GENETIC ANALYSIS OF YIELD COMPONENTS AND NET-ASSIMILATION RATE IN RICE *(Oryza sativa* L.)

THESIS

By

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Submitted to

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IN

Partial fulfilment of the requirements for the degree

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Dedicated
to
my
Revered
Parents

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CERTIFICATE – I

This is to certify that the thesis entitled **"Genetic analysis of yield components and net-assimilation rate in rice *(Oryza sativa* L.)"** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Plant Breeding** of Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, is a bonafide research work carried out by **Mr. Sanjeev Kumar (Admission No. A-2000-40-13)** son of **Sh. Ashok Kumar** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

21.5.2004
(H.B. Singh)
Chairman,
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Place : Palampur
Dated: the 21st May, 2004

CERTIFICATE – II

This is to certify that the thesis entitled " **Genetic analysis of yield components and net-assimilation rate in rice *(Oryza sativa* L.)"** submitted by **Mr. Sanjeev Kumar** son of **Sh. Ashok Kumar** to Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, in partial fulfilment of the requirements for the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Plant Breeding**, has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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INTRODUCTION

Rice *(Oryza sativa* L., 2n=2x=24) is one of the most important staple cereal crop of the world and provides food for half of the world population. Production and consumption wise, it is predominantly a crop of developing countries, accounting for 35-60% of the calories intake.

About 95 per cent of the total rice is grown in less developed countries, primarily in Asia. It is cultivated in about 155 million hectares with production of 596.90 million tonnes in the world (F.A.O., 2000). In India it covers an area of about 44.8 million hectares with annual production of 75.32 million tonnes and productivity 2.98 tonnes per hectare (Survey of Indian Agriculture, 2004). The total rice production has remained static for the last ten years (3008 kg/ha) which is far below the world average.

In Himachal Pradesh, rice occupies 86.221 thousand hectares area with production 120.4 thousand tonnes and productivity 15 q/ha (Anonymous, 2001) and is the major *Kharif* crop next to maize. Kangra district occupies 1st position in area (37.9 thousand hectares) with production 82.9 thousand tonnes. The average yield of milled rice in H.P. is lower (15 q/ha) than the national average 16 q/ha (State Statistical Abstract H.P. 1999).

The population of rice consumers is increasing at the rate of 1.8% in a year. But the rate of growth in rice production has slowed down. It is estimated that rice production is to increase 50 per cent by 2025 (G. Khush

The knowledge of genetic system controlling quantitative traits is important for devising the efficient selection programme. As such normal breeding methods like pure-line selection and pedigree methods may not yield tangible results especially when further genetic improvement in grain yield is sought. This is mainly due to existing undesirable linkages among components of yield. It is therefore of paramount importance to know the extent of heterosis, combining ability and type of gene action involved for genetic amelioration and formulating breeding strategy for improvement in yield and yield attributing traits.

The exploitation of hybrid vigour appears to be an alternative for making further breakthrough in crop yield of rice, for which substantial quantity of exploitable heterosis must be available. The success in heterosis exploitation in China has generated great enthusiasm among rice breeders in India and elsewhere in the world to examine the feasibility of adopting this technology to augment rice production (Lin and Yuan, 1980).

Therefore, in the present study, the diallel mating design (Hayman, 1954 and Griffing, 1956) involving the traditional cultivars and improved semi-dwarf varieties adapted to the agro climatic conditions of Himachal Pradesh were used to generate the breeding material with the following objectives:

1. To study the nature and magnitude of gene actions for various traits,
2. to identify the desirable parents/crosses on the basis of their gca and sca effects,
3. to work out heterosis for grain yield over the best check variety and
4. to study the association of net assimilation rate (NAR) with yield and other yield contributing traits

Review of Literature

Chapter II

REVIEW OF LITERATURE

The relevant reports pertaining to various aspects of the present study are briefly reviewed under the following sub-heads:

2.1 Combining ability and gene action

2.2 Heterosis and inbreeding depression

2.3 Correlation and path analysis

2.4 Disease (i) Leaf Blast (ii) Neck Blast

2.1 Combining ability and gene action

Identification of superior parents is of paramount importance for the development of superior varieties/hybrids, Dhillon (1975) stated that the wrong choice of parents might undo an efficiently planned and well executed programme. In the past quarter century, quantitative genetics and advanced biometrical models like diallel, partial diallel and line x tester have played a leading role in providing basic information regarding the genetic make up of different polygenic traits.

Sprague and Tatum (1942) were the first to give clear-cut explanation of the concept of combining ability. They defined general combining ability "as the average performance of a line in a number of hybrid combinations" and specific combining ability as the cases in which certain combinations did relatively better or worse than would be expected on the basis of average performance of the lines involved.

Diallel system provides reliable information on the components of variance and on gca and sca variances and effects. Thus, it helps in the selection of suitable parents for hybridization as well as in the choice of appropriate breeding procedures.

Griffing (1956^{a}) has given four different methods for diallel analysis depending upon the material used in the experimentation. Matzinger and Kempthorne (1956^{b}) showed that estimates of gca include additive genetic variance and portion of the additive based higher order epistatic variance and the estimates of (sca) variance include dominance and other portion of epistatic variance. Estimation of additive and dominance genetic variances can be obtained from the diallel cross only in the absence of epistasis. The gca and sca have been reported to be important for agronomical and yield characters.

