.33	7.36	63.24 **	45.76 **	21.36 *
Grain yield (g)	65.86 **	53.66 **	70.98 **	27.85 **	11.63	41.96 **	53.10 **	36.06 **	49.50 **
Straw yield (g)	-4.98	-9.79	-6.84	1.98	-10.11	-7.16	32.81 *	17.95	9.55
Harvest index	49.41 **	29.99 *	47.19 **	19.99	-3.21	32.24 *	10.66	-6.66	23.19

* , ** = Significant at 5% and 1% levels respectively

Table 12 (Cont...)

Characters	PRH-26			PRH-27			PRH-28		
	MP	BP	SH	MP	BP	SH	MP	BP	SH
Plant height (cm)	24.30 **	5.39 *	15.37 **	29.69 **	10.90 **	18.93 **	27.57 **	8.76 **	17.48 **
Number of productive tillers	-13.14	-19.15 *	-20.00 **	-9.30	-14.29	-17.89 *	-25.84 **	-31.96 **	-30.53 **
Days to 50% flowering	-1.93 *	-10.57 **	-2.87 **	3.21 **	-4.13 **	0.00	-7.28 **	-15.11 **	-8.61 **
Days to maturity	-2.41 **	-9.62 **	-2.95 **	2.46 **	-3.56 **	0.00	-7.09 **	-13.54 **	-8.12 **
Grain filling duration	-4.00	-6.25 *	-3.23	0.00	-1.59	0.00	-6.45 **	-7.94 **	-6.45 *
Flag leaf area (cm^2)	40.95 **	29.26 **	17.05 **	46.44 **	32.71 **	23.40 **	-2.13	-7.85	-21.17 **
Length of main panicle (cm)	14.31 **	11.17 **	16.01 **	23.49 **	22.16 **	23.12 **	-3.31	-3.41	-4.74
Weight of main panicle (g)	43.17 **	3.28	41.36 **	44.93 **	4.62	42.86 **	41.47 **	1.68	40.86 **
Weight of all panicles (g)	42.97 **	27.59 **	42.08 **	30.10 **	13.92	32.53 **	13.41	-3.91	20.90 *
Weight per panicle (g)	61.77 **	57.81 **	77.60 **	41.29 **	32.91 *	61.41 **	51.16 **	41.23 **	74.02 **
Number of filled spikelets	4.75	-7.36 *	10.38 **	-13.82 **	-22.76 **	-10.73 **	-12.14 **	-22.70 **	-6.80
Number of unfilled spikelets	32.45 **	-55.14 **	16.67	32.43 **	-50.65 **	28.36 **	16.59	-56.55 **	13.01
Total spikelets in main panicle	15.78 **	14.22 **	12.76 **	4.48	3.53	4.11	-0.47	-2.84	0.72
Panicle density	-8.50 *	-16.67 **	-4.86	-30.44 **	-36.77 **	-27.50 **	-9.53 *	-20.13 **	-2.16
Spikelet fertility (%)	-9.01 *	-21.08 **	-2.12	-16.77 **	-25.39 **	-14.25 **	-10.78 **	-20.44 **	-7.47
1000-grain weight (g)	12.42 **	0.58 **	6.20 **	15.87 **	1.41 **	12.63 **	4.62 **	-6.60 **	-0.88 **
Biomass yield (g)	23.01 *	2.77	11.45	13.85	-3.18	0.51	5.25	-15.97	2.42
Grain yield (g)	43.54 **	28.20 **	54.74 **	5.17	-5.90	13.11	17.58 **	1.63	32.37 **
Straw yield (g)	-9.69	-9.70	-6.72	-4.88	-7.80	-4.78	-18.92	-24.09	-10.14
Harvest index	42.34 **	24.75	38.85 *	12.77	-2.81	12.54	35.57 *	20.94	29.23

*, ** = Significant at 5% and 1% levels respectively

Table 12 (Cont...)

Characters	PRH-33		
	MP	BP	SH
Plant height (cm)	34.25 **	20.92 **	25.50 **
Number of productive tillers	-15.34 *	-26.61 **	-15.79 *
Days to 50% flowering	5.00 **	-0.94	0.48
Days to maturity	4.43 **	-1.09	0.00
Grain filling duration	2.52	-1.61	-1.61
Flag leaf area (cm^2)	-2.25	-17.00 **	0.01
Length of main panicle (cm)	4.79 *	-0.19	3.75
Weight of main panicle (g)	19.60 **	-5.07	33.72 **
Weight of all panicles (g)	21.24 *	15.63	28.75 **
Weight per panicle (g)	37.45 **	15.63	52.90 **
Number of filled spikelets	-32.53 **	-41.67 **	-22.63 **
Number of unfilled spikelets	78.83 **	-38.79 **	71.64 **
Total spikelets in main panicle	7.37 *	5.43	13.15 **
Panicle density	-34.57 **	-41.56 **	-25.43 **
Spikelet fertility (%)	-36.92 **	-46.68 **	-31.62 **
1000-grain weight (g)	-8.34 **	-24.24 **	-13.04 **
Biomass yield (g)	33.95 **	25.52 *	4.50
Grain yield (g)	38.99 **	29.56 **	42.35 **
Straw yield (g)	1.12	-14.11	-11.38
Harvest index	16.28	3.22	36.22 *

Plant height (cm): Among the parental lines, PRR 77 recorded the maximum height of 103.20 cm, while PMS 2A was the shortest with a height of 66.30 cm. The parental mean value was 88.32 cm. Among the hybrids, however, the range for this character was from 96.60 cm (PRH 21) to 113.70 cm (PRH 3), with a mean of 107.28 cm. For all the 13 hybrids the mid-parent and standard heterosis were not only positive, but also highly significant. The Ha ranged from 19.35% in PRH 2 to 53.00% in PRH 6, while Hc varied from 7.57% in PRH 21 to 26.61% in PRH 3. For heterobeltiosis, the range was from 3.65% in PRH 21 to 42.16% in PRH 6, with 12 of the 13 hybrids demonstrating significant to highly significant positive Hb, except PRH 21.

Number of productive tillers per plant: PMS 2A produced a maximum of 11.50 tillers, while PRR 75 had only 7.40 tillers among the parents. The mean number of productive tillers in parental lines was 9.17. While in case of hybrids, the range for this character was from 6.60 (PRH 28) to 9.20 (PRH 21), with a mean of 7.99. The Ha varied from -25.84% for PRH 28 to 17.42% for PRH 15, with five hybrids manifesting significant negative heterosis. Only one hybrid (PRH 15) demonstrated significant positive Ha. The range of Hb was from -31.96% for PRH 28 to 12.35% for PRH 15. Eleven of the 13 hybrids exhibited negative Hb, of which seven were significant. Only two hybrids showed positive, though non-significant Hb values. Similarly, Hc ranged from -30.53% in PRH 28 to -3.16% in PRH 21. When compared with the check, all the hybrids displayed negative values, seven of them being significant.

Days to 50% flowering: In terms of the number of days to 50% flowering the parental lines varied from 93.50 days (Pusa 5A) to 113.50 days (TCP 97-24), the mean value being 101.54 days. Among the hybrids, PRH 7 flowered earliest in 90.00 days and PRH 21 was the latest with 106.50 days. The mean of hybrids for this character was 99.46 days. The Ha ranged from -7.28% for PRH 28 to 6.13% for PRH 17, while the range of Hb was from -15.11% for PRH 28 to 5.85% for PRH 17. Compared with the check, 9 hybrids were significantly early, the range of Hc being -13.88% for PRH 7 to 1.91% for PRH 21. For this character, negative heterosis was predominant with six hybrids manifesting highly significant heterobeltiosis (-15.11% to -4.13%). Only in two hybrids, PRH 6 and PRH 17, highly significant positive Hb was observed indicating their lateness over the better parent.

Days to maturity: Days to maturity in parental genotypes ranged from 121.00 in PRR 77 to 145.50 in TCP 97-24. The mean number of days to maturity in parental lines was 131.31. Among the hybrids, days to maturity ranged from 118.50 for PRH 7 to 138.00 for PRH 21, with a mean of 128.31. The Ha varied from -7.09% for PRH 28 to 4.43% for PRH 33. Six hybrids showed significant negative Ha and an equal number manifested significant positive Ha for this character. Hb ranged from -13.54% for PRH 28 to 2.82% for PRH 17; with only two hybrids demonstrating significant positive Hb and eight showing significant negative Hb indicating earliness over their respective better parents. The standard heterosis was found to range between -12.55% for PRH 7 and 1.85% for PRH 21 with nine hybrids manifesting negative heterosis and only one showing positive heterosis.

Grain-filling duration (days): Among the parents, grain-filling duration was the shortest in PRR 77 (27.00 days) and longest in TCP 97-24 (32.00 days), the mean being 29.77 days. While, in hybrids it ranged from 25.50 days (PRH 2) to 31.50 days (PRH 21), with a mean of 28.85 days. Six hybrids exhibited significant negative Ha with the range being -10.53% for PRH 2 to 2.52% for PRH 33. All the hybrids exhibited heterobeltiosis in negative direction and 9 of them were significantly early than their better parents, with the range being -11.48% for PRH 5 to 0.00% for PRH 21. Compared with the check, heterosis ranged from -17.74% (PRH 2) to 1.61% (PRH 21), with 8 hybrids showing significant negative values.

Flag leaf area (cm^2): The parental lines differed significantly with respect to flag leaf area; the range being 40.55 cm^2 in Pusa 5A to 65.77 cm^2 in PRR 77 and the mean value being 51.83 cm^2. In case of hybrids, the flag leaf area was minimum in PRH 15 (40.14 cm^2) and maximum in PRH 21 (67.10 cm^2), with a mean of 55.24 cm^2. The range of Ha was from -19.12% in PRH 15 to 46.44% in PRH 27, while Hb ranged from -31.62% in PRH 15 to 32.71% in PRH 27. Hc varied from -25.23% in PRH 15 to 24.99% in PRH 21. Four of the hybrids showed significant positive Hb for this character and three showed significant negative Hb values.

Length of main panicle (cm): The length of main panicle among parents varied from 20.65 cm in PMS 2A to 29.45 cm in PRR 77. The parental mean value was 25.44 cm. The main panicle was the shortest in PRH 28 (24.10 cm) and longest in PRH 16 (31.70 cm). The F_1 mean value for this character was 27.80 cm. The Ha varied from -3.86% (PRH 17) to 25.92% (PRH 16), while Hb ranged from -11.21% in PRH 17 to 24.80% in PRH 16. When compared with the check, the heterosis was found to range between -4.74% (PRH 28) and 25.30% in PRH 16. Six of the 13 hybrids exhibited highly significant positive Hb for this character, while only two showed highly significant negative Hb values.

Weight of main panicle (g): In general, the maintainer lines had the low weighing main panicles of 1.77 g (PMS 2B), 1.82 g (Pusa 5B) and 2.49 g (IR 58025B). While among restorers, the range for this character was from 2.84 g (PRR 76) to 5.27 g (PRR 22). The fertile parental mean value was 3.60 g. Among the hybrids PRH 21 produced the lowest weighing main panicle of 3.69 g, while PRH 5 produced the heaviest main panicle of 5.21 g. The F_1 mean for this character was 4.39 g. Thus none of the hybrids could produce main panicle heavier than that of PRR 22. However, the mid-parent heterosis was not only positive, but also highly significant in case of all the hybrids. The Ha values ranged between 14.55% (PRH 2) and 113.99% (PRH 16). The Hb values were significantly positive for three hybrids and an equal number of them were significantly negative; the range of Hb being -20.30% (PRH 7) to 75.84% (PRH 16). When compared with the check all the hybrids scored highly significant positive superiority for this character; the range of Hc being 22.43% (PRH 21) to 73.09% (PRH 5).

Weight of all panicles (g): Among B lines, the weight of all panicles of a plant ranged from 12.10 g (PMS 2B) to 14.60 g (IR 58025B), while in case of restorers, it varied from 11.75 g (PRR 24) to 21.70 g (PRR 22). The mean of fertile parents for this character was 15.63 g. In case of hybrids, the weight of all panicles varied from 14.25 g (PRH 6) to 27.61 g (PRH 2), with a mean value of 19.53 g. As in case of main panicle weight, the values for Ha were positive for all the hybrids, however for this character, only 9 of the 13 hybrids were significantly superior to the mid-parent value; the range for Ha being 6.31% (PRH 6) to 83.88% (PRH 5). Hb ranged between -5.38% (PRH 17) and 77.45% (PRH 5) and four hybrids were significantly better, while none of the hybrids were significantly inferior to their better parents. Compared with the check, 10 hybrids manifested highly significant positive heterosis for this character and none exhibited significant negative heterosis. The range of Hc was from -1.38% (PRH 6) to 91.87% (PRH 2).

Weight per panicle (g): The mean of fertile parents for this character was 1.73 g and the range was from 1.10 g in PMS 2B to 2.19 g in PRR 22. Among hybrids, the average panicle weight was minimum in PRH 6 (1.74 g) and maximum in PRH 2 (3.33 g) with the mean being 2.47 g. Mid-parent heterosis ranged from -0.22% in PRH 15 to 101.77% in PRH 5, while Hb ranged from -9.65% (PRH 15) to 107.16% (PRH 5). Nine hybrids exhibited significant superiority to the check variety for this character and the Hc ranged between 14.25% in PRH 6 and 118.70% in PRH 2.

Number of filled spikelets in the main panicle: The range for this character among the fertile parental genotypes was from 95.90 in PRR 80 to 196.90 in PRR 22, while the mean of the same was 129.58. Among hybrids, the range for this character was from 60.20 (PRH 21) to 161.10 (PRH 2), with a mean of 109.90. In this case too, none of the hybrids was superior to the restorer PRR 22. The Ha ranged from -54.08% for PRH 21 to 44.34% for PRH 16, while Hb varied from -59.41% for PRH 21 to 47.50% for PRH 16. Eleven of the 13 hybrids manifested highly significant negative Hb for this character. The other two hybrids, however, demonstrated their superiority by showing highly significant positive Hb. Similarly, the range of Hc was from -46.15% in PRH 21 to 44.10% in PRH 2.

Number of unfilled spikelets in the main panicle: PRR 80 had the least number of unfilled spikelets (30.50), while PMS 2B had the highest number of unfilled spikelets (97.60) in the main panicle; the parental mean being 54.69. Among hybrids, this character ranged from 56.20 (PRH 7) to 117.40 (PRH 33), with a mean of 78.02. This indicates that hybrids have more number of unfilled spikelets than their restorer parents. The Ha for this character ranged from -12.46% for PRH 7 to 78.83% for PRH 33, while Hb ranged from -68.41% for PRH 7 to -35.92% for PRH 15. All the 13 hybrids manifested highly significant negative Hb for this character indicating their superiority over their respective female parents for this character. Hc varied from -17.84% in PRH 7 to 71.64% in PRH 33 with three hybrids showing positive values.

Total number of spikelets in the main panicle: PRR 80 had only 126.40 spikelets in the main panicle, whereas PRR 22 had the maximum of 244.70 spikelets. The mean of the parents was 183.86 spikelets. Among the hybrids, this character varied from 138.50 (PRH 21) to 230.10 (PRH 2), with a mean value of 187.92. Thus in this case too, none of the hybrids had more spikelets than the restorer PRR 22. Mid-parent heterosis for this character deviated equally in both negative and positive directions and ranged from -31.71% for PRH 21 to 33.59% for PRH 16. While the range for Hb was from -36.82% for PRH 21 to 17.26% for PRH 16. Four hybrids exhibited significant negative Hb for this character indicating their inferiority to their better parents and only two could demonstrate significant superiority over their better parents. Standard heterosis ranged from -23.14% in PRH 21 to 27.69% in PRH 2.

Panicle density: Among the parents, panicle density was minimum in PRR 78 (3.86) and maximum in PRR 22 (6.81), with a mean of 5.06. The value for this character among hybrids ranged from 2.21 (PRH 21) to 5.76 (PRH 2), with a mean of 3.95. Ha ranged from -59.37% in PRH 21 to 14.02% in PRH 16, while Hb ranged from -60.89% in PRH 21 to 18.19% in PRH 16. Ten of the 13 hybrids exhibited significant negative Ha for this character and only one demonstrated significant positive Ha. The similar trend was observed in Hb values with 11 hybrids exhibiting significant negative heterosis and only one manifesting significant positive Hb. The range of Hc was from -50.10% in PRH 21 to 30.43% in PRH 2, with seven hybrids showing significant negative heterosis and only one exhibiting significant positive Hc value.

Spikelet fertility (%): Among the fertile parental genotypes, spikelet fertility ranged from 54.48% in PMS 2B to 80.47% in PRR 22, with a mean value of 70.71%. Whereas, among the hybrids it ranged from 42.42% (PRH 33) to 70.01% (PRH 2), with a mean of 58.14%. None of the hybrids had spikelet fertility more than the restorer PRR 22. Ha ranged from -36.92% in PRH 33 to 7.11% in PRH 16, with eight hybrids exhibiting significant negative Ha values and only one demonstrating significant positive Ha. Heterobeltiosis showed negative trend for this character, with the range being -46.68% (PRH 33) to -4.96% (PRH 16). Twelve of the hybrids were significantly poorer to their restorer parents for this character. Standard heterosis ranged between -31.62% in PRH 33 and 12.85% in PRH 2 and four hybrids were found to be significantly poor while three were significantly superior compared to the check.

1000-grain weight (g): The parental range for test grain weight was from 14.48 g (PMS 2A) to 24.17 g (PRR 72), with a mean of 21.16 g. Among the hybrids, the range varied from 18.08 g (PRH 2) to 24.25 g (PRH 5) with a mean of 21.96 g. The mid-parent heterosis for 1000-grain weight ranged between -8.34% in PRH 33 and 25.88% in PRH 5, with 11 hybrids showing significant positive heterosis and the other two showing significant negative heterosis. Hb for this character varied from -24.24% in PRH 33 to 15.59% in PRH 5, with eight hybrids manifesting significant superiority and five exhibiting negative values. Similarly, with respect to the check variety, heterosis was found to vary equally in both negative and positive directions and ranged from -14.13% in PRH 2 to 15.17% in PRH 5, with nine hybrids manifesting significant positive heterosis and four showing significant negative values.

Biomass production (g): The plant dry weight among the parental lines ranged between 19.84 g in PMS 2A and 36.95 g in TCP 97-33 with a mean of 27.55 g. However, hybrids produced more biomass than their parents and it ranged from 29.95 g (PRH 6) to 41.97 g (PRH 2), with a mean of 33.13 g. The mid-parent heterosis varied from 5.25% in PRH 28 to 63.24% in PRH 21, with 10 hybrids exhibiting significant superiority. The range of heterobeltiosis was from -15.97% (PRH 28) to 45.76% (PRH 21), with five hybrids producing significantly high biomass. Compared with the check, only two hybrids were significantly superior and none was significantly poor. The hybrid PRH 6 was the one which showed the lowest Hc (-1.20%) and PRH 2 exhibited the highest Hc (38.45%).

Grain yield (g): Grain yield ranged from 7.65 g in PMS 2B to 13.10 g in PRR 22, with a mean value of 9.99 g for the fertile parental genotypes. Its range among the hybrids varied between 10.14 g (PRH 27) and 15.32 g (PRH 16), with a mean of 13.12 g. The Ha was found to vary between 5.17% in PRH 27 and 72.89% in PRH 5, with all the hybrids, except PRH 27, exhibiting highly significant positive heterosis. The Hb ranged from -5.90% for PRH 27 to 74.91% for PRH 5, with seven hybrids showing significant positive values. Only PRH 27 showed negative Hb, which too was non-significant. Over the check, all hybrids except PRH 27 manifested highly significant positive heterosis ranging from 13.11% in PRH 27 to 70.98% in PRH 16.

Straw yield (g): Straw yield was only 13.00 g in PRR 24 and 26.11 g in Pusa 5B, with a mean of 19.67 g for the fertile parental genotypes. However, in case of hybrids, this character ranged from 15.62 g (PRH 5) to 27.86 g (PRH 2) and the average was 20.01 g. The Ha ranged from -25.64% in PRH 7 to 32.81% in PRH 21, with only one hybrid each showing significantly positive and negative values. Hb ranged from -29.18% (PRH 5) to 17.95% (PRH 21) with two hybrids showing significant negative heterobeltiosis. Compared to the check, only one hybrid exhibited significant positive heterosis and none manifested significant negative heterosis. The range for Hc was from -26.86% in PRH 5 to 30.44% in PRH 2.

Harvest index: The harvest index was 0.25 in Pusa 5B and 0.41 in PRR 75, with a mean of 0.34 for the fertile parental genotypes. For hybrids, the value for this character ranged from 0.33 (PRH 27) to 0.48 (PRH 5), with the mean of 0.40. The mid-parent heterosis ranged from 2.21% in PRH 2 to 51.30% in PRH 7 with six hybrids demonstrating significant superiority. Hb varied between -6.66% in PRH 21 and 29.99% in PRH 16 with only three hybrids exhibiting significant superiority over the better parent. Though all hybrids exhibited positive standard heterosis for this character, the deviation was significant in only eight hybrids. The Hc for harvest index ranged from 12.54% in PRH 27 to 63.08% in PRH 5.

4.2 Genetic analysis of yield components and physiological and biochemical characters

4.2.1 Nature and magnitude of character association

4.2.1.1 Experiment I

Simple correlation coefficients were computed separately for yield components and the physiological and biochemical parameters for the hybrids of

Expt.1 and are presented in Tables 13 and 14. In addition, correlation coefficients were also calculated for the pairs of yield components and the physiological and biochemical parameters and the results are presented in Table 15.

4.2.1.1.1 Yield and yield components

As clear from Table 13, the results of association between pairs of yield components among the hybrids revealed that grain yield was highly correlated with flag leaf area (0.93), length of main panicle (0.95), weight per panicle (0.86), 1000-grain weight (0.86) and biomass yield (0.91). Significant correlation was also obtained with harvest index (0.71). Characters like, number of spikelets in main panicle and spikelet fertility also exhibited high but non-significant positive association with grain yield, as indicated by values of the correlation coefficient of 0.59 and 0.42, respectively. Number of productive tillers however, exhibited non-significant negative correlation with grain yield with the coefficient of -0.54.

Among the yield components themselves, number of productive tillers exhibited a significant and positive association with days to 50% flowering, indicated by a correlation coefficient value of 0.61. However, it exhibited significant and negative association with weight per panicle (-0.65) and spikelet fertility (-0.66). Days to 50% flowering exhibited highly significant negative correlation with total number of spikelets in panicle and spikelet fertility and significant negative correlation with weight per panicle.

Flag leaf area had positive correlation with all other yield components studied, being highly significant with length of main panicle (0.86), weight per panicle (0.82) and biomass yield (0.89). With 1000-grain weight as well, it exhibited significant positive association (0.72). Its association with total number of spikelets in panicle, spikelet fertility and harvest index were also positive though non-significant. In case of panicle length, highly significant correlation was found with weight per panicle

Table 13: Estimates of simple correlation coefficients for yield and yield components in hybrids of Expt. 1

	Characters	1	2	3	4	5	6	7	8	9	10	11
1	Number of productive tillers	1.00										
2	Days to 50% flowering	0.60 *	1.00									
3	Flag leaf area (cm^2)	-0.23	-0.57	1.00								
4	Length of main panicle (cm)	-0.20	-0.50	0.86 **	1.00							
5	Weight per panicle (g)	-0.65 *	-0.69 *	0.82 **	0.84 **	1.00						
6	Total spikelets in main panicle	-0.36	-0.81 **	0.55	0.69 *	0.65 *	1.00					
7	Spikelet fertility (%)	-0.66 *	-0.87 **	0.46	0.30	0.57	0.51	1.00				
8	1000-grain weight (g)	0.17	-0.11	0.72 *	0.75 **	0.56	0.17	0.09	1.00			
9	Biomass yield (g)	-0.27	-0.58	0.89 **	0.95 **	0.85 **	0.75 **	0.39	0.62 *	1.00		
10	Harvest index	0.04	-0.19	0.58	0.52	0.49	0.03	0.25	0.89 **	0.35	1.00	
11	Grain yield (g)	-0.20	-0.54	0.93 **	0.95 **	0.86 **	0.59	0.42	0.86 **	0.91 **	0.71 *	1.00

*, ** = Significant at 5% and 1% levels respectively.

(0.85), 1000-grain weight (0.75) and biomass yield (0.95). Its association with total number of spikelets in panicle was also significantly positive (0.69).

Weight per panicle was found to have highly significant and positive association with biomass yield as indicated by value of the correlation coefficient (0.85), in addition to its significant association with number of spikelets in panicle (0.65). Its correlation with spikelet fertility, 1000-grain weight and harvest index were also positive though non-significant. The character, number of spikelets in panicle, exhibited highly significant relationship with biomass yield (0.75) and non-significant positive association with spikelet fertility (0.51). 1000-grain weight was highly correlated with harvest index (0.89) and grain yield (0.86), in addition to being significantly correlated with biomass yield (0.62). However, the association between biomass yield and harvest index was only moderately positive (0.35) and non-significant.

4.2.1.1.2 Physiological and biochemical characters

In case of correlation among pairs of physiological and biochemical characters in hybrids of Expt. 1 (Table 14), grain yield was found to be highly correlated with leaf area and LAI at flowering (0.92) and LAD in tillering to flowering phase (0.90). It was also significantly associated with α-amylase activity at 48 hrs of germination (0.70) and NRA at flowering (0.65). However, it had inverse and non-significant relationship with LAR in tillering to flowering phase as indicated by the coefficient value of -0.30.

For correlation among the physiological and biochemical parameters themselves, CGR in tillering to flowering phase was not associated significantly with any other parameter. However, its correlation with RGR and NAR in the same growth phase was higher and positive as suggested by the coefficient values of 0.49 and

Table 14: Estimates of simple correlation coefficients for physiological and biochemical parameters in hybrids of Expt. 1

	Characters	1	2	3	4	5	6	7	8	9	10
1	CGR (Tillering - flowering)	1.00									
2	RGR (Tillering - flowering)	0.49	1.00								
3	NAR (Tillering - flowering)	0.55	0.93 **	1.00							
4	Leaf area (Flowering)	-0.06	-0.48	-0.38	1.00						
5	LAR (Tillering - flowering)	0.25	0.61	0.37	-0.63	1.00					
6	LAI (Flowering)	-0.06	-0.48	-0.38	1.00	-0.63	1.00				
7	LAD (Tillering - flowering)	-0.10	-0.49	-0.46	0.94 **	-0.53	0.94 **	1.00			
8	α-Amylase activity (at 48 hrs)	0.13	0.28	0.22	0.47	0.26	0.47	0.36	1.00		
9	NRA (Flowering)	-0.33	-0.37	-0.39	0.67 *	-0.46	0.67 *	0.77 **	0.16	1.00	
10	Grain yield (g)	0.09	-0.21	-0.21	0.92 **	-0.30	0.92 **	0.90 **	0.70 *	0.65 *	1.00

* , ** = Significant at 5% and 1% levels respectively.

0.55. Conversely, it exhibited negative and non-significant correlation with NRA at flowering stage.

RGR at tillering to flowering phase exhibited highly significant association with NAR in the same growth phase (0.93). Its association with LAR in the same phase was quite high and positive (0.61), but non-significant. RGR was found to exert negative non-significant association with leaf area and LAI at flowering (-0.48) and LAD during tillering and flowering (-0.49). However, NAR calculated for tillering to flowering growth phase did not exhibit any significant association with any of the physiological and biochemical traits as well as grain yield.

Leaf area at flowering stage exhibited highly significant correlation with grain yield and also with LAD at tillering to flowering growth phase (0.94). In addition, it was significantly correlated with NRA at flowering (0.68). The LAD in tillering to flowering phase exhibited highly significant correlation (0.77) with NRA at flowering. Interestingly, it was found that, α-amylase activity did not correlate significantly with any of the physiological or biochemical parameters studied.

4.2.1.1.3 Yield components and 'physiological and biochemical characters'

Correlation coefficients were also calculated for the pairs of yield components and the physiological and biochemical parameters in hybrids of Expt. 1 and the results have been presented in Table 15. It is clear from the table that the number of productive tillers was significantly and negatively associated with CGR at tillering to flowering phase (-0.51), while being positively associated with nitrate reductase activity at flowering stage (0.51). Its correlation with RGR, NAR and LAR at tillering to flowering phase was non-significant but negative. The character, days to 50% flowering exhibited negative correlation with most of the physiological characters, but being significant only in case of CGR at tillering to flowering phase (-0.60). Its

Table 15: Estimates of simple correlation coefficients for 'yield components' and 'physiological and biochemical parameters' in hybrids of Expt. 1

Characters	Number of productive tillers	Days to 50% flowering	Flag leaf area	Length of main panicle	Weight per panicle	Total number of spikelets	Spikelet fertility	1000-grain weight	Biomass yield	Harvest index	Grain yield
CGR (Tillering - flowering)	-0.51	**-0.60**	0.02	0.08	0.32	**0.60**	0.52	-0.16	0.10	0.00	0.09
RGR (Tillering - flowering)	-0.21	-0.33	-0.07	-0.41	-0.10	-0.07	0.42	-0.24	-0.38	0.15	-0.21
NAR (Tillering - flowering)	-0.30	-0.38	-0.06	-0.40	-0.02	0.03	0.38	-0.32	-0.30	0.00	-0.21
LAR (Tillering - flowering)	-0.33	-0.06	-0.29	-0.42	-0.15	-0.36	0.39	-0.22	-0.51	0.18	-0.30
LAI (Flowering)	-0.09	-0.39	**0.85**	**0.94**	**0.79**	**0.59**	0.17	**0.77**	**0.94**	0.49	**0.92**
LAD (Tillering - flowering)	0.01	-0.20	**0.82**	**0.93**	**0.72**	0.45	0.04	**0.86**	**0.87**	0.57	**0.90**
α-Amylase activity (at 48 hrs)	-0.52	**-0.72**	**0.72**	0.53	**0.75**	0.33	**0.77**	**0.50**	0.53	**0.65**	**0.70**
NRA (Flowering)	0.51	0.17	0.51	0.56	0.24	0.01	-0.22	**0.90**	0.46	**0.70**	**0.65**
Grain yield	-0.20	-0.54	**0.93**	**0.95**	**0.86**	**0.59**	0.42	**0.86**	**0.91**	**0.71**	1.00

Figures undertlined indicate significance at 5% level, and those in **bold** indicate significance at 1% level.

negative correlation with RGR and NAR at the same phase and LAI at flowering was, however, non-significant and moderate.

Flag leaf area exhibited highly significant and positive association with LAI at flowering and LAD during tillering to flowering phase as indicated by the coefficient values of 0.85 and 0.82. However, it exhibited negative and non-significant association with LAR at tillering to flowering phase (-0.29). The panicle length was highly correlated with LAI at flowering (0.94) and LAD at tillering to flowering (0.93) and significantly associated also with NRA at flowering stage (0.56). The character, average panicle weight, was also found to follow a similar pattern, being highly significantly correlated with LAI and LAD in the respective growth stages. However, its positive correlation with NRA at flowering was non-significant (0.25).

Total number of spikelets in panicle was highly influenced by CGR at tillering to flowering phase (0.60) and LAI at flowering (0.59). Its positive correlation with LAD during tillering to flowering, although high, was non-significant. Spikelet fertility was significantly and positively associated only with CGR at tillering to flowering (0.52), among the various physiological and biochemical parameters. However, its non-significant association with RGR, NAR and LAR at tillering to flowering phase was also positive but moderate.

The character 1000-grain weight exhibited highly significant and positive correlation with the physiological and biochemical attributes such as LAI at flowering (0.77), LAD at tillering to flowering (0.86) and NRA at flowering (0.90). Biomass yield exhibited significant inverse relationship with LAR at flowering to tillering phase as indicated by the value of correlation coefficient of -0.51. However, it exhibited very high and direct correlation with LAI at flowering stage and LAD at tillering to flowering phase as clear from the correlation values of 0.94 and 0.87 respectively. It also exhibited significant positive association with NRA at flowering stage. However, its correlation with CGR at tillering to flowering phase was quite low, although positive.

Finally, harvest index manifested a highly significant and positive relationship with only NRA at flowering stage as indicated by the correlation coefficient value of 0.70, although, it also exhibited significant positive association with LAI at flowering stage (0.49) and LAD at tillering to flowering phase (0.58). Like biomass yield, this character too, exhibited non-significant association of low magnitude with CGR, RGR and NAR at tillering to flowering phase.

4.2.1.2 Experiment II

Simple correlation coefficients among various character pairs computed separately for restorers and hybrids have been presented in Tables 16 and 17 respectively.

4.2.1.2.1 Estimates of correlation coefficients in parents

The results of association between character pairs among the restorer parents (Table 16) revealed that grain yield was highly correlated with number of productive tillers and biomass yield, with coefficients of 0.80 and 0.86 respectively. Characters like length of main panicle and average weight per panicle also exhibited significant correlation with grain yield per plant, with positive coefficients of 0.62 and 0.72 respectively. Total spikelets in the main panicle also exhibited high but non-significant correlation coefficient of 0.55 for its association with grain yield. However, harvest index showed negative but non-significant association with grain yield (-0.28).

Among the yield components themselves, number of productive tillers had a highly significant and positive association with biomass yield, indicated by the correlation coefficient of 0.87. However, with harvest index, the relationship was

Table 16: Estimates of simple correlation coefficients for yield and yield components in restorers of Expt. 2

	Characters	1	2	3	4	5	6	7	8	9	10	11
1	Number of productive tillers	1.00										
2	Days to 50% flowering	-0.02	1.00									
3	Flag leaf area (cm^2)	-0.35	-0.39	1.00								
4	Length of main panicle (cm)	0.57	-0.42	0.51	1.00							
5	Weight per panicle (g)	0.22	-0.09	0.44	0.54	1.00						
6	Total spikelets in main panicle	0.09	0.06	0.40	0.49	0.69 *	1.00					
7	Spikelet fertility (%)	-0.23	-0.12	0.24	0.21	0.33	0.40	1.00				
8	1000-grain weight (g)	-0.17	0.12	0.07	-0.28	0.21	-0.36	-0.38	1.00			
9	Biomass yield (g)	0.87 **	0.28	-0.53	0.30	0.35	0.26	-0.16	-0.11	1.00		
10	Harvest index	-0.61 *	-0.42	0.90 **	0.23	0.33	0.29	0.12	0.30	-0.73 *	1.00	
11	Grain yield (g)	0.79 **	0.03	-0.08	0.62 *	0.72 *	0.55	-0.13	0.11	0.86 **	-0.28	1.00

* , ** = Significant at 5% and 1% levels respectively.

significantly negative (-0.61). The character also exhibited negative but non-significant association with flag leaf area (-0.35), spikelet fertility (-0.23) and 1000-grain weight (-0.17). Days to 50% flowering failed to exhibit any significant association with any of the yield component in either direction. Flag leaf area, however, exhibited a highly significant relationship with harvest index, indicated by a high value of 0.90. It exhibited positive but non-significant association with length of main panicle (0.51), weight per panicle (0.44) and number of total spikelets in main panicle (0.40). However, it exhibited non-significant and negative association with biomass yield, indicated by the coefficient of -0.54.

Like days to 50% flowering, the character length of main panicle did not manifest any significant association with any of the yield components in either direction. However as stated before, it manifested significant association with grain yield. Nevertheless as expected, it exhibited moderate positive association with average panicle weight (0.54). Its association with total number of spikelets in panicle was also considerably high (0.49), although non-significant. However, 1000-grain weight exhibited non-significant and negative association with this character as indicated by the coefficient of -0.28.

The average panicle weight manifested significant and positive association with only number of total spikelets in panicle (0.69). It exhibited relatively moderate but positive association with spikelet fertility (0.33), 1000-grain weight (0.21), biomass yield (0.35) and harvest index (0.33).

Characters like number of total spikelets in main panicle, spikelet fertility, 1000-grain weight and harvest index did not exhibit significant association with any yield component or grain yield. The character, total number of spikelets however exhibited high but non-significant coefficient of 0.55 for its association with grain yield.

Biomass yield exhibited highly significant and positive association with number of productive tillers as indicated by the correlation coefficient of 0.87, in addition to its highly significant positive association with grain yield (0.86). However, it exhibited inverse relationship with harvest index as indicated by the value of -0.73. Harvest index, in turn exhibited significant negative relationship with number of productive tillers (-0.61). However, it had highly significant positive relationship with flag leaf area (0.90). Surprisingly, its association with grain yield was negative, although quite weak as indicated by the value of -0.28.

4.2.1.2.2 Estimates of correlation coefficients in hybrids

The correlation coefficients computed for hybrids for various character pairs are presented in Table 17. The results revealed that in case of the hybrids of Expt. 2, grain yield was correlated only with average weight per panicle and harvest index, with coefficients of 0.64 and 0.67 respectively. Characters like biomass yield (0.54), total number of spikelets in panicle (0.43) and spikelet fertility (0.34) exhibited non-significant but positive correlation with grain yield. However, days to 50% flowering exhibited non-significant negative relationship with grain yield, with the coefficient of -0.37.

Among the yield components, only three significant associations were observed. Days to 50% flowering were found to be negatively and significantly correlated with average panicle weight (-0.61), which in turn was found to be positively and significantly associated with total number of spikelets in panicle (0.66) and spikelet fertility (0.68). As a matter of fact, the character days to 50% flowering also exhibited non-significant and negative relationship with total number of spikelets in panicle (-0.33) and spikelet fertility (-0.56). In addition, the trait also expressed inverse non-significant relationship with harvest index (-0.49) and grain yield (-0.37).

Table 17: Estimates of simple correlation coefficients for yield and yield components in hybrids of Expt. 2

	Characters	1	2	3	4	5	6	7	8	9	10	11
1	Number of productive tillers	1.00										
2	Days to 50% flowering	0.47	1.00									
3	Flag leaf area (cm^2)	0.27	0.52	1.00								
4	Length of main panicle (cm)	0.29	0.35	0.52	1.00							
5	Weight per panicle (g)	-0.55	-0.61 *	0.06	0.36	1.00						
6	Total spikelets in main panicle	-0.08	-0.33	-0.16	0.22	0.66 *	1.00					
7	Spikelet fertility (%)	-0.34	-0.56	0.08	0.37	0.68 *	0.36	1.00				
8	1000-grain weight (g)	-0.09	-0.13	-0.24	0.34	-0.19	-0.10	0.24	1.00			
9	Biomass yield (g)	0.45	0.07	0.54	0.19	0.34	0.33	0.28	-0.58	1.00		
10	Harvest index	-0.22	-0.49	-0.41	-0.18	0.33	0.20	0.12	0.48	-0.35	1.00	
11	Grain yield (g)	0.17	-0.37	0.07	0.19	0.64 *	0.43	0.34	0.25	0.54	0.67 *	1.00

*, ** = Significant at 5% and 1% levels respectively.

Number of productive tillers exhibited a non-significant and positive association with days to 50% flowering (0.47), biomass yield (0.45). However, its correlation with flag leaf area and length of main panicle, although positive was weak, indicated by smaller coefficients of 0.27 and 0.29, respectively. In contrast, with average panicle weight, the relationship was non-significantly negative (-0.55). The character also exhibited moderate negative and non-significant association with spikelet fertility (-0.34) and harvest index (-0.22). Flag leaf area exhibited high but non-significant association with panicle length (0.52) and biomass yield (0.54). It exhibited negative and non-significant association with harvest index (-0.40) and 1000-grain weight (-0.24).

The character, length of main panicle, exhibited moderately positive and non-significant correlations with weight per panicle (0.36), spikelet fertility (0.37) and 1000-grain weight (0.34). Similarly the character, weight per panicle, exhibited non-significant and moderately positive association with biomass yield (0.34) and harvest index (0.33). Number of total spikelets in main panicle also showed moderate correlation with spikelet fertility (0.36) and biomass yield (0.33). 1000-grain weight, on the other hand, exhibited high but non-significant negative correlation with biomass yield (-0.58), in addition to showing moderate positive association (0.48) with harvest index.

4.2.2 Genetic analysis of yield and yield components in F_2 populations

In order to study the pattern and extent of variation for various yield components and grain yield, nine F_2 populations from three AxR, BxR and RxB crosses, involving the CMS lines, PMS 2A, Pusa 5A and IR 58025A, their respective maintainers and the restorers, Pusa 1127, Pusa 1124 and PRR 78, were analyzed. Data were recorded on 200 plants in each of the nine F_2 populations on 16 yield components and grain yield and the range of variation, general mean, coefficients of phenotypic (PCV), genotypic (GCV) and environmental (ECV) variation are presented below crosswise.

Cross I (PMS 2A, PMS 2B and Pusa 1127)

This cross combination involved the CMS line PMS 2A, its maintainer, PMS 2B and the restorer, Pusa 1127. The range of variation, general mean, coefficients of phenotypic (PCV), genotypic (GCV) and environmental (ECV) variation in F_2 populations of this cross combination are presented in Table 18.

Plant height (cm): The range for plant height in AF_2-1 (F_2 of cross PMS 2A x Pusa 1127) was 50.00 cm to 116.00 cm, in BF_2-1 (F_2 of cross PMS 2B x Pusa 1127) it varied from 49.00 cm to 127.00 cm, while it was 58.00 cm to 127.00 cm in RF_2-1 (F_2 of cross Pusa 1127 x PMS 2B). The maximum range for plant height was found in BF_2-1. The mean plant heights of the F_2 populations were 80.62 cm, 82.43 cm and 85.03 cm respectively for AF_2-1, BF_2-1 and RF_2-1. For this character, the coefficient of environmental variation (ECV) was found to be 4.99%. The coefficient of phenotypic variation (PCV) was the maximum in BF_2-1 (20.20%) followed by AF_2-1 (18.31%) and RF_2-1 (17.16%). The GCV also followed similar pattern with BF_2-1 exhibiting maximum genotypic variation of 15.21% followed by AF_2-1 (13.32%) and RF_2-1 (12.17%).

Number of productive tillers: The number of productive tillers in AF_2-1 varied from 5 to 12, in BF_2-1 from 5 to 11, while the maximum range was found in RF_2-1 and was from 4 to 12. The means for number of productive tillers in the F_2 populations were 7.98, 8.41 and 8.32 respectively for AF_2-1, BF_2-1 and RF_2-1. The coefficient of phenotypic variation (PCV) was maximum in AF_2-1 (20.35%) followed by RF_2-1 (19.55%) and BF_2-1 (15.70%). The GCV also followed similar pattern with AF_2-1 exhibiting maximum genotypic variation of 7.24% followed by RF_2-1 (6.44%) and

Table 18: Estimates of range, mean, PCV, ECV and GCV for different characters in F_2 populations of cross involving PMS 2A, PMS 2B and Pusa 1127

Character		AF_2-1	BF_2-1	RF_2-1
Plant height (cm)	Range	50.00 - 116.00	49.00 - 127.00	58.00 - 127.00
	Mean	80.62	82.43	85.03
	PCV	18.31	20.20	17.16
	ECV		**4.99**	
	GCV	13.32	15.21	12.17
Number of productive tillers	Range	5.00 - 12.00	5.00 - 11.00	4.00 - 12.00
	Mean	7.98	8.41	8.32
	PCV	20.35	15.70	19.55
	ECV		**13.11**	
	GCV	7.24	2.59	6.44
Flag leaf area (cm^2)	Range	10.91 - 81.80	11.55 - 88.22	10.91 - 74.67
	Mean	38.53	39.81	40.07
	PCV	35.24	35.78	32.97
	ECV		**10.54**	
	GCV	24.70	25.24	22.43
Length of main panicle (cm)	Range	20.50 - 31.50	18.00 - 31.00	21.00 - 32.50
	Mean	24.01	25.80	25.72
	PCV	9.45	9.71	9.24
	ECV		**5.83**	
	GCV	3.62	3.88	3.41
Weight of main panicle (g)	Range	0.58 - 4.35	0.54 - 4.92	0.85 - 6.69
	Mean	2.17	2.39	2.82
	PCV	31.35	37.98	40.61
	ECV		**17.65**	
	GCV	13.70	20.33	22.96
Weight of all panicles (g)	Range	1.72 - 22.79	1.50 - 21.20	2.66 - 27.91
	Mean	10.34	11.06	11.34
	PCV	37.99	40.82	40.48
	ECV		**18.26**	
	GCV	19.73	22.56	22.22
Weight per panicle (g)	Range	0.36 - 2.85	0.41 - 2.73	0.56 - 3.42
	Mean	1.30	1.32	1.36
	PCV	31.90	37.60	38.52
	ECV		**18.43**	
	GCV	13.47	19.17	20.09
Number of filled spikelets	Range	21.00 - 175.00	25.00 - 227.00	35.00 - 281.00
	Mean	80.61	99.98	117.68
	PCV	38.35	41.02	46.66
	ECV		**12.91**	
	GCV	25.44	28.11	33.75
Number of unfilled spikelets	Range	17.00 - 232.00	10.00 - 152.00	6.00 - 176.00
	Mean	99.22	73.01	84.87
	PCV	37.73	41.31	42.66
	ECV		**18.44**	
	GCV	19.29	22.87	24.22

Table 18 (Cont...)

Character		AF$_2$-1	BF$_2$-1	RF$_2$-1
Total spikelets in main panicle	Range	82.00 - 301.00	101.00 - 299.00	126.00 - 347.00
	Mean	179.83	172.98	202.54
	PCV	23.93	24.02	21.80
	ECV		**11.02**	
	GCV	12.91	13.00	10.78
Panicle density	Range	0.80 - 6.48	1.15 - 8.11	1.40 - 9.62
	Mean	3.36	3.88	4.58
	PCV	33.56	38.14	40.99
	ECV		**12.31**	
	GCV	21.25	25.83	28.68
Spikelet fertility (%)	Range	10.10 - 90.34	22.13 - 93.75	25.16 - 96.69
	Mean	44.82	57.80	58.10
	PCV	31.28	28.23	30.21
	ECV		**12.75**	
	GCV	18.53	15.48	17.46
1000-grain weight (g)	Range	15.34 - 24.02	15.36 - 22.22	14.17 - 24.55
	Mean	18.54	19.01	18.98
	PCV	11.00	8.14	11.39
	ECV		**3.16**	
	GCV	7.84	4.98	8.23
Biomass yield (g)	Range	9.83 - 48.28	9.43 - 48.49	11.03 - 54.87
	Mean	23.55	22.44	28.02
	PCV	32.78	35.13	34.00
	ECV		**15.84**	
	GCV	16.94	19.29	18.16
Grain yield (g)	Range	1.15 - 18.74	1.00 - 20.57	1.67 - 21.97
	Mean	6.85	7.29	8.40
	PCV	40.13	48.20	48.20
	ECV		**16.67**	
	GCV	23.46	31.53	31.53
Straw yield (g)	Range	8.62 - 40.86	8.39 - 27.92	8.73 - 35.96
	Mean	16.70	15.15	19.62
	PCV	32.88	29.09	29.27
	ECV		**20.57**	
	GCV	12.31	8.52	8.70
Harvest index	Range	0.08 - 0.45	0.11 - 0.54	0.13 - 0.55
	Mean	0.29	0.32	0.30
	PCV	28.43	27.37	28.26
	ECV		**15.10**	
	GCV	13.33	12.27	13.16

AF$_2$-1 = F$_2$ of cross PMS 2A x Pusa 1127
BF$_2$-1 = F$_2$ of cross PMS 2B x Pusa 1127
RF$_2$-1 = F$_2$ of cross Pusa 1127 x PMS 2B

PCV = Coefficient of phenotypic variation
ECV = Coefficient of environmental variation, and
GCV = Coefficient of genotypic variation

BF_2-1 (2.59%). For this character, the coefficient of environmental variation (ECV) was higher than plant height and was found to be 13.11%.

Flag leaf area (cm^2): The mean flag leaf area was the highest for RF_2-1 (40.07 cm^2), followed by BF_2-1 (39.81 cm^2) and for AF_2-1 it was the least (38.53 cm^2). In addition, the maximum range for flag leaf area was found in BF_2-1 (11.55 cm^2 to 88.22 cm^2) followed by AF_2-1 (10.91 cm^2 to 81.80 cm^2) and RF_2-1 (10.91 cm^2 to 74.67 cm^2). The PCV and GCV were maximum in BF_2-1 (35.78% and 25.24%) followed by AF_2-1 (35.24% and 24.70%) and RF_2-1 (32.97% to 22.43%). For this character, the ECV was found to be 10.54%.

Length of main panicle (cm): Among the characters studied, this character manifested the least variation in all the three F_2 populations. For this character, BF_2-1 showed the maximum range (18.00 cm to 31.00 cm) followed by RF_2-1 (21.00 cm to 32.50 cm) and AF_2-1 (20.50 cm to 31.50 cm). The mean values for AF_2-1, BF_2-1 and RF_2-1 were 24.01 cm, 25.80 cm and 25.72 cm respectively. The PCV and GCV values were also maximum in BF_2-1 (9.71% and 3.88%), followed by AF_2-1 (9.45% and 3.62%) and RF_2-1 (9.24% and 3.41%). ECV for this character was found to be 5.83%.

Weight of main panicle (g): In AF_2-1 the weight of main panicle varied from 0.58 g to 4.35 g, in BF_2-1 it varied from 0.54 g to 4.92 g, while it ranged from 0.85 g to 6.69 g in RF_2-1. Thus the maximum range for this character was found in BF_2-1. The mean values for the weight of main panicle in the F_2 populations were 2.17 g, 2.39 g and 2.82 g respectively for AF_2-1, BF_2-1 and RF_2-1. For this character, the coefficient of environmental variation was found to be 17.65%. The coefficient of phenotypic variation (PCV) was the maximum in RF_2-1 (40.61%) followed by BF_2-1 (37.98%) and AF_2-1 (31.35%). The GCV also followed similar pattern with RF_2-1 exhibiting maximum genotypic variation of 22.96% followed by BF_2-1 (20.33%) and AF_2-1 (13.70%).

Weight of all panicles (g): The mean for this character was the highest for RF_2-1 (11.34 g), followed by BF_2-1 (11.06 g) and for AF_2-1 it was the least (10.34 g). The maximum range for the weight of all panicles was found in BF_2-1 (1.50 g to 21.20 g) followed by AF_2-1 (1.72 g to 22.79 g) and RF_2-1 (2.66 g to 27.91 g). The PCV and GCV were maximum in BF_2-1 (40.82% and 22.56%) followed by RF_2-1 (40.48% and 22.22%) and AF_2-1 (37.99% to 19.73%). For this character, the ECV was found to be 18.26%.

Weight per panicle (g): For this character, the maximum range was found in AF_2-1, which varied from 0.36 g to 2.85 g. In BF_2-1 the weight per panicle ranged from 0.41 g to 2.73 g, while in RF_2-1 the range was from 0.56 g to 3.42 g. The F_2 means for weight per panicle were 1.30 g, 1.32 g and 1.36 g respectively for AF_2-1, BF_2-1 and RF_2-1. PCV was maximum in RF_2-1 (38.52%) followed by BF_2-1 (37.60%) and AF_2-1 (31.90%). GCV also followed similar pattern with RF_2-1 exhibiting maximum genotypic variation of 20.09% followed by BF_2-1 (19.17%) and AF_2-1 (13.47%). For this character, the coefficient of environmental variation (ECV) was found to be quite high and was of the magnitude of 18.43%.

Number of filled spikelets in main panicle: RF_2-1 recorded the highest mean number of filled spikelets in main panicle (117.68) followed by BF_2-1 (99.98) and AF_2-1 (80.61). Whereas the range for this character was maximum in BF_2-1 (25-227), followed by AF_2-1 (21-175) while RF_2-1 had the lowest range of (35-281). The ECV for this character was 12.91% while the PCV and GCV were maximum in RF_2-1 (46.66% and 33.75%) followed by BF_2-1 (41.02% and 28.11%) and AF_2-1 (38.35% and 25.44%).

<u>Number of unfilled spikelets in main panicle</u>: Of all the characters studied, this character manifested the greatest variation in all the three F_2 populations. For this character too, RF_2-1 exhibited the maximum range (6 to 176) followed by BF_2-1 (10 to 152) and AF_2-1 (17 to 232), with the mean values of 99.22, 73.01 and 84.87 respectively for AF_2-1, BF_2-1 and RF_2-1. The PCV and GCV values also followed similar pattern, being maximum in RF_2-1 (42.66% and 24.22%), followed by BF_2-1 (41.31% and 22.87%) and AF_2-1 (37.73% and 19.29%). ECV for this character was found to be 18.44%.

<u>Total number of spikelets in main panicle</u>: The range for total number of spikelets in AF_2-1 was 82 to 301, in BF_2-1 it varied from 101 to 299, while it was much higher in RF_2-1 and was 126 to 347. However, the maximum range for this character was found in AF_2-1. The F_2 means for this character were 179.83, 172.98 and 202.54 respectively for AF_2-1, BF_2-1 and RF_2-1. PCV was maximum in BF_2-1 (24.02%) followed by AF_2-1 (23.93%) and RF_2-1 (21.80%). GCV also followed similar pattern with BF_2-1 exhibiting maximum variation of 13.00% followed by AF_2-1 (12.91%) and RF_2-1 (10.78%).

<u>Panicle density</u>: The range for panicle density in AF_2-1 varied from 0.80 to 6.48, in BF_2-1 from 1.15 to 8.11, while in RF_2-1 it varied from 1.40 to 9.62. The means for panicle density in the F_2 populations were 3.36, 3.88 and 4.58 respectively for AF_2-1, BF_2-1 and RF_2-1. PCV was maximum in RF_2-1 (40.99%) followed by BF_2-1 (38.14%) and AF_2-1 (33.56%). GCV also followed similar pattern with RF_2-1 exhibiting maximum variation of 28.68% followed by BF_2-1 (25.83%) and AF_2-1 (21.25%). For this character ECV was found to be 12.31%.

<u>Spikelet fertility (%)</u>: The mean for this character was the highest for RF_2-1 (58.10%), followed by BF_2-1 (57.80%) and, for AF_2-1 it was the least (44.82%). However, maximum range for spikelet fertility was found in AF_2-1 (10.10% to 90.34%) followed

by BF_2-1 (22.13% to 93.75%) and RF_2-1 (25.16% to 96.69%). The PCV and GCV were maximum in AF_2-1 (31.28% and 18.53%) followed by RF_2-1 (30.21% and 17.46%) and BF_2-1 (28.23% to 15.48%). For this character ECV was 12.75%.

1000-grain weight (g): For 1000-grain weight RF_2-1 showed maximum range (14.17 g to 24.55 g) followed by AF_2-1 (15.34 g to 24.02 g) and BF_2-1 (15.36 g to 22.22 g), with mean values of 18.98 g, 18.54 g and 19.01 g respectively. The PCV and GCV values also followed similar pattern, being maximum in RF_2-1 (11.39% and 8.23%), followed by AF_2-1 (11.00% and 7.84%) and BF_2-1 (8.14% and 4.98%). Among the F_2 populations of this cross combination, ECV for this character was found to be the lowest 3.16% among all the characters studied.

Biomass yield (g): The range for this character in AF_2-1 was 9.83 g to 48.28 g, in BF_2-1 it varied from 9.43 g to 48.49 g, while the biomass yield varied from 11.03 g to 54.87 g in RF_2-1. The mean values for biomass yield in the F_2 populations were 23.55 g, 22.44 g and 28.02 g respectively for AF_2-1, BF_2-1 and RF_2-1. For this character, the coefficient of environmental variation was found to be 15.84%. The coefficient of phenotypic variation (PCV) was the maximum in BF_2-1 (35.13%) followed by RF_2-1 (34.00%) and AF_2-1 (32.78%). BF_2-1 exhibited maximum genotypic variation of 19.29% followed by RF_2-1 (18.16%) and AF_2-1 (16.94%).

Grain yield (g): The mean grain yield was the highest in RF_2-1 (8.40 g), followed by BF_2-1 (7.29 g) and AF_2-1 (6.85 g). The maximum range for this character was found in BF_2-1 (1.00 g to 20.57 g) followed by AF_2-1 (1.15 g to 18.74 g) and RF_2-1 (1.67 g to 21.97 g). The PCV and GCV values were found to be the same in BF_2-1 and RF_2-1 (48.20% and 31.53%) followed by AF_2-1 (40.13% to 23.46%). For this character, ECV was found to be 16.67%.

Straw yield (g): The RF_2-1 recorded the highest mean straw yield (19.62 g) followed by AF_2-1 (16.70 g) and BF_2-1 (15.15 g), whereas the range for this character was maximum in AF_2-1 (8.62 g to 40.86 g), followed by RF_2-1 (8.73 g to 35.96 g). While BF_2-1 had the lowest range of (8.39 g to 27.92 g). The ECV for this character (20.57%) was found to be the highest among the characters studied in the three F_2 populations of this cross combination. The PCV and GCV values were maximum in AF_2-1 (32.88% and 12.31%) followed by RF_2-1 (29.27% and 8.70%) and BF_2-1 (29.09% and 8.52%).

Harvest index: Maximum range for harvest index was observed in AF_2-1 (0.08 to 0.45) followed by BF_2-1 (0.11 to 0.54) and RF_2-1 (0.13 to 0.55), with the mean values of 0.29, 0.32 and 0.30 respectively. The PCV and GCV values were maximum in AF_2-1 (28.43% and 13.33%), followed by RF_2-1 (28.26% and 13.16%) and BF_2-1 (27.37% and 12.27%). ECV for this character was found to be 15.10%.

Cross II (Pusa 5A, Pusa 5B and Pusa 1124)

This cross combination involved the CMS line Pusa 5A, its maintainer, Pusa 5B and the restorer, Pusa 1124. The range of variation, general mean, coefficients of phenotypic (PCV), genotypic (GCV) and environmental (ECV) variation in F_2 populations of this cross combination are presented in Table 19.

Plant height (cm): Plant height in AF_2-2 (F_2 of cross Pusa 5A x Pusa 1124) varied from 51.00 cm to 117.00 cm; in BF_2-2 (F_2 of cross Pusa 5B x Pusa 1124) it varied from 55.00 cm to 123.00 cm, while it was 58.00 cm to 128.00 cm in RF_2-2 (F_2 of cross Pusa 1124 x Pusa 5B). Thus the maximum range for plant height was observed in AF_2-2. The mean plant heights of the F_2 populations were 88.17 cm, 90.41 cm and 92.84 cm respectively for AF_2-2, BF_2-2 and RF_2-2. For this character, the coefficient of environmental variation was 5.31%. PCV and GCV were maximum in AF_2-2 (16.68% and 11.37%) followed by BF_2-2 (15.71% and 10.40%) and RF_2-2 (15.81% and 10.50%).

Table 19: Estimates of range, mean, PCV, ECV and GCV for different characters in F_2 populations of cross involving Pusa 5A, Pusa 5B and Pusa 1124

Character		AF_2-2	BF_2-2	RF_2-2
Plant height (cm)	Range	51.00 - 117.00	55.00 - 123.00	58.00 - 128.00
	Mean	88.17	90.41	92.84
	PCV	16.68	15.71	15.81
	ECV		**5.31**	
	GCV	11.37	10.40	10.50
Number of productive tillers	Range	3.00 - 12.00	5.00 - 13.00	4.00 - 13.00
	Mean	8.42	8.71	8.84
	PCV	22.40	20.01	21.73
	ECV		**16.24**	
	GCV	6.16	3.77	5.49
Flag leaf area (cm^2)	Range	21.17 - 99.61	17.64 - 93.51	18.45 - 90.95
	Mean	52.12	54.09	52.56
	PCV	29.79	26.32	28.36
	ECV		**9.77**	
	GCV	20.02	16.55	18.59
Length of main panicle (cm)	Range	20.00 - 29.00	21.00 - 31.00	20.50 - 30.50
	Mean	24.90	25.35	25.63
	PCV	7.56	9.49	8.71
	ECV		**5.59**	
	GCV	1.97	3.90	3.12
Weight of main panicle (g)	Range	0.65 - 4.85	0.84 - 4.92	1.85 - 4.99
	Mean	3.19	3.35	3.44
	PCV	21.90	24.50	20.61
	ECV		**15.95**	
	GCV	5.95	8.55	4.66
Weight of all panicles (g)	Range	3.51 - 23.40	5.80 - 24.40	3.47 - 25.94
	Mean	10.07	12.06	11.66
	PCV	38.01	34.21	40.82
	ECV		**19.07**	
	GCV	18.94	15.14	21.75
Weight per panicle (g)	Range	0.48 - 3.55	0.80 - 3.34	0.70 - 3.49
	Mean	1.20	1.39	1.32
	PCV	40.15	34.82	40.69
	ECV		**21.49**	
	GCV	18.66	13.33	19.20
Number of filled spikelets	Range	46.00 - 195.00	50.00 - 222.00	55.00 - 289.00
	Mean	105.58	124.23	137.55
	PCV	29.20	31.60	36.37
	ECV		**11.20**	
	GCV	18.00	20.40	25.17
Number of unfilled spikelets	Range	21.00 - 209.00	13.00 - 155.00	15.00 - 158.00
	Mean	82.77	76.01	67.82
	PCV	43.24	39.68	45.10
	ECV		**18.77**	
	GCV	24.47	20.91	26.33

Table 19 (Cont...)

Character		AF_2-2	BF_2-2	RF_2-2
Total spikelets in main panicle	Range	73.00 - 309.00	98.00 - 327.00	128.00 - 333.00
	Mean	188.35	200.24	205.37
	PCV	22.67	21.18	21.78
	ECV		**7.93**	
	GCV	14.74	13.25	13.85
Panicle Density	Range	1.74 - 7.22	2.21 - 7.82	2.19 - 9.97
	Mean	4.24	4.90	5.37
	PCV	27.03	28.54	34.24
	ECV		**8.91**	
	GCV	18.12	19.63	25.33
Spikelet fertility (%)	Range	15.42 - 87.20	24.29 - 93.09	27.92 - 94.58
	Mean	56.06	62.04	66.98
	PCV	24.73	21.94	21.23
	ECV		**10.36**	
	GCV	14.37	11.58	10.87
1000-grain weight (g)	Range	17.74 - 26.42	17.66 - 24.52	17.47 - 26.13
	Mean	21.84	21.22	21.45
	PCV	9.44	7.43	9.17
	ECV		**3.22**	
	GCV	6.22	4.21	5.95
Biomass yield (g)	Range	19.62 - 49.55	16.45 - 47.55	15.76 - 52.28
	Mean	32.31	32.55	34.40
	PCV	19.87	17.31	20.14
	ECV		**10.97**	
	GCV	8.90	6.34	9.17
Grain yield (g)	Range	2.85 - 21.44	3.33 - 23.07	3.27 - 23.57
	Mean	8.54	9.09	10.60
	PCV	38.68	45.17	44.12
	ECV		**16.25**	
	GCV	22.43	28.92	27.87
Straw yield (g)	Range	13.07 - 38.28	12.82 - 37.47	11.16 - 40.83
	Mean	23.77	23.46	23.80
	PCV	20.19	20.90	21.27
	ECV		**16.87**	
	GCV	3.32	4.03	4.40
Harvest Index	Range	0.12 - 0.57	0.11 - 0.54	0.11 - 0.57
	Mean	0.26	0.28	0.31
	PCV	31.96	34.36	33.10
	ECV		**12.44**	
	GCV	19.52	21.92	20.66

AF_2-2 = F_2 of cross Pusa 5A x Pusa 1124
BF_2-2 = F_2 of cross Pusa 5B x Pusa 1124
RF_2-2 = F_2 of cross Pusa 1124 x PMS 2B

PCV = Coefficient of phenotypic variation
ECV = Coefficient of environmental variation, and
GCV = Coefficient of genotypic variation

Number of productive tillers: The mean numbers of productive tillers in F_2 populations were 8.42, 8.71 and 8.84 for AF_2-2, BF_2-2 and RF_2-2 respectively. The character in AF_2-2 varied from 3 to 12, in BF_2-2 from 5 to 13, while in RF_2-2 it varied from 4 to 13. The coefficient of phenotypic variation (PCV) was maximum in AF_2-2 (22.40%) followed by RF_2-2 (21.73%) and BF_2-2 (20.01%). The GCV also followed similar pattern with AF_2-2 exhibiting maximum variation of 6.16% followed by RF_2-2 (5.49%) and BF_2-2 (3.77%). For this character, the coefficient of environmental variation (ECV) was found to be 16.24%.

Flag leaf area (cm^2): The mean for this character was the highest for BF_2-2 (54.09 cm^2), followed by RF_2-2 (52.56 cm^2) and AF_2-2 (52.12 cm^2). Maximum range for flag leaf area was observed in BF_2-2 (17.64 cm^2 to 93.51 cm^2) followed by RF_2-2 (18.45 cm^2 to 90.95 cm^2) and AF_2-2 (21.17 cm^2 to 99.61 cm^2). The PCV and GCV were maximum in AF_2-2 (29.79% and 20.02%) followed by RF_2-2 (28.36% and 18.59%) and BF_2-2 (26.32% to 16.55%). ECV for this character was found to be 9.77%.

Length of main panicle (cm): For this character RF_2-2 exhibited maximum range (20.50 cm to 30.50 cm) followed by BF_2-2 (21.00 cm to 31.00 cm) and AF_2-2 (20.00 cm to 29.00 cm), with mean values of 25.63 cm, 25.35 cm and 24.90 cm respectively. The PCV and GCV values were maximum in BF_2-2 (9.49% and 3.90%), followed by RF_2-2 (8.71% and 3.12%) and AF_2-2 (7.56% and 1.97%). ECV for this character was 5.59%.

Weight of main panicle (g): The range for this character in AF_2-2 was 0.65 g to 4.85 g, in BF_2-2 it varied from 0.84 g to 4.92 g, while it was 1.85 g to 4.99 g in RF_2-2. Thus the maximum range for this character was found in AF_2-2. The mean values for the weight of main panicle in the F_2 populations were 3.19 g, 3.35 g and 3.44 g. PCV was the maximum in BF_2-2 (24.50%) followed by AF_2-2 (21.90%) and RF_2-2 (20.61%).

GCV also followed similar pattern with BF_2-2 exhibiting maximum variation of 8.55% followed by AF_2-2 (5.95%) and RF_2-2 (4.66%).

<u>Weight of all panicles (g)</u>: The mean for this character was the highest for BF_2-2 (12.06 g), followed by RF_2-2 (11.66 g) and for AF_2-2 it was the least (10.07 g). Maximum range for the weight of all panicles was found in RF_2-2 (3.47 g to 25.94 g) followed by AF_2-2 (3.51 g to 23.40 g). The range was the least in BF_2-2 (5.80 g to 24.40 g). The PCV and GCV were maximum in RF_2-2 (40.82% and 21.75%) followed by AF_2-2 (38.01% and 18.94%) and BF_2-2 (34.21% to 15.14%). For this character, ECV was found to be 19.07%.

<u>Weight per panicle (g)</u>: The weight per panicle in AF_2-2 ranged from 0.48 g to 3.55 g, in BF_2-2 from 0.80 g to 3.34, while in RF_2-2 it varied from 0.70 g to 3.49 g. The maximum range for this character was observed in AF_2-2. The means for weight per panicle in the F_2 populations were 1.20 g, 1.39 g and 1.32 g respectively. PCV and GCV were maximum in RF_2-2 (40.69% and 19.20%) followed by AF_2-2 (40.15% and 18.66%) and BF_2-2 (34.82% and 13.33%). For this character, the coefficient of environmental variation (ECV) was found to be the highest of all the characters studied and was of the magnitude of 21.49%.

<u>Number of filled spikelets in main panicle</u>: The RF_2-2 recorded the highest mean number of filled spikelets in the main panicle (137.55) followed by BF_2-2 (124.23) and AF_2-2 (105.58). Similarly, the range for this character was maximum in RF_2-2 (55-289), followed by BF_2-2 (50-222) and AF_2-2 had the lowest range of (46-195). The ECV for the character was 11.20% while the PCV and GCV were maximum in RF_2-2 (36.37% and 25.17%) followed by BF_2-2 (31.60% and 20.40%) and AF_2-2 (29.20% and 18.00%).

<u>Number of unfilled spikelets in main panicle</u>: Of all the characters studied, this character exhibited the greatest variation in all the three F_2 populations. For this

character BF_2-2 exhibited maximum range (13 to 155) followed by RF_2-2 (15 to 158) and AF_2-2 (21 to 209), with the mean values of 82.77, 76.01 and 67.82 respectively for AF_2-2, BF_2-2 and RF_2-2. The PCV and GCV values were maximum in RF_2-2 (45.10% and 26.33%) followed by AF_2-2 (43.24% and 24.47%) and BF_2-2 (39.68% and 20.91%). ECV for this character was found to be 18.77%.

Total number of spikelets in main panicle: The maximum range for this character was found in AF_2-2 and was 73 to 309, while in BF_2-2 it varied from 98 to 327, whereas it was 128 to 333 in RF_2-2. The F_2 means for this character were 188.35, 200.24 and 205.37 respectively. For this character, the coefficient of environmental variation (ECV) was found to be 7.93%. The coefficient of phenotypic variation (PCV) was the maximum in AF_2-2 (22.67%) followed by RF_2-2 (21.78%) and BF_2-2 (21.18%). GCV followed similar pattern with AF_2-2 exhibiting maximum genotypic variation of 14.74% followed by RF_2-2 (13.85%) and BF_2-2 (13.25%).

Panicle density: Panicle density in AF_2-2 varied from 1.74 to 7.22, in BF_2-2 from 2.21 to 7.82, while in RF_2-2 it varied from 2.19 to 9.97. The means for panicle density in F_2 populations were 4.24, 4.90 and 5.37 respectively for AF_2-2, BF_2-2 and RF_2-2. PCV and GCV values were maximum in RF_2-2 (34.24% and 25.33%) followed by BF_2-2 (28.54% and 19.63%) and AF_2-2 (27.03% and 18.12%). For this character, the coefficient of environmental variation (ECV) was 8.91%.

Spikelet fertility (%): The mean for this character was highest for RF_2-2 (66.98%), followed by BF_2-2 (62.04%) and AF_2-2 (56.06%). However, the maximum range for spikelet fertility was found in AF_2-2 (15.42% to 87.20%) followed by RF_2-2 (27.92% to 94.58%) and BF_2-2 (24.29% to 93.09%). The PCV and GCV were maximum in AF_2-2 (24.73% and 14.37%) followed by BF_2-2 (21.94% and 11.58%) and RF_2-2 (21.23% to 10.87%). ECV for this character was found to be 10.36%.

<u>1000-grain weight (g)</u>: Of all the characters studied, this character exhibited the least variation in all the three F_2 populations. For this character RF_2-2 showed the maximum range (17.47 g to 26.13 g) followed by AF_2-2 (17.74 g to 26.42 g) and BF_2-2 (17.66 g to 24.52 g), with the mean values of 21.45 g, 21.84 g and 21.22 g respectively. The PCV and GCV values also followed similar pattern, being maximum in AF_2-2 (9.44% and 6.22%), followed by RF_2-2 (9.17 and 5.95%) and BF_2-2 (7.43% and 4.21%). ECV for this character was 3.22%.

<u>Biomass yield (g)</u>: In AF_2-2 the biomass yield ranged from 19.62 g to 49.55 g, in BF_2-2 it varied from 16.45 g to 47.55 g, while the maximum range for this character was found in RF_2-2 and was 15.76 g to 52.28 g. The mean values for biomass yield in the F_2 populations were 32.31 g, 32.55 g and 34.40 g respectively for AF_2-2, BF_2-2 and RF_2-2. For this character, the coefficient of environmental variation was found to be 10.97%. The coefficient of phenotypic variation (PCV) was maximum in RF_2-2 (20.14%) followed by AF_2-2 (19.87%) and BF_2-2 (17.31%). GCV followed same pattern with RF_2-2 exhibiting maximum genotypic variation of 9.17% followed by AF_2-2 (8.90%) and BF_2-2 (6.34%).

<u>Grain yield (g)</u>: The mean for this character was the highest for RF_2-2 (10.60 g), followed by BF_2-2 (9.09 g) and for AF_2-2 it was the least (8.54 g). The maximum range for grain yield was observed in AF_2-2 (2.85 g to 21.44 g) followed by RF_2-2 (3.27 g to 23.57 g) and BF_2-2 (3.33 g to 23.07 g). The PCV and GCV were maximum in BF_2-2 (45.17% and 28.92%) followed by RF_2-2 (44.12% and 27.87%) and AF_2-2 (38.68% to 22.43%). For this character, the ECV was found to be 16.25%.

<u>Straw yield (g)</u>: RF_2-2 recorded the highest mean straw yield (23.80 g) followed by AF_2-2 (23.77 g) and BF_2-2 (23.46 g), while the range for this character was maximum in RF_2-2 (11.16 g to 40.83 g), followed by AF_2-2 (13.07 g to 38.28 g) and BF_2-2 (12.82 g to 36.98 g). The ECV for this character was 16.87% while the PCV and GCV

were maximum in RF_2-2 (21.27% and 4.40%) followed by BF_2-2 (20.90% and 4.03%) and AF_2-2 (20.19% and 3.32%).

Harvest index: For this character RF_2-2 showed the maximum range (0.11 to 0.57) followed by BF_2-2 (0.11 to 0.54) and AF_2-2 (0.12 to 0.57), with the mean values of 0.26, 0.28 and 0.31 respectively for AF_2-2, BF_2-2 and RF_2-2. The PCV and GCV values were maximum in BF_2-2 (34.36% and 21.92%), followed by RF_2-2 (33.10% and 20.66%) and AF_2-2 (31.96% and 19.52%). ECV for this character was found to be 12.44%.

Cross III (IR 58025A, IR 58025B and PRR 78)

This cross combination involved the CMS line IR 58025A, its maintainer, IR 58025B and the restorer, PRR 78. The range of variation, general mean, coefficients of phenotypic (PCV), genotypic (GCV) and environmental (ECV) variation in F_2 populations of this cross combination are presented in Table 20.

Plant height (cm): The range for plant height in AF_2-3 (F_2 of cross IR 58025A x PRR 78) was 56.00 cm to 118.00 cm, in BF_2-3 (F_2 of cross IR 58025B x PRR 78) it varied from 58.00 cm to 121.00 cm, while it was 56.00 cm to 121.00 cm in RF_2-3 (F_2 of cross PRR 78 x IR 58025B). The mean plant heights of the F_2 populations were 89.07 cm, 92.68 cm and 92.69 cm respectively. ECV for this character was 4.23%, while PCV and GCV were maximum in BF_2-3 (15.39% and 11.16%) followed by RF_2-3 (13.55% and 9.32%) and RF_2-3 (12.62% and 8.39%).