Knowledge of gene actions and relative importance of genes in determining different agro morphological characteristics is important for the success of any breeding programme. Heredity variance is partitioned into three components viz., additive, dominance and epistatic, which results from average effects of genes and intra and inter-allelic interactions. Wright (1935) defined these three components as additive genetic variance, variance due to dominance and variance due to deviation from the additive which is due to the interaction of non-allelic genes.

Singh *et al.* (1980) revealed the predominance of non-additive gene action, parent IET3618 was a good general combiner for yield per plant and days to 50 per cent flowering and parent Saket4 for days to flowering 50 per cent and plant height.

Haque *et al.* (1981) reported additive genetic effects were important for number of days to flowering, plant height, 1000 grain weight and yield per plant and non-additive genetic effects important for number of days to 50 per cent flowering and plant height. In general, additive genetic effects were greater and more important than non-additive effects. Parent Dharial had the best combining ability for number of days to 50 per cent flowering and 100-grain weight and IET665 best for plant height. Kim *et al.* (1981) reported GCA and SCA estimates were significant for all characters, gca estimates for Ai-non-Tsao-7 and Kuei-lu-ai-8 were negative for number of days to flowering, while SCA for distant crosses were positive for number of days to heading.

Singh and Shrivastava (1982) reported the highest positive gca effects occurred in Surjmari for panicle length, the highest heterosis for a range of traits occurred in IR-28 x HP-235 and Karuna x HP-235. Amirthadavarathianam (1983) reported that Chithariyan was a good general combiner for all characters, while Poongar x IR-8 and Chithariyan x Kannagi were identified as a good cross combinations. Shrivastava and Seshu (1983) reported GCA variances were significant for all sixteen traits whereas, SCA variances for only 12 traits, GCA was more important than SCA, Leb Mue Nahng 111, IR 42 and RPW-17 were good general combiners, whereas the crosses IR-54 x PIB-33, IR1060-90 x RPW6-17 and IR-54 x LMN-111 were good specific combiners.

Clement and Poisson (1984) reported additive effects and narrow sense heritability estimates of 60 per cent (Griffing's 1956 method) and 49 per cent (Hayman's 1954 method), observed for grain length, both GCA and SCA variances were highly significant. Subramanian *et al.* (1984) reported GCA variances were higher than SCA variances for yield per plant and 10 related quantitative characters, hybrids with SCA for yield, short stature and high quality are identified.

Panwar *et al.* (1985) revealed that Parents Sona, IR-8, Jhona-349, BJ-1 and IR2153-43-2-5-4 were good general combiners and may be useful for intercrossing or biparental crossing. Singh and Singh (1985) reported good general combining ability (GCA) effects for grain length, grain breadth and grain length:breadth ratio were found in parents CP-231 and T-9. Sinha *et al.* (1985) reported the best general combiners for yield and its components were parents T-141, AS-01 and Vijaya, but for protein percentage SL-016 and AD-27 were best, Vijay x T-142 and Vijaya x AS-01 showed high SCA for yield.

Ghosh and Hossain (1986) revealed that the foreign varieties viz., Dee-geo-woo-gen and IR-8 had higher GCA effects than the Indian varieties (BUI, Satika and BJ-1), F_1 hybrids from crosses between the foreign and Indian varieties had higher positive SCA effects than crosses between the foreign or crosses between the Indian varieties for most of the yield components. Kumar *et al.* (1986) reported that height was governed predominantly by additive effects with some dominance gene action, parents TKM-6, 30 kR, TKM-9 and IR-50 were good general combiners for dwarf stature, while the crosses TKM6 30 kR x TKM6, TKM6 35 kR x TKM9 and TKM6 x DGWG had high SCA.

Kuo and Liu (1986) revealed that additive effects were more important than dominance effects for grain length, width, length: breadth ratio and 100-grain weight. Kuo and Liu (1986) showed that additive effects were more important than dominance effects for grain length, width and length:breadth ratio and 1000 grain weight. Zaman and Siddiq (1986) reported the genotypes IR-8 and IR-28 were good general combiners, in the F_1, Blue Belle x IR-30 and, IR-30 x IR-20 in F_2 were the best crosses.

Moeljopawiro (1986) reported GCA and SCA effects were significant for all traits like grain width and 1000 grain weight, although the former were important than latter. Sood and Siddiq (1986) reported crude protein content ranged from 7.85 to 12.77 per cent, both additive and non-additive genetic effects were involved with former predominating. Kuo and Liu (1987) revealed that both additive and dominance genetic effects were important for inheritance of grain yield, biological yield and harvest index, dominance effects being the more important for grain yield and biological yield.

Murai *et al.* (1987) reported non-additive gene action for 100-grain weight and grain length. Tripathy and Misra (1987) reported predominance of additive genetic effects for the traits days to 50 per cent flowering initiation and 100-grain weight. Sardana and Borthakur (1987) reported genetic variability, gca and sca were significant for grain yield per plant, days to 50 per cent flowering and plant height, both additive and non-additive gene effects were improved for all the traits.

Cheema *et al.* (1988) reported both additive and non-additive gene effects influenced plant height and days to flowering but non-additive gene effects alone affected productive tillers per plant, heterosis with respect to both mid parental value and better parent was found for all characters except days to flowering. Gupta et al. (1988) revealed that GCA and SCA variances for protein content of the grains were highly significant in both hybrid generations, the best general combiners were parents T22A and Mahsuri for protein content.

Kalaimani *et al.* (1988) indicated that GCA was greater than SCA for yield and characters related to yield, the best combiners were IR-8 for all characters related to yield, 340 and AD-73 for earliness and grain weight, CO-37 for yield and IR-20 for grains per panicle. Kaushik and Sharma (1988) revealed that predominance of additive gene action for plant height and panicle length, while predominance for non-additive gene action for yield per plant.