Number of productive tillers: The number of productive tillers in AF_2-3 varied from 3 to 15 and in BF_2-3 and RF_2-3 from 3 to 16. The means for number of productive tillers in F_2 populations were 7.71, 7.80 and 7.77 respectively for AF_2-3, BF_2-3 and RF_2-3. PCV was maximum in BF_2-3 (36.31%) followed by RF_2-3 (35.93%) and AF_2-3 (32.80%). GCV also followed the pattern with BF_2-3 exhibiting maximum genotypic

Table 20: Estimates of range, mean, PCV, ECV and GCV for different characters in F_2 populations of cross involving IR 58025A, IR 58025B and PRR 78

Character		AF_2-3	BF_2-3	RF_2-3
Plant height (cm)	Range	56.00 - 118.00	58.00 - 121.00	56.00 - 121.00
	Mean	89.07	92.68	92.69
	PCV	12.62	15.39	14.13
	ECV		**4.23**	
	GCV	8.39	11.16	9.90
Number of productive tillers	Range	3.00 - 15.00	3.00 - 16.00	3.00 - 16.00
	Mean	7.71	7.80	7.77
	PCV	32.80	36.31	35.93
	ECV		**14.72**	
	GCV	18.08	21.59	21.21
Flag leaf area (cm^2)	Range	26.07 - 104.10	27.11 - 111.16	29.19 - 105.15
	Mean	61.48	58.77	60.16
	PCV	26.61	30.28	28.78
	ECV		**7.61**	
	GCV	19.00	22.67	21.17
Length of main panicle (cm)	Range	20.50 - 32.50	20.50 - 33.50	20.50 - 33.50
	Mean	27.62	27.84	28.13
	PCV	8.55	8.45	8.32
	ECV		**5.84**	
	GCV	2.71	2.61	2.48
Weight of main panicle (g)	Range	0.66 - 4.99	0.69 - 5.24	0.83 - 5.49
	Mean	2.86	3.00	3.31
	PCV	31.07	30.63	30.02
	ECV		**15.78**	
	GCV	15.29	14.85	14.24
Weight of all panicles (g)	Range	1.26 - 31.28	1.53 - 32.61	2.89 - 33.95
	Mean	13.30	13.72	15.11
	PCV	41.31	40.24	38.37
	ECV		**16.73**	
	GCV	24.58	23.51	21.64
Weight per panicle (g)	Range	0.42 - 3.41	0.51 - 3.45	0.93 - 4.08
	Mean	1.73	1.83	2.03
	PCV	35.94	34.64	33.75
	ECV		**16.88**	
	GCV	19.06	17.76	16.87
Number of filled spikelets	Range	14.00 - 198.00	13.00 - 224.00	19.00 - 224.00
	Mean	102.19	114.64	106.17
	PCV	39.65	36.61	37.31
	ECV		**10.16**	
	GCV	29.49	26.45	27.15
Number of unfilled spikelets	Range	11.00 - 286.00	11.00 - 272.00	11.00 - 277.00
	Mean	91.19	85.73	88.61
	PCV	47.77	41.11	40.48
	ECV		**20.62**	
	GCV	27.15	20.49	19.86

Table 20 (Cont...)

Character		AF_2-3	BF_2-3	RF_2-3
Total spikelets in main panicle	Range	71.00 - 409.00	74.00 - 426.00	104.00 - 424.00
	Mean	193.38	200.37	194.78
	PCV	27.18	30.54	26.77
	ECV		**11.25**	
	GCV	15.93	19.29	15.52
Panicle Density	Range	0.55 - 7.31	0.73 - 7.78	0.62 - 7.43
	Mean	3.70	4.12	3.77
	PCV	35.65	36.15	39.60
	ECV		**12.00**	
	GCV	23.65	24.15	27.60
Spikelet fertility (%)	Range	5.67 - 90.76	20.18 - 91.85	7.69 - 92.90
	Mean	52.84	57.21	54.51
	PCV	33.59	26.79	31.04
	ECV		**10.61**	
	GCV	22.98	16.18	20.43
1000-grain weight (g)	Range	13.19 - 26.80	15.68 - 29.16	14.10 - 27.50
	Mean	20.58	21.40	21.06
	PCV	10.69	11.28	11.18
	ECV		**3.36**	
	GCV	7.33	7.92	7.82
Biomass yield (g)	Range	8.69 - 54.77	11.84 - 59.95	9.90 - 55.59
	Mean	32.33	32.65	35.32
	PCV	28.97	28.72	26.03
	ECV		**11.12**	
	GCV	17.85	17.60	14.91
Grain yield (g)	Range	0.51 - 24.57	1.05 - 27.75	0.69 - 26.52
	Mean	9.58	10.50	10.44
	PCV	45.70	42.48	42.45
	ECV		**13.21**	
	GCV	32.49	29.27	29.24
Straw yield (g)	Range	8.90 - 37.67	9.94 - 38.42	9.43 - 39.42
	Mean	22.75	22.15	24.88
	PCV	25.48	25.57	21.11
	ECV		**14.96**	
	GCV	10.52	10.61	6.15
Harvest Index	Range	0.09 - 0.56	0.08 - 0.63	0.07 - 0.62
	Mean	0.30	0.32	0.30
	PCV	31.90	32.90	35.56
	ECV		**12.11**	
	GCV	19.79	20.79	23.45

AF_2-3 = F_2 of cross IR 58025A x PRR 78
BF_2-3 = F_2 of cross IR 58025B x PRR 78
RF_2-3 = F_2 of cross PRR 78 x IR 58025B

PCV = Coefficient of phenotypic variation
ECV = Coefficient of environmental variation, and
GCV = Coefficient of genotypic variation

variation of 21.59% followed by RF_2-3 (21.21%) and AF_2-3 (18.08%). For this character, the coefficient of environmental variation (ECV) was found to be 14.72%.

Flag leaf area (cm^2): The mean flag leaf area was the highest for AF_2-3 (61.48 cm^2), followed by RF_2-3 (60.16 cm^2) while for BF_2-3 it was the least (58.77 cm^2). However, the maximum range for flag leaf area was exhibited in BF_2-3 (27.11 cm^2 to 111.16 cm^2) followed by AF_2-3 (26.07 cm^2 to 104.10 cm^2) and R2-3 (29.19 cm^2 to 105.15 cm^2). For this character, the PCV and GCV were 26.61% and 19.00% in AF_2-3, 30.28% and 22.67% in BF_2-3 and 28.78% and 21.17% in RF_2-3. For this character, the ECV was 7.61%.

Length of main panicle (cm): Of all the characters studied, this character manifested the least variation in all the three F_2 populations of this cross combination. For this character BF_2-3 and RF_2-3 showed the range of 20.50 cm to 33.50 cm followed by AF_2-3 (20.50 cm to 32.50 cm), with the mean values of 27.62 cm, 27.84 cm and 28.13 cm for AF_2-3, BF_2-3 and RF_2-3 respectively. The PCV and GCV values were maximum in AF_2-3 (8.55% and 2.71%), followed by BF_2-3 (8.45% and 2.61%) and RF_2-3 (8.32% and 2.48%). ECV for this character was found to be 5.84%.

Weight of main panicle (g): The maximum range for this character was observed in AF_2-3 and was 0.66 g to 4.99 g, while in BF_2-3 it varied from 0.69 g to 5.24 g and in RF_2-3 it was 0.83 g to 5.49 g. The mean values for the weight of main panicle in the F_2 populations were 2.86 g, 3.00 g and 3.31 g respectively for AF_2-3, BF_2-3 and RF_2-3. The coefficient of environmental variation for weight of main panicle was 15.78%. For this character, the PCV and GCV values were 31.07% and 15.29% in AF_2-3, 30.63% and 14.85% in BF_2-3 and 30.02% and 14.24% in RF_2-3.

Weight of all panicles (g): The mean for this character was the highest for RF_2-3 (15.11 g), followed by BF_2-3 (13.72 g) and for AF_2-3 (13.30 g). The maximum range for this character was observed in AF_2-3 (1.26 g to 31.28 g) followed by BF_2-3 (1.53 g to 32.61 g) and RF_2-3 (2.89 g to 33.95 g). The PCV and GCV were maximum in AF_2-3 (41.31% and 24.58%) followed by BF_2-3 (40.24% and 23.51%) and RF_2-3 (38.37% and 21.64%). For this character, the ECV was found to be 16.73%.

Weight per panicle (g): The weight per panicle in AF_2-3 varied from 0.42 g to 3.41 g, in BF_2-3 from 0.51 g to 3.45, while in RF_2-3 the range was from 0.93 g to 4.08 g. The maximum range was found in AF_2-3. The means for weight per panicle in the F_2 populations were 1.73 g, 1.83 g and 2.03 g respectively for AF_2-3, BF_2-3 and RF_2-3. The PCV and GCV values were maximum in AF_2-3 (35.94% and 19.06%) followed by BF_2-3 (33.64% and 17.76%) and RF_2-3 (33.75% and 16.87%). For this character ECV was of the magnitude of 16.88%.

Number of filled spikelets in main panicle: BF_2-3 recorded the highest mean number of filled spikelets in the main panicle (114.64) followed by RF_2-3 (106.17) and AF_2-3 (102.19). The range for this character was maximum in BF_2-3 (13-224), followed by AF_2-3 (14-198) while RF_2-3 had the lowest range of (19-224). The ECV for this character was 10.16% while the PCV and GCV were maximum in AF_2-3 (39.65% and 29.49%) followed by RF_2-3 (37.31% and 27.15%) and BF_2-3 (36.61% and 26.45%).

Number of unfilled spikelets in main panicle: Among the characters studied, this character showed the greatest variation in all the three F_2 populations. For this character AF_2-3 exhibited the maximum range (11 to 286) followed by RF_2-3 (11 to 277) and BF_2-3 (11 to 272), with the mean values of 91.19, 85.73 and 88.61 respectively for AF_2-3, BF_2-3 and RF_2-3. The PCV and GCV values ranged from 47.77% and 27.15% in AF_2-3 to 40.48% and 19.86% in RF_2-3. ECV for this character was found to be 20.62%, which was the highest of all the characters studied in this cross combination.

Total number of spikelets in main panicle: AF_2-3 had a minimum of 71 and a maximum of 409 spikelets in the main panicle, being the maximum range among the three F_2 populations. In BF_2-3 the range varied from 74 to 426, while in RF_2-3 it was 104 to 424. The F_2 populations means for this character were 193.38, 200.37 and 194.78 respectively for AF_2-3, BF_2-3 and RF_2-3. For this character ECV was found to be 11.25%, while PCV and GCV were maximum in BF_2-3 (30.54% and 19.29%) followed by AF_2-3 (27.18% and 15.93%) and RF_2-3 (26.77% and 15.52%).

Panicle density: Panicle density in AF_2-3 varied from 0.55 to 7.31, in BF_2-3 from 0.73 to 7.78, while in RF_2-3 it varied from 0.62 to 7.43. The means for panicle density in F_2 populations were 3.70, 4.12 and 3.77 respectively for AF_2-3, BF_2-3 and RF_2-3. The PCV and GCV were maximum in RF_2-3 (39.60% and 27.60%) followed by BF_2-3 (36.15% and 21.15%) and AF_2-3 (35.65% and 23.65%). ECV for this character was found to be 12.00%.

Spikelet fertility (%): The mean for this character was highest for BF_2-3 (57.21%), followed by RF_2-3 (54.51%) and for AF_2-3 (52.84%). However, the maximum range for spikelet fertility was found in AF_2-3 (5.67% to 90.76%) followed by RF_2-3 (7.69% to 92.90%) and BF_2-3 (20.18% to 91.85%). The PCV and GCV also followed the same pattern, being maximum in AF_2-3 (33.59% and 22.98%) followed by RF_2-3 (31.04% and 20.43%) and BF_2-3 (26.79% and 16.18%). For this character, the ECV was found to be 10.61%.

1000-grain weight (g): For this character AF_2-3 manifested the maximum range (13.19 g to 26.80 g) followed by RF_2-3 (14.10 g to 27.50 g) and BF_2-3 (15.68 g to 29.16 g). While the mean values for AF_2-3, BF_2-3 and RF_2-3 were 20.58 g, 21.40 g and 21.06 g respectively. The PCV and GCV values were maximum in BF_2-3 (11.28 and 7.92%), followed by RF_2-3 (11.18% and 7.82%) and AF_2-3 (10.69% and 7.33%). ECV for this character was found to be 3.36%, which was the lowest among the characters studied.

Biomass yield (g): The range for this character in AF_2-3 was 8.69 g to 54.77 g, in BF_2-3 it varied from 11.84 g to 59.95 g. While in RF_2-3 the range varied from 9.90 g to 55.59 g in RF_2-3. The mean values for biomass yield in the F_2 populations were 32.33 g, 32.65 g and 35.32 g respectively for AF_2-3, BF_2-3 and RF_2-3. For this character, the coefficient of environmental variation was 11.12%, while the PCV and GCV values were maximum in AF_2-3 (28.97% and 17.85%) followed by BF_2-3 (28.72% and 17.60%) and RF_2-3 (26.03% and 14.91%).

Grain yield (g): The mean grain yield was highest in BF_2-3 (10.50 g), followed by RF_2-3 (10.44 g) and AF_2-3 (9.58 g). The maximum range for grain yield was found in AF_2-3 (0.91 g to 24.57 g) followed by RF_2-3 (0.69 g to 26.52 g) and BF_2-3 (1.05 g to 27.75 g). The PCV and GCV were maximum in AF_2-3 (45.70% and 32.49%) followed by BF_2-3 (42.48% and 29.27%) and RF_2-3 (42.45% to 29.24%). ECV for this character was found to be 13.21%.

Straw yield (g): RF_2-3 recorded the highest mean straw yield of 24.88 g followed by AF_2-3 (22.75 g) and BF_2-3 (22.15 g), while the range for this character was maximum in AF_2-3 (8.90 g to 37.67 g), followed by RF_2-3 (9.43 g to 39.42 g). BF_2-3 had the lowest range of 9.94 g to 38.42 g. The ECV for this character was 14.96% while the PCV and GCV were maximum in BF_2-3 (25.57% and 10.61%) followed by AF_2-3 (25.48% and 10.52%) and RF_2-3 (21.11% and 6.15%).

Harvest index: For this character RF_2-3 showed the maximum range (0.07 to 0.62) followed by BF_2-3 (0.08 to 0.63) and AF_2-3 (0.09 to 0.56), with the mean values of 0.30, 0.32 and 0.30 respectively for AF_2-3, BF_2-3 and RF_2-3. The PCV and GCV values also followed the same pattern and were maximum in RF_2-3 (35.56% and 23.45%), followed by BF_2-3 (32.90% and 20.79%) and AF_2-3 (31.90% and 19.79%). ECV for this character was found to be 12.11%.

4.2.2.1 Frequency distributions for yield components and grain yield

Frequency distributions were worked out for all the characters to ascertain the pattern of variation in the nine F_2 populations. The distributions were plotted for the F_2 populations separately for twelve representative characters *viz.* i) plant height, ii) number of productive tillers, iii) flag leaf area, iv) weight of main panicle, v) weight per panicle, vi) biomass production, vii) total number of spikelets in the main panicle, viii) spikelet fertility, ix) 1000-grain weight, x) grain yield, xi) straw yield and xii) harvest index and are presented in figures 4a through 6c. Vertical lines depicting means of the parents, respective F_1 and the F_2 were drawn on the graphs for comparison. All the distributions were subjected to goodness-of-fit test for normal distribution (One sample Kolmogorov-Smirnov test, "KS test") and the results are presented in Tables 21, 22 and 23. Percentages of transgressive segregants obtained for each character in desirable direction were also calculated and are presented in Table 24. The F_2 populations were designated as AF_2 (F_2 of cross AxR), BF_2 (F_2 of cross BxR) and RF_2 (F_2 of cross RxB). The results are presented below.

4.2.2.1.1 One sample Kolmogorov-Smirnov test for normal distribution (KS test)

As clear from the figures of F_2 distributions for various characters (figures 4a through 6c) and also from the Kolmogorov-Smirnov Z values (Tables 21, 22 and 23), most of the characters followed normal distribution in all the nine F_2 populations, indicating that the inheritance was polygenic for those characters. However, some characters like, number of productive tillers, flag leaf area, weight per panicle, biomass yield and grain yield in AF_2-1, number of productive tillers, grain yield and harvest index in RF_2-1 followed a distribution that significantly deviated from normal at 5% probability level, while following the normal curve at 1% level. Similar distributions were observed in case of number of productive tillers and grain yield in AF_2-2, weight of all panicles and grain yield in BF_2-2, number of unfilled spikelets in

Table 21: Kolmogorov-Smirnov test for normal distribution in F_2 populations of cross involving PMS 2A, PMS 2B and Pusa 1127

Characters	AF_2-1 (PMS 2A x Pusa 1127)				BF_2-1 (PMS 2B x Pusa 1127)				RF_2-1 (Pusa 1127 x PMS 2B)			
	Mean	SD	Kolmogorov-Smirnov Z	Prob.	Mean	SD	Kolmogorov-Smirnov Z	Prob.	Mean	SD	Kolmogorov-Smirnov Z	Prob.
Plant height (cm)	80.62	14.76	0.76	0.61	82.43	16.65	0.59	0.88	85.03	14.59	0.62	0.84
Number of productive tillers	7.98	1.62	1.61 *	0.01	8.41	1.32	3.10 **	0.00	8.32	1.63	1.61 *	0.01
Flag leaf area (cm^2)	38.53	13.58	1.55 *	0.02	39.81	14.24	1.24	0.10	40.07	13.21	1.16	0.14
Length of main panicle (cm)	24.01	2.27	0.92	0.37	25.80	2.51	0.97	0.31	25.72	2.38	1.09	0.19
Weight of main panicle (g)	2.17	0.68	1.10	0.18	2.39	0.91	0.85	0.46	2.82	1.15	1.02	0.25
Weight of all panicles (g)	10.34	3.93	1.07	0.20	11.06	4.52	1.36	0.05	11.34	4.59	0.98	0.29
Weight per panicle (g)	1.30	0.41	1.41 *	0.04	1.32	0.49	0.97	0.30	1.36	0.53	0.95	0.32
Number of filled spikelets	80.61	30.91	0.98	0.29	99.98	41.01	0.93	0.36	117.68	54.91	1.17	0.13
Number of unfilled spikelets	99.22	37.43	1.09	0.19	73.01	30.16	0.81	0.54	84.87	36.20	1.33	0.06
Total spikelets in main panicle	179.83	43.03	0.63	0.82	172.98	41.54	0.78	0.58	202.54	44.15	0.90	0.39
Panicle density	3.36	1.13	0.80	0.55	3.88	1.48	0.92	0.37	4.58	1.88	1.34	0.06
Spikelet fertility (%)	44.82	14.02	0.84	0.48	57.80	16.31	0.64	0.80	58.10	17.55	0.82	0.52
1000-grain weight (g)	18.54	2.04	0.63	0.83	19.01	1.55	0.61	0.86	18.98	2.16	0.61	0.85
Biomass yield (g)	23.55	7.72	1.61 *	0.01	22.44	7.88	1.05	0.22	28.02	9.53	0.99	0.29
Grain yield (g)	6.85	2.75	1.56 *	0.02	7.29	3.51	1.34	0.06	8.40	4.05	1.41 *	0.04
Straw yield (g)	16.70	5.49	1.30	0.07	15.15	4.41	0.79	0.56	19.62	5.74	0.89	0.41
Harvest index	0.29	0.08	0.93	0.35	0.32	0.09	0.68	0.75	0.30	0.08	1.42 *	0.04

* Deviation from normal distribution is significant at 5% probability level.

** Deviation from normal distribution is significant at 1% probability level, i.e., the distribution is NOT normal.

Table 22: Kolmogorov-Smirnov test for normal distribution in F_2 populations of cross involving Pusa 5A, Pusa 5B and Pusa 1124

Characters	AF_2-2 (Pusa 5A x Pusa 1124)				BF_2-2 (Pusa 5B x Pusa 1124)				RF_2-2 (Pusa 1124 x Pusa 5B)			
	Mean	SD	Kolmogorov-Smirnov Z	Prob.	Mean	SD	Kolmogorov-Smirnov Z	Prob.	Mean	SD	Kolmogorov-Smirnov Z	Prob.
Plant height (cm)	88.17	14.71	1.01	0.26	90.41	14.21	0.89	0.41	92.84	14.68	1.29	0.07
Number of productive tillers	8.42	1.89	1.47 *	0.03	8.71	1.74	0.92	0.37	8.84	1.92	1.35	0.05
Flag leaf area (cm^2)	52.12	15.53	0.97	0.31	54.09	14.24	0.87	0.44	52.56	14.91	1.05	0.22
Length of main panicle (cm)	24.90	1.88	1.12	0.16	25.35	2.40	1.04	0.23	25.63	2.23	1.04	0.23
Weight of main panicle (g)	3.19	0.70	1.31	0.07	3.35	0.82	0.60	0.86	3.44	0.71	0.48	0.98
Weight of all panicles (g)	10.07	3.83	1.10	0.18	12.06	4.13	1.55 *	0.02	11.66	4.76	1.35	0.05
Weight per panicle (g)	1.20	0.48	1.21	0.11	1.39	0.48	1.25	0.09	1.32	0.54	1.24	0.09
Number of filled spikelets	105.58	30.83	0.97	0.31	124.23	39.25	0.80	0.54	137.55	50.03	1.32	0.06
Number of unfilled spikelets	82.77	35.79	1.11	0.17	76.01	30.16	0.81	0.54	67.82	30.59	1.56 *	0.02
Total spikelets in main panicle	188.35	42.70	0.58	0.89	200.24	42.41	0.63	0.83	205.37	44.73	1.04	0.23
Panicle density	4.24	1.15	0.75	0.64	4.90	1.40	0.85	0.46	5.37	1.84	1.27	0.08
Spikelet fertility (%)	56.06	13.86	0.87	0.44	62.04	13.61	0.50	0.96	66.98	14.22	0.68	0.74
1000-grain weight (g)	21.84	2.06	0.84	0.48	21.22	1.58	0.68	0.74	21.45	1.97	0.54	0.93
Biomass yield (g)	32.31	6.42	1.04	0.23	32.55	5.63	0.53	0.94	34.40	6.93	0.92	0.37
Grain yield (g)	8.54	3.31	1.56 *	0.02	9.09	4.11	1.42 *	0.04	10.60	4.68	1.20	0.11
Straw yield (g)	23.77	4.80	0.64	0.81	23.46	4.90	0.51	0.96	23.80	5.06	0.57	0.90
Harvest index	0.26	0.08	1.25	0.09	0.28	0.10	1.30	0.07	0.31	0.10	1.09	0.19

* Deviation from normal distribution is significant at 5% probability level.
** Deviation from normal distribution is significant at 1% probability level, i.e., the distribution is NOT normal.

Table 23: Kolmogorov-Smirnov test for normal distribution in F_2 populations of cross involving IR 58025A, IR 58025B and PRR 78

Characters	AF_2-3 (IR 58025A x PRR 78)				BF_2-3 (IR 58025B x PRR 78)				RF_2-3 (PRR 78 x IR 58025B)			
	Mean	SD	Kolmogorov-Smirnov Z	Prob.	Mean	SD	Kolmogorov-Smirnov Z	Prob.	Mean	SD	Kolmogorov-Smirnov Z	Prob.
Plant height (cm)	89.07	11.24	1.10	0.18	92.68	14.26	0.76	0.61	92.69	13.10	1.39 *	0.04
Number of productive tillers	7.71	2.53	1.24	0.10	7.80	2.83	1.35	0.05	7.77	2.79	1.21	0.11
Flag leaf area (cm^2)	61.48	16.36	1.21	0.11	58.77	17.80	1.39 *	0.04	60.16	17.31	1.09	0.19
Length of main panicle (cm)	27.62	2.36	1.19	0.12	27.84	2.35	1.32	0.06	28.13	2.34	1.39 *	0.04
Weight of main panicle (g)	2.86	0.89	0.56	0.91	3.00	0.92	0.62	0.84	3.31	0.99	0.46	0.99
Weight of all panicles (g)	13.30	5.49	0.83	0.49	13.72	5.52	0.83	0.49	15.11	5.80	1.03	0.24
Weight per panicle (g)	1.73	0.62	0.64	0.80	1.83	0.63	0.83	0.49	2.03	0.69	0.85	0.47
Number of filled spikelets	102.19	40.52	0.57	0.90	114.64	41.96	0.93	0.35	106.17	39.61	0.61	0.85
Number of unfilled spikelets	91.19	43.56	1.46 *	0.03	85.73	35.24	2.14 **	0.00	88.61	35.87	2.33 **	0.00
Total spikelets in main panicle	193.38	52.56	0.88	0.42	200.37	61.18	1.16	0.13	194.78	52.14	1.01	0.26
Panicle density	3.70	1.32	1.21	0.11	4.12	1.49	0.67	0.77	3.77	1.49	1.02	0.26
Spikelet fertility (%)	52.84	17.75	0.61	0.85	57.21	15.33	1.01	0.26	54.51	16.92	0.73	0.66
1000-grain weight (g)	20.58	2.20	0.49	0.97	21.40	2.41	0.53	0.94	21.06	2.36	0.76	0.61
Biomass yield (g)	32.33	9.36	0.55	0.92	32.65	9.38	0.84	0.48	35.32	9.19	0.64	0.80
Grain yield (g)	9.58	4.38	0.93	0.36	10.50	4.46	0.93	0.35	10.44	4.43	0.75	0.62
Straw yield (g)	22.75	5.80	0.71	0.69	22.15	5.66	0.97	0.31	24.88	5.25	0.70	0.72
Harvest index	0.30	0.09	0.84	0.48	0.32	0.11	0.80	0.54	0.30	0.11	0.97	0.30

* Deviation from normal distribution is significant at 5% probability level.

** Deviation from normal distribution is significant at 1% probability level, i.e., the distribution is NOT normal.

Fig 4a: AF_2-1 distributions for various characters

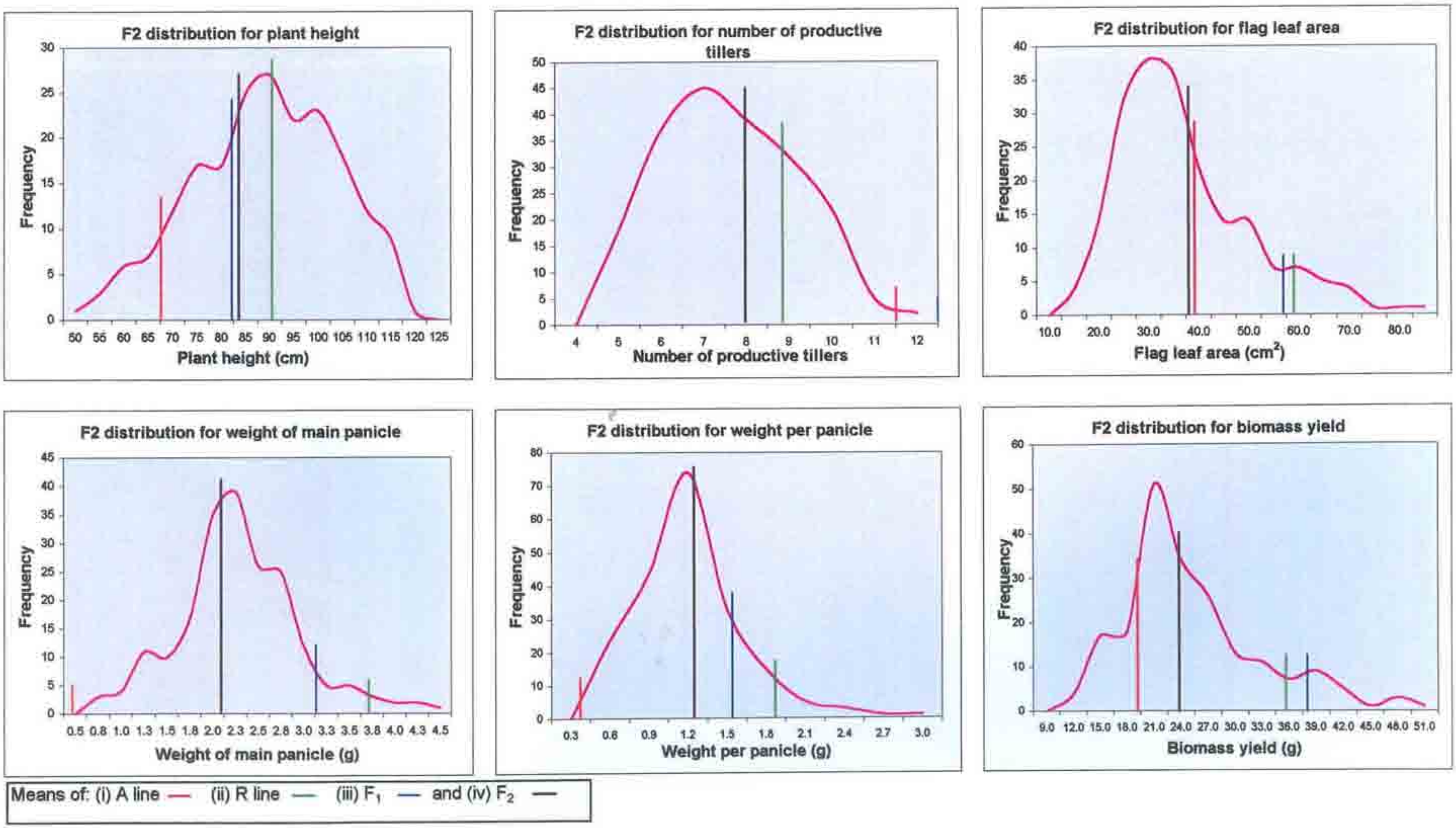
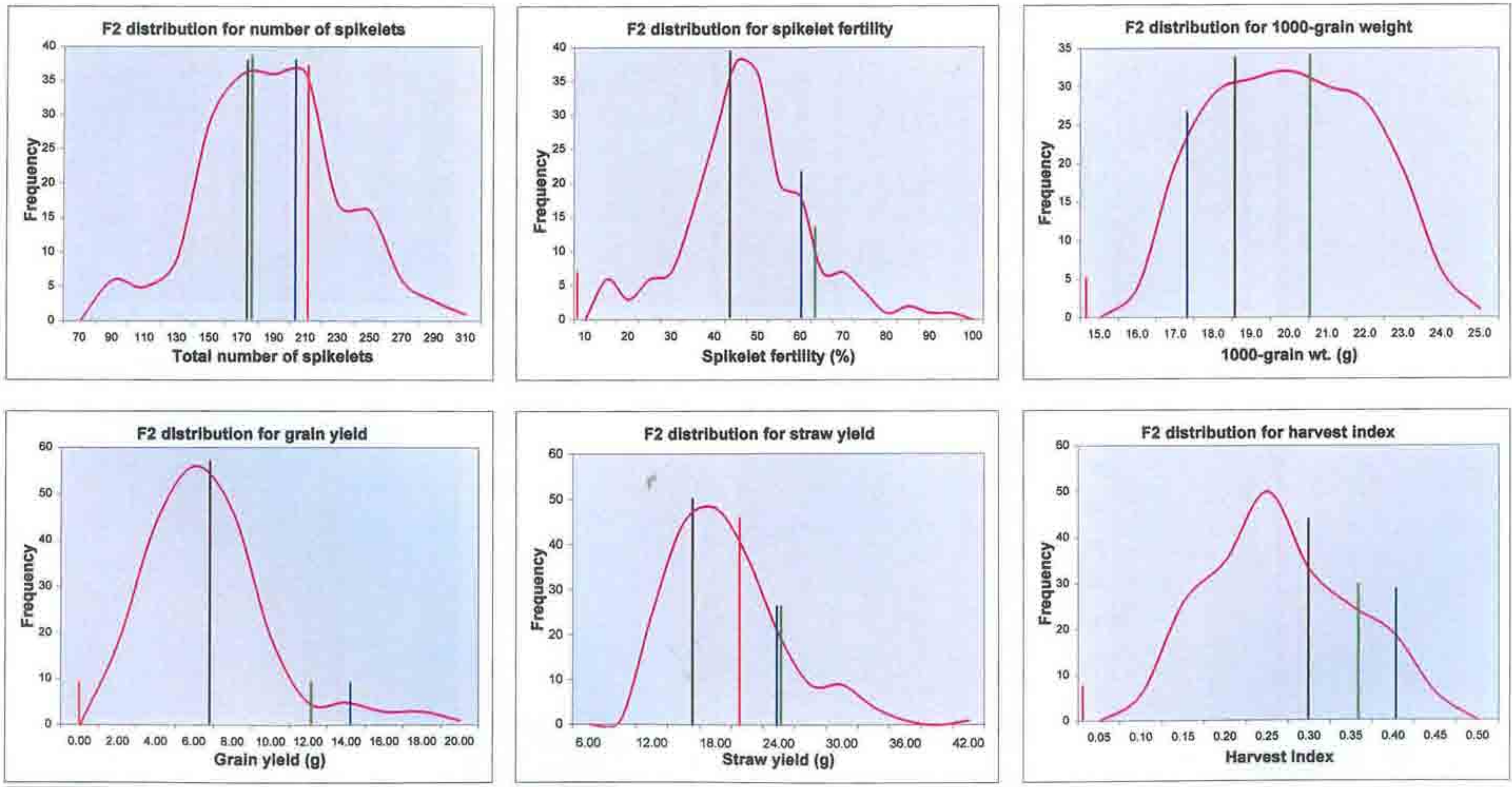
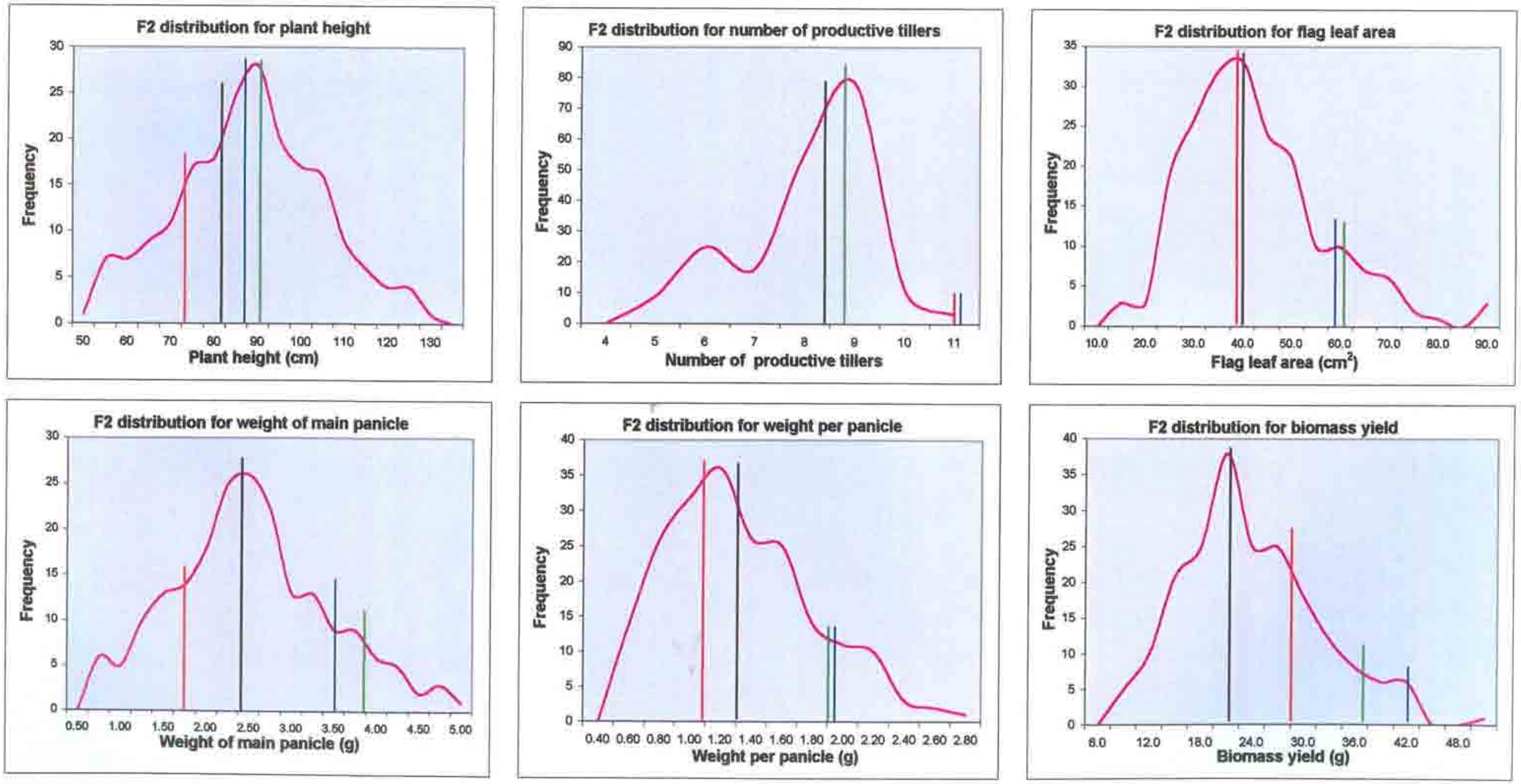


Fig 4a: AF_2-1 distributions for various characters (Cont ...)