Guimaraes (1989) revealed that Araguaea, A8-204-1, Guiabana and IRAT-216 were good general combiners and having moderate to high phenotypic variability and low neck blast scores. Manuel and Palanisamy (1989) reported that all the nine characters were governed by additive and non-additive gene actions, the ratio of gca and sca variances revealed the predominance of additive gene action for days to flowering. Majumdar *et al.* (1990) reported both additive and non-additive gene actions were important for components of growth period duration.

Lokaprakash *et al.* (1991) revealed both GCA and SCA variances were highly significant for all characters indicating the importance of both additive and non-additive gene actions. Murty *et al.* (1991) revealed the involvement of both additive and non-additive gene effects with the pre-dominance of the former. Ram *et al.* (1991) observed the influence of non-additive genetic variance was more than the additive genetic variance for all the characters, the degree of dominance revealed over dominance for panicle length and grain yield whereas, complete dominance for days to panicle emergence and partial dominance for the rest of the characters.

Xu and Shan (1991) reported significant additive and non-additive gene actions and the latter appears to be solely due to dominance, high tillering ability was inherited as a partial dominant character conditioned by 2 or more blocks of genes. Niranjana *et al.* (1992) reported cultivars Halubbalu and Gowrisanna were good general combiners for grain yield, total dry matter (TDM) and net-assimilation rate (NAR). Bong and Singh (1993) reported to achieve uniformity in the texture of cooked rice and cooking time for hybrids, parents must have intermediate amylose content. Ghosh (1993) reported that variances for GCA were significant for all 21 traits, whereas sca variances were significant for only 19 traits, of these SCA was not important for days to flowering. Singh *et al.* (1993) reported pre-dominance of non-additive gene effects for kernel length, whereas additive gene effect for kernel breadth and L/B ratio.

Nguyen and Bui (1993) indicated the importance of additive and non-additive gene actions, although latter was more prevalent for all traits except leaf area index (LAI), parent OM 80 was the best combiner for yield and OM201 for net-assimilation rate (NAR) from heading to harvest. IR-46, OM80, IR-68 and OM-86 were best for LAI, IR-36 for NAR from panicle initiation to heading, IR-8, IR-36 and IR-46 for CGR and IR-36, IR-42 and OM-201 for harvest index. Chakraborty *et al.* (1994) reported both additive and non-additive gene actions, additive gene effect was predominant for characters like days to 50 per cent flowering and 100-grain weight, but plant height exhibited preponderance of non-additive gene action in their inheritance.

Geetha *et al.* (1994) reported preponderance of additive gene action for plant height, grain length, grain breadth and 100-grain weight and non-additive gene action for grain yield/plant. Kasturi *et al.* (1995) reported additive nature of gene action was predominant for all the characters, high heritability in narrow sense was also established for all the characters. Verma *et al.* (1995) revealed predominance of additive gene action for all the characters except for biological yield per plant.

Chakraborty and Hazarika (1996) reported both additive and non-additive gene actions were important in controlling all the characters studied, epistatic effects of mainly duplicate type were predominant over additive and dominance effects for all the traits. Katre and Jambhale (1996) reported that *Mahsuri* and *Kasturi* were good general combiners for yield and other important traits under both transplanted and direct seeded conditions, Jaya was the best general combiner under transplanted condition and Prarbhavati under direct seeded condition.

Sharma and Mani (1997) reported predominance of non-additive gene effects for amylose content, both additive and non-additive gene effects were equally important for kernel elongation, Pusa Basmati-1, UPR85-71, 8-1, Basmati 370 and Haryana Basmati-1 were good general combiners for cooking quality. Sarma and Mani (1997) reported non-additive gene effects appeared to be predominant for amylose content, while both additive and non-additive gene effects were equally important for kernel elongation ratio.

Borgohan and Sarma (1998) indicated the preponderance of additive gene action for grain yield per plant, plant height and days to 50 per cent flowering. The best general combiners for grain yield and most of its components were DWR-2, DWR-1, DWR-5 and DWR-7, hence these parents should be exploited in hybridization programme. Dong *et al.* (1998) reported amylose content values of hybrid (F_1's) with a female Japonica parent were a little higher than that those whose female parent was an Indica line.

Geetha (1998) reported the protein content per grain (PPG) found to be mainly controlled by additive gene action, IR-50, ADT-37 and ADT-41 were identified to be the best combiners to use as the parents in hybridization programme. Honarnejad *et al.* (1998) reported additive and non-additive genetic effects for the traits like grain length:breadth ratio of paddy and brown rice and grain amylose content. Geetha *et al.* (1998) reported predominance of additive gene action for all the characters studied, IR-50 and ADT-41 were the best parents based on per se performance and GCA effects.

Honarnejad *et al.* (1998) reported additive gene effects for grain length: breadth ratio, grain yield and amylose content, genetic advance from selection is likely to be high for these traits. Li *et al.* (1998) revealed amylose content was mainly controlled by additive gene effects, Waxuan 35 exhibited high blast resistance combined with good combining ability and heritability, an alternative grain shape but low cooking ability and heritability for amylose content.

Mandal *et al.* (1998) reported both additive and non-additive gene effects and a high narrow sense heritability (71%) with the predominan~~t~~ce of additive gene effects. Singh *et al.* (1998) reported GCA and SCA variances were significant for all the traits, Laloo 14 was a good general combiner for grain yield per plant, earliness and harvest index. Dwivedi *et al.* (1999) revealed that both GCA and SCA effects were influenced by environments, the magnitude of SCA variances were relatively higher than the gca variances and thus predominance of non-additive gene action.

Thirumeni and Subramanian (2000) reported the hybrid SSRC92076/TRY 1 was found to be superior for grain yield per plant and hence recommended for commercial exploitation. Sharma and Mani (2001) reported predominance of non-additive gene effects for days to flowering, plant height, panicle length, 100-grain weight, grain yield/plant and amylose content, while both additive and non-additive gene effects were equally important for harvest index and kernel elongation ratio. Predominance of non-additive genetic variances suggested that exploitation of hybrid vigour should be good strategy for improving the grain yield and other attributes.

Singh *et al.* (2001) reported predominance of non-additive gene action for amylose content, L/B ratio and grain yield. Basmati 370 was the best general combiner for all quality traits and grain yield. Zuo *et al.* (2001) reported the endosperm nuclear genes mainly influenced amylose content and grain length with an additive effect and mainly protein content with dominant gene action. Babu and Reddy (2002) reported additive gene action for plant height, panicle length, 1000 grain weight, grain length, grain bradth and L/B ratio and pre-dominance of non-additive gene action for days to 50 per cent flowering.

Kumari *et al.* (2002) revealed that all the characters were much influenced by different types of gene actions additive, dominance and epistasis. In crosses Plate Blanc MNI x Akihiari (C_1) and N22 x IR50 (C_2), the dominance and epistatic effects were predominant, the cross Dular x Toyonishiki (C_4 was marked by additive and additive x additive gene effects. The present study would suggest multiple crossing programme and selection of superior segregants in later generations for increasing the potential in wide compatible varieties involving indica/Japonica crosses.

Reddy (2002) reported cross combinations Gayatri/Lunishree, Uttralprabhal/CN718-8-21-10 showed good combining ability effects for grain yield and most of its components. Won *et al.* (2002) reported additive genetic effects were significant for both amylose content and grain yield but not for protein content indicating the importance of additive gene action for amylose content and grain yield, whereas the dominance effects were highly significant for amylose content, protein content and grain yield.

Bhave *et al.* (2003) reported IR-8 and S8025 were the good general combiners for most of the characters. IR-8 for plant height and IR62829A, RTN73, KJT1 and KJT7 were good general combiners for days to 50 per cent flowering and maturity. Hazardone had the highest GCA for grain yield and low GCA for test weight, whereas SCA for grain yield was highest in Hazardane x N22, Jaya x T21 and Cauvery x Dhaneshwar. Patil *et al.* (2003) revealed additive gene action for days to 50 per cent flowering and non-additive gene action for panicle length and grain yield per plant.

2.2 Heterosis and inbreeding depression

The discovery of hybrid vigour has been recognized as one of the major land marks in the annals of Plant Breeding and its utilization in breeding hybrid varieties of both self and cross-pollinated crops. Heterosis is the phenomenon in which the hybrid between two genetically dissimilar parents shows increased vigour at least over the mid parent value. Kolreuter (1761-1766) was the first to reported hybrid vigour in hybrids of tabacco, Datura etc.

Most of the early plant hybridizers including Mendel (1865) had noticed this phenomenon. Shull (1910, 1911) coined the term heterosis from two greek words, heter (different) and osis (condition) to replace his own earlier word stimulus of heterozygous (Chaudhary, 1982). The phenomenon of heterosis in rice was first reported by Jones (1926) for number of culms and yield. Since then several researchers (Stansel and Craigmiles, 1966; Yuan, 1966; Craigmiles *et al.*, 1968; Watanabe, 1971; Athwal and Virmani, 1972 and Swaminathan *et al.*, 1972) had suggested the possibility of developing commercial hybrid varieties in rice.

Srivastava and Seshu (1982) reported heterosis was observed for grain yield per plant and plant height, the highest yielding hybrid IR36 x CR1002 yielded 62.5 per cent more than its better parent. Virmani *et al.* (1982) reported 73 per cent heterosis for yield, 50 per cent heterobetiosis and 34 per cent relative to the commercial varieties IR-36 and IR-42. Zeng (1983) reported heterosis for grain weight per plant. was closely and positively correlated with heterosis for six other characters, number of panicles per plant and the number of filled grains per plant had the greatest direct effect on heterosis for grain weight per plant, number of tillers per plant and number of spikelets per panicle had indirect effect through the first two characters, respectively.

Richaria and Singh (1983) reported the heterosis for yield in different crosses was mostly due to simultaneous heterosis for early flowering, plant height and panicle length, two crosses were good combinations for grain yield.

Ponnuthurai and Virmani (1983) reported the heterosis was attributed to simultaneous heterosis for plant height and harvest index. Nijaguma and Mahadevappa (1983) reported marked variations in the expression of heterosis and heterobeltiosis for days to heading, harvest index and grain yield in different crosses, whereas 1000 grain weight manifested highly significant heterosis and heterobeltiosis in all the crosses.

Kumar *et al.* (1983) reported maximum heterosis over the better parent was 22.32 per cent for grain yield, 21.8 per cent for panicle length and 25.48 per cent for 100-grain weight. Kumar *et al.* (1984) reported heterosis for yield per plant was highest in crosses 07107 x AS308 and 0797 x AS08. Subramanian *et al.* (1984) reported heterosis was greater if the semi-dwarf varieties were taken as female, six combinations showing > 20 per cent heterosis for grain yield. Anand *et al.* (1986) reported that heterosis for yield was greatest in TKM-6 mutant 2 x TKM-6 (96.92%) and heterobeltiosis was greatest in IR-36 x TKM-6 mutant 2 (82.45%).