Means of: (i) A line — (ii) R line — (iii) F_1 — and (iv) F_2 —

Fig 4b: BF_2-1 frequency distributions for various characters



Means of: (i) B line — (ii) R line— (iii) F_1— and (iv) F_2—

Fig 4b: BF_2-1 frequency distributions for various characters (Cont...)

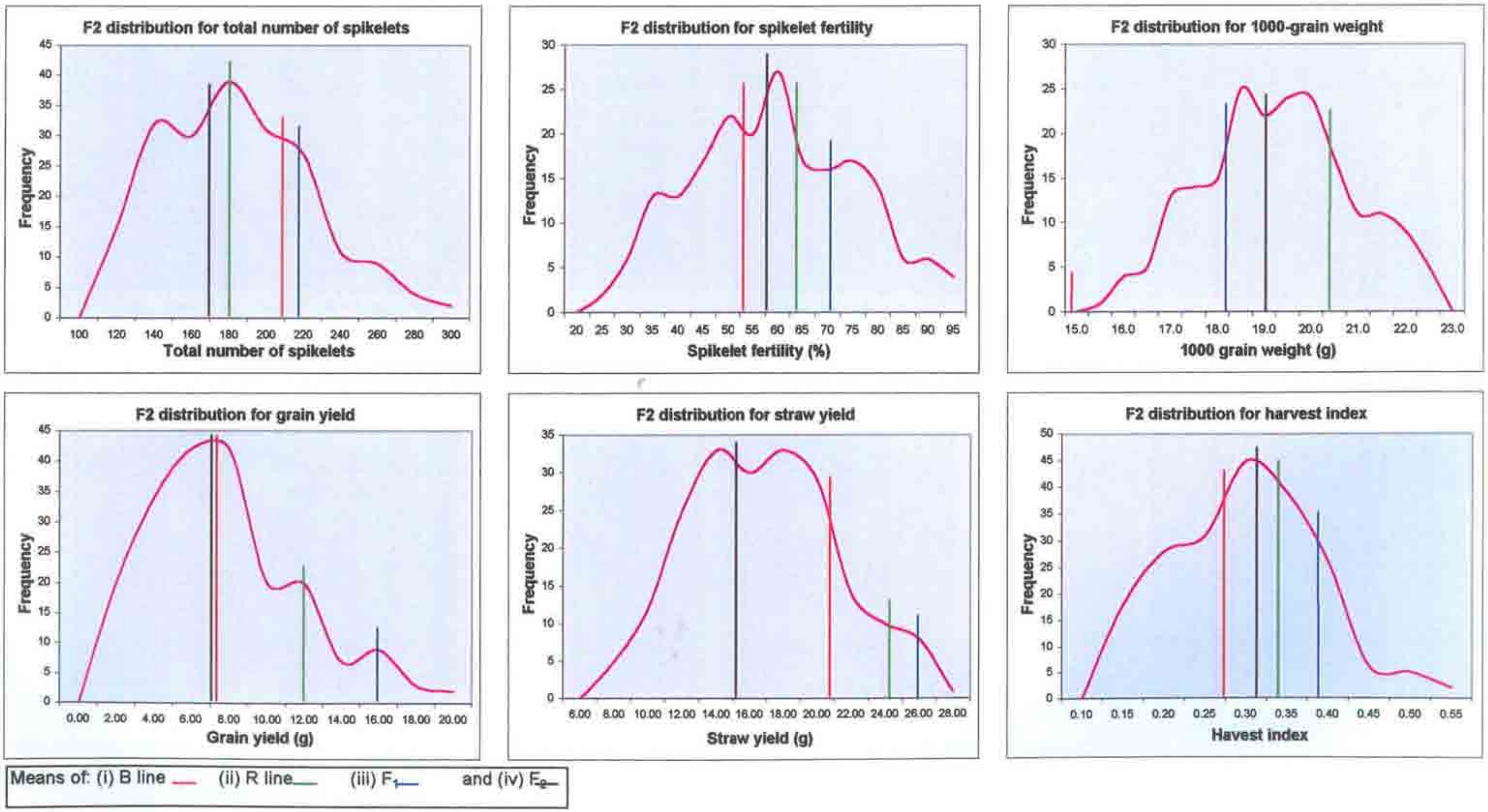
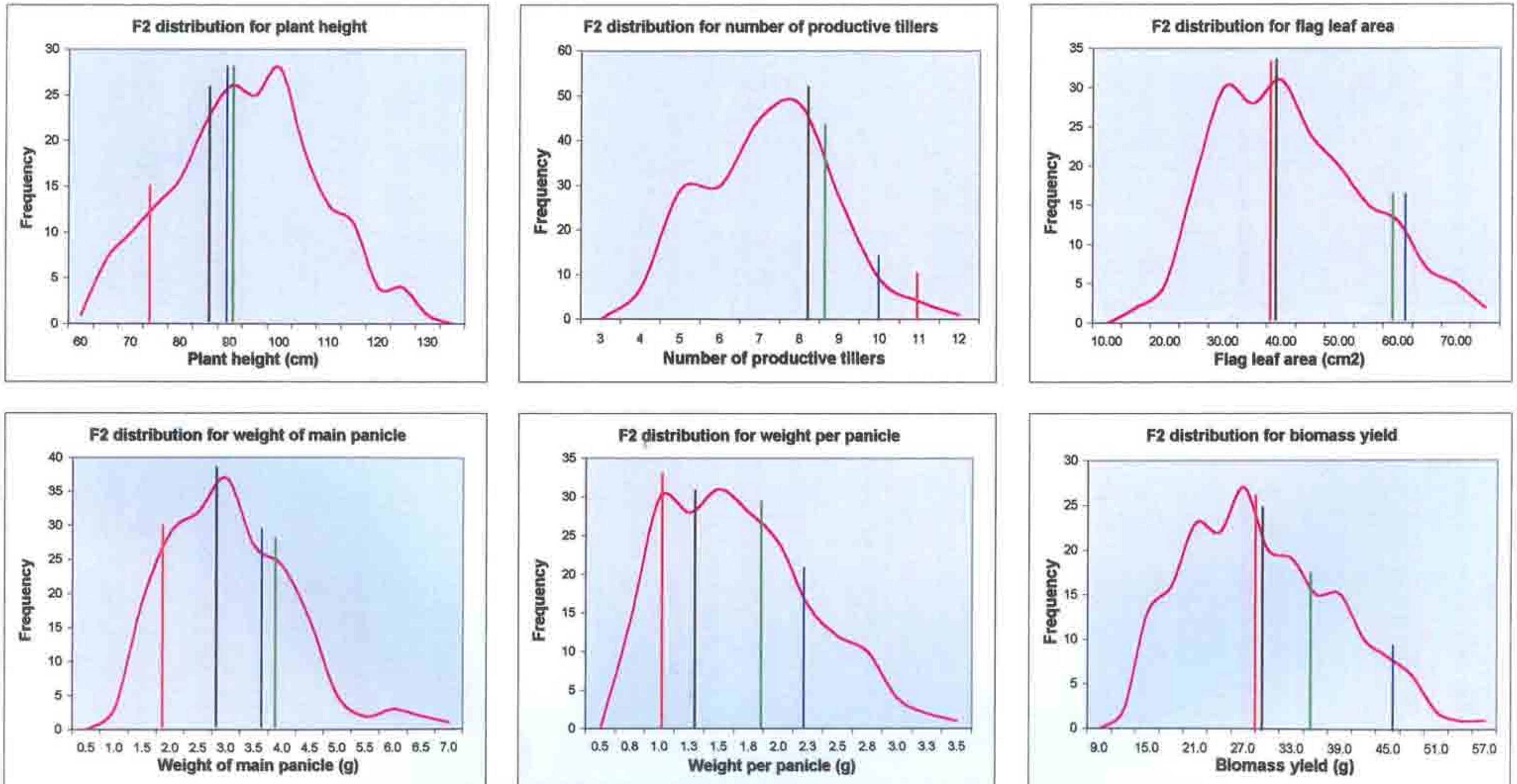
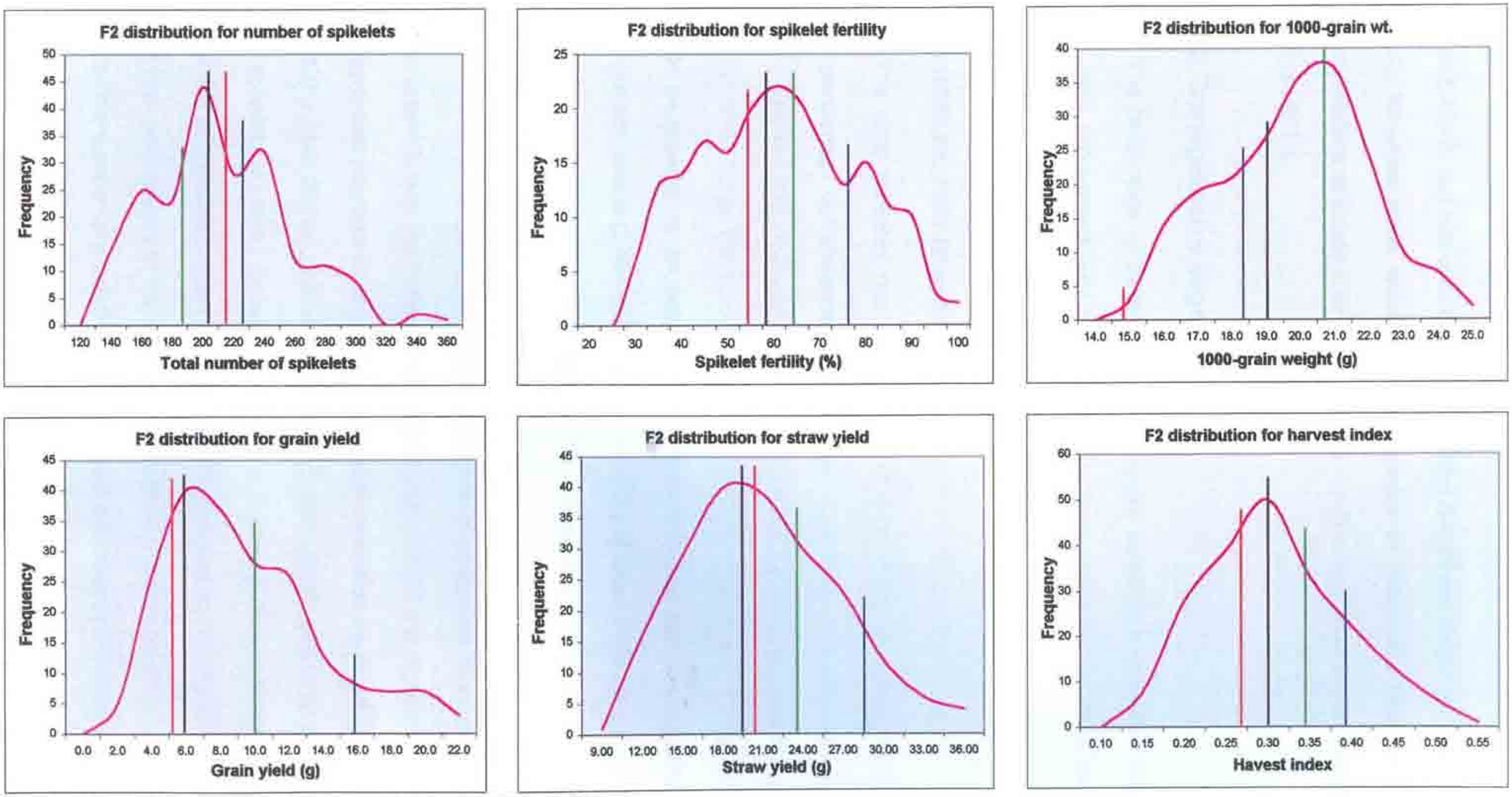


Fig 4c: RF_2-1 frequency distributions for various characters



Means of: (i) B line — (ii) R line — (iii) F_1 — and (iv) F_2 —

Fig 4c: RF_2-1 frequency distributions for various characters (Cont...)



Means of: (i) B line (ii) R line (iii) E_1 and (iv) E_2

RF_2-2 and AF_2-3, flag leaf area in BF_2-3 and plant height and length of main panicle in RF_2-3. Whereas some characters like, number of productive tillers in BF_2-1, number of unfilled spikelets in BF_2-3 and RF_2-3 significantly deviated from the normal curve even at 1%.

4.2.2.2 Transgressive segregation

The percentage of transgressive segregants obtained in desirable direction for the yield components and grain yield have been presented in Table 24. The results are described here crosswise.

Cross I (PMS 2A, PMS 2B and Pusa 1127)

The table indicates that in AF_2-1 (F_2 of cross PMS 2A x Pusa 1127), the highest percentage of transgressive segregants in desirable direction was obtained for straw yield (54.50%) followed by length of main panicle (38.00%) and 1000-grain weight (31.50%). While the number of productive tillers showed only 1.00% of the F_2 plants to be superior to the better parent, followed by flag leaf area (1.50%) and weight of main panicle (2.50%). In case of BF_2-1 (F_2 of cross PMS 2B x Pusa 1127) as well, straw yield exhibited the highest percentage of transgressive segregants (56.50%) in desirable direction followed by number of unfilled spikelets (37.00%) and length of main panicle (34.50%), while the number of productive tillers did not show any transgression over the better parent. Straw yield showed the highest percentage of transgressive segregants (47.00%) in desirable direction in RF_2-1 (F_2 of cross Pusa 1127 x PMS 2B) too, followed by length of main panicle (46.50%) and number of filled spikelets (43.50%). Some characters like number of filled spikelets (43.50%), total number of spikelets in main panicle (41.00%), spikelet fertility (39.50%) etc. also showed high percentages of transgressive segregants in desirable direction in RF_2-1. Whereas, the number of productive tillers showed the lowest percentage (0.50%) of

Table 24: Percentage of transgressive segregants in desirable direction in F_2 populations of the three cross combinations

Characters	AF_2-1	BF_2-1	RF_2-1	AF_2-2	BF_2-2	RF_2-2	AF_2-3	BF_2-3	RF_2-3
Plant height (cm)	12.50	26.00	14.00	13.00	20.50	15.50	20.50	24.00	18.50
Number of productive tillers	1.00	0.00	0.50	0.00	2.00	2.00	10.50	18.50	18.50
Flag leaf area (cm^2)	1.50	9.50	7.00	30.50	33.50	31.50	41.50	33.50	37.00
Length of main panicle (cm)	38.00	34.50	46.50	19.50	28.00	30.00	21.50	33.50	36.00
Weight of main panicle (g)	2.50	7.50	18.50	7.50	11.00	18.00	12.00	14.00	22.50
Weight of all panicles (g)	4.00	8.00	17.50	0.50	1.50	3.50	12.50	12.50	16.00
Weight per panicle (g)	4.50	10.50	28.00	17.50	19.00	23.50	10.50	10.00	30.50
Number of filled spikelets	12.00	33.00	43.50	19.50	42.00	55.00	27.00	33.50	32.50
Number of unfilled spikelets	13.50	37.00	30.00	19.50	30.00	45.50	33.50	32.50	34.50
Total spikelets in main panicle	19.00	19.00	41.00	50.00	54.00	56.00	40.00	53.00	56.50
Panicle density	12.50	19.00	25.50	24.00	47.50	54.50	22.00	35.50	68.50
Spikelet fertility (%)	8.50	32.50	39.50	15.00	24.00	22.00	22.00	27.00	25.00
1000-grain weight (g)	31.50	16.00	26.00	32.00	18.00	26.50	2.00	7.00	4.50
Biomass yield (g)	9.50	6.50	20.00	0.00	0.00	2.00	11.50	27.00	17.00
Grain yield (g)	6.00	11.00	18.50	2.50	4.50	9.00	16.00	14.00	15.50
Straw yield (g)	54.50	56.50	47.00	45.00	50.00	50.50	44.00	35.50	26.50
Harvest index	15.00	23.00	24.50	7.00	17.00	22.00	24.50	29.50	35.00

AF_2-1 = F_2 of cross PMS 2A x Pusa 1127
BF_2-1 = F_2 of cross PMS 2B x Pusa 1127
RF_2-1 = F_2 of cross Pusa 1127 x PMS 2B

AF_2-2 = F_2 of cross Pusa 5A x Pusa 1124
BF_2-2 = F_2 of cross Pusa 5B x Pusa 1124
RF_2-2 = F_2 of cross Pusa 1124 x PMS 2B

AF_2-3 = F_2 of cross IR 58025A x PRR 78
BF_2-3 = F_2 of cross IR 58025B x PRR 78
RF_2-3 = F_2 of cross PRR 78 x IR 58025B

transgressive segregants, followed by flag leaf area (7.00%) and plant height (14.00%).

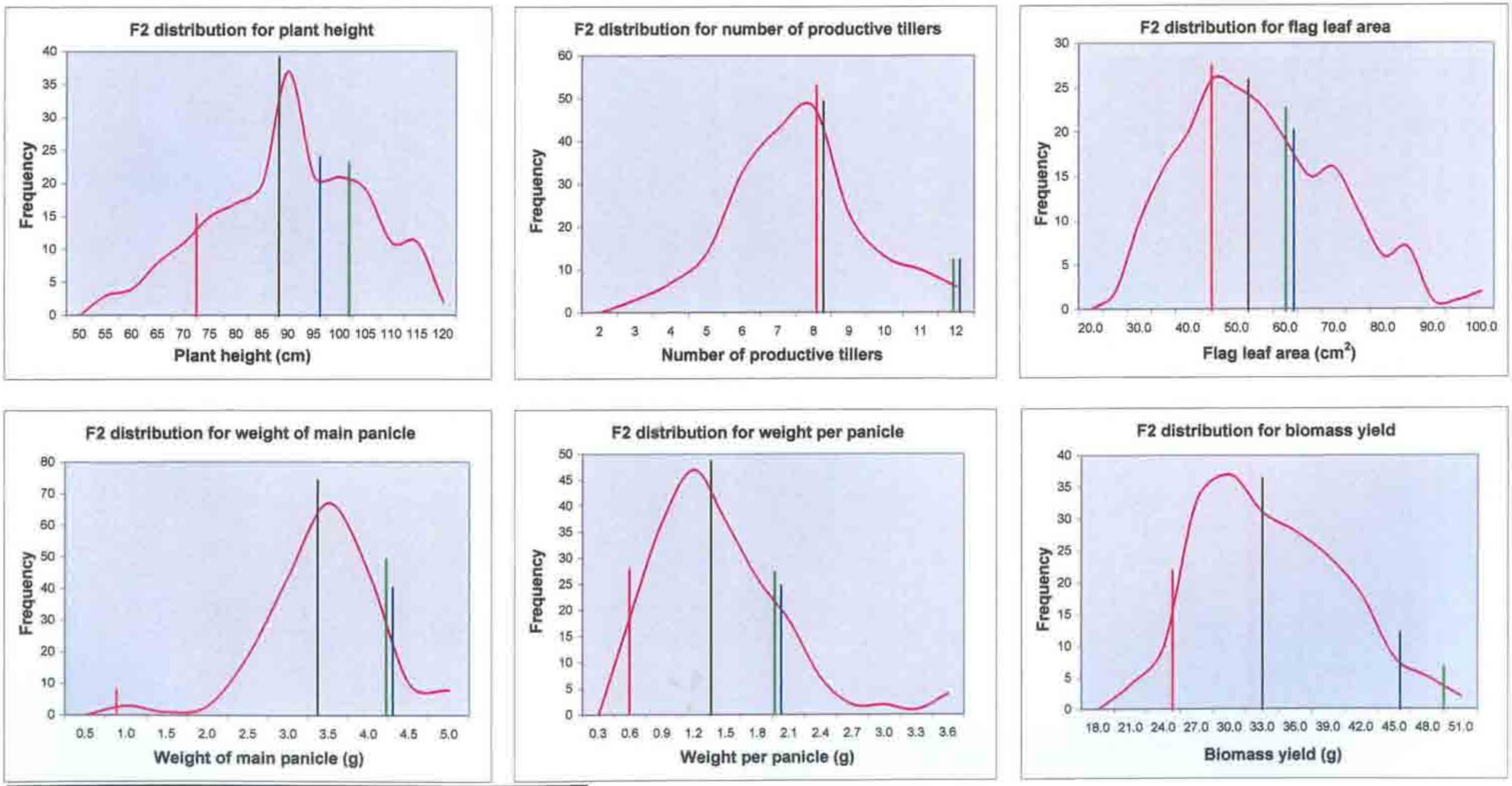
Cross II (Pusa 5A, Pusa 5B and Pusa 1124)

In AF_2-2 (F_2 of cross Pusa 5A x Pusa 1124), as much as 50.00% of the F_2 plants showed transgressive segregation for total number of spikelets in the main panicle, followed by straw yield (45.00%), 1000-grain weight (32.00%) and flag leaf area (30.50%). Whereas number of productive tillers and biomass yield per plant did not show any transgression. In case of BF_2-2 (F_2 of cross Pusa 5B x Pusa 1124), total number of spikelets in main panicle showed the highest percentage of transgressive segregants (54.00%) followed by straw yield (50.00%) and panicle density (47.50%). Characters like number of filled spikelets (42.00%), flag leaf area (33.50%), number of unfilled spikelets in main panicle (30.00) also showed high percentages of transgressive segregants in desirable direction. While, biomass yield did not show any transgression and characters like weight of all panicles (1.50%), number of productive tillers (2.00%), grain yield (4.50%) showed quite low percentages of transgressive segregants. In case of RF_2-2 (F_2 of cross Pusa 1124 x Pusa 5B), total number of spikelets in main panicle showed the highest percentage of transgressive segregants (56.00%), followed by number of filled spikelets (55.00%), panicle density (54.50%), straw yield (50.50%), number of unfilled spikelets in main panicle (45.50%), flag leaf area (31.50%) and length of main panicle (30.00%). Biomass yield and number of productive tillers showed only 2.00% percent of transgressive segregants followed by weight of all panicles (3.50%) and grain yield (9.00%).

Cross III (IR 58025A, IR 58025B and PRR 78)

In case of AF_2-3 (F_2 of cross IR 58025A x PRR 78), straw yield showed the highest percentage (44.00%) of transgressive segregants, followed by flag leaf area

Fig 5a: AF_2-2 frequency distributions for various characters



Means of: (i) A line — (ii) R line — (iii) F_1 — and (iv) F_2 —

Fig 5a: AF_2-2 frequency distributions for various characters (Cont ...)

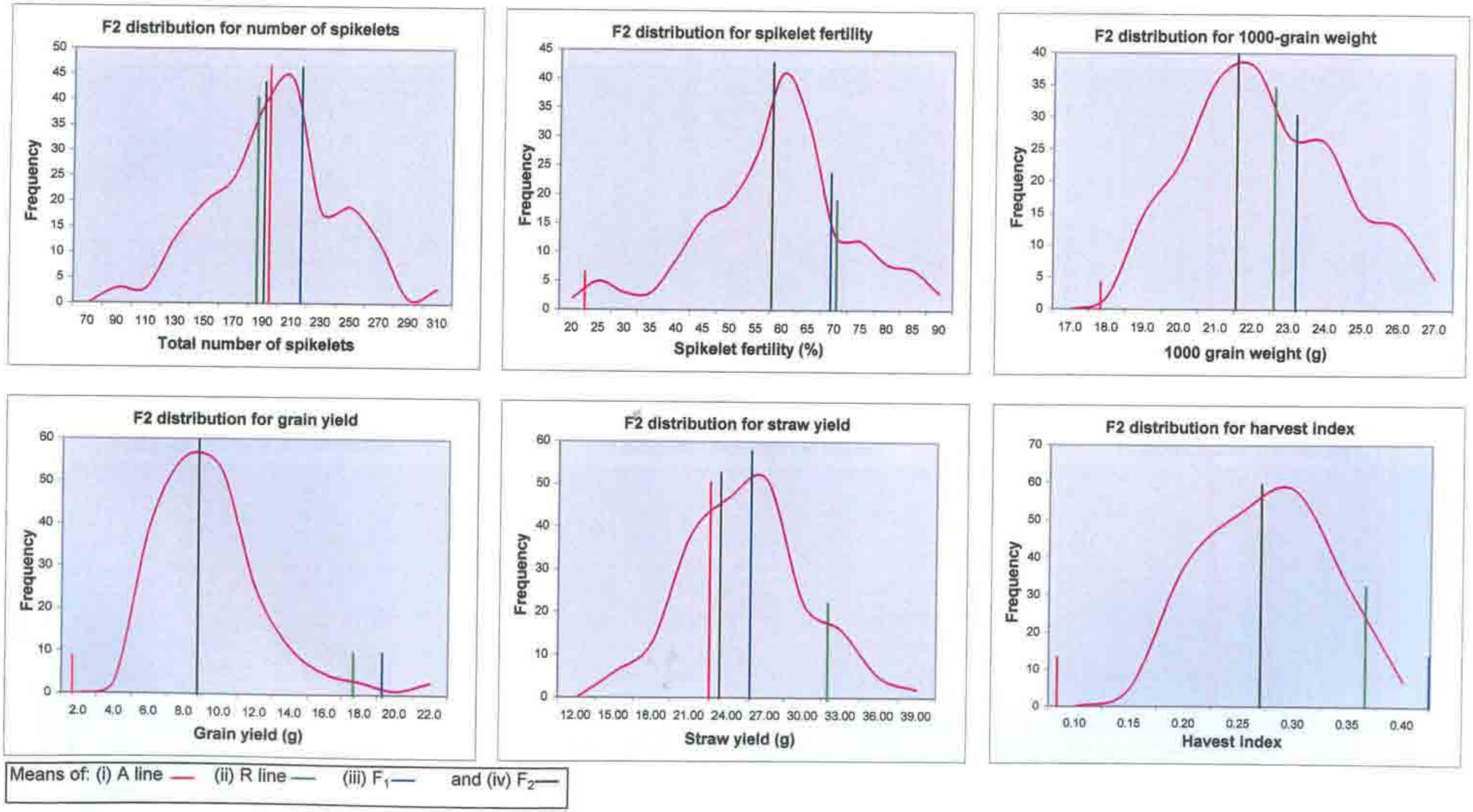


Fig 5b: BF_2-2 frequency distributions for various characters

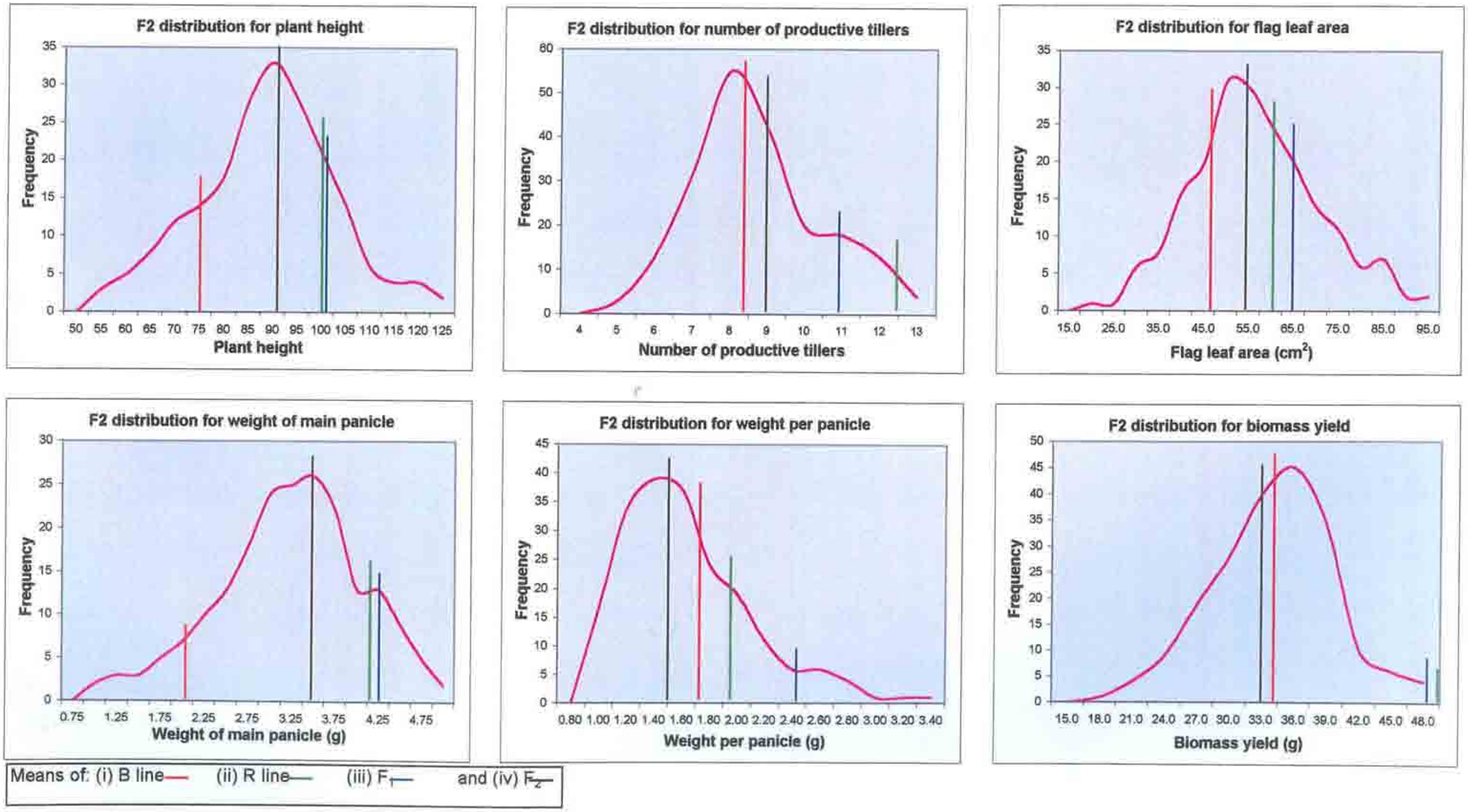


Fig 5b: BF_2-2 frequency distributions for various characters (Cont...)

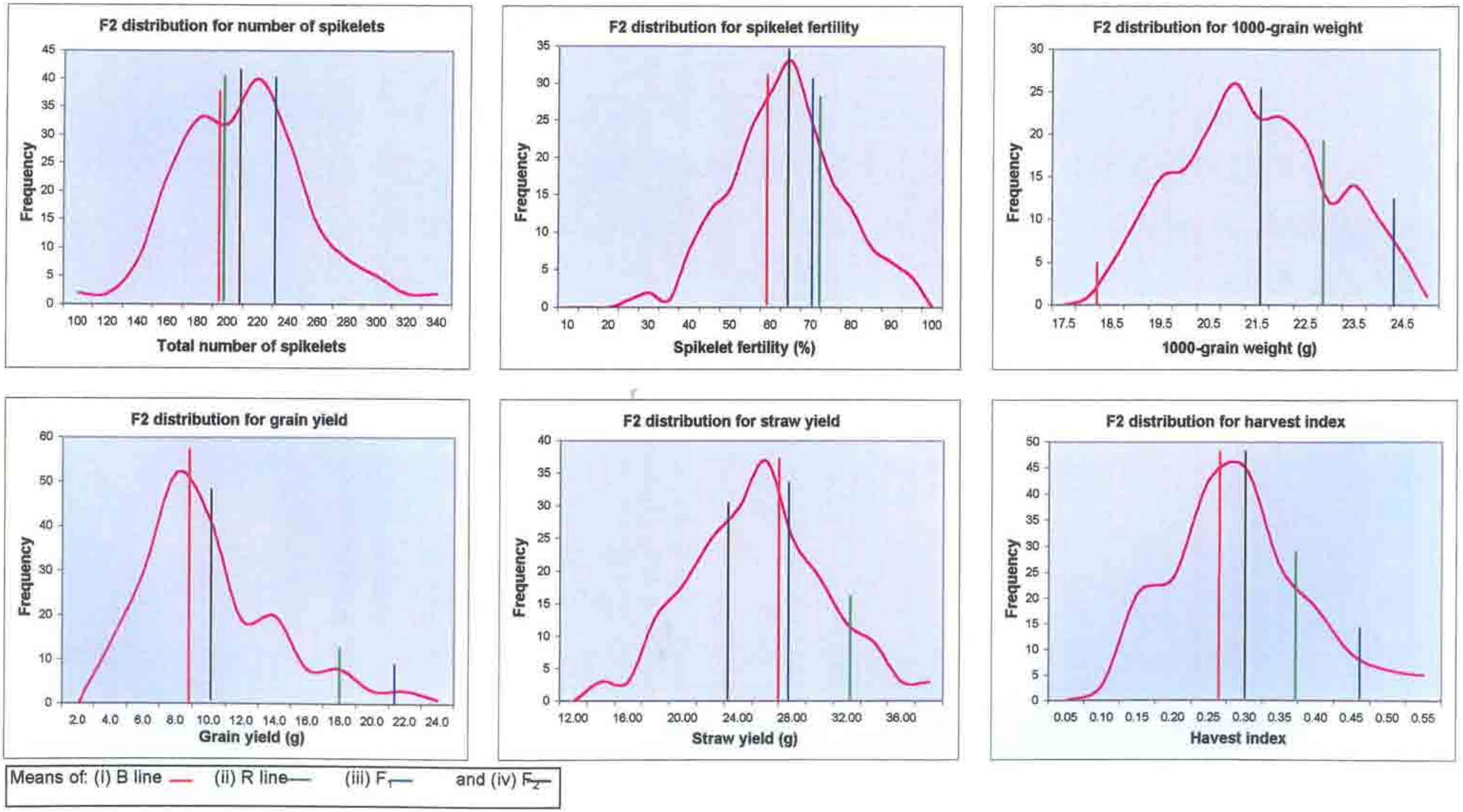
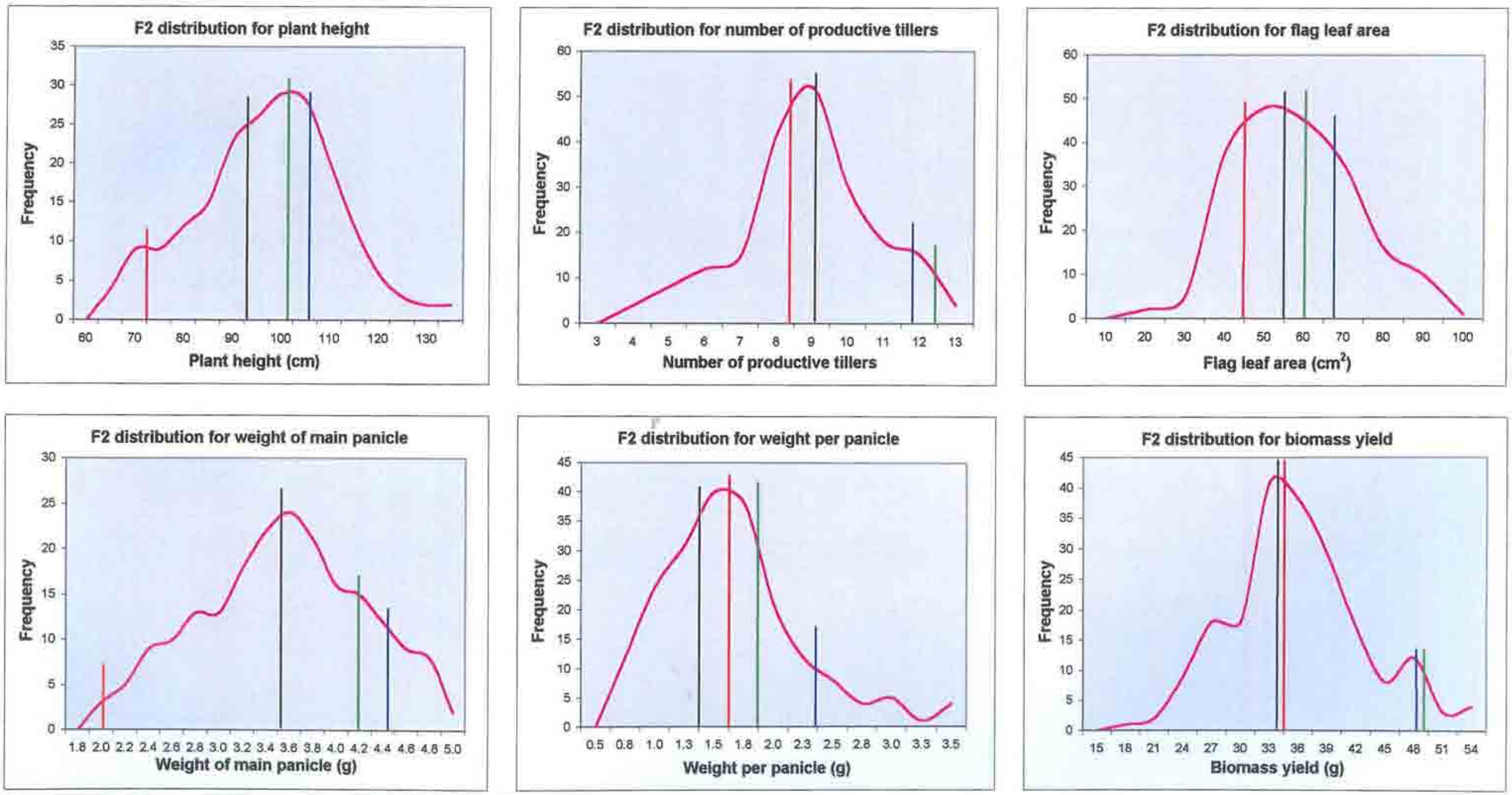
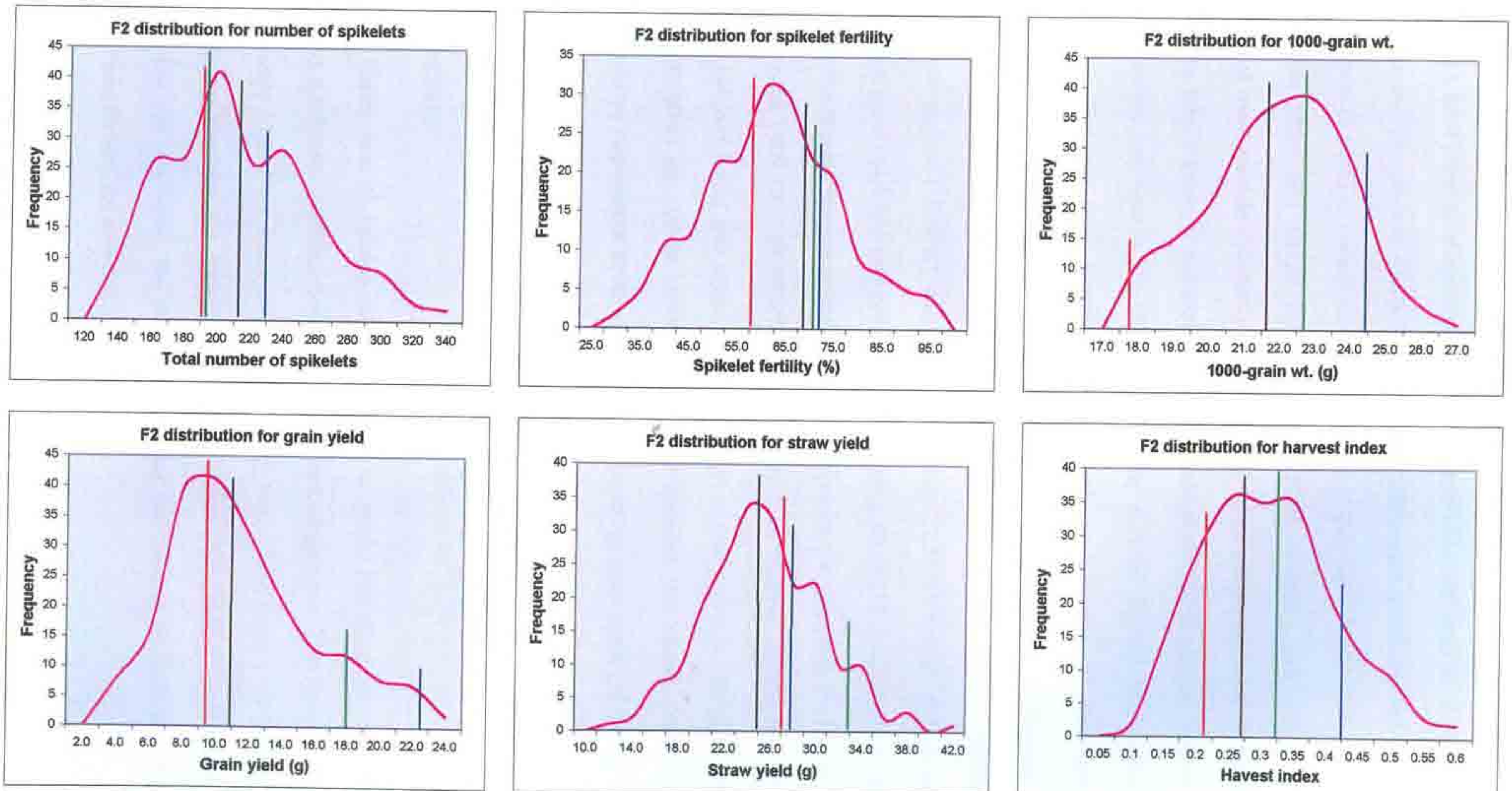


Fig 5c: RF_2-2 frequency distributions for various characters



Means of: (i) B line (ii) R line (iii) F_1 and (iv) F_2

Fig 5c: RF_2-2 frequency distributions for various characters (Cont...)