Kumar and Ravi (1986) indicated the importance of both additive and non-additive gene actions in the control of the characters, only two hybrids out yielded the best variety but many hybrids were heterotic for yield components and seed set was highest in KMS-4. Kaushik and Sharma (1986) reported that the highest effects for grain yield were shown by crosses Himalaya-1 x Phul Patas 72 and China-988 x Himdhan, which gave, respectively 38.8 and 26.9 per cent better parent heterosis and 32.3 and 26.9 per cent heterosis over the best variety, Himdhan. Heterosis for grain yield was due to increase in panicle length and 100-grain weight.

Kalaimani and Kadambavanasundarana (1987) showed significant heterosis for yield and yield components such as 100-grain weight. Paramasivan *et al.* (1987) reported desirable heterosis for grain yield and its components by hybrids ADT-27 x 15194 and T6190 x PIB15. Prakash and Mahadevappa (1987) reported positive heterosis over mid parent by hybrids V204/IR13419-113-1 and V20/IR9761-19-1.

Paramasivan and Sreerangasany (1988) reported three crosses ADT27 x CO34, IR24 x TNAU1941 and CO44 x TNAU-1942 exhibited maximum grain yield per plant due to the manifestation of heterosis in two or three traits such as panicle length and grain weight in each hybrid combinations. Rangaswamy and Natarajanmoorthy (1988) showed standard heterosis of upto 13.41 per cent and heterobeltiosis of upto 112 per cent, standard heterosis for grain yield reached a maximum of only 8 per cent with Er-HIU-Non and IET 6208 as parents due to high spikelet sterility.

Sarawgi and Shrivastava (1988) indicated high mean heterosis for yield per plant and biological yield and number of tillers per plant under irrigation conditions. The best specific combinations under irrigated conditions were IR-36 x Roti and IR-36 x R68-1, yielding 199 and 180 per cent higher than the grain yield over better parent. Manuel and Palamisamy (1989) observed 46 per cent heterobeltiosis for yield in the cross AS01 x CO33 and highest standard heterosis for yield in the cross ASD16 x IR-50 and positive correlation between grain yield and days to flowering.

Mandal and Saron (1989) revealed the cross MR365A x Milyong 54 showed varying magnitude of heterobeltiosis/standard heterosis for character viz., kernel length/breadth ratio. Kaw and Delacruz (1991) revealed manifestation of heterosis for three physio-chemical grain quality characters in 102 F_1 rice hybrids, average heterosis 2.2 per cent for amylose content was recorded over the mid parent in the Japonica x Indica crosses. Peng and Virmani (1991) revealed hybrids significantly outyielded their better parents, one hybrid IR1976-27-3-3-1-2XIR2797-105-2-2-3 showed significant increase over check by 33.6 per cent.

Ali and Khan (1995) reported desirable heterosis for all the characters except plant height and heterobeltiosis was positive over the better parent in most of the crosses for grain yield per plant. Chauhan and Chauhan (1995) reported positive heterosis for grain length and except the cross RR51-1 x Kalinga-111, all the crosses exhibited negative heterobeltiosis for grain breadth. Low level of heterosis and inbreeding depression in general was recorded for grain size and shape.

Murty and Kulkarni (1996) revealed that magnitude of heterosis was medium for leaf area at early stage, total biological yield and grain yield and it was comparatively low for harvest index. Rogebell *et al.* (1998) indicated that IR-59788-37-1-12-1, IR61457-8-3-3-1, IR4595-4-1-1-3, IR-54717-C10-43-1-2-2-2 and IR54717-C10-113-1-2-2-2 were high heterotic for grain yield per plant. Seetharamaiah *et al.* (1999) reported plant height, followed by panicle length did not play significant role in the expression of heterosis for grain yield was manifested through more number of spikelets per panicle and number of ears bearing m^{-2}, negative standard heterosis was observed for test weight due to bold grains and high test weight of check variety Prabhat.

Annadurai and Nadarajan (2001) reported that with respect to productive tillers per plant, 12 hybrids showed positive heterobeltiosis and none of the hybrids recorded positive standard heterosis. Janardhanan *et al.* (2001) reported relative heterosis, standard heterosis and heterobeltiosis for plant height, panicle length and single plant yield.

Kwon *et al.* (2002) reported highest heterosis for grain yield among the eight traits studied. Patil *et al.* (2003) reported positive heterosis for early flowering by cross combinations TGMS 15 X ADT 36, Peiai 64S X ADT 36, TGMS 18 X White pooni and for panicle length by crosses TGMS 18 X C20 and Peiai 64S X C20. Satish and Ramaiah (2003) revealed the heterotic combinations ARC5780 X BPT1768, ARC5780 X NLR33641, BPT5204 X BPT1768, BPT5204 X BPT4358 showed positive heterosis for grain yield.

2.3 Correlation and path analysis

Murty *et al.* (1986) reported net-assimilation rate was positively associated with dry matter. Murty and Pattanaik (1986) reported that NAR was positively correlated with total dry matter production. Hussain *et al.* (1987) reported protein content was negatively correlated with most characters including cooking quality traits except grain breadth and red grain types had higher protein content than white.

Rachangdale *et al.* (1987) reported higher yields in late dwarf cultivar were ascribed to the higher NAR and LAI during the post flowering period, dwarf cultivar had more functioning leaves with erect habit during the grain filling stage, tall cultivars were poor yielder despite higher LAI and DM production upto the tillering stage. Burondkar *et al.* (1988) reported that the yield was positively correlated with total dry matter production (DM), net-assimilation rate and various yield components. The high yielding cultivar RTN-1 and TRN-24 showed higher leaf area during the grain filling period compared with other cultivars.

Miyagawa and Kuroda (1988) indicated yields were positively correlated with leaf area index. Murty *et al.* (1990) reported leaf area at early crop growth stage mean net-assimilation rate (NAR), total dry matter production (TDM) and harvest index showed positive association with grain yield.

Chau and Bhargawa (1993) reported grain yield was positively correlated with post flowering, total dry matter production (TDM) and leaf area duration during grain filling, while it was negatively correlated with leaf area index and total dry matter at flowering. Chauhan *et al.* (1994) reported net-assimilation rate (NAR) had high (>75%) heritability associated with high genetic advance indicating the predominance of additive gene effects in the inheritance of this trait.

Reddy *et al.* (1994) reported dry matter production and grain yield were positively associated with each other and also with net-assimilation rate (NAR) and harvest index, while leaf area index had no significant effect on dry matter production (DMP) and grain yield. Kuo *et al.* (1995) reported heterosis over the mid parent was usually in the positive direction for amylose content, while over high parent in the negative direction.

Chauhan *et al.* (1996) reported grain yield of rice was correlated with leaf area index (LAI), harvest index and other growth parameters. Singh *et al.* (1997) reported panicle length was potential selection criteria for yield improvement. Ni *et al.* (1996) demonstrated that cultivar xiangging may decrease amylose content, while cultivar T1027 may increase amylose content.

Sahoo and Guru (1997) reported among cultivars, Sarathi attained the highest grain yield accompanied with maximum dry matter production at harvest, while leaf area index was positively associated with grain yield. Singh and Zaman (1998) concluded that in order to develop heterotic hybrids, there is need to identify parents with high physiological efficiency in terms of leaf area index and leaf area per plant.

Balasubramanian *et al.* (1999) reported that relationship between pre-flowering dry matter production and spikelet production was not linear. Chauhan *et al.* (1999) reported dry matter accumulation and leaf area index were correlated at 30, 45 days after emergence and 50 per cent flowering, net-assimilation rate (NAR), leaf area duration between 30 and 45 days after rice emergence and leaf area index at 30 and 45 days were significantly associated with dry matter accumulation at 50 per cent flowering. Christopher *et al.* (1999) showed positive correlation of kernel length with length:breadth ratio.

Meenakshi *et al.* (1999) reported that productive tillers per plant, grains per panicle, dry matter production and harvest index were positively correlated with grain yield. Venkataramana *et al.* (2000) indicated harvest index contributed highest positive direct effect on grain yield and positive indirect effect via 100-grain weight. Chandrarsekhar *et al.* (2001) revealed that cultivar TNRH-16 recorded maximum plant height (85.7 cm), leaf area index (3.93) and hybrid TNRH-16 also produced maximum dry matter of 14065 kg/ha as compared to other cultivars. Nayak *et al.* (2001) revealed positive correlation of grain yield with plant height and panicle length at both phenotypic and genotypic levels; path coefficient analysis also revealed that 100-grain weight contributed to the grain yield of the plant.

Sharma and Haloi (2001) revealed that there was remarkable variation in all the crop growth variables viz. leaf area index (LAI), net-assimilation rate (NAR) and dry matter production (RDMP). Leaf area index in scented rice increased from 30 days after transplanting to 60 days after transplanting, whereas specific leaf weight enhanced upto 90 days after transplanting, flag leaf area exhibited a significant positive relationship with grain yield.

Misra and Verma (2002) reported grain yield was positively correlated with biological yield and harvest index both at genotypic and phenotypic levels. Singh *et al.* (2002) indicated grain yield positively correlation with length of panicle, days to maturity and test weight. Verma *et al.* (2002) reported yield can be improved by direct selection for days to 50 per cent flowering. Surek and Beser (2003) reported grain yield correlated with biological yield and harvest index, biological yield and harvest index had highest direct effect on grain yield.

2.4 Disease reactions

Wu and Peng (1980) reported from the results of inoculation studies on plants of the F_1's and F_2's from crosses between the varieties Topochoz, Tetep, Tadukan and Memorika which were resistant to four local races of *Pyricularia oryzae* and Iomello which is susceptible to all four, it was concluded that genes for resistance were dominant and they may be one or two in number instead of four.

Asaga (1981) indicated that field resistance to *Pyricularia oryzae* in Yamabiko (Pi.a), Norin 29, Kusabue (Pi.K) and Toride-1 were polygenically controlled with additive effects, estimates of eight genes for leaf blast resistance and fifteen for panicle blast resistance were obtained from the cross Toride-1 x Yamabika. Bhatt and Chauhan (1984) reported 53.7 per cent genotypes of rice were appeared resistant after 30 days but only 2.8 per cent after 40 days, after 57 days, only the resistant control VL-8 remained fully resistant.

Arulmozhi and Vaidyanatham (2000) revealed that among the parents screened, IR 500 and *Oryza nivara* showed susceptible reaction and *Oryza rufipogon* exhibited resistant reaction, the F_1 generation of IR50/*O. nivara* hybrid was also susceptible, however the F_2 population segregated in a ratio of 13 susceptible, 3 resistant, the F_1 generation of IR-50/*O. rufipogon* hybrids was resistant and the progeny segregated as 3r:IS.