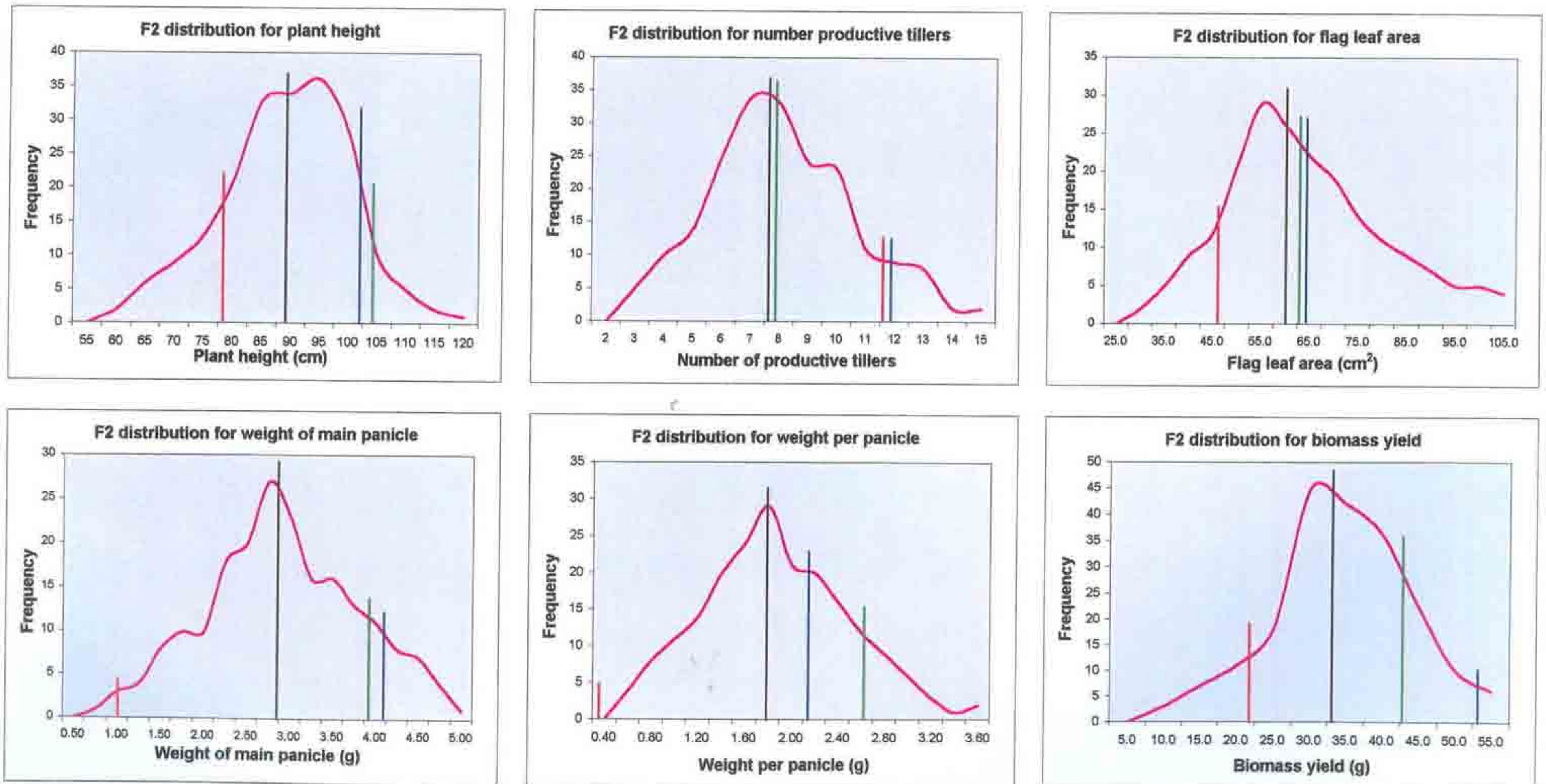
Means of: (i) B line — (ii) R line — (iii) F_1— and (iv) F_2—

(41.50%), total number of spikelets in main panicle (40.00%) and number of unfilled spikelets in main panicle (33.50%). Whereas, 1000-grain yield showed the lowest percentage (2.00%) of transgressive segregants in this case, followed by number of productive tillers and weight per panicle (10.50%), biomass yield (11.50%) and weight of main panicle (12.00%). While in case of BF_2-3 (F_2 of cross IR 58025B x PRR 78), total number of spikelets in main panicle showed the highest frequency of transgressive segregants (53.00%) followed by panicle density and straw yield (35.50%), flag leaf area, length of main panicle and number of filled spikelets (33.50%) and number of unfilled spikelets (32.50%). Whereas, 1000-grain yield showed the lowest percentage of transgressive segregants (7.00%), followed by weight per panicle (10.00%), weight of all panicles (12.50%), weight of main panicle and grain yield (14.00%) and number of productive tillers (18.50%). Panicle density showed the highest frequency (68.50%) of transgressive segregants in case of RF_2-3 (F_2 of cross PRR 78 x IR 58025B), followed by total number of spikelets in main panicle (56.50%), flag leaf area (37.00%), length of main panicle (36.00%), harvest index (35.00%) etc. While, 1000-grain weight showed the lowest percentage of transgressive segregants in RF_2-3 (4.50%) followed by grain yield (15.50%), weight of all panicles (16.00%) and biomass yield (16.00%).

4.3 Effects of sterility inducing cytoplasm on various characters

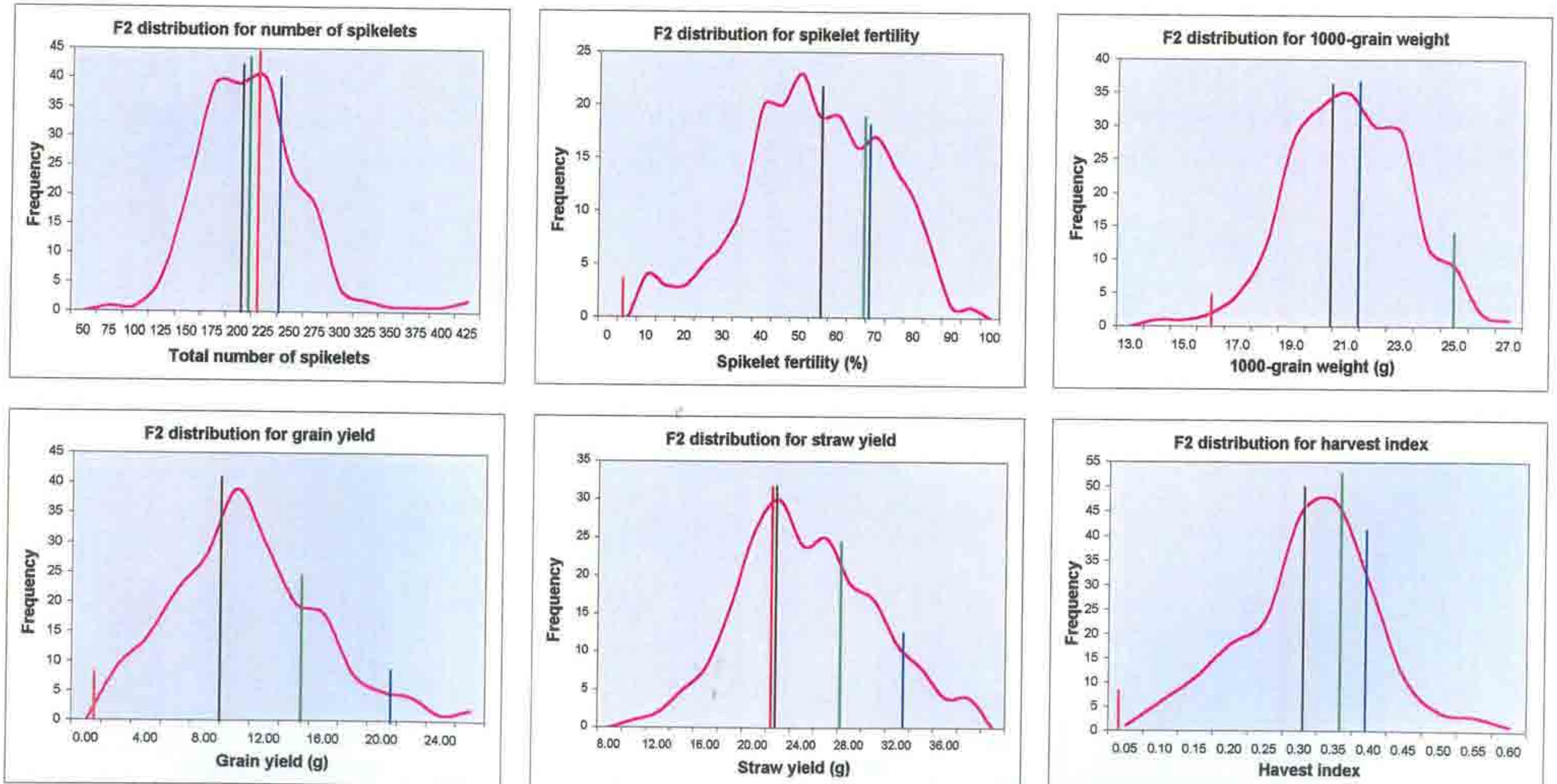
Three sets of hybrids were evaluated to study the effect of male sterility inducing cytoplasm (wild abortive, WA) on various characters. The first set involved the hybrids PMS 2A x Pusa 1127 (AF_1-1) and PMS 2B x Pusa 1127 (BF_1-1), the second set involved the hybrids Pusa 5A x Pusa 1124 (AF_1-2) and Pusa 5B x Pusa 1124 (BF_1-2), while the third set involved the hybrids IR 58025A x PRR 78 (AF_1-3) and IR 58025B x PRR 78 (BF_1-3).

Fig 6a: AF_2-3 frequency distributions for various characters



Means of: (i) A line — (ii) R line — (iii) F_1 — and (iv) F_2 —

Fig 6a: AF_2-3 frequency distributions for various characters (Cont ...)



Means of: (i) A line — (ii) R line — (iii) F_1 — and (iv) F_2 —

Fig 6b: BF_2-3 frequency distributions for various characters

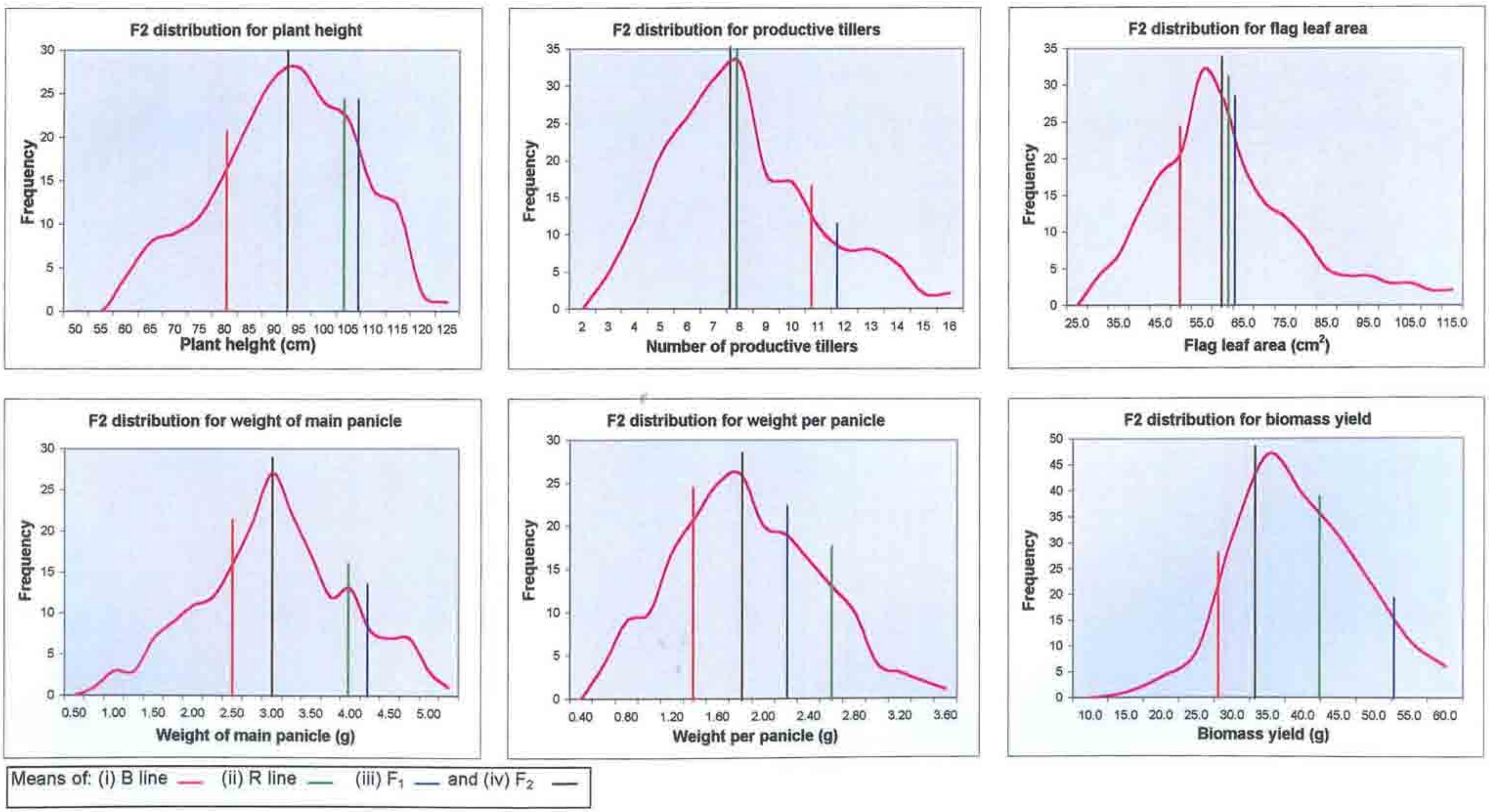


Fig 6b: BF_2-3 frequency distributions for various characters (Cont …)

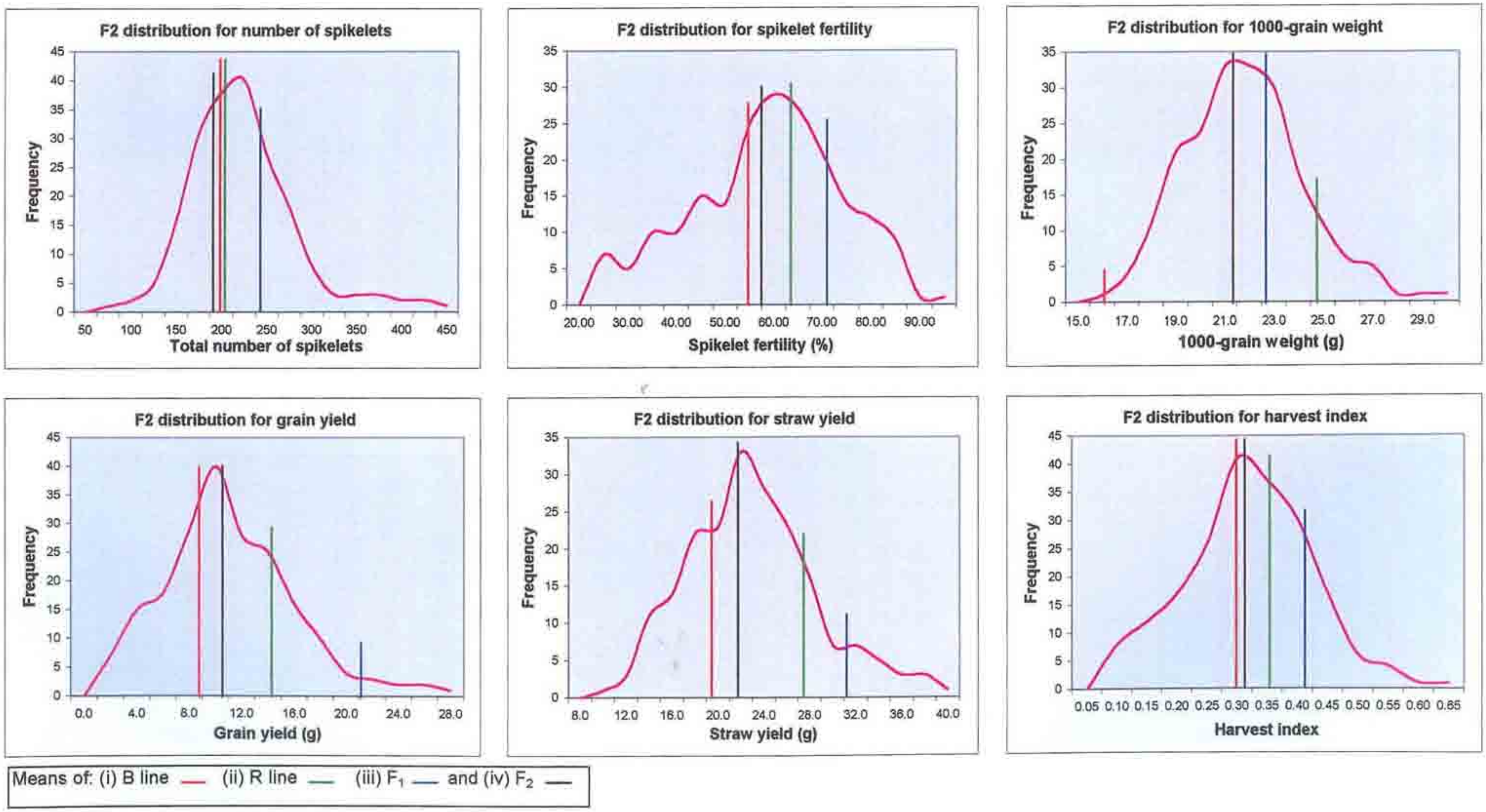
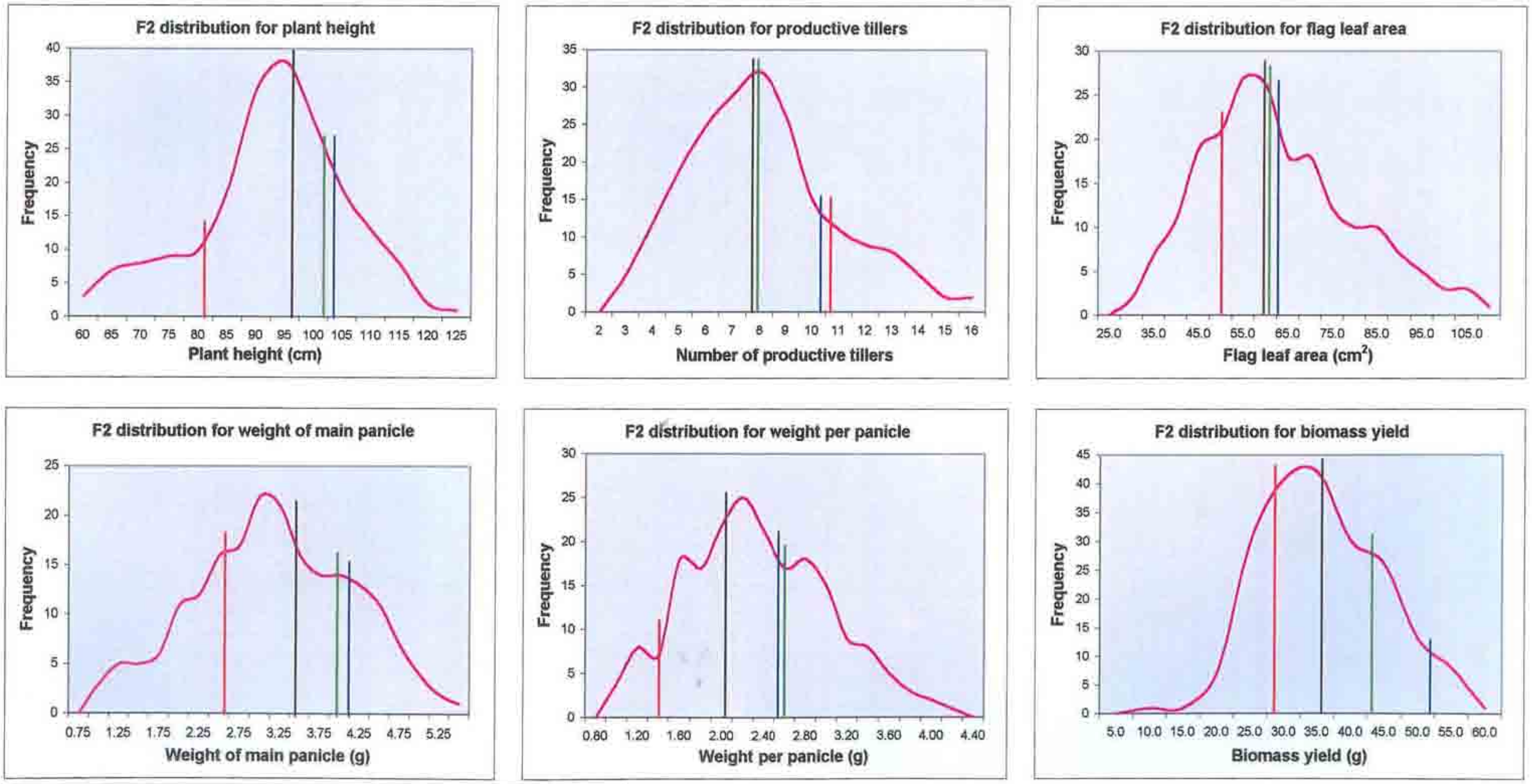
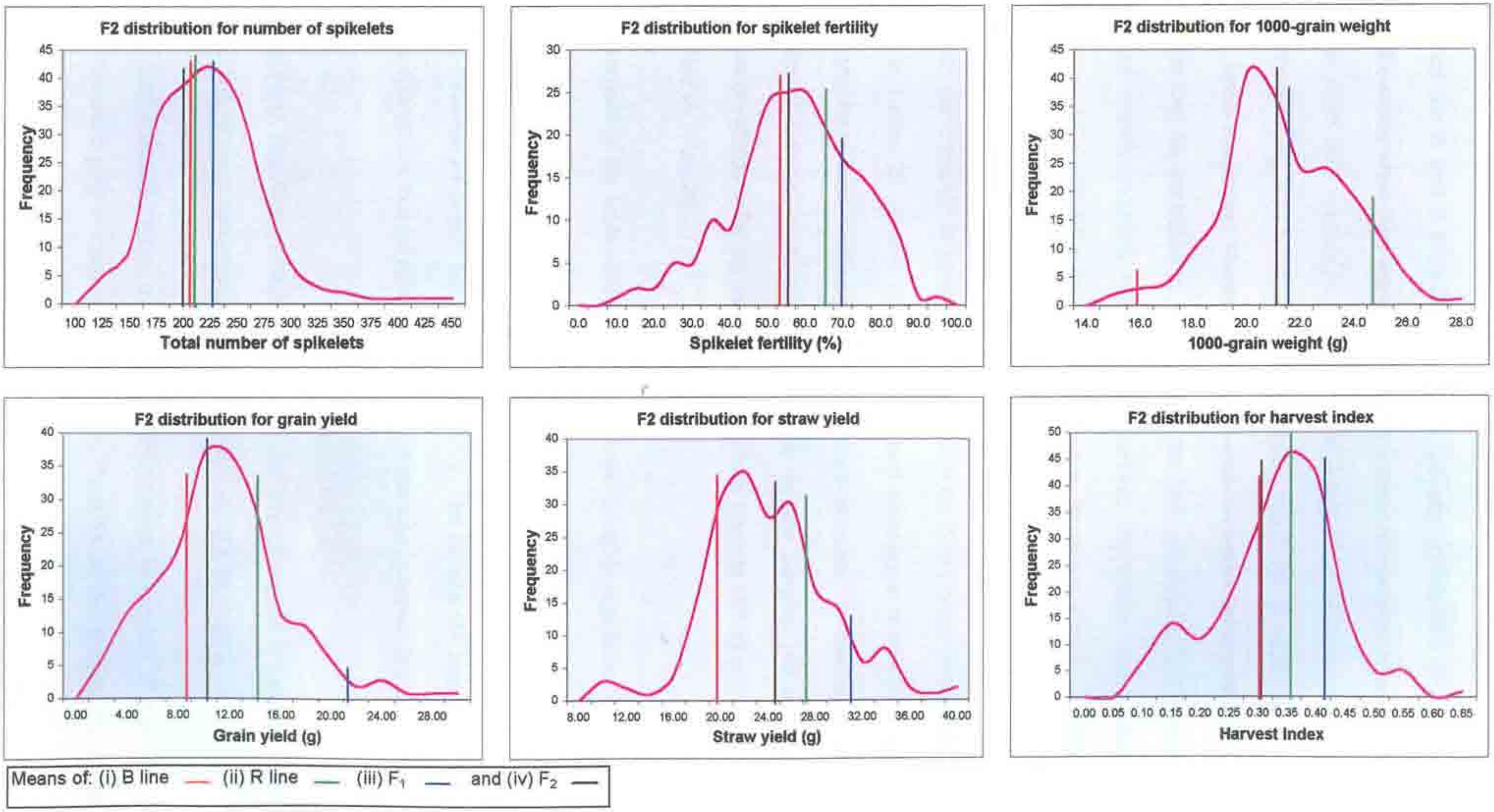


Fig 6c: RF_2-3 frequency distributions for various characters



Means of: (i) B line — (ii) R line — (iii) F_1 — and (iv) F_2 —

Fig 6c: RF_2-3 frequency distributions for various characters (Cont ...)



Since the A and B lines are isonuclear, genetic constitution of the hybrids would be the same when they were crossed with a common restorer. However, the A and B lines differ with respect to cytoplasm; the A line is alloplasmic, carrying the male sterility inducing 'wild abortive' (WA) cytoplasm and B line is euplasmic, having the native, fertile cytoplasm. Therefore any difference in performance of the AxR and BxR hybrids can be attributed to the effect of the WA cytoplasm. The associated influence of sterility inducing cytoplasm on various characters was studied by comparing the AF_1s with BF_1s for all the characters. Student's 't' test was used for comparing the hybrids.

Mean performance of parents and hybrids of the three cross combinations is presented in Tables 25, 26 and 27. The nature and magnitude of effects of sterility inducing cytoplasm was worked out as per cent increase or decrease in the performance of hybrids involving the A lines as female parents (AF_1s) over the performance of hybrids involving the B lines as female parents (BF_1s) and the results are presented in Table 28.

A perusal of the table reveals that significant to highly significant differences existed between AF_1s and BF_1s for 38 of 53 characters studied (some characters studied at different growth phases). Rest of the characters did not show significant differences between AF_1s and their respective BF_1s. The results are presented here only for the characters that exhibited significant differences between the two kinds of hybrids.

<u>Plant height (cm)</u>: Significant reduction in plant height was observed in case of all the three AF_1s. The range of cytoplasmic effect was from -6.19% to -4.85%.

<u>Number of productive tillers per plant</u>: Significant increase in number of productive tillers was observed only in case of AF_1 involving Pusa 5A as the female parent. In

Table 25: Mean performance of parents (PMS 2A, PMS 2B and Pusa 1127) and their hybrids (AF_1-1, BF_1-1and RF_1-1) for various characters

Characters	PMS 2A	PMS 2B	Pusa 1127	AF_1-1 [@]	BF_1-1 [#]	RF_1-1 [$]
Plant height (cm)	68.30	74.60	91.70	82.60 **	87.70 *	90.60
Number of productive tillers	11.50	11.00	8.80	12.20 **	11.10	10.10
Days to 50% flowering	104.00	103.00	95.50	94.50 **	89.50 **	86.50 **
Days to maturity	138.50	134.00	125.50	122.00 **	120.50 **	116.00 **
Grain filling duration	34.50	31.00	30.00	27.50 **	31.00 **	29.50 **
Flag leaf area (cm^2)	39.53	39.50	60.53	57.97	58.73	63.33
Length of main panicle (cm)	20.90	21.90	26.65	22.25 **	24.55 **	24.75
Weight of main panicle (g)	0.53	1.77	3.78	3.21	3.49	3.62
Weight of all panicles (g)	3.90	12.10	16.59	19.85	20.99	22.51
Weight per panicle (g)	0.34	1.10	1.91	1.67	1.94	2.23
Number of filled spikelets	0.00	113.90	117.60	130.80	156.00 *	171.60
Number of unfilled spikelets	218.50	97.60	64.90	79.50 **	64.90 *	54.20
Total number of spikelets	218.50	211.50	182.50	210.30	220.90	225.80
Panicle density	0.00	5.22	4.43	5.90 **	6.36	6.94
Spikelet fertility (%)	0.00	54.48	64.52	61.75	70.79 **	75.98 *
1000-grain weight (g)	14.33	14.53	20.61	17.65 **	18.13	18.31
Biomass yield (g)	19.36	28.61	36.61	38.35	42.28 *	46.72
Grain yield (g)	0.00	7.65	12.17	14.16	16.33	18.26
Straw yield (g)	19.36	20.95	24.45	24.20	25.95	28.46
Harvest index	0.00	0.27	0.34	0.38	0.39	0.39
CGR (mg/day/plant)						
Seedling - tillering	204.73	212.84	304.03	320.98 **	361.77 **	386.68 **
Tillering - flowering	161.58	244.90	267.74	386.36 **	335.42 **	470.97 **
Flowering - maturity	97.26	318.29	443.13	468.87 **	568.45 **	673.15 **
Whole duration	141.83	213.49	283.77	315.19 **	350.86 **	402.77 **
RGR (mg/g/plant/day)						
Seedling - tillering	42.05	39.90	43.83	38.29 **	46.05 **	48.90 **
Tillering - flowering	11.47	15.75	13.61	17.21 **	15.13 **	20.46 **
Flowering - maturity	5.48	13.64	15.58	14.85 **	17.39 **	18.76 **
NAR ($mg/dm^2/day$)						
Seedling - tillering	127.45	127.62	166.83	146.60 **	156.67	159.58 **
Tillering - flowering	14.93	22.18	23.67	29.24 **	24.32 **	33.00 *
Flowering - maturity	9.85	35.92	49.66	46.76 **	54.64	63.84

Table 25 (Cont…)

Characters	PMS 2A	PMS 2B	Pusa 1127	AF_1-1 @	BF_1-1 #	RF_1-1 $
Leaf area (cm^2/plant)						
Seedling	2.55	2.67	3.75	5.75 *	5.66 **	6.03
Tillering	955.62	990.50	1,028.00	1,171.00 **	1,255.00 *	1,311.27
Flowering	1,222.62	1,228.07	1,244.00	1,485.00 **	1,515.00 **	1,553.00 **
Maturity	785.26	615.59	615.70	638.60 **	679.20 **	677.61 **
LAR (cm^2/g)						
Seedling - tillering	33.06	31.33	26.33	26.16	29.46 **	30.70
Tillering - flowering	77.05	71.14	57.61	58.90	62.41 *	62.14
Flowering - maturity	55.76	38.05	31.43	31.79	31.92	29.45 **
LAI						
Tillering	3.19	3.30	3.43	3.90 **	4.18 *	4.37
Flowering	4.08	4.09	4.15	4.95 **	5.05 **	5.18 **
Maturity	2.62	2.05	2.05	2.13 *	2.26 **	2.26 **
LAD						
Tillering - flowering	90.74	90.59	71.58	68.17 **	66.48 *	73.99 **
Flowering - maturity	108.76	95.26	92.99	97.33	113.37 **	109.67 *
α-Amylase activity (mg/seed/min)						
at 24 hrs	5.00	6.00	10.00	12.83 **	13.33 *	13.33
at 48 hrs	8.00	9.25	15.00	18.33 **	20.00 **	20.83 *
at 72 hrs	15.00	17.75	22.75	23.50	24.83 **	25.00
NRA (μ moles NO_2/g fr.wt./hr)						
Seedling	575.40	588.50	638.90	625.10	740.00 **	633.60 **
Tillering	876.00	836.30	935.00	979.50 **	1,077.00 **	1,021.00 **
Flowering	924.00	886.70	872.00	1,033.00 **	984.00 **	975.10
25 days after flowering	222.00	228.00	287.00	265.30 **	260.40 *	259.80
Nitrogen (%) in grain	1.46	1.45	1.45	1.46	1.49	1.45
Protein (%) in grain	8.69	8.63	8.63	8.69	8.87	8.63
Amylose (%) in grain	20.50	20.70	25.50	26.50 *	27.00	26.80
Starch (%) in grain	66.50	70.50	68.70	70.60	72.50	73.00

AF_1-1 = PMS 2A x Pusa 1127; BF_1-1 = PMS 2B x Pusa 1127,
RF_1-1= Pusa 1127 x PMS 2B

@ = The AF_1 is compared with better parent (either A or R) to test the significance.

= To test significance.of the effect of male-sterile cytoplasm, the BF_1 is compared with AF_1.

$ = To test significance of reciprocal cross differences, the RF_1 is compared with BF_1.

* , ** = Significant at 5% and 1% levels, respectively.

Table 26: Mean performance of parents (Pusa 5A, Pusa 5B and Pusa 1124) and their hybrids (AF_1-2, BF_1-2and RF_1-2) for various characters

Characters	Pusa 5A	Pusa 5B	Pusa 1124	AF_1-2 [@]	BF_1-2 [#]	RF_1-2 [$]
Plant height (cm)	70.10	74.40	101.50	95.50 **	101.80 **	105.70 *
Number of productive tillers	8.40	8.00	12.40	12.50	10.90 *	11.60
Days to 50% flowering	93.00	92.00	100.50	93.00 **	91.00 **	88.00 **
Days to maturity	123.50	122.50	130.00	124.00 **	120.50 **	119.50 **
Grain filling duration	30.50	30.50	29.50	31.00 **	29.50 **	31.50 **
Flag leaf area (cm^2)	43.30	43.49	59.74	62.07	63.06	66.28
Length of main panicle (cm)	24.30	24.80	26.50	25.15 *	27.90 **	28.05
Weight of main panicle (g)	0.56	1.82	4.15	4.18	4.21	4.39
Weight of all panicles (g)	3.40	12.63	22.82	23.48	25.38	27.50
Weight per panicle (g)	0.41	1.63	1.88	1.91	2.36 *	2.32
Number of filled spikelets	0.00	102.40	127.90	141.70 **	153.60	157.80
Number of unfilled spikelets	188.80	80.60	55.90	66.90 **	68.30	64.70
Total number of spikelets	188.80	183.00	183.80	208.60 **	221.90	222.50
Panicle density	0.00	4.14	4.84	5.65 **	5.51	5.63
Spikelet fertility (%)	0.00	56.54	69.93	68.03	69.30	70.91
1000-grain weight (g)	17.57	17.87	22.79	23.09	24.05 **	24.36
Biomass yield (g)	23.23	34.61	49.91	45.45	48.26	49.23
Grain yield (g)	0.00	8.50	17.71	19.04	21.06	22.17
Straw yield (g)	23.23	26.11	32.20	26.40	27.20	27.06
Harvest index	0.00	0.25	0.36	0.43 *	0.45	0.46
CGR (mg/day/plant)						
Seedling - tillering	254.21	332.73	400.54	419.98 **	438.10	469.23 **
Tillering - flowering	228.81	244.19	427.63	375.56 **	392.23 *	454.12 **
Flowering - maturity	175.90	413.48	592.03	509.84 **	631.49 **	628.86
Whole duration	188.04	282.55	383.86	366.50 **	400.57 **	411.95
RGR (mg/g/plant/day)						
Seedling - tillering	49.19	48.56	46.12	46.83	52.28 **	51.02
Tillering - flowering	15.06	12.61	15.50	14.38 **	15.46 **	18.71 **
Flowering - maturity	8.61	14.86	14.60	13.79 **	16.54 **	16.34 **
NAR (mg/dm^2/day)						
Seedling - tillering	138.31	175.69	162.87	166.82	170.73	184.20
Tillering - flowering	17.47	18.30	28.26	24.53	25.15	28.56
Flowering - maturity	15.32	41.72	50.94	47.58	57.72	56.62

Table 26 (Cont...)

Characters	Pusa 5A	Pusa 5B	Pusa 1124	AF_1-2 [@]	BF_1-2 [#]	RF_1-2 [$]
Leaf area (cm^2/plant)						
Seedling	3.05	3.00	5.00	5.03 **	5.15 *	5.05
Tillering	1,083.62	1,127.15	1,390.48	1,429.30	1,456.32	1,448.47 *
Flowering	1,569.25	1,570.75	1,647.08	1,640.70 **	1,669.79	1,701.00 **
Maturity	811.30	576.71	786.00	653.50 **	669.46 **	676.70
LAR (cm^2/g)						
Seedling - tillering	35.62	27.70	28.36	28.13	30.71 **	27.76 **
Tillering - flowering	86.37	69.10	54.98	58.74 **	61.56 *	60.90
Flowering - maturity	56.30	35.69	28.74	29.03 **	28.68	28.90
LAI						
Tillering	3.61	3.76	4.63	4.76	4.85	4.83 *
Flowering	5.23	5.24	5.49	5.47	5.57	5.67 **
Maturity	2.70	1.92	2.62	2.18 **	2.23 **	2.26
LAD						
Tillering - flowering	97.73	93.13	108.85	92.10 **	107.33 **	101.83 **
Flowering - maturity	121.01	109.16	119.63	118.53 **	115.01	124.83 **
α-Amylase activity (mg/seed/min)						
at 24 hrs	5.00	6.50	11.25	14.00 **	14.50 *	14.67
at 48 hrs	8.25	9.25	16.25	20.00 **	20.17	21.67 **
at 72 hrs	15.75	16.00	25.25	29.50 **	30.00	31.50 **
NRA (μ moles NO_2/g fr.wt./hr)						
Seedling	604.30	617.80	814.80	733.50 **	714.00	776.00 **
Tillering	920.00	912.00	1,144.20	1,004.00 **	1,081.00 **	1,152.50 **
Flowering	966.40	1,028.50	1,125.60	1,188.00 **	1,134.00 **	1,140.30
25 days after flowering	444.00	354.00	373.00	233.90	245.00	226.30
Nitrogen (%) in grain	1.38	1.40	1.56	1.51	1.55	1.52
Protein (%) in grain	8.21	8.33	9.28	8.98	9.22	9.04
Amylose (%) in grain	19.00	19.60	20.50	21.50 **	21.00	21.20
Starch (%) in grain	68.80	70.80	73.90	76.60 *	77.00	76.90

AF_1-2 = Pusa 5A x Pusa 1124; BF_1-2 = Pusa 5B x Pusa 1124,
RF_1-2 = Pusa 1124 x Pusa 5B

@ = The AF_1 is compared with better parent (either A or R) to test the significance.

= To test significance.of the effect of male-sterile cytoplasm, the BF_1 is compared with AF_1.

$ = To test significance of reciprocal cross differences, the RF_1 is compared with BF_1.

* , ** = Significant at 5% and 1% levels, respectively.

Table 27: Mean performance of parents (IR 58025A, IR 58025B and PRR 78) and their hybrids (AF_1-3, BF_1-3 and RF_1-3) for various characters

Characters	IR 58025A	IR 58025B	PRR 78	AF_1-3 @	BF_1-3 #	RF_1-3 $
Plant height (cm)	77.60	80.80	103.70	102.00	107.20 **	104.30
Number of productive tillers	11.50	10.70	7.90	11.90 *	11.60	10.20
Days to 50% flowering	94.00	91.50	91.00	91.00 **	86.00 **	89.00 **
Days to maturity	123.50	120.00	119.50	118.00 **	114.50 **	117.00 **
Grain filling duration	29.50	28.50	28.50	27.00 **	28.50 **	28.00 **
Flag leaf area (cm^2)	46.05	49.68	63.03	64.76	64.25	64.43
Length of main panicle (cm)	23.80	24.50	28.95	28.60	28.70	28.30
Weight of main panicle (g)	0.82	2.49	3.90	4.08	4.19	4.11
Weight of all panicles (g)	3.55	14.60	19.84	24.93	26.77	25.49
Weight per panicle (g)	0.31	1.37	2.60	2.16 *	2.32	2.53 *
Number of filled spikelets	3.40	108.10	132.10	150.60	173.90	156.20
Number of unfilled spikelets	204.30	93.20	69.50	77.90 **	69.50	69.30
Total number of spikelets	207.70	201.30	201.60	228.50	243.40	225.50
Panicle density	0.14	4.43	4.57	5.27	6.11	5.55
Spikelet fertility (%)	1.48	54.95	65.80	66.97	71.40	69.23
1000-grain weight (g)	15.83	15.95	24.90	21.54 **	22.25 **	21.68
Biomass yield (g)	22.10	28.23	42.36	52.73	52.90	52.19
Grain yield (g)	0.06	8.51	14.71	20.38	21.72	21.10
Straw yield (g)	22.03	19.72	27.64	32.35	31.18	31.09
Harvest index	0.00	0.30	0.35	0.39	0.41	0.41
CGR (mg/day/plant)						
Seedling - tillering	243.37	287.50	411.32	484.38 **	539.25 **	471.33 **
Tillering - flowering	274.29	250.82	281.75	311.60	443.83 **	359.75 **
Flowering - maturity	108.27	280.40	566.18	608.59 **	529.68 **	571.14 **
Whole duration	178.94	235.22	354.44	396.05	418.32 **	416.95 **
RGR (mg/g/plant/day)						
Seedling - tillering	40.56	42.62	50.78	51.60	57.88 **	53.03 **
Tillering - flowering	16.74	13.89	12.13	11.62	15.72 **	12.65 **
Flowering - maturity	5.29	11.68	16.83	16.05 **	13.29 **	14.19 **
NAR (mg/dm^2/day)						
Seedling - tillering	117.36	143.93	187.96	200.25 **	213.46	192.80 *
Tillering - flowering	19.17	19.35	19.88	20.46 **	28.02 **	24.78
Flowering - maturity	8.91	28.53	53.60	49.88 **	42.23	45.83

Table 27 (Cont...)

Characters	IR 58025A	IR 58025B	PRR 78	AF_1-3 [@]	BF_1-3 [#]	RF_1-3 [$]
Leaf area (cm^2/plant)						
Seedling	3.68	3.50	4.00	5.28	5.18	5.37
Tillering	1,205.15	1,163.88	1,264.74	1,346.00 **	1,426.00 **	1,360.27 **
Flowering	1,684.30	1,440.00	1,583.12	1,720.46	1,756.55 **	1,770.75 **
Maturity	843.30	640.40	663.00	829.00 **	859.64 **	838.77 **
LAR (cm^2/g)						
Seedling - tillering	34.60	29.64	27.07	25.78 *	27.17 **	27.54
Tillering - flowering	87.41	71.88	61.05	56.91 **	56.22	57.01 *
Flowering - maturity	59.47	41.13	31.44	32.21	31.50 **	31.00
LAI						
Tillering	4.02	3.88	4.22	4.49 **	4.75 **	4.53 **
Flowering	5.61	4.80	5.28	5.73 **	5.86 **	5.90 **
Maturity	2.81	2.13	2.21	2.76	2.87 **	2.80 **
LAD						
Tillering - flowering	84.28	72.05	96.35	109.46 **	103.96	105.41
Flowering - maturity	124.27	98.90	106.69	114.73	124.27 **	121.78
α-Amylase activity (mg/seed/min)						
at 24 hrs	7.50	8.25	10.50	13.33 **	14.17 **	15.00 **
at 48 hrs	10.25	11.00	16.00	19.50 **	20.17 *	20.83
at 72 hrs	20.25	20.50	24.25	26.83 **	27.33	28.33 *
NRA (μ moles NO_2/g fr.wt./hr)						
Seedling	628.50	625.10	750.30	769.00	677.00 **	731.70 **
Tillering	960.00	979.50	1,056.00	1,098.50 *	1,067.00	1,053.90
Flowering	1,008.00	1,071.70	1,053.50	1,107.00 **	1,131.30 *	1,083.00 **
25 days after flowering	324.00	210.10	235.00	370.50	369.00 **	366.00 **
Nitrogen (%) in grain	1.34	1.36	1.76	1.59 **	1.64	1.61
Protein (%) in grain	7.97	8.09	10.47	9.46 **	9.76	9.58
Amylose (%) in grain	22.30	22.60	27.40	29.30 **	29.50	29.50
Starch (%) in grain	70.60	70.00	78.50	78.00	78.80	78.50

AF_1-3 = IR 58025A x PRR 78; BF_1-3= IR 58025B x PRR 78,
RF_1-3= PRR 78 x IR 58025B

@ = The AF_1 is compared with better parent (either A or R) to test the significance.

= To test significance.of the effect of male-sterile cytoplasm, the BF_1 is compared with AF_1.

$ = To test significance of reciprocal cross differences, the RF_1 is compared with BF_1.

* , ** = Significant at 5% and 1% levels, respectively.

the other two AF_1s, although the cytoplasmic effect was positive, it was non-significant. The cytoplasmic effect ranged from 2.50% to 14.68%.

Days to 50% flowering: The AF_1s flowered two to five days later than their respective BF_1s, the range of cytoplasmic effect being 2.20% to 5.81%. All the differences were highly significant.

Days to maturity: The AF_1s matured 1.50 to 3.50 days later than their respective BF_1s. Cytoplasmic effect ranged from 1.24% to 3.06%, with all the differences being highly significant.

Grain filling duration (days): With respect to this character, the male sterility inducing cytoplasm had negative effects in two of the three AF_1s, the range being -11.29% to 5.08%. All the effects were highly significant. The grain filling duration was 1.50 days more in AF_1-2, while it was 3.50 days less in AF_1-1.

Length of main panicle (cm): With respect to this character, the WA cytoplasm had significant negative effects in two of the three AF_1s, the range being -9.37% to -0.35%. The length of main panicle in AF_1s was less compared to the respective BF_1s by 0.1 cm to 2.30 cm.

Weight per panicle (g): The average weight of panicles was less in case of all AF_1s compared with their respective BF_1s; however, it was significant only in case of AF_1-2. The average weight per panicle was 0.16 g to 0.45 g less in AF_1s than in their respective BF_1s.

Number of filled spikelets in the main panicle: All the BF_1s were superior to the respective AF_1s for this character. The effect of the WA cytoplasm ranged from -16.15% to -7.75%, although the effect was significant only AF_1-1.

Table 28: Nature and magnitude of effects (%) of sterility inducing cytoplasm on various characters of the three AF_1s as compared to their respective BF_1s

Characters	AF_1-1	AF_1-2	AF_1-3
Plant height (cm)	-5.82 *	-6.19 **	-4.85 **
Number of productive tillers	9.91	14.68 *	2.59
Days to 50% flowering	5.59 **	2.20 **	5.81 **
Days to maturity	1.24 **	2.90 **	3.06 **
Grain filling duration (days)	-11.29 **	5.08 **	-5.26 **
Flag leaf area (cm^2)	-1.30	-1.58	0.80
Length of main panicle (cm)	-9.37 **	-9.86 **	-0.35
Weight of main panicle (g)	-8.21	-0.71	-2.58
Weight of all panicles (g)	-5.43	-7.50	-6.86
Weight per panicle (g)	-13.70	-19.23 *	-6.95
Number of filled spikelets	-16.15 *	-7.75	-13.40
Number of unfilled spikelets	22.50 *	-2.05	12.09
Total number of spikelets	-4.80	-5.99	-6.12
Panicle density	-7.35	2.43	-13.83
Spikelet fertility (%)	-12.76 **	-1.83	-6.21
1000-grain weight (g)	-2.61	-3.98 **	-3.19 **
Biomass yield (g)	-9.29 *	-5.83	-0.31
Grain yield (g)	-13.34	-9.58	-6.18
Straw yield (g)	-6.74	-2.93	3.78
Harvest index	-3.59	-4.36	-6.28
CGR (mg/day/plant)			
Seedling - tillering	-11.27 **	-4.14	-10.18 **
Tillering - flowering	15.19 **	-4.25 *	-29.79 **
Flowering - maturity	-17.52 **	-19.26 **	14.90 **
Whole duration	-10.17 **	-8.51 **	-5.32 **
RGR (mg/g/plant/day)			
Seedling - tillering	-16.85 **	-10.43 **	-10.85 **
Tillering - flowering	13.69 **	-6.98 **	-26.09 **
Flowering - maturity	-14.62 **	-16.63 **	20.82 **
NAR ($mg/dm^2/day$)			
Seedling - tillering	-6.43	-2.29	-6.19
Tillering - flowering	20.21 **	-2.49	-26.99 **
Flowering - maturity	-14.42	-17.57	18.11

Table 28 (Cont...)

Characters	AF_1-1	AF_1-2	AF_1-3
Leaf area (cm^2/plant)			
Seedling	1.61 **	-2.33 *	1.93
Tillering	-6.69 *	-1.86	-5.61 **
Flowering	-1.98 **	-1.74	-2.05 **
Maturity	-5.98 **	-2.36 **	-3.56 **
LAR (cm^2/g)			
Seedling - tillering	-11.20 **	-8.40 **	-5.09 **
Tillering - flowering	-5.63 *	-4.59 *	1.23
Flowering - maturity	-0.42	1.21	2.25 **
LAI			
Tillering	-6.69 *	-1.86	-5.61 **
Flowering	-1.98 **	-1.74	-2.05 **
Maturity	-5.98 **	-2.38 **	-3.56 **
LAD			
Tillering - flowering	2.54 *	-14.19 **	5.29
Flowering - maturity	-14.14 **	3.06	-7.68 **
α-Amylase activity (mg/seed/min)			
at 24 hrs	-3.75 *	-3.47 *	-5.93 **
at 48 hrs	-8.35 **	-0.84	-3.31 *
at 72 hrs	-5.34 **	-1.66	-1.83
NRA (μ moles NO_2/g fr.wt./hr)			
Seedling	-15.53 **	2.73	13.59 **
Tillering	-9.05 **	-7.12 **	2.95
Flowering	4.98 **	4.76 **	-2.15 *
25 days after flowering	1.88 *	-4.53	0.41 **
Nitrogen (%) in grain	-2.01	-2.58	-3.05
Protein (%) in grain	-2.01	-2.58	-3.05
Amylose (%) in grain	-1.84	2.40	-0.68
Starch (%) in grain	-2.62	-0.52	-1.02

AF_1-1 = PMS 2A x Pusa 1127

AF_1-2 = Pusa 5A x Pusa 1124

AF_1-3 = IR 58025A x PRR 78

* , ** = Significant at 5% and 1% levels, respectively

Number of unfilled spikelets in the main panicle: For this character, only AF_1-1 showed significant positive value and the other two AF_1s showed negative values. The range of influence of the WA cytoplasm was from -2.05% to 22.50%.

Spikelet fertility (%): For this character, the influence of the male sterility inducing cytoplasm ranged from -12.76% to -1.83%, with only AF_1-1 showing significantly negative value. With respect to value, spikelet fertility in AF_1s was 1.27% to 9.03% less compared to the respective BF_1s.

1000-grain weight (g): With respect to this character, the sterility inducing cytoplasm had significant negative effects in two of the three AF_1s, the range being -3.98% to -2.61%. The 1000-grain weight was less in all AF_1s as compared to the respective BF_1s by 0.47 to 0.96 g.

Biomass yield (g): For this character, the sterility inducing cytoplasm had significant negative effect only in one of the three AF_1s, the range being -9.29% to -0.31%. The plant weight was 0.16 to 3.93 g less in the AF_1s, as compared to the respective BF_1s.

Crop growth rate (CGR, mg/day/plant): Highly significant influence of the male sterility inducing cytoplasm was observed for this character, calculated for different growth phases. For CGR during seedling to tillering, all the three AF_1s exhibited negative effect of the WA cytoplasm, ranging from -11.27% to -4.14%, however, the effect was significant only in two hybrids. For CGR at tillering to flowering, two hybrids showed significant negative effects of the WA cytoplasm, while one exhibited positive effect. The range for cytoplasmic influence on this character was from -29.79% to 15.19%. Highly significant differences were also observed for CGR at flowering to maturity, negative in AF_1-1 and AF_1-2 and positive in AF_1-3. The range of cytoplasmic effects was from -19.26% to 14.90%. Whereas for CGR calculated for whole crop duration, the sterility inducing cytoplasm had significant negative effects in case of all the AF_1s, ranging from -10.17% to -5.32%.

Relative growth rate (RGR, mg/g/plant/day): Like CGR, highly significant influence of the male sterility inducing cytoplasm was observed for this character as well. For RGR at seedling to tillering phase, all the AF_1s showed highly significant negative effect of the WA cytoplasm, ranging from -16.85% (AF_1-1) to -10.43% (AF_1-2). For RGR at tillering to flowering phase, two of the hybrids displayed highly significant negative effects of the WA cytoplasm, while AF_1-1 showed highly significant positive effect. The range for cytoplasmic influence on this character was from -26.09% in AF_1-3 to 13.69% in AF_1-1. Highly significant differences were also observed for RGR at flowering to maturity, negative in AF_1-1 and AF_1-2 and positive in AF_1-3. The range of cytoplasmic effects was from -16.63% in AF_1-2 to 20.82% in AF_1-3.

Net assimilation rate (NAR, $mg/dm^2/day$): In case of NAR, significant effect of the male sterility inducing cytoplasm was observed only during one growth stage, tillering to flowering and that too, only in two of the three AF_1s. The effect was positive and highly significant in AF_1-1, 20.21%, while it was negative and highly significant in AF_1-3, -26.99%. In AF_1-2, although the effect was negative, it was non-significant.

Leaf area (cm^2): Significant to highly significant influence of the male sterility inducing cytoplasm was observed for this character, recorded at different growth stages. At seedling stage, AF_1-1 displayed highly significant and positive influence of the male sterility inducing cytoplasm, whereas AF_1-2 showed significant negative effect. The cytoplasmic effect ranged from -2.33% to 1.61%. Similarly, for leaf area at tillering stage, all the hybrids exhibited negative effects of the WA cytoplasm, however, it was significant only in two hybrids, the range being -6.69% to -1.86%. The same pattern was observed in case of leaf area at flowering stage, with all AF_1s showing negative values and only two of them being highly significant. The range for cytoplasmic effect was from -2.05% to -1.74%. Highly significant negative influence of the WA cytoplasm was also observed for leaf area at maturity in all the AF_1s, the range being -5.98% to -2.38%.

Leaf area ratio (LAR, cm^2/g): LAR was also significantly influenced by the male sterility inducing cytoplasm. For LAR at seedling to tillering phase, all the AF_1s displayed highly significant negative effect of the WA cytoplasm, ranging from -11.20% (AF_1-1) to -5.09% (AF_1-3). For LAR at tillering to flowering phase, two hybrids exhibited significant negative effects of the WA cytoplasm, while AF_1-3 showed positive although non-significant effect. The range for cytoplasmic influence on this character was from -5.63% in AF_1-1 to 1.23% in AF_1-3. Highly significant and positive effect of the WA cytoplasm was observed for LAR at flowering to maturity stage in case of AF_1-3 only. The range of cytoplasmic effects was from -0.42% in AF_1-1 to 2.25% in AF_1-3.

Leaf area index (LAI): Significant to highly significant influence of the male sterility inducing cytoplasm was observed for this character as well, recorded at different crop growth stages. At tillering stage, AF_1-1 and AF_1-3 exhibited significant negative influence of the WA cytoplasm, whereas the negative effect in AF_1-2 was non-significant. The cytoplasmic effect at tillering stage ranged from -6.69% to -1.86%. For LAI at flowering stage, the same pattern prevailed. However, for LAI at maturity, all the AF_1s showed highly significant negative effect of the WA cytoplasm the range of cytoplasmic effect being -5.98% to -2.38%.

Leaf area duration (LAD): The WA cytoplasm exhibited significant positive influence on this character at tillering to flowering phase in AF_1-1, while for the same stage; it showed highly significant negative influence in AF_1-2. In case of AF_1-3, the effect was positive and non-significant. At flowering to maturity stage however, the effect was highly significant and negative in case of AF_1-1 and AF_1-3, whereas it was positive and non-significant in AF_1-2.

α-Amylase activity (mg maltose/seed/min): The WA cytoplasm had negative influence on this character at all the three stages. For this character, an interesting pattern of cytoplasmic effect was observed. When, the activity was measured at 24 hours after soaking the seeds, all the AF_1s demonstrated significantly negative influence of the cytoplasm on this character, the range being -3.47% to -5.93%. At 48 hours after soaking, the negative and significant cytoplasmic effect was observed only in two hybrids, AF_1-1 and AF_1-3 and the range was -8.35% to -0.84%. The effect was further reduced to only one hybrid, AF_1-1 at 72 hours after soaking, where it was significantly negative. The range of the cytoplasmic influence at this stage was from -5.34% to -1.66%.

Nitrate reductase activity (NRA, μ moles KNO_2/g fr.wt./hr): Highly significant influence of the male sterility inducing cytoplasm was observed for this character, recorded at different growth stages. At seedling stage, AF_1-1 displayed highly significant negative effect of the WA cytoplasm (-15.53%), while AF_1-3 showed highly significant positive influence (13.59%). At tillering stage, the effect was highly significant and negative in AF_1-1 and AF_1-2 and positive but non-significant in AF_1-3. For NRA at flowering stage, the effect was found to reverse in the AF_1s and was significantly positive in AF_1-1 and AF_1-2 and significantly negative in AF_1-3. The effect ranged from -2.15% to 4.98%. At maturity stage, AF_1-1 and AF_1-3 showed significant and positive influence of the WA cytoplasm, whereas it was negative and non-significant in case of AF_1-2. The range of cytoplasmic effect was from -4.53% to 1.88%.

4.4 Effects of reciprocal cross differences on various characters

Three sets of hybrids, each consisting of an F_1 (BxR), designated as BF_1 and respective reciprocal F_1 (RxB) designated as RF_1 were evaluated to study the effect of reciprocal cross differences on various characters. The first set involved the hybrids PMS 2B x Pusa 1127 (BF_1-1) and Pusa 1127 x PMS 2B (RF_1-1), the second set involved the hybrids Pusa 5B x Pusa 1124 (BF_1-2) and Pusa 1124 x Pusa 5B

(RF_1-2), while the third set involved the hybrids IR 58025B x PRR 78 (BF_1-3) and PRR 78 x IR 58025B (RF_1-3). The associated influence of reciprocal cross differences on various characters was studied by comparing the BF_1s with RF_1s for all the characters. Student's 't' test was used for comparing the hybrids.

Since the reciprocal crosses do not differ with respect to nuclear genome, any difference in the performance of reciprocal hybrids as against the direct hybrids can be attributed to the organellar genome differences and its interaction with the nuclear genome. The organellar genome constitution of reciprocal hybrid is likely to be different as compared to the direct hybrid, because of the maternal inheritance of the cytoplasm. Hence any difference in performance of the BF_1 and RF_1 hybrids can be attributed to the effect of the reciprocal cross differences.

Mean performance of the parents and hybrids of the three cross combinations is presented in Tables 25, 26 and 27. The nature and magnitude of reciprocal cross effects was worked out as per cent increase or decrease in the performance of hybrids involving the R lines as female parents (RF_1s) over the performance of hybrids involving the B lines as female parents (BF_1s) and the results are presented in Table 29.

A perusal of the table reveals that significant to highly significant differences existed between BF_1s and RF_1s for 29 of the 53 characters studied. Rest of the characters did not show significant differences between the BF_1s and RF_1s. The results are presented hereunder only for the characters that showed significant differences between the two kinds of hybrids.

<u>Plant height (cm)</u>: Significant increase in plant height was observed only in case of RF_1-2, while in case of RF_1-1, though the effect was positive, it was non-significant. The range of the reciprocal cross effect was from -2.71% to 3.83%. In terms of values, the difference in plant height varied from -2.90 cm to 3.90 cm.

Table 29: Nature and magnitude of reciprocal (RxB) differences (%) for various characters over the respective BF_1s (BxR) in the three cross combinations

Characters	RF_1-1	RF_1-2	RF_1-3
Plant height (cm)	3.31	3.83 *	-2.71
Number of productive tillers	-9.01	6.42	-12.07
Days to 50% flowering	-3.35 **	-3.30 **	3.49 **
Days to maturity	-3.73 **	-0.83 **	2.18 **
Grain filling duration	-4.84 **	6.78 **	-1.75 **
Flag leaf area (cm^2)	7.82	5.10	0.29
Length of main panicle (cm)	0.81	0.54	-1.39
Weight of main panicle (g)	3.49	4.35	-1.79
Weight of all panicles (g)	7.25	8.35	-4.78
Weight per panicle (g)	15.42	-1.79	8.85 *
Number of filled spikelets	10.00	2.73	-10.18
Number of unfilled spikelets	-16.49	-5.27	-0.29
Total number of spikelets	2.22	0.27	-7.35
Panicle density	9.08	2.10	-9.27
Spikelet fertility (%)	7.34 *	2.32	-3.05
1000-grain weight (g)	1.04	1.30	-2.56
Biomass yield (g)	10.50	2.01	-1.33
Grain yield (g)	11.79	5.28	-2.85
Straw yield (g)	9.68	-0.52	-0.28
Harvest index	0.40	3.43	-1.74
CGR (mg/day/plant)			
Seedling - tillering	6.89 **	7.11 **	-12.59 **
Tillering - flowering	40.41 **	15.78 **	-18.94 **
Flowering - maturity	18.42 **	-0.42	7.83 **
Whole duration	14.79 **	2.84	-0.33 **
RGR (mg/g/plant/day)			
Seedling - tillering	6.20 **	-2.40	-8.39 **
Tillering - flowering	35.18 **	21.04 **	-19.57 **
Flowering - maturity	7.87 **	-1.16 **	6.79 **
NAR (mg/dm^2/day)			
Seedling - tillering	1.86 **	7.89	-9.68 *
Tillering - flowering	35.65 *	13.56	-11.56
Flowering - maturity	16.84	-1.92	8.54

Table 29 (Cont...)

Characters	RF_1-1	RF_1-2	RF_1-3
Leaf area (cm^2/plant)			
Seedling	6.54	-1.92	3.67
Tillering	4.48	-0.54 *	-4.61 **
Flowering	2.51 **	1.87 **	0.81 **
Maturity	-0.23 **	1.08	-2.43 **
LAR (cm^2/g)			
Seedling - tillering	4.20	-9.59 **	1.40
Tillering - flowering	-0.44	-1.07	1.40 *
Flowering - maturity	-7.75 **	0.77	-1.59
LAI			
Tillering	4.48	-0.54 *	-4.61 **
Flowering	2.51 **	1.87 **	0.81 **
Maturity	-0.23 **	1.08	-2.43 **
LAD			
Tillering - flowering	11.30 **	-5.12 **	1.39
Flowering - maturity	-3.26 *	8.53 **	-2.00
α-Amylase activity (mg/seed/min)			
at 24 hrs	0.00	1.15	5.86 **
at 48 hrs	4.15 *	7.44 **	3.27
at 72 hrs	0.68	5.01 **	3.66 *
NRA (μ moles NO_2/g fr.wt./hr)			
Seedling	-14.38 **	8.68 **	8.08 **
Tillering	-5.20 **	6.61 **	-1.23
Flowering	-0.90	0.56	-4.27 **
25 days after flowering	-0.23	-7.63	-0.81 **
Nitrogen (%) in grain	-2.68	-1.94	-1.83
Protein (%) in grain	-2.68	-1.94	-1.83
Amylose (%) in grain	-0.74	0.95	0.00
Starch (%) in grain	0.69	-0.13	-0.38

RF_1-1 = Pusa 1127 x PMS 2B
RF_1-2 = Pusa 1124 x Pusa 5B
RF_1-3 = PRR 78 x IR 58025B

* , ** = Significant at 5% and 1% levels, respectively

Days to 50% flowering: The RF_1s flowered three days earlier than the respective BF_1s, the range of reciprocal cross effect being -3.30% to 3.49%. All the differences were highly significant.

Days to maturity: The RF_1-1 and RF_1-2 showed negative values for reciprocal cross effects, indicating earliness of the hybrids. However, RF_1-3 matured 2.50 days later than BF_1-3. Reciprocal cross effects ranged from -3.73% to 2.18%, with all the differences being highly significant.

Grain filling duration (days): With respect to this character, the reciprocal cross effects were negative in case of RF_1-1 and RF_1-3 and positive in case of RF_1-2. The range of the effect was from -4.84% to 6.78%. All the effects were highly significant.

Weight per panicle (g): In case of RF_1-3, significant positive effect of the reciprocal differences was observed for this character. The weight per panicle was 8.85% more in RF_1-3, as compared with that of BF_1-3. The range of the effect varied from -1.79% to 15.42%.

Spikelet fertility (%): For this character, the influence of the reciprocal cross effects ranged from -3.05% to 7.34%, with only RF_1-1 showing significantly positive performance.

Crop growth rate (CGR, mg/day/plant): Highly significant influence of the reciprocal cross effects was observed for this character, calculated for different growth stages. For CGR at seedling to tillering phase, RF_1-1 and RF_1-2 showed highly significant positive effects, while RF_1-3 showed highly significant negative effect. The reciprocal cross effects at this phase varied from -12.59% to 7.11%. For CGR at tillering to flowering, also the same situation prevailed and the effect ranged from -18.94% to as much as 40.41%. For CGR at flowering to maturity, RF_1-1 and RF_1-3 demonstrated highly significant and positive reciprocal cross effects, while RF_1-2 did not show any significant effect. The effects ranged from -0.42% to 18.42%. Whereas for CGR calculated for whole crop duration, the reciprocal cross effects ranged between -0.33% and 14.79%. The effects were found to be highly significant in case of RF_1-3 (-0.33%) and RF_1-1 (14.79%).

Relative growth rate (RGR, mg/g/plant/day): Like CGR, highly significant influence of reciprocal cross effects was observed for this character as well. For RGR calculated at seedling to tillering phase, RF_1-1 demonstrated highly significant positive effect (6.20%) and RF_1-3 exhibited highly significant negative effect (-8.39%). While, for RGR calculated for tillering to flowering phase, RF_1-1 and RF_1-2 showed highly significant and positive reciprocal cross effects, while in RF_1-3, the effect was negative and highly significant. The range of the influence on this character was from -19.57% in RF_1-3 to as high as 35.18% in RF_1-1. Highly significant differences were also observed for RGR at flowering to maturity, positive in RF_1-1 and RF_1-3 and negative in RF_1-2. The range of reciprocal cross effects varied between -1.16% (RF_1-2) and 7.87% (RF_1-1).

Net assimilation rate (NAR, mg/dm^2/day): In case of NAR, significant reciprocal cross effects were observed during two growth stages, seedling to tillering and tillering to flowering. In the first growth phase, seedling to tillering, highly significant positive influence on NAR was observed in RF_1-1 (1.86%), whereas in case of RF_1-3, the effect was significant but negative (-9.68%). In the second growth phase, tillering to flowering, significant and positive influence on NAR was observed only in case of RF_1-1 (35.65%). Non-significant positive effects were observed in case of RF_1-2 (13.56%) while, in RF_1-3, the effect was non-significant and negative (-11.56).

Leaf area (cm^2): Significant to highly significant influence of the reciprocal cross effects was observed for this character, recorded at different growth stages. For leaf area at tillering stage, RF_1-2 and RF_1-3 exhibited significant negative effects;

however, the effect was non-significant and positive in case of RF_1-1. The reciprocal effects ranged between -4.61% and 4.48%. While, in case of leaf area at flowering stage, all RF_1s displayed highly significant positive values, ranging from 0.81% to 2.51%. For leaf area at maturity stage, RF_1-1 and RF_1-3 exhibited highly significant and negative values, -0.23% and -2.43% respectively.

<u>Leaf area ratio (LAR)</u>: LAR was also significantly influenced by the reciprocal cross effects. For LAR at seedling to tillering phase, RF_1-2 showed highly significant negative effect. The range varied between -9.59% (RF_1-2) and 4.20% (RF_1-1). For LAR at tillering to flowering phase, only RF_1-3 showed significant positive effect. The reciprocal cross influence on this character varied between -1.07% (RF_1-2) and 1.40% (RF_1-3). Highly significant negative effect on LAR at flowering to maturity stage was observed only in case of RF_1-1. The range of reciprocal cross effects was from -7.75% in RF_1-1 to 0.77% in RF_1-3.

<u>Leaf area index (LAI)</u>: For this character, significant to highly significant reciprocal cross effects were observed at different growth stages. At tillering stage, RF_1-2 and RF_1-3 exhibited significant negative effects; however, the effect was non-significant and positive in case of RF_1-1. The reciprocal effects ranged between -4.61% and 4.48%. While, in case of LAI measured at flowering stage, all RF_1s displayed highly significant positive values, ranging from 0.81% to 2.51%. For LAI at maturity stage, RF_1-1 and RF_1-3 exhibited highly significant and negative values, -0.23% and -2.43% respectively.

<u>Leaf area duration (LAD)</u>: Reciprocal cross effects showed highly significant positive influence on this character during tillering to flowering stage in RF_1-1, while for the same stage; it showed highly significant negative influence in RF_1-2. At flowering to maturity stage however, the effect on LAD was significant and negative in case of RF_1-1 and highly significant and positive in RF_1-2.

α-Amylase activity (mg maltose/seed/min): The reciprocal cross effects were found to be positive for this character at all the three stages. When the activity was measured at 24 hours after soaking the seeds, only RF_1-3 showed highly significant positive influence on this character, the range being 0.00% to 5.86%. At 48 hours after soaking, significant effect on α-amylase activity was observed only in two hybrids, RF_1-1 and RF_1-2 and the range was 3.27% to 7.44%. Similarly, significant reciprocal effect on α-amylase activity at 72 hours after seed soaking was observed in case of RF_1-2 and RF_1-3. The range of the reciprocal cross influence was from 0.68% to 5.01%.

Nitrate reductase activity (NRA, μ moles KNO_2/g fr.wt./hr): Highly significant influence of the reciprocal cross differences was observed for NRA at seedling, tillering and maturity stages. At seedling stage, RF_1-1 showed highly significant negative effect (-14.38%), while RF_1-2 and RF_1-3 showed highly significant positive influence (8.68% and 8.08% respectively). At tillering stage, the effect was highly significant and negative in RF_1-1 (-5.20%) and significant and positive in RF_1-2 (6.61%). At flowering stage, only RF_1-3 exhibited significant and negative effect. At maturity stage, too, only RF_1-3 showed highly significant and negative influence (-0.81%) on NRA. The range for the reciprocal cross effect at maturity stage was from -7.63% to -0.23%.

DISCUSSION

Existence of heterosis in rice was first reported by Jones (1926), who observed marked increase in number of productive tillers and grain yield in some rice hybrids in comparison to their parents. Commercial exploitation of heterosis in rice was first demonstrated in China in 1976 after development of the first set of stable and high yielding three-line hybrids. The area under hybrid rice in China rapidly increased to about 17 m ha by 1995. The high productivity of hybrid rice enabled China to reduce its total rice area from 34.4 m ha in 1978 to 30.0 m ha in 2000 and at the same time increased its rice production from 89.0 m tons to 131.54 m tons.