Chauhan *et al.* (2000) reported that the rice accessions Arrozoas Indios, CNA108-8-42, CNA4136, IRAT-267 and Akashi were resistant to leaf blast, fifty seven accessions exhibited moderate resistance, among indigenous accessions only Pallavi besides Akashi was resistant and nineteen were moderately resistant. Hedge and Kumar (2001) reported IET 13549 and IET 16332 showed resistance to leaf blast and neck blast. Nagaraju *et al.* (2001) reported KAUM57-18-1-1-, KAUm59-29-2-1 were highly resistant, 21 entries resistant, 33 moderately resistant, 22 moderately susceptible and 12 susceptible.

Material and Methods

MATERIAL AND METHODS

The present investigation entitled, "Genetic analysis of yield components and net-assimilation rate in rice *(Oryza sativa* L.)" was carried out in the Department of Plant Breeding and Genetics of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur during *Kharif* 2001 to 2003.

3.1 Experimental material

The experimental material comprised nine diverse genotypes of rice viz., HPR-1164, HPR-2047, China-988, VL91-1754, VL93-3613, VL93-6052, IR57893-08, VLDhan 221 and JD-8. These genotypes were crossed in all possible combinations, excluding reciprocals (in diallel fashion) in the polyhouse at Seed Production Unit and Rice Research Station, Malan during *Kharif* season 2001 and 2002. During *Kharif* 2002, resulting seeds of 36 hybrids (F_1's) were first germinated in seed germinator at temperature range of 25-30°C for seven to ten days. Thereafter, these seedlings were transplanted to earthen pots having soil of uniform composition (Soil 2 parts : FYM 1 part : Sand 1 part). Thirty five days old seedlings were transplanted to the field in three replications, comprising of three rows of each parent and one row of each hybrid (F_1's) of 3m length. Single seedling was transplanted per hill with row to row spacing of 20 cm and plant to plant 15 cm, respectively. Recommended doses of fertilizers and agronomical practices were applied.

Table 3.1 Description of material used

Sr. No.	Name of genotype	Pedigree	Features
1.	HPR-1164	IR4195-83-3-2x IR9758k-2	Long bold grains, 50 per cent flowering in 91 days, semi dwarf, and moderately resistant to leaf blast and neck blast
2.	HPR-2047	HPU-741x Kalijhini	Long bold grain type, tolerant to stem borer, 50 per cent flowering in 82 days
3.	China-988	Introduction	Tall early maturing, medium bold grains, widely adaptable, susceptible to blast, suitable for rain fed and irrigated conditions up to 1500 m altitude and yielding 25 q/ha
4.	VL91-1754	China-4xBG-367	50 per cent flowering in 103 days, short bold grains, resistant to stem borer, leaf folder, moderately resistant to blast, recommended to hilly areas of U.P. and H.P.
5.	VL93-3613	HPU-799x VLDhan-221	Medium bold grain type, 50 per cent flowering in 90 days, intermediate height, moderately resistant to leaf blast and neck blast
6.	VL93-6052	Parvati Krishi Anusandhan, Almora, U.A.	Intermediate height, medium bold grain type, 50 per cent flowering in 92 days, resistant to glumes discoloration, moderately resistant to leaf blast and neck blast
7.	IR57893-08	China-8x IRAT-104	Intermediate height, 50 per cent flowering in 95 days, suitable for rainfed and irrigated conditions, medium short grain type and resistant to leaf blast and neck blast.
8.	VLDhan-221	IR203-521-1-1-1x China-1039	Medium tall early maturing, high yielding, medium bold grains, resistant to main diseases of rice and yield 28 q/ha
9.	JD-8	Genetic Division of IARI, New Delhi	Intermediate height, 50 per cent flowering in 74 days, suitable for direct seeded under rainfed conditions, long bold grains and has wide adaptability

3.2 Layout of the experiment

During *Kharif* 2003, nine parent thirty six hybrids (F_1's) and their thirty six F_2's were raised in Randomized Block Design with three replications at the Experimental Farm of the Department of Plant Breeding and Genetics. Each replication comprised of three rows of each parent and F_2's and single row of each hybrid in 3m length under agronomical cultural practices. The net-assimilation rate was estimated between 60 and 90 days from the date of transplanting.

3.3 Recording of observations

The data were recorded on the basis of 10 randomly selected plants per replication in non-segregating generations (parents and hybrids) and 25 plants per replication in segregating generation (F_2's) on the following traits:

1. **Days to 50 per cent flowering :** Number of days from the date of seedling emergence to the date of 50 per cent flowering were calculated.

2. **Plant height (cm) :** Height of the tallest panicle was measured from the ground level to the tip of the panicle (excluding awns) at maturity.

3. Net-assimilation rate (NAR) gm cm^{-2} day^{-1}

(i) Leaf area (cm^2) : It was computed by plucking all the leaves and recording the leaf area with the "Basic Area Measurement System" at 60 and 90 days after transplanting.

(ii) Leaf area index (%) : It was calculated as below:

$$\text{Leaf Area Index} = \frac{\text{Leaf area plant}^{-1} \text{ (cm}^2\text{)}}{\text{Area of land covered by that plant (cm}^2\text{)}}$$

(iii) Net-assimilation rate (NAR)

(W_2-W_1) (InA_2-InA_1) / (A_2-A_1) (t_2-t_1), where, InA_2 and InA_1 are the natural log values of leaf area at time t_2 and t_1, respectively.