However, further genetic improvement in productivity of rice would depend on to what extent the various morpho-physiological and biochemical characters governing grain yield can be manipulated simultaneously despite their undesirable association. The lack of information on these characters appears to be a major barrier in enhancing the genetic yield potential of rice hybrids. The physiological and biochemical explanation for phenotypic expression of characters like biomass yield, harvest index, photosynthetic efficiency, greater vigor in growth, leaf area, early flowering, etc. in heterotic hybrids and the knowledge of inter-relationship among these components and their direct and indirect effects on grain yield will be useful for plant breeders for better selection of parents (Akita, 1988).

It is well known that most of the yield contributing characters are quantitative in nature and are governed by a large number of genes or QTLs. However in addition, they are also greatly affected by the environment reducing the response to selection. Hence it is important to observe the extent and pattern of variation for these characters in segregating populations like F_2 and to distinguish the part of the variation that is genetic in nature. In addition, transgressive segregants obtained for desirable characters can be selected and used in breeding programs for further improvement in grain yield. Utilization of this variability will minimize the efforts and economize the breeding program.

Availability of stable cytoplasmic male sterility and fertility restoration system is vital for commercial exploitation of heterosis. The discovery of 'wild abortive' (WA) male sterility inducing cytoplasm and subsequent development of commercially exploitable three-line hybrid breeding system, made a breakthrough in exploitation of heterosis in rice (Lin and Yuan, 1980). Presently, about 95% of the rice hybrids world-over are based on this single source of cytosterility.

In addition to the fear that increased genetic homogeneity of a vital character like cytoplasmic male sterility could make it vulnerable to diseases and pests, the WA cytoplasm is known to have undesirable effects on many characters of economic importance. The effects vary with cytoplasmic source and cytoplasm / nuclear interactions. Hence it is important to understand the nature and magnitude of influence of the cytoplasm on various characters and select desirable heterotic combinations with the least negative effect of the sterility inducing cytoplasm.

Since heterosis is a phenomenon of superior growth, development, differentiation and maturation caused by interaction of genes, metabolism and environment, a simple explanation of heterosis based solely on the nuclear genome heterozygosity appears untenable (Shrivastava, 1981). As the reciprocal hybrids do not differ from direct hybrids with respect to nuclear genome, any difference in performance of the two can be attributed to the organelle genome differences and their interactions with the nuclear genome. The organelle genome constitution of reciprocal hybrids is likely to be different from that of direct hybrids, because of maternal inheritance of cytoplasm. Hence any difference in performance of the direct- and reciprocal- hybrids can be attributed to the effect of the organelle genomes.

Keeping in view the above-mentioned facts, present investigation was undertaken with the following objectives:

1) To study heterosis for various morpho-physiological and biochemical parameters influencing yield components and their association with grain yield,

2) Genetic analysis of selected morpho-physiological and biochemical characters,

3) To study the reciprocal differences in relation to heterosis for yield and yield components.

The results obtained from the present investigation have been discussed in this chapter in the light of up to date literature on the topic.

Variability and heritability

A wide range of variation was observed for characters like number of productive tillers, plant height, flag leaf area, panicle length, panicle weights, spikelet number, 1000-grain weight, biomass yield and harvest index in both the experiments. Wide variability was also noticed for physiological and biochemical characters such as growth parameters, leaf area and associated characters, α-amylase activity and nitrate reductase activity at various stages of growth in the material of Expt. 1.

Wide ranges of variability for these traits were also coupled with high phenotypic and genotypic coefficients of variation. In agreement with the present findings, wide range of variability for yield components and various physiological and biochemical attributes have been reported earlier by several workers (Vinaya Rai and Murty, 1979; Yuan and Shien, 1980; Amirthadevarathinam, 1983; Maurya *et al.*, 1986). High broad sense heritability estimates were obtained for all characters with heritability ranging from 64.97% for straw yield to 98.76% for LAR in seedling to tillering phase, in Expt. 1 and from 80.61% for grain filling duration to 98.93% for spikelet fertility. High estimates of broad sense heritability were also reported by some workers for characters like days to flowering and maturity and number of productive tillers per plant (Maurya, 1976), grain filling duration in maize (Perenzen *et al.*, 1980) and biomass yield in rice (Vinaya Rai and Murty, 1979).

Existence of significantly high level of variation for the various morpho-physiological and biochemical traits in the material studied is an indicative of possibilities of improving the genetic yield potential of rice hybrids via exploitation of heterosis in these component traits.

Extent of heterosis for various characters

Heterosis can be measured either as the deviation of F_1 values over the mid-parental performance (mid-parent heterosis or simple heterosis) or over the better parent (better-parent heterosis or heterobeltiosis) or over the performance of a standard or check variety (standard heterosis). From a practical point of view, standard heterosis is considered the best measure of commercially utilizable heterosis.

Hybrid vigor in rice was first reported by Jones (1926) and further studies have indicated the presence of exploitable level of heterosis. Virmani *et al.* (1981) extensively studied the nature and extent of heterosis for various characters and reported heterobeltiosis to range from -91.0% to 368.6% for grain yield, -70.0% to 55.0% for number of grains per panicle, -31.0% to 14.0% for 1000-grain weight and -45% to 50.5% for number of productive tillers per plant. Similarly significant heterosis, heterobeltiosis and standard heterosis have been reported by other workers for various characters like grain yield, number of grains per panicle, 1000-grain weight, number of productive tillers per plant, plant height, days to 50% flowering, biomass yield, crop growth rate, leaf area, nitrate reductase activity and α-amylase activity (Pillai, 1961; Rao, 1965; Carnahan *et al.*, 1972; Chang *et al.*, 1973; Murayama, 1973; Murayama *et al.*, 1974; Saini *et al.*, 1974; Singh and Singh, 1978; Li *et al.*,1982; Blanco *et al.*, 1986; Kim and Rutger, 1988; Wells *et al.*, 1988; Manonmani *et al.*, 1993; Kumar *et al.*, 1994; Moon *et al.*, 1994; Ramesha *et al.*, 1999; Stuber, 1999).

The most convincing report on the presence and possibilities of exploiting heterosis on commercial scale based on a large scale, replicated yield trials appeared from Chinese workers (Lin and Yuan, 1980). The best hybrid yielded 12.8 tons per ha as compared to the 10.4 tons of the check variety. Yield component analysis at IRRI indicated that yield heterosis has been mainly due to increased spikelet number per panicle and 1000-grain weight. In hybrids, the reduction in number of productive tillers is compensated by increased number of spikelets per panicle. Dry matter production and harvest index were also found to play a major role in determining grain yield in rice hybrids.

Yield and yield components

In the present study, two experiments were conducted to investigate the nature and magnitude of heterosis for 19 yield determining characters and grain yield over the better parent as well as standard check. The results suggest both the nature and magnitude of heterosis to differ from character to character depending on cross combination. Considerable heterosis was observed both in positive and negative directions.

Heterosis in negative direction is desired as far as plant height is concerned. In the present study, two hybrids of Expt. 1 manifested negative heterobeltiosis, while in Expt. 2, all of the hybrids manifested positive heterobeltiosis, which was significant in all hybrids except PRH 21. When compared with the check varieties only one hybrid of Expt. 1 manifested significant negative heterosis and five demonstrated highly significant positive heterosis. In Expt. 2, all the hybrids manifested highly significant positive standard heterosis. Positive heterosis in plant height has been reported by many workders (Chang *et al.*, 1973; Govinda Raj, 1983; Kim and Rutger, 1988). While Pillai (1961) and Singh and Singh (1978) reported negative heterosis for plant height. The highest heterosis in plant height was observed in case of PRH 6 (42.16%), indicating its vulnerability to lodging. In view of the fact that height is an expression of vigor that may lead to unfavorable grain /straw ratio resulting in lower grain yield due to lodging, it is necessary to select desirable hybrids that are short in stature or alternatively, have stronger culm.

For number of productive tillers, most of the hybrids in Expt. 2 showed negative heterobeltiosis and standard heterosis. While no significant reduction in number of tillers was observed in Expt. 1, either in relation to better parent or the check variety. The observation of reduction in number of productive tillers in hybrids is in conformity with the findings of Virmani *et al.* (1981, 1982). Although many workers (Pillai, 1961; Namboodiri, 1963; Rao, 1965; Singh and Singh, 1978; Govinda Raj, 1983; Kumar *et al.*, 1994) have reported positive heterosis for number of productive tillers, it is a fact that mere presence of high heterosis for this character may not result in higher yield, especially in those hybrids where spikelet fertility is greatly affected due to varying levels of fertility restoration or poor panicle exertion (Zhu, 1979; Rangaswamy *et al.*, 1987; He and Shen, 1991). Sometimes, high tillering observed in rice hybrids leads to sterility due to non-synchrony of late emerging tillers and imbalance of source: sink relationships. Conversely, lack of proper restoration and the resulting high sterility may result into diversion of photosynthates to vegetative growth in the form of profuse tillering with less number of productive tillers. Hence there is a need to give due consideration to both the number of productive tillers and spikelet fertility.

Rao (1994) found that grain yield recorded in various tillers indicated higher values for the main shoot and primary tillers and subsequently declined for rest of the tillers. Harvest index recorded for the main shoot was also higher than the primary, secondary and tertiary tillers, in that order. The secondary and tertiary tillers contributed little to grain yield and actually had negative effect. Hence, she suggested that selection of breeding lines with low tiller number would be beneficial in enhancing yield potential of rice. This was clear from the present investigation as well. The restorers of Expt. 1 had varied numbers of productive tillers, 7.90 (PRR 78), 8.80 (Pusa 1127) and 12.40 (Pusa 1124). The corresponding weights of the main panicles were 3.90 g, 3.78 g and 4.15 g. However, when the weight of main panicles were compared with the average weight per panicle, then it was found that PRR 78 had the highest weight per panicle (2.60 g), followed by Pusa 1127 (1.91 g) and Pusa 1124 (1.88 g). Thus, it is clear that higher numbers of productive tillers did not contribute significantly to grain yield and that they may actually have negative effect on grain yield and harvest index. In addition, it has been reported that in hybrids, the reduction in number of productive tillers is compensated by increased number of spikelets per panicle (Virmani *et al.*, 1982). This has been observed in the present study as well. Majority of the hybrids in the present study manifested heterobeltiosis for number of spikelets.

For days to flowering, negative heterosis has been reported by several workers (Chang *et al.*, 1973; Singh *et al.*, 1980 and Fujimaki and Yoshida, 1984). However, some studies have reported both positive and negative heterosis for this character (Karunakaran, 1968). In the present study, most of the hybrids from both the experiments showed negative heterosis over the better parent, which is in desired direction. Early flowering coupled with high standard heterosis for grain yield would be of advantage in areas with short growing seasons or multiple cropping systems. In this regard, PRH 7 and PRH 16 would be promising.

For days to maturity, all hybrids in Expt. 1 and most hybrids in Expt. 2 showed highly significant negative heterobeltiosis, which was in desirable direction. On the other hand, when compared to the respective check variety, most hybrids in Expt. 1 showed significant positive heterosis. This was due to the fact that the check variety, Pusa 834, was significantly early than the hybrids. Lin and Yuan (1980) have reported positive heterosis for this character, while, Ponnuthurai *et al.* (1984) reported negative heterosis.

Several investigators in the past have suggested that it should be possible to increase grain yield by combining optimal duration for vegetative phase and the duration of grain filling. Daynard and Kannenberg (1976) reported positive relationship between grain filling duration and grain yield in corn. In the present study, most of the hybrids in both the experiments exhibited negative heterobeltiosis and standard heterosis for grain filling duration. In other words, the hybrids had higher rate of grain filling than their parental lines and thus completed the process in less time than the parental lines. In general, it was observed that late maturing genotypes also had longer grain filling duration.

The flag leaf contributes significant amount of photosynthates to developing grains in rice panicle. In Expt. 1, all the hybrids showed highly significant positive standard heterosis and most of them also exhibited positive heterobeltiosis. However, in Expt. 2, about half of the hybrids exhibited negative heterobeltiosis and the other half of them exhibited positive heterobeltiosis. When compared with the check, however, majority of the hybrids were superior, showing positive heterosis. The results are in conformity with the findings of Singh *et al.* (1996) who observed positive heterosis for flag leaf area. Similarly, Wan and Zhong (1981) found a highly significant correlation between flag leaf area and panicle weight.

Rice hybrids in general have large panicles and more spikelets per panicle than conventional varieties. In the present study, panicle weights were recorded for the main panicle as well as for all panicles of a plant. From this, average weight per panicle was also calculated. It was found that there existed a large difference between the weight of main panicle and the average weight per panicle, indicating that contribution of the main panicle to grain yield per plant was significantly higher than other panicles. Similar results were also obtained by Rao (1994). She observed that the main shoot possessed large panicle, more number of spikelets and higher percentage of high-density grains in comparison to the primary, secondary and tertiary tillers. The mother shoot and the primary tillers had higher number of high-density grains, harvest index and yield. Secondary and tertiary tillers contributed little to grain yield resulting in low harvest index.

In the present study, in Expt. 1, only two hybrids manifested significant heterobeltiosis for average weight per panicle, while in case of standard heterosis, eight of nine hybrids exhibited significant positive values. In Expt. 2, seven hybrids exhibited positive heterobeltiosis and nine exhibited positive standard heterosis for this character. The higher average weight of the panicles could be because of higher number of filled grains per panicle and higher spikelet fertility.

For number of filled spikelets, seven hybrids of Expt. 1 manifested positive heterobeltiosis and all of them manifested standard heterosis. However, in case of Expt. 2, most of the hybrids exhibited significantly negative heterobeltiosis. When compared with the check, five exhibited significant negative heterosis and four hybrids showed significant positive heterosis. The negative heterosis for this character in some of the hybrids could be due to the strong negative effect of the male sterility inducing cytoplasm on panicle exertion (Zhu, 1979), which was also observed during the course of the present investigation (data not presented). The male parents of these hybrids have native, fertile cytoplasm and high spikelet fertility, resulting in complete panicle exertion. While hybrids have the male sterility inducing cytoplasm, owing to its maternal inheritance, which may have a negative effect on panicle exertion in those hybrids, leading to basal spikelet sterility. This is clear from the fact that the average number of filled spikelets in the main panicle of the restorers (having native, fertile cytoplasm) was 136.01, while that of the hybrids (having the male sterility inducing WA cytoplasm) was only 109.90. Thus, on an average, the hybrids in Expt. 2 had about 20% less number of filled spikelets than their restorer parents, which is reflected as negative heterobeltiosis. The results obtained are in conformity with those of Virmani *et al.* (1981), who reported heterobeltiosis for this character to range from -70% to 55%. Even in case of Expt. 1, the AxR (AF_1) hybrids had significantly less number of filled spikelets in the panicle, as compared to their respective BF_1s or RF_1s.

Spikelet sterility is one of the constraints in hybrid rice breeding program as it affects the economic yield considerably. Weak or varying level of fertility restoration leads to increased spikelet sterility resulting in reduced grain yield. In addition, as explained before, with the WA cytoplasm reduced panicle exertion is a problem even with complete fertility restoration, which leads to basal spikelet sterility. Thus it may be noted that in these hybrids, poor panicle exertion is the real problem and not the source or sink or even assimilate translocation. Developing a hybrid combination involving parental lines with improved panicle exertion might help in improving the basal spikelet fertility of the resulting hybrid and thus contribute towards increased grain yield.

In the present study, only one hybrid, RF_1-1, in Expt. 1 showed positive heterobeltiosis for spikelet fertility while, none of the hybrids was showed significant negative heterobeltiosis. When compared to the check, all the hybrids were significantly superior. However, in case of Expt. 2, all the hybrids except PRH 16 showed highly significant negative heterobeltiosis for this character, indicating inferiority of the hybrids compared to their restorer parents. Three hybrids showed significant positive standard heterosis and four showed significant negative standard heterosis. Average yield of hybrids showing positive standard heterosis for spikelet fertility was 13.39 g, while that of the hybrids exhibiting negative standard heterosis was 12.96 g. Thus negative effect of the male sterility inducing cytoplasm is evident from the highly significant negative heterobeltiosis observed for spikelet fertility in most of the hybrids in Expt. 2. Similar results were also obtained by Rao (1985) and Ramesha *et al.* (1999). While, Kim (1985) did not find significant heterosis in spikelet fertility and stated that spikelet fertility did not contribute significantly to heterosis.

It is obvious therefore that the hybrids, in spite of having low spikelet fertility, showed heterosis for grain yield and this is primarily because of increased number of grains per panicle. Hence, increasing spikelet fertility in hybrids may result in further increase in grain yield.

Performance of any cross is normally estimated on the basis of the final grain yield, which in turn is affected by several characters contributing to yield. For example, Joshi (2001) observed high positive heterosis in several yield components; however, the grain yield was low. On further analysis, it was discovered that high negative heterosis for spikelet fertility masked the positive and significant performance of the other yield components, resulting in poor grain yield. Hence parental lines should be selected with great care to develop a good hybrid. While selecting parental lines, CMS lines having good panicle exertion and restorers giving good fertility restoration should be preferred.

Most of the hybrids in Expt. 1 manifested significant positive heterobeltiosis and all of them exhibited highly significant positive standard heterosis for number of spikelets in the main panicle. While, in Expt. 2, two hybrids showed positive heterobeltiosis and four exhibited negative heterobeltiosis. However, when compared to the check variety, majority of the hybrids manifested significant positive heterosis. The results obtained are in conformity with those reported by Blanco *et al.* (1986) and Kim (1985). Virmani *et al.* (1981, 1982) concluded that heterosis in grain yield was primarily due to increased number of spikelets per panicle and the work of Pillai (1961), Singh and Singh (1978), Govinda Raj (1983) and Panwar *et al.* (1983) give credence to the present findings.

For 1000-grain weight, six of the nine hybrids showed significant negative heterobeltiosis, while two of them exhibited significant negative standard heterosis and four manifested significant positive standard heterosis in Expt. 1. However, in

Expt. 2, half of the hybrids showed positive heterobeltiosis for this character and the rest of them showed negative heterobeltiosis. It was found that in Expt. 1, those hybrids, which exhibited negative standard heterosis for 1000-grain weight, also had less standard heterosis for grain yield and *per se* performance. While, this association was not observed in case of Expt. 2. The results are in conformity with those obtained by Kim and Rutger (1988), who observed high correlation between 1000-grain weight and grain yield. Kumar *et al.* (1994), however, observed that heterosis in grain weight differed according to cross combination.

It is apparent from the results presented and previous reports that grain number per panicle and 1000-grain weight are negatively correlated. Since both these traits are equally important yield components, their simultaneous improvement, by developing a hybrid that would combine both these traits, may significantly increase heterosis for grain yield.

Kumar *et al.* (1994) noted that grain weight is highly correlated to grain size, which in turn, depends on the size and shape of lemma and palea of the mother plant. In Expt. 2, it was observed that, the hybrids exhibiting negative standard heterosis for 1000-grain weight, had either PMS 2A or IR 58025A as the maternal parent (except PRH 28, which had Pusa 5A as the maternal parent). The CMS lines PMS 2A and IR 58025A have small grains, having 1000-grain weight of only 14.48 g and 15.78 g, respectively, compared to 17.55 g of Pusa 5A. In addition, all the hybrids (except PRH 28) having the maternal parent Pusa 5A exhibited high positive standard heterosis for 1000-grain weight.

A perusal of the data on relative magnitudes of heterobeltiosis and standard heterosis indicates superiority of many hybrids over their respective better parents as well as the check varieties in respect of biomass yield, grain yield and harvest index. While increased grain yield was invariably due to increased dry matter production in some of the hybrids, it was on account of high harvest index as well. Seven hybrids in Expt. 1 exhibited consistent and significant standard heterosis for biomass yield, harvest index and grain yield. This kind of desirable association has been reported by Rao (1965), Virmani *et al.* (1981) Ponnuthurai *et al.* (1984) and Kim (1985).

According to Sinha and Khanna (1975), both the source and sink capacity should increase if yield is to be improved and such a phenomenon has been observed in the present investigation. It was observed that all the hybrids exhibiting positive standard heterosis for biomass production also manifested positive standard heterosis for grain yield. Some of the hybrids like RF_1-2, BF_1-3 and PRH 16 were particularly superior. Similar results were obtained by Virmani *et al.* (1981, 1982). As a matter of fact, hybrid superiority to conventional varieties in biomass yield has been reported widely. Ponnuthurai *et al.* (1984) and Kim (1985) found that high yielding hybrids also showed significant heterobeltiosis for total dry matter and harvest index. Kim and Rutger (1988) noted that hybrids that gave high grain yields also produced high biomass. Zhende (1988) also observed that hybrid rice accumulates more total dry matter than conventional rice.

In the present investigation, the relationship between biomass yield and harvest index varied with the cross. In some cases, for instance, the high biomass yield was not accompanied with high harvest index. This was found in case of AF_1-3 and PRH 21. Similar results were obtained by Yamaguchi *et al.* (1985) who reported that rice hybrids accumulated relatively more dry matter but they tended to have lower harvest index as compared to purelines.

In terms of harvest index, RF_1-2 had the highest value (0.46) in Expt. 1, with biomass yield of 49.23 g. While in Expt. 2, the hybrid PRH 5 had the highest harvest index of 0.48, with a biomass yield of 30.16 g. On the other hand, AF_1-3, with 52.73 g of biomass, had the harvest index of only 0.39. Similarly, in Expt. 2, the hybrid producing the highest biomass of 41.97 g (PRH 2) had the harvest index of only 0.34. These observations are contrary to those of Sitaramaiah *et al.* (1998), who observed that high yielding hybrids also recorded higher biomass yield and higher harvest index.

Thus it can be said that, generally, high yielding hybrids have higher biomass production. However, higher yield depends not only on higher biomass production, but also on efficient partitioning of photosynthates to grains. Hence it will be more useful to select hybrids which have efficient partitioning ability, indicated by higher harvest index, than those producing higher biomass but with inefficient partitioning. In this respect, the hybrid PRH 5 will be the most promising.

Physiological and biochemical characters

Nine hybrids were studied for heterosis over better parent and standard check for various physiological and biochemical attributes. It was observed that both the nature and magnitude of heterosis differed, not only from character to character, but also at different growth stages and in different cross combination. Considerable heterosis was observed both in positive and negative directions for all the characters studied. The salient findings of the present investigation are discussed below.

Heterobeltiosis for crop growth rate (CGR), which ultimately helps in building up of the total biomass varied considerably from phase to phase. During seedling to tillering phase, heterobeltiosis for CGR ranged from 4.85% to 31.10%, while during tillering to flowering phase it ranged widely from -12.18% to 75.90%. Heterobeltiosis for CGR during flowering to maturity phase also varied considerably, from -13.88% to 51.91%. The high yielding hybrid, RF_1-2 showed high CGR in tillering to flowering phase and also significant heterobeltiosis for CGR in the same phase. While another high yielding hybrid, BF_1-3 had comparatively lower CGR in this phase, but quite high in seedling to tillering phase. When CGR for the whole growth duration was taken into account, these hybrids manifested higher values of 411.95 (RF_1-2) and 418.32 (BF_1-3). These hybrids showed high CGR during active growth phase and also produced high grain yield. Similar results were also reported by Ponnuthurai *et al.* (1984) who observed high heterosis in CGR during vegetative growth phase but little heterosis after heading. They found that hybrids showing higher heterosis in biomass yield also exhibited heterosis in CGR at the initial stage, but this heterosis in CGR decreased with growth. Sitaramaiah *et al.* (1998) also observed that CGR increased up to 45 days after planting and decreased later in all the six hybrids. With respect to RGR during the same growth phase, these three hybrids also expressed high *per se* values as well as significant heterobeltiosis for RGR.

The net assimilation rate (NAR) is the indirect measure of photosynthetic efficiency of a plant and in the present study it has been estimated at three different phases, *viz.* seedling to tillering, tillering to flowering and flowering to maturity. The data shows that NAR was very high in the early growth phase, seedling to tillering and decreased with the age of the crop. Only two hybrids exhibited positive heterobeltiosis for NAR in seedling to tillering phase and one hybrid exhibited negative heterobeltiosis. While, during tillering to flowering phase, most of the hybrids exhibited positive heterobeltiosis, of which four were significant and only two manifested negative values. The three best yielding hybrids, RF_1-2, BF_1-3 and RF_1-3 showed mean mid-parent heterosis of 30.60% for NAR during tillering to flowering phase, indicating thereby that high NAR in this phase is of crucial importance for building up of high biomass and grain yield. Similar heterosis in NAR was observed by Murayama *et al.* (1982). However, Yamauchi and Yoshida (1985) reported only a little heterosis for NAR.

To achieve required biomass yield, optimum LAI has to be ensured first. The present study with respect to leaf area, LAR, LAI and LAD shows considerable variation in heterosis among hybrids for these traits. It was found that most of the hybrids exhibited positive heterobeltiosis for leaf area in seedling, tillering and flowering stages. However, at maturity, four hybrids exhibited negative heterobeltiosis. Similar results were obtained for LAI as well. Most of the hybrids also exhibited high standard heterosis for leaf area and LAI at maximum tillering, flowering and maturity stages. Blanco *et al.* (1986) also found similar results and indicated that heterosis in leaf area development during seedling stage would be the key to vigorous growth after transplanting in hybrids. They also observed that during vegetative growth, the LAI of hybrid rice increases rapidly, which favors production of more carbohydrates from photosynthesis in hybrid plants. Zhende (1988) states that hybrid rice has higher LAI and higher ratio of upper to middle layer leaf area, as well as better light intensity distribution in the canopy. The increase in upper to middle layer leaf area ratio favors photosynthesis, resulting in yield heterosis at later stages.

Conversely, most of the hybrids exhibited negative heterobeltiosis for LAR in all the three growth phases. However, all the hybrids expressed positive standard heterosis. Whereas, for LAD in tillering to flowering phase, four hybrids manifested negative heterobeltiosis and only one exhibited positive heterobeltiosis. At later growth phase (tillering to maturity), four hybrids, including the three high yielding hybrids, exhibited positive heterobeltiosis for LAD and two hybrids exhibited negative values. In this case too, all the hybrids manifested positive standard heterosis. These results are in agreement with those obtained by Zhende (1988), who observed that the leaf area duration is significantly longer in hybrids than it is in conventional rice varieties.

α-Amylase is an amylolytic enzyme synthesized *de novo* in seeds of rice and wheat. It is a primary enzyme in conversion of starch to simple sugars that provide energy for the growing seedlings. In the present investigation on α-amylase activity at various stages of growth of germinating seeds, all hybrids manifested significant heterosis over the respective better parents as well as the standard check at all the three stages. Similar results were obtained by several workers. Li *et al.* (1982) observed heterobeltiosis of as much as 433% in α-amylase activity of a hybrid. They observed germination speed of a hybrid and its three parental lines was in the order of 'hybrid > R line > B line > A line'. A similar order was found in the activity of their α-amylases. Yang *et al.* (1990) also observed greater amylase activity in hybrid seeds compared to that in the parents. Karrer *et al.* (1993) found significant positive correlation among seedling vigor, α-amylase activity and accumulation of mRNA from a rice α-amylase gene, RAmy1A. Their study thus correlates α-amylase enzyme activity with seedling vigor.

Nitrate reductase (NR) is the enzyme that catalyzes reduction of nitrate to nitrite, the rate-limiting step in the reduction of nitrate to ammonia (Beevers and Hageman, 1969). For nitrate reductase activity (NRA), most of the hybrids in the present investigation exhibited the advantage at tillering and flowering stages and not at seedling or maturity stages. In addition, four hybrids exhibited negative heterobeltiosis in seedling stage and five at maturity stage (25 days after flowering). The high yielding hybrid RF_1-2 exhibited non-significant positive heterobeltiosis at tillering and flowering stages and significant negative heterobeltiosis at seedling to maturity stage. Such variations for NRA in rice have been demonstrated by Rao *et al.* (1979), Yuan and Shien (1980) and Pal and Pal (1986). The results obtained in the present investigation on NRA are in agreement with those obtained by Manonmani *et al.* (1993) who observed that the enzyme activity was low in seedling stage and increased at flowering stage (up to 70 days after sowing) and declined thereafter.

With respect to grain nitrogen and grain protein content, five hybrids were found to show negative heterobeltiosis and only one hybrid exhibited positive heterobeltiosis. However, compared with the check, none of the hybrids were superior. This could be due to two reasons: (a) absence of exploitable level of variation among parental genotypes for these characters, indicated by a narrow range (1.33% – 1.76%) for grain nitrogen content, as well as for grain protein content (7.91% – 10.47%) and (b) due to the fact that these parameters are difficult to improve beyond a certain limit.

Amylose is a linear fraction of starch, which has a major influence on cooking and eating quality of rice. For amylose content, though all hybrids exhibited positive heterobeltiosis, only four of them were significantly superior to their better parents. However, compared to the check variety, none of the hybrids was significantly superior. Similarly, for starch content, five hybrids exhibited significant positive heterobeltiosis but all of them failed to express standard heterosis.

In terms of the *per se* performance for grain yield of the three restorers, Pusa 1124 was the highest yielding (17.71 g), followed by PRR 78 (14.71 g) and Pusa 1127 (12.17 g). Analysis of the performance of Pusa 1124 reveals that, it had high number of productive tillers, high weight of main panicle as well as of all panicles, high spikelet fertility, even though it had less numbers of filled and total spikelets in the main panicle, high biomass yield and high harvest index. In terms of physiological parameters, it had high CGR during various growth phases and also for the whole crop duration, high leaf area and LAI throughout the growth duration and also high LAD. Similarly, in terms of biochemical parameters, activities of the enzymes α-amylase and nitrate reductase were very high compared to those in the other two restorers.

Analysis of the level of heterobeltiosis for grain yield and the *per se* performance of hybrids in Expt. 1 reveled that RF_1-1 exhibited the highest heterobeltiosis (50.11%) for grain yield; however, in terms of *per se* performance, it ranked seventh, with only 18.26 g grain yield per plant. Similar results were obtained in case of BF_1-1 as well. On the contrary, the hybrid, RF_1-2 exhibited moderate heterobeltiosis of 25.19% (6^{th} rank), but a very high *per se* performance (22.17 g grain yield per plant), being the first. The other two high yielding hybrids, BF_1-3 and RF_1-3 ranked second and third respectively for both the level of heterobeltiosis as well as in terms of their *per se* performance. Similarly, in Expt. 2, it was found that the hybrid PRH 5 exhibited heterobeltiosis of as much as 74.91% followed by PRH 16, which manifested 53.66% heterobeltiosis. However, in terms of *per se* performance, PRH 16 scored highest with grain yield of 15.32 g per plant, followed by PRH 5 (14.54 g). The hybrid PRH 3 scored third in heterobeltiosis (37.18%) for grain yield, while on the basis of *per se* performance, it ranked seventh with grain yield of 13.51 g per plant. Conversely, PRH 2 exhibited only 7.79% heterobeltiosis (11^{th} rank), but in terms of *per se* performance for grain yield per plant, it scored 4^{th} (14.12 g).

From the foregoing discussion it is obvious that although the percentage of heterosis is important, if a cross with high percentage of heterosis is associated with low *per se* performance, its practical value from a breeding point of view is rather low. In some cases, on the other hand, higher *per se* performance may be associated with relatively low heterosis. Both the situations are not as much of value, as the one combining high heterosis and high *per se* performance. From this point of view, BF_1-3 sounds promising. Analysis of this hybrid in particular, shows that it had less number (9.60) of productive tillers, which however were better yielding as indicated by the high average weight of panicles (2.81 g), which was the highest among all the genotypes in Expt. 1. It also had the highest numbers of filled and total spikelets in the main panicle, high spikelet fertility and highest biomass yield. Taking into account the physiological traits, the hybrid exhibited the highest advantage in CGR in seedling to tillering phase and also for the whole crop duration. RGR was also high in the initial growth phase. For leaf area and LAI, however BF_1-3 exhibited highest values only at maturity stage indicating high LAD, although it showed superiority during the initial growth stages as well. However, for the biochemical parameters, the hybrid did not show exceptionally superior performance as compared to other hybrids.

Genetic analysis of various characters

In order to improve various component characters governing yield, it is important to know the nature of association among those traits and also their inheritance pattern. In the present study, an effort was made to study the nature and magnitude of association among various yield components and physiological and biochemical characters. In addition, the pattern of variation for yield components was also studied in nine F_2 populations, each comprising 200 plants. The results of the present study are discussed below.

Nature and magnitude of character association

To formulate an objective selection criteria for effective improvement of biological yield or grain yield, it is important to have basic information on the nature and strength of relationships between biological yield or grain yield and the various yield components as well as the physiological and biochemical parameters. The present study reveals that biological and grain yield are associated positively with parameters like number of productive tillers, average panicle weight, biomass yield, harvest index, leaf area, LAI, LAD, NRA etc.

Study of character association separately among the parents and hybrids is essential because it is a well known fact that the strength of association varies depending on the type of test material used and also from material to material. However, as the number of restorer parents in Expt. 1 was only three, the correlation coefficients were calculated only for hybrids, separately for yield components, physiological and biochemical parameters and also for pairs of yield components and the physiological and biochemical parameters. However, in Expt. 2, the correlation coefficients were calculated separately for parents and hybrids for pairs of yield components.

The association of various characters with grain yield has been worked out by using purelines and segregating populations in rice. Grain yield has been found to show high positive correlation with number of productive tillers and grain number (Chauhan *et al.*, 1986; Raj and Siddiq, 1986; Kim and Rutger, 1988), 1000-grain weight (Sukanya and Rathinam, 1986; Vijayakumar *et al.*, 1997), biomass yield (Siddiq and Reddy, 1984; Ganesan and Subramaniam, 1990), harvest index (Vinaya Rai and Murty, 1979; Sukanya and Rathinam, 1986), flag leaf area (Daskalov *et al.*, 1986; Bashar *et al.*, 1991) and growth parameters such as CGR, RGR and NAR (Burondkar *et al.*, 1988; Murty *et al.*, 1986; Murty and Sahu, 1987).

Grain yield and yield components

The estimates of correlation coefficients worked out for hybrids of Expt.1 indicate that the yield components such as flag leaf area (0.93), length of main panicle (0.95), weight per panicle (0.86), 1000-grain weight (0.86) and biomass yield (0.91) had significant positive correlation with grain yield. Similar observations on the positive correlation between grain yield and flag leaf area have been made by Daskalov *et al.* (1986), while Wan and Zhong (1981) found a highly significant correlation between flag leaf area and panicle weight. Sukanya and Rathinam (1986) and Vijayakumar *et al.* (1997) reported high correlation between 1000-grain weight and grain yield per plant. Virmani *et al.* (1981, 1982) concluded that number of spikelets per panicle was significantly associated with grain yield, to such an extent that it compensated for the reduction caused in number of productive tillers per plant. This was observed even in the present study. The number of spikelets in panicle exhibited positive and comparatively higher, but non-significant association with grain yield (0.59), as against the negative and non-significant association of the number of productive tillers with grain yield (-0.20).

The significant inverse relationship between number of productive tillers and average panicle weight (-0.65) supports the observations of Rao (1994) that more number of secondary and tertiary tillers contributed little to grain yield and actually had negative effect on grain yield. In addition, the significant inverse relationship between number of productive tillers and spikelet fertility (-0.66) supports the findings of He and Shen (1991) that, sometimes high tillering observed in rice hybrids is due to sterility. The positive and significant relationship between flag leaf area and grain yield indicates that flag leaf contributes significantly to grain yield per plant, with its positive effect on spikelet fertility, weight per panicle and 1000-grain yield. These results are in conformity with those obtained by Wan and Zhong (1981) and Daskalov *et al.* (1986).

It was found that weight per panicle was positively associated with total number of spikelets in panicle, spikelet fertility, 1000-grain weight and also influenced the biomass yield and grain yield. Similar results were obtained by Chauhan *et al.* (1986), Raj and Siddiq (1986), Sukanya and Rathinam (1986) and Vijayakumar *et al.* (1997). 1000-grain weight was found to have highly significant positive association with harvest index and grain yield. These results are in accordance with the findings of Kim and Rutger (1988) and Vijayakumar *et al.* (1997). Significant positive correlation between HI and grain yield has been reported by several workers in rice (Sahu and Murty, 1976; Vinaya Rai and Murty, 1979 and Sukanya and Rathinam, 1986). The present study also indicates a significant positive association between harvest index and grain yield.

Sharma *et al.* (1987) observed that the two major yield components, biomass yield and harvest index show positive correlation with yield, but correlation between them is negative. However, in the present study, a moderately positive correlation was observed between biomass yield and harvest index, indicating the possibility of breaking the negative correlation between these yield components and increasing the grain yield significantly.

The estimates of correlation coefficients worked out separately for restorer parents and hybrids of Expt. 2 revealed that the principal components that influence yield are different in parents, which are purelines and hybrids. It was also noted that the number of significant relationships for various character pairs was much less in Expt. 2, compared to that in Expt. 1, for the same set of yield components. This could be due to the fact that, estimates of correlation are the property of the population analyzed and these cannot be applied to other population as such.

It was observed that, in parents, grain yield was significantly and positively associated with the number of productive tillers, panicle length, average weight per panicle and biomass yield. However, its correlation with harvest index was found to be weak and in negative direction. The number of productive tillers was found to influence biomass yield positively. This is expected, as biomass would increase with increase in number of tillers. However, its inverse relationship with harvest index indicates that presence of more numbers of secondary and tertiary tillers would have a negative effect on harvest index. These observations are in complete agreement with those of Rao (1994).

On the contrary, flag leaf area positively and significantly influenced harvest index. However, it was found to be inversely associated with biomass yield in parents and positively associated with the same character in hybrids. Panicle length was found to be non-significantly and positively associated with weight per panicle and number of spikelets in panicle. As expected, the weight per panicle was significantly associated with number of spikelets in panicle.

The estimates of correlation coefficients in hybrids indicate that the attributes that influence grain yield differ in magnitude than those in parents. For example, in contrast to the observation in parents, number of productive tillers did not have significant association with any of the yield component or grain yield. Interestingly, it was observed that the character was negatively, although non-significantly correlated with weight per panicle, total number of spikelets in panicle and spikelet fertility, in hybrids of both the experiments. However, its correlation with 1000-grain weight, biomass production, harvest index and grain yield was not of the same nature and magnitude.

Similarly, days to 50% flowering was negatively associated with weight per panicle, total number of spikelets in panicle, spikelet fertility, harvest index and grain yield in both the experiments. While compared to the similar associations in parents, the nature as well as magnitude was different. Similar situations were found for the association of flag leaf area with number of spikelets in panicle, biomass yield, harvest index and grain yield. As against the negative relationship between harvest index and grain yield in parents, the hybrids exhibited significant positive association between the two characters.

The results indicate that the overall superiority of the hybrids is largely because of significantly increased panicle weights, high number of spikelets per panicle, 1000-grain weight, biomass yield and harvest index. Virmani (1986) also found that high yielding hybrids also had high harvest index and biomass yield. However, Yamaguchi *et al.* (1985) did not find positive correlation between grain yield and harvest index.

Grain yield and physiological and biochemical parameters

Table 14 clearly indicates that in relation to the physiological and biochemical characters, grain yield was significantly correlated with leaf area at flowering, LAD at tillering to flowering, α-amylase activity and NRA at flowering. Among the components, CGR, RGR, NAR and LAR were found to be positively associated among themselves. This is expected as these growth parameters are based on biomass production at various phases of crop growth phases, the leaf area production in those stages and the time interval spent in each phase.

Some negative correlations were also observed in the present study. The crop growth rate during tillering to flowering phase was non-significantly and inversely associated with NRA at flowering. However, this could be due to the fact that different genotypes express different growth rates for the same growth phase. In other words, as clear from Table 5, there was considerable variation in CGR among the hybrids during tillering to flowering stage offering opportunity for selecting appropriate hybrids.

The negative association, although non-significant, between leaf area at flowering and NAR at tillering to flowering phase suggests the need to strike a balance between these two parameters, which constitute the relative growth rate of the plant consequently affecting the biological and grain yield.

The highly significant correlation of leaf area at flowering with LAD at tillering to flowering (0.94), indicated that the high leaf area produced by the hybrids at flowering stage was retained for long time, which helped them in building high amounts of photosynthates and ultimately high grain yield, as confirmed by the highly significant positive correlation of leaf area with grain yield (0.92) and also of LAD at tillering to flowering phase with grain yield (0.90). These findings support the observations of Alluri and Vergera (1976) and Yoshida (1981). In addition, significant associations of leaf area and LAD with NRA at flowering indicate high photosynthates production by the hybrids. NRA in turn, was significantly related with grain yield, supporting the findings of Yang and Sung (1980).

These results indicate that with respect to the improvement of biological yield and grain yield, parameters like crop growth rate, leaf area, LAD, NRA are of considerable importance because they constitute a set of characters that show very strong positive relationship with biological and grain yield, either directly or indirectly. In view of such close association, it is quite logical to believe that by manipulating the genetic potential for high crop growth rate, LAI, LAD and NRA, significant improvement could be made in biological and grain yield. Efforts to improve even one of these traits will simultaneously promote the other traits, as these traits are highly inter-correlated. Nevertheless, one should take into account, the other physiological parameters associated with these traits, to improve the biological yield. High LAI, especially at flowering is very important, not only for realizing high biomass production, but also for high grain yield, since photosynthates formed from the start of flowering will be directed to development of the grains. Thus, dry matter production follows a positive relationship with grain yield confirming the observations of Vergera *et al.* (1970). Hence maintenance of optimum LAI especially at flowering stage is an important pre-requisite to have high grain and biological yields, as well as high harvest index.

Yield components and physiological and biochemical parameters

In view of the complex nature of the yield components and their dependence on the various physiological and biochemical characters, it would be necessary to have a precise knowledge about the nature and strength of association between these traits. It was found that the number of productive tillers exhibited negative association with many of the physiological and biochemical characters (Table 15). However, the association was significant with CGR at tillering to flowering phase (-0.51). Association with RGR and NAR was also negative, though non-significant. As mentioned above, this could be due to the fact, that these negative associations are limited only to the particular growth stage, tillering to flowering, which was used for correlation analysis. Hence, these associations do not necessarily indicate inverse relationships between these character pairs in all the growth stages of the crop.

The number of days to 50% flowering was found to negatively influence the growth parameters, CGR, RGR and NAR, which is expected, as the rate of growth is inversely related to time. Flag leaf area was highly correlated with leaf area per plant (0.85), which is natural. However, its positive and high correlation with LAD at tillering to flowering indicates that the flag leaf area in the hybrids was maintained for a significantly longer duration. The highly significant and positive associations of weight per panicle with LAI at flowering stage (0.79) and LAD at tillering to flowering (0.72) are in full agreement with the observations of Yaoxing (1996). CGR at tillering to flowering significantly increased the total number of spikelets in the panicle, as indicated by the correlation coefficient of 0.60. In addition, the spikelet number in panicle was significantly influenced by LAI at flowering in positive direction (0.59) and also by LAD at tillering to flowering, though non-significantly (0.45). These results underscore importance of these physiological characters *per se* and significance of their relationships with yield components and ultimately grain yield.

Spikelet fertility was also significantly influenced by CGR in tillering to flowering phase as indicated by the correlation coefficient (0.52). This must have been indirectly through production of higher photosynthates and biomass during this phase and also efficient translocation of this food material to the grains during post-anthesis period. Similarly, RGR and NAR also influenced spikelet fertility positively, though non-significantly. The character, 1000-grain weight was highly influenced by LAI at flowering (0.77), LAD at tillering to flowering phase (0.86) and NRA at flowering stage (0.90). These factors once again underscore importance of these characters in producing high biological and grain yield through production of more photosynthates and their efficient translocation. This is also clear from significant positive correlations of these traits with biomass yield and harvest index.

The present findings on the nature and association between various character pairs indicate the importance of flag leaf area, number of spikelets in panicle, spikelet fertility, 1000-grain weight and harvest index for increasing biological as well as grain yields. At the same time, the study also underscores the importance of other physiological and biochemical characters such as CGR, RGR, LAI, LAD and NRA at various growth phases for increased biological and grain yields.

In general, it has been observed that the two major yield components, biomass yield and harvest index, show positive correlation with grain yield, but negative correlation between themselves (Sharma *et al.*, 1987), therefore, simultaneous improvement of both these characters has been rather too difficult. However, as revealed by present finding, the strength of correlation between these traits varies with the breeding material. The study, in fact, showed that it is possible to weaken the negative association between these desirable yield components and to combine them favorably by selecting desirable parental lines and following appropriate breeding strategy. Singh (1988) has reported a similar trend in cotton where the negative correlation of boll number with boll weight and biomass with harvest index has been changed to positive by selective intermating among segregates of a selected cross combination.

Genetic analysis of yield and yield components in F_2 populations

Most of the yield contributing characters are quantitative in nature and are governed by a large number of genes or QTLs. Hence to observe the extent and pattern of variation for these characters and to distinguish the part of the variation that is genetic in nature, present investigation was undertaken on nine F_2 populations from three AxR, BxR and RxB crosses, involving three CMS lines, PMS 2A, Pusa 5A and IR 58025A, their respective maintainers and three restorers, Pusa 1127, Pusa 1124 and PRR 78. Frequency of transgressive segregants was also worked out for the characters, which indicates the scope of variation in the F_2 populations and their possible use in breeding program. The salient findings of the study are discussed here.

Among the characters studied in the nine F_2 populations, the maximum phenotypic variation (measured as coefficient of phenotypic variation, PCV) was observed for grain yield and numbers of filled and unfilled spikelets in the main panicle. This could be because of segregation for pollen fertility. As the fertility restorer (*Rf*) gene(s) segregate in F_2 population, the plants would segregate from completely sterile to completely fertile. As outcrossing in rice is very less, the plants with high pollen fertility would produce higher yields. However, the male sterile plants would produce seed only when fertilized by pollen from fertile plants, resulting in large variation for grain yield. The large variation in number of unfilled spikelets can also be explained on the same grounds.

Variation was also high for other panicle characteristics such as weight of main panicle, weight of all panicles, average weight per panicle, panicle density and spikelet fertility. All this variation can be traced to segregation for the *Rf* gene(s). Considerably high variation was also observed for biomass yield, straw yield and harvest index. This could result due to variation in different characters in the F_2 plants.

The least PCV was observed for length of the main panicle followed by 1000-grain weight in the nine F_2 populations. This indicates the stable nature of these characters owing to the least environmental influence. However, Kumar *et al.* (1994) explained the variation in 1000-grain weight by observing that 1000-grain weight is highly correlated to grain size, which is a product of grain length and width that are inherited independently, which leads to variation in grain weights. Genetic analysis of 1000-grain weight by Murai *et al.* (1987), Kaushik and Sharma (1988) and Siddiq *et al.* (1994) revealed that it is predominantly under the control of non-additive gene effects. However, some workers have reported that 1000-grain weight is controlled by additive gene effects (Tripathy and Mishra, 1987) and by both additive and non-additive gene effects (Sardana and Borthakur, 1987; Mao and Virmani, 1994).

As expected, grain yield also exhibited the highest genotypic variation (measured in terms of genotypic coefficient of variation, GCV), followed by numbers of filled and unfilled spikelets. As stated earlier, variation in pollen fertility resulting due to segregation of *Rf* genes could be the main factor behind the high GCV values obtained for the yield attributes. The same explanation would hold true for high genotypic variation observed for other yield attributes such as weights of main panicle, all panicles, average weight per panicle, spikelet fertility and panicle density. However, GCV value for total number of spikelets was much less, indicating relatively stable nature of the character. High GCV values were obtained for flag leaf area coupled with low ECV values. This indicates that much of the phenotypic variation observed in the F_2 populations was due to underlying genetic differences. The lowest GCV values were obtained for panicle length and 1000-grain weight, again indicating their stable nature.

In terms of the environmental coefficient of variation (ECV), the highest values were obtained again for the numbers of filled and unfilled spikelets, indicating that these characters are affected greatly by environmental (or external) factors, such as availability of enough load of fertile pollen in the field. Consequently, weights of main panicle, all panicles and average weight per panicle, in addition to spikelet fertility, panicle density, grain yield and harvest index also exhibited significant environmental variation. In comparison, the ECV for total number of spikelets in main panicle was quite low. As expected, the least variation was observed for 1000-grain weight and panicle length. Flag leaf area also showed less environmental variation. These results indicate that these traits are quite stable and form characteristics of a particular genotype.

For some characters like number of productive tillers, flag leaf area, length of main panicle, it was found that the phenotypic as well as genotypic variation in the F_2 populations depended on the level of contrast of the character in the parental genotypes. Higher differences in parents gave rise to higher variation in the F_2 population. However, this condition was not consistent in case of yield parameters, which are highly influenced by the environment, such as numbers of filled and unfilled spikelets, weights of panicles, biomass yield, grain yield and harvest index.

The frequency distributions diagrammatically presented in figures 4a through 6c indicate that most of the distributions followed the normal curve. The frequency distributions for all the 17 characters in all the nine F_2 populations were subjected to goodness-of-fit test for normal distribution (One sample Kolmogorov-Smirnov test, "KS test") and the results have been presented in Tables 21, 22 and 23. Analysis of these tables indicate that for characters like number of productive tillers, flag leaf area, weight per panicle, biomass yield and grain yield in AF_2-1, the deviation of the frequency distribution from the normal curve was significant at 5% probability level. However, at 1% probability level, these distributions followed the normal curve. Alternatively, for characters like, number of productive tillers in BF_2-1, number of unfilled spikelets in BF_2-3 and RF_2-3, the frequency distribution significantly deviated from the normal curve even at 1% probability level. However, deviations for these characters were inconsistent and differed with the F_2 populations. This indicates that the deviations may be due to sampling fluctuations. Incorporating data from large samples may eliminate the deviations making the distribution normal.

Existence or creation of genetic variability is a must for selecting desirable genotypes in any crop. Selecting and using transgressive segregants from a cross between diverse parental lines will utilize the large genetic variation for breeding highly heterotic hybrids. Hence in the present investigation, F_2 populations from the nine crosses were screened for transgressive segregants in desirable direction. The results are presented in Table 24 and discussed hereunder.

Some characters like panicle length, 1000-grain weight and total spikelets in main panicle exhibited high percentage of transgressive segregants in desirable direction consistently in most of the F_2 populations. This indicates that this consistency is due to underlying genetic variation for the character and not merely due to the positive influence of the environment on the character. This also indicates polygenic nature of these traits. Transgressive segregants result due to accumulation of desirable genes from the two parents. Hence, if a trait is governed by polygenes, there is a greater chance of occurrence of transgressive segregants in segregating populations like F_2. However, the percentage of transgressive segregants for flag leaf area in the F_2 populations of first cross combination was much less compared to those obtained in the second and third cross combinations. This could be due to presence of identical alleles (or genes) governing flag leaf area in the parental genotypes. Hence, no transgressive segregants could be detected for this character.

Transgressive segregants were also observed for yield components such as numbers of filled spikelets, weights of panicles, spikelet fertility and harvest index. However, as clear from the high environmental variation observed for these characters, selecting these transgressive segregants for improving yield may not be successful. For grain yield, however, the percentage of transgressive segregants obtained was low compared to other yield parameters.

Interestingly, it was observed that in case of the third cross combination, involving IR 58025A, IR 58025B and PRR 78, the percentage of transgressive segregants was much high for most of the characters, than that observed in the first and second cross combinations. This could be due to the parental lines being genetically more diverse in this cross combination than those of the first and second cross combinations. It is worth to note that BF_1-3 and RF_1-3 were among the highest yielding hybrids from resulting from this cross combination in Expt. 1, which strengthens the proposition of diversity of the parental lines.

The present study on segregation pattern of various yield attributes in the nine F_2 populations indicates that most of the characters are quantitatively inherited. It is well known that the quantitative traits are mostly governed by non-additive and epistatic gene actions. Hence heterosis breeding is the most suitable approach to break the genetic yield ceiling in rice. In fact, Xiao *et al.* (1995) have already shown that dominance is the major genetic basis of heterosis in rice, while Yu *et al.* (1997) have shown that epistasis is the genetic basis of heterosis in an elite rice hybrid. In addition, Zhang *et al.* (2001) have demonstrated epistasis underlying the genetic basis of quantitative characters and heterosis in rice. They have listed several QTLs governing yield and yield components, which were detected using several kinds of DNA markers (Table 30). This indicates that a major part of variation in even complex traits like grain yield or number of grains per panicle is in fact governed by relatively a small number of QTLs with major effects. Yet these QTLs do not account for complete variation observed for the trait in question, which indicates that the remaining variation may be controlled by a large number of genes (polygenes) with small individual effect.

Effect of sterility inducing cytoplasm on various characters

The 'wild abortive' (WA) male sterility inducing cytoplasm from *Oryza sativa* f. *spontanea* has been gainfully utilized to ease the system of controlled pollination and thereby to pave a way for exploiting heterosis in rice. Some investigations indicated that the sterility inducing cytoplasm influences expression of certain agronomic characters in addition to inducing male sterility. However, such reports are in scanty with respect to the physiological and biochemical characters, which are also equally

Table 30 : QTLs detected for yield and yield components (Zhang *et al.*, 2001)

Character	QTL#	Flanking markers	LOD score	A	D	IL
Yield	yd1	R753-C161	3.5	-0.3	3.2	0
	yd1b	RG101-C922	2.6	-1.7	-0.3	3
	yd4	R514-C2807	2.4	-1.8	1.4	4
	yd5	G193-RZ649	3.3	-0.5	3.4	3
	yd5a	C624-C246a	2.7	-1.4	2.9	0
	yd5b	RG360-R1674	2.5	1.5	0.2	4
	yd6	R565-R902	2.8	1.7	0.4	4
	yd7[b]	RG128-C1023	3.5	-1.8	2.3	2
	yd8	C483-R1629	3.2	0.8	2.4	1
	yd11[b]	C950-G389b	3.2	-0.5	2.7	1
Tillers per plant	tp4	C820-C56	3.1	-0.4	-0.1	2
	tp5	G1458-G193	2.8	-0.4	0.2	2
	tp7	RZ471-MX2	3.2	0.5	-0.5	6
	tp10	C677-G4003	2.7	-0.2	-0.5	4
Grains per panicle	gp1a	R753-C161	3.1	-5.2	4.4	0
	gp1b	RG173-RG532	4.2	-7.9	-3.5	4
	gp3	R1966-G144	8.3	10.0	-3.6	1
	gp5[b]	G193-RZ649	2.4	-1.3	10.3	1
	gp6[b]	RG653-G342	2.5	4.1	-5.6	1
	gp7	C1023-R1440	4.7	-5.2	6.5	2
	gp11	C950-G389b	3.1	-0.7	7.3	0
1000-grain weight	gw1[b]	R753-C161	3.5	0.7	1.5	1
	gw3[c,d]	R19-RZ403	11.4	-1.8	-0.4	8
	gw3a	C944-C746	9.5	-1.4	0.2	3
	gw3b	R1966-G144	11.4	-1.7	-0.7	9
	gw5[c]	RG360-C734	8.5	1.3	0.1	1
	gw6	R1952-C226	2.6	0.7	0.5	3
	gw6b	R565-R902	4.7	1.0	0.3	5
	gw7[b,d,e]	RG128-C1023	2.3	-1.0	0.2	3
	gw8	C1121-RG333	2.7	0.7	-0.7	5
	gw9	R2638-RG570	4.1	1.2	-0.3	0
	gw11[e]	RM4-RG98	2.2	-0.6	0.7	1

= Numbers following the two letters represent the chromosomal locations of the QTLs.

A = Additive effect, D = Dominance effect, IL = Number of loci with which the QTL interacts.

[b, c, d, e] = Pairs of interacting loci within a character.

important in expression of heterosis. Such an understanding would facilitate selection of the desirable heterotic combinations with least negative effect of the sterility inducing cytoplasm on traits of economic importance.

Since only a part of the mitochondrial genome accounts for male sterility, it provides a scope for selection of mitochondrial recombinants that would not possess undesirable effects, through a technique such as somatic hybridization. Further, replacement of the chloroplast genome of the male sterility inducing cytoplasm to eliminate the chlorotic effects in hybrids is also feasible through development of cybrids. Therefore, present investigation was undertaken to study the effect of male sterility inducing cytoplasm on various yield parameters and physiological and biochemical characters influencing grain yield.

Three sets of hybrids were evaluated to study the effect of male sterility inducing cytoplasm on various characters. First set involved the hybrids PMS 2A x Pusa 1127 (AF_1-1) and PMS 2B x Pusa 1127 (BF_1-1), the second set involved the hybrids Pusa 5A x Pusa 1124 (AF_1-2) and Pusa 5B x Pusa 1124 (BF_1-2), while the third set involved the hybrids IR 58025A x PRR 78 (AF_1-3) and IR 58025B x PRR 78 (BF_1-3).

Zhu (1979) found that the sterility inducing cytoplasm reduced plant height, panicle exertion and number of grains per panicle, while there was no significant effect on panicle length and dimensions of flag leaf. Lu *et al.* (1980) found negative effects of the sterility inducing cytoplasm on number of spikelets per panicle, number of filled spikelets per panicle, 1000-grain weight and grain yield.

Comparison of the three AF_1s with their respective BF_1s revealed significant differences between them for 38 of 53 characters (some characters studied at different growth phases) (Table 28). The results are discussed here for the characters that exhibited significant differences between the two kinds of hybrids.

Significant reduction in plant height was observed in case of all the three AF_1s. Generally, the A lines are shorter than the corresponding B lines, because of reduced length of the uppermost internode, which is due to negative influence of the sterility inducing cytoplasm. Negative effects of the sterility inducing cytoplasm on plant height have been reported earlier by Wan (1980), Young and Virmani (1990).

An interesting feature of the effects of the WA cytoplasm was the positive influence on the number of productive tillers. All the three AF_1s had higher number of productive tillers as compared to their counterparts; however, the effect was significant only in case of AF_1-2. Such significant positive effect of the sterility inducing cytoplasm on tillering has been reported by other workers as well (Lu *et al.*, 1980; Wan, 1980; Zhuang and Wu, 1982; Virmani and Edwards, 1983). High tillering observed in the A line hybrids may probably due to consequent effect of sterility. Varying degree of sterility in the A line hybrids appears to enhance tillering as the extra food material, which is not utilized for grain development could probably be diverted to vegetative growth in the form of extra tillers.

Highly significant positive effect of the male sterility inducing cytoplasm on days to 50% flowering and days to maturity was observed, which was in undesirable direction. The period form seedling to heading was longer in AF_1s compared to their counterparts. Delayed flowering in the AF_1s can be traced to their female parents, which also flowered late as compared to the respective maintainer lines. The results are in full agreement with the findings of Wan (1980) and Saran and Sahai (1985).

Among the various yield influencing parameters, characters like grain filling duration, length of main panicle, weight per panicle, number of filled spikelets, spikelet fertility, 1000-grain weight and biomass yield demonstrated cross specific nature of the effect and magnitude of the sterility inducing cytoplasm. Regarding panicle traits, the common effect of the sterility inducing cytoplasm was general reduction in the length of main panicle, weight of panicles, numbers of filled and total spikelets and spikelet fertility. These results are in full agreement with those obtained by Zhu (1979), Lu *et al.* (1980) and Viraktamath (1987). The sterility inducing cytoplasm exhibited positive influence on the number of unfilled spikelets per panicle, which was, obviously, undesirable.

For spikelet fertility, all the AF_1s showed deviation in negative direction, which tend to support the findings of Muker and Sharma (1993) and Shen and Xue (1997). This negative effect of the sterility inducing cytoplasm on spikelet fertility was, however, significant only in case of AF_1-1, indicating that the effect can be reduced by selecting appropriate combinations. The WA cytoplasm also has negative effect on panicle exertion (Zhu, 1979; Rangaswamy *et al.*, 1987; He and Shen, 1991), reducing the basal spikelet fertility.

As stated earlier, reports on the effects of the male sterility inducing cytoplasm on physiological and biochemical parameters influencing grain yield and harvest index in rice are in scanty (Sasahara *et al.*, 1986 and Chen *et al.*, 1987). In the present study, the WA cytoplasm, in general, had significant negative effects on CGR as well as RGR in all stages of growth of the crop. However, the effects differed according to cross combination, as well as growth stage. Thus negative influence of the WA cytoplasm on these important growth parameters in AF_1s may have resulted in their poor performance compared to their respective BF_1s.

Negative influence of the male sterility inducing cytoplasm in AF_1s also continued for NAR, leaf area, LAR, LAI, LAD and also on activities of the enzymes α-amylase and nitrate reductase. However, for grain related biochemical components, negative effects of the WA cytoplasm were not significant in any case. For NAR at tillering to flowering, the effect ranged widely, from -26.99% in AF_1-3 to 20.21% in AF_1-1. While, these two hybrids expressed extreme differences, which were highly significant, the hybrid AF_1-2 did not exhibit a significant difference of the cytoplasm. This once again indicates cross specific nature of influence of the WA cytoplasm on various characters.

However, despite presence of significant negative effects of the sterility inducing cytoplasm on various characters, the overall effects on grain yield per plant and harvest index, although negative, were not significant. This could be due to character compensation. Negative effects of the WA cytoplasm on grain yield ranged from -6.18% to -13.34%, while those on harvest index ranged from -3.59% to -10.42%.

A perusal of Table 28 reveals another interesting fact. For some characters, including leaf area at seedling stage, LAD at tillering to flowering and NRA at 25 days after flowering, it was observed that lower magnitude of influence of the WA cytoplasm on those characters in a cross was significant, however, higher values in other cross(es) were non-significant. This is due to the fact that the AF_1s were compared with the respective BF_1s for calculating the effect of the sterility inducing cytoplasm and not with other AF_1s. Each of the AF_1s and BF_1s had different magnitude of variation, which resulted in a different 't' value for each set. Hence, for example, for LAD at tillering to flowering, the value of 2.54% in AF_1-1 was significant; while the higher value of 5.29% in AF_1-3 was non-significant for negative effect of the male sterility inducing cytoplasm. The same holds true for the above-mentioned characters as well.

In summary, the present investigation broadly indicates that the sterility inducing cytoplasm affect several characteristics in hybrids in terms of their *per se* values as well as the extent of heterosis. Some of the effects in the A line hybrids such as plant height, days to 50% flowering, days to maturity and tillering are similar to those observed in the respective female parents. As some of the effects appear to be a result of sterility, it is possible to reduce or overcome the expression of negative heterosis by careful selection of the parents. In addition, the use of these cytosterile lines, which would suppress the fertility to a minimum extent and the use of effective restorer lines would help in overcoming the negative effects of the sterility inducing cytoplasm in some cases.

Effect of reciprocal cross differences on various characters

To study the influence of reciprocal cross differences on yield components and the physiological and biochemical parameters influencing grain yield, three sets of hybrids, each consisting of an F_1 (BxR), designated as BF_1 and respective reciprocal F_1 (RxB) designated as RF_1 were evaluated. The first set involved the hybrids PMS 2B x Pusa 1127 (BF_1-1) and Pusa 1127 x PMS 2B (RF_1-1), the second set involved the hybrids Pusa 5B x Pusa 1124 (BF_1-2) and Pusa 1124 x Pusa 5B (RF_1-2), while the third set involved the hybrids IR 58025B x PRR 78 (BF_1-3) and PRR 78 x IR 58025B (RF_1-3).

Associated influence of the reciprocal cross differences on various characters was studied by comparing the BF_1s with respective RF_1s for all the characters. The nature and magnitude of reciprocal cross influence was worked out as per cent increase or decrease in performance of RF_1s over the performance of BF_1s and the results are presented in Table 29. Significant to highly significant differences existed between BF_1s and RF_1s for 29 of the 53 characters studied. The results are discussed here for characters that exhibited significant differences between the two kinds of hybrids.

Among the yield components, significant reciprocal cross differences were observed only for five characters, *viz.* plant height, days to 50% flowering, days to maturity, grain filling duration, weight per panicle and spikelet fertility. Although,

ps e|F 1 d RF 2 t lln than their corresponding h BF_1s the influence was

Interestingly, as clear from Table 29, RF_1-3 did not perform as well as the other two RF_1s. This is due to the fact that the restorer parent, PRR 78, is an isocytoplasmic restorer with WA cytoplasm. Influence of the WA cytoplasm on the *per se* performance of PRR 78 is indicated by reduction in weight of main panicle as well as of all panicles, spikelet fertility, biomass yield, grain yield and harvest index. However, the restorer performed better than other restorer Pusa 1127 which had normal cytoplasm. In addition, despite having the sterility inducing (WA) cytoplasm, PRR 78 was the tallest of the three restorers and was observed to have nearly complete panicle exertion (data not presented). This could be due to favorable nucleo-cytoplasmic interactions in PRR 78 that may have masked the negative effect of the WA cytoplasm. This indicates that it is possible to breed for desirable restorers or hybrids having the least effect of the WA cytoplasm on desirable traits.

Taking this into account, the cross PRR 78 x IR 58025B, would produce a hybrid with WA cytoplasm. Hence, theoretically, the hybrids, AF_1-3 (IR 58025A x PRR 78) and RF_1-3 (PRR 78 x IR 58025B) will have the same nuclear as well as cytoplasmic genotype and hence they are expected to perform similarly. In fact, this has been observed in the present investigation. A comparison of performance of the two hybrids indicates only minor differences in their performance. However, RF_1-3 had more grain yield and harvest index compared to that of AF_1-3, which may be due to higher number of productive tillers, higher panicle weights resulting due to higher number of filled grains and spikelet fertility in RF_1-3.

To sum up, the present study on reciprocal cross differences broadly indicates influence of reciprocal effects on several characters in terms of their *per se* values as well as on the extent of heterosis. Hence, it is important to consider performance of both the direct and reciprocal hybrids while selecting a desirable hybrid combination. If performance of the reciprocal hybrid is significantly superior to the direct hybrid, production of the reciprocal hybrid may be considered using tools such as male gametocides or environmentally induced genetic male sterility (EGMS) system.

The present findings reveal the importance of association of various physiological and biochemical characters with yield and yield components and a possibility for their utilization in breeding programs. The study also reveals the effects of the sterility inducing cytoplasm on various yield components as well as on the physiological and biochemical characters. In addition, the present investigation has tried to explain the reciprocal cross differences observed and their use in formulating appropriate breeding strategy. Thus the findings of the present investigation may serve in formulating selection criteria in first eliminating undesirable crosses and concentrating more on the few desirable cross combinations which are likely to throw transgressive segregants. Such an effort would economize the breeding program by isolating potential recombinant inbred lines, having superior morpho-physiological and biochemical traits, which can be used as parents in hybrid breeding program, which is expected to increase the genetic yield potential of the resulting hybrids.

SUMMARY

Exploitation of hybrid vigor is one of the means to raise the genetic yield ceiling in crop plants. After successful demonstration of commercially exploitable heterosis in rice by China and followed by India, the world witnessed a major breakthrough in increasing the yield potential of rice. However, to enhance the present level of heterosis, a critical understanding of morpho-physiological and biochemical characters affecting grain yield is essential, which has remained untapped so far. Identifying the physiological and biochemical processes responsible for high grain yield may help plant breeders to develop very high yielding genotypes.

In addition, there are reports of negative influence of the male sterility inducing (WA) cytoplasm on various characters of economic importance. Hence, it is important to understand the nature and magnitude of influence of the WA cytoplasm on various characters, particularly of physiological and biochemical nature, for their successful manipulation. Such an understanding would facilitate selection of desirable heterotic combinations with the least negative effect of the cytoplasm.

Since heterosis is a phenomenon of superior growth, development, differentiation and maturation caused by interaction of genes, metabolism and environment, a logical approach to explain heterosis would be to take into account contribution of the nuclear genome as well as of the organelle genomes.

Keeping in view the lack of information on these aspects, the present investigation was carried out with the following objectives:

1) To study heterosis for various morpho-physiological and biochemical parameters influencing yield components and their association with grain yield,
2) Genetic analysis of selected morpho-physiological and biochemical characters,
3) To study the reciprocal differences in relation to heterosis for yield and yield components.

The materials and methods used, salient findings and conclusions drawn from the present investigation are summarized topic wise as follows:

Magnitude of heterosis for various characters

Two separate experiments were conducted to study the nature and magnitude of heterosis on various characters. The first experiment involved nine hybrids and their parents along with a check variety. These were evaluated in randomized block design with two replications. Observations were recorded on yield, yield components and various physiological and biochemical characters. The second experiment was laid out similarly with thirteen hybrids, their parents and a check variety. In this experiment observations were recorded only for yield and yield components.

The nature and extent of heterosis over better parent and standard check were found to vary depending on cross combination and the character under study. Majority of the hybrids exhibited significant positive heterobeltiosis for weight of panicles, number of filled spikelets, biomass yield, harvest index and grain yield. In Expt. 1, high heterobeltiosis was also observed for growth parameters, leaf area, leaf area duration, nitrate reductase activity and α-amylase activity. Heterobeltiosis for grain yield per plant varied from 7.53% to 50.11% in Expt. 1 and from -5.90% to 74.91% in Expt. 2. The hybrids, RF_1-2 (Pusa 1124 x Pusa 5B) and BF_1-3 (IR 58025B x PRR 78) were found to be superior in Expt.1, while in Expt. 2, the hybrids PRH 16 (Pusa 5A x PRR 76) and PRH 5 (Pusa 5A x PRR 24) were superior. It was found that, in many cases high biomass yield was associated with low harvest index. However, the hybrids BF_1-3 in Expt. 1 and PRH 5 in Expt. 2 were particularly superior, which combined high biomass with high harvest index.

In terms of heterosis and heterobeltiosis for physiological and biochemical characters, the high yielding hybrids also exhibited high crop growth rate, particularly during initial vegetative growth phase, high leaf area and leaf area duration. They also exhibited high heterobeltiosis for α-amylase activity in germinating seeds. However, in terms of grain characteristics such as contents of nitrogen, protein, amylose and starch, the hybrids did not exhibit significant superiority.

Nature and magnitude of character association

Simple correlation coefficients computed for pairs of yield components indicated that the magnitude of association varied between hybrids and parents. In hybrids, grain yield was significantly and positively correlated with flag leaf area, weight per panicle, number of spikelets in panicle, spikelet fertility, 1000-grain weight, biomass yield and harvest index. While, in case of pollen parents (Expt. 2), grain yield was positively influenced by number of productive tillers, length and weight of panicles, number of spikelets in panicle and biomass yield. Taking into account the physiological and biochemical characters, grain yield was positively influenced by leaf area, leaf area duration, α-amylase activity and nitrate reductase activity. When correlation coefficients were computed for pairs of yield components and physiological and biochemical characters, it was found that, leaf area at flowering, leaf area duration, α-amylase activity and nitrate reductase activity were the most important characters as they were significantly correlated with flag leaf area, panicle length, panicle weight, number of spikelets per panicle, spikelet fertility, 1000-grain weight, biomass yield, harvest index and finally, grain yield.

Pattern of variation for yield components in F_2 populations

Studies on the pattern of variation and segregation for yield and yield components in nine F_2 populations reveled that most of the traits followed normal distribution, indicative of polygenic nature of those characters. All the yield related traits such as number of filled spikelets, panicle weight, panicle density and spikelet fertility and grain yield varied greatly with high coefficients of phenotypic (PCV) as well as genotypic (GCV) variation. However, some characters like, panicle length and 1000-grain weight exhibited very low PCV and GCV values indicating their relatively stable nature. It was found that, for some characters, high contrast in parents gave rise to large variation in the F_2 populations. Some characters like panicle length, 1000-grain weight and spikelets per panicle exhibited high percentage of transgressive segregants in desirable direction in most of the F_2 populations. Transgressive segregants were also observed for characters like number of filled spikelets, weights of panicles, spikelet fertility and harvest index. These extreme genotypes are presumed to result due to accumulation of desirable genes coming from both the parents. These could be used as parents in hybrid breeding program, which is expected to increase the genetic yield potential of the resulting hybrids.

Effects of male sterility inducing cytoplasm on various characters

In hybrid rice breeding program based on CMS, the effect of male sterility inducing (WA) cytoplasm on yield contributing morpho-physiological and biochemical characters is of much importance. In order to study influence of the cytoplasm on various morpho-physiological and biochemical characters, an investigation was carried out by evaluating three sets of AxR (AF_1) and BxR (BF_1) hybrids. Associated influence of the sterility inducing cytoplasm on various characters was studied by comparing the AF_1s with respective BF_1s.

It was observed that the nature and magnitude of effects of the WA cytoplasm varied with character in question and also the cross combination. In general, the WA cytoplasm negatively influenced yield component characters like, plant height, panicle length, number of filled grains and weight per panicle, spikelet fertility, 1000-grain weight, biomass yield, harvest index and grain yield, while it enhanced number productive tillers and growth duration. Negative effect of the WA cytoplasm was evident in case of all the physiological and biochemical characters in various growth stages. Thus the *per se* performance the AF_1s was found to be lower than that of the respective BF_1s, indicating an overall negative effect of the WA cytoplasm. Since some of the effects were obviously the outcome of the extent of sterility, it is possible to reduce or overcome the negative influence of cytosterility by choosing appropriate restorers and CMS lines that suppress fertility restoration the least.

Influence of reciprocal cross differences on various characters

To study the influence of reciprocal cross differences on yield components and various physiological and biochemical characters influencing grain yield, three sets of hybrids, each consisting of an F_1 (BxR), designated as BF_1 and respective reciprocal F_1 (RxB) designated as RF_1, were evaluated. Since reciprocal hybrids do not differ from direct hybrids with respect to nuclear genome, any difference in performance of these two can be attributed to their organellar genome differences. The organellar genome constitution of a reciprocal hybrid is likely to be different than that of the direct hybrid, because of maternal inheritance of the cytoplasm. Associated influence of the reciprocal cross differences on various characters was studied by comparing the BF_1s with respective RF_1s.

Among the yield components, significant reciprocal cross differences were observed for five characters, *viz.* plant height, days to 50% flowering, days to maturity, grain filling duration, weight per panicle and spikelet fertility. Significant reciprocal differences were also observed for all the physiological and biochemical characters studied, except for grain characters such as, contents of nitrogen, protein, starch and amylose. The overall performance of reciprocal hybrids (RxB), in general, was found to be superior to that of the respective direct hybrids (BxR). The estimates of reciprocal cross differences thus provide a good choice for deciding the order of parents and producing new hybrid combinations which could be superior to the direct hybrids. If performance of the reciprocal hybrid is significantly superior, its production may be considered using tools such as male gametocides or environmentally induced genetic male sterility (EGMS) system.

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