4. Panicle length (cm) : Length of main panicle (excluding awns) was measured at maturity.

5. Days to maturity : The number of days taken from sowing date to complete maturity was recorded.

6. Grain yield/plant (gm) : The weight of the grain produced from each plant was recorded.

7. Biological yield/plant (gm) : Oven dried plants (excluding roots) were individually weighed before threshing.

8. Harvest index (%) : It was calculated as below:

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield/plant}}{\text{Biological yield/plant}} \times 100$$

9. 100-grain weight (gm) : Three random samples of 100 well filled grains from bulk produce of each replication were counted and weighed.

10. Grain length (mm) : Length of five dehusked grains from the main panicle of each plant was measured by using dial micrometer.

11. Grain breadth (mm) : Breadth of five dehusked grains was measured as above to obtain the average value.

12. Length/Breadth ratio : It was calculated by dividing the grain length to grain breadth as recorded.

13. Amylose content (%) : Amylose content was estimated by manual method using acetate buffer and amylose-amylopectin (70% starch) standard, outlined by Julino (1971).

The sample was finely ground to pass through a 100 mesh sieve. One hundred milligram of each sample was weighed and taken in test tube to which ethanol (1 ml) and 1 N sodium hydroxide (9 ml) were added. The test tube was heated for 10 minutes in boiling water bath to gelatinize the starch, cooled and transferred with several washings of H_2O into 100 ml volumetric flask. The colour was developed by adding 1 N acetic acid (1 ml) and iodine solution (2 ml). The volume was made, shaken and allowed to stand for 20 minutes. Then absorbance was read at 620 nm using Spectronic-20.

The standard curve was prepared by heating 40 mg of potato amylose in similar fashion and volume was made to 100 ml. The solution (0, 1, 2, 3, 4 and 5 ml) was pipetted in 100 ml volumetric flasks. The 1 N acetic acid (0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 ml) and Iodine solution (2 ml) were added. The absorbance was measured at 620 nm after 20 minutes. Amylose content of sample was obtained with reference to standard curve obtained by plotting the absorbance reading against concentration.

14. Protein content (%) : A composite seed sample from the bulk produce of each replication was analysed for the estimation of nitrogen content. The grains after dehusking were ground to fine powder. Total nitrogen was estimated by the standard micro Kjehldahl method. The protein percentage was calculated as follows:

% Protein (Brown rice) = % N x 6.25

15. Leaf blast : Leaf blast was visually assessed as the infected leaf area based on five top most leaves of five randomly chosen tillers (IRRI, 1988).

16. Neck blast : One week before harvesting neck blast was recorded as percentage of tillers having neck blast in each entry.

3.4 Statistical analysis

To test the significance of differences among different genotypes/breeding material used in the study, the data on mean values for yield, its components and grain quality traits was analysed as per the standard procedure, for a randomized complete block design (Panse and Sukhatme, 1984).

The following model was used for the analysis:

$$Y_{ij} = \mu + g_i + r_j + e_{ij}$$

where,

Y_{ij} = Phenotypic observation of i^{th} genotype grown in j^{th} replication

μ = General mean

g_i = Genotypic effect of the i^{th} genotype

r_j = Effect of j^{th} replication

e_{ij} = Error component associated with ij^{th} observation

The analysis of variance based on this model leads to the following break-up of variance components with assumption that the effects are random i.e. where g_i, r_j and e_{ij} are uncorrelated.

Analysis of variance

Source of variation	df	Sum of squares	Mean squares	'F' ratio	Expected mean square
1. Replications	(r-1)	Sr	Mr=Sr/(r-1)	Mr/Me	$\sigma^2e+g\sigma^2r$
2. Genotype	(g-1)	Sg	Mg=Sg/(g-1)	Mg/Me	$\sigma^2e+r\sigma^2g$
3. Error	(r-1) (g-1)	Se	Me=Se/(r-1)(g-1)	-	σ^2e
Total	(rg-1)				

where,

r = Number of replications

g = Number of genotypes

σ^2g = Genotypic variance

σ^2p = Phenotypic variance

σ^2e = Error variance

Standard Error (S.E.) of a genotype mean was calculated by the formula:

$$SE(m) = \pm (Me/r)^{1/2}$$

The standard error (SE) of genotypic difference was calculated as :

$$SE(d) = \pm (2Me/r)^{1/2}$$

Critical difference : Critical difference (CD) was calculated as:

$$CD = SE(d) \times `t'$$

where,

SE(d) = Standard error of difference

t = tabulated value of 't' at 5 per cent and 1 per cent level of significance at error degrees of freedom.

3.5 Components of variation

3.5.1 Coefficient of variation (C.V.) : The coefficient of variation was calculated as per the following formula:

$$\text{Coefficient of variation (\%)} = \frac{(\text{Me})^{1/2}}{\text{Grand mean}} \times 100$$

3.5.2 Genotypic coefficient of variation : The genotypic coefficient of variation was calculated by the formula:

$$\text{GCV(\%)} = \frac{(\text{Genotypic variance})^{1/2}}{\text{Grand mean}} \times 100$$

(Burton, 1952)

$$\text{PCV (\%)} = \frac{(\text{Phenotypic variance})^{1/2}}{\text{Grand mean}} \times 100$$

(Burton and DeVane, 1953)

3.5.3 Heritability : Heritability in broad sense (H) was calculated as the ratio of genotypic variance to the phenotypic variance :

$$\text{H(\%)} = \sigma^2 g/\sigma^2 p \times 100$$ (Burton and Devane, 1953)

where,

$\sigma^2 g$ = Genotypic variance

$\sigma^2 p$ = Phenotypic variance

3.5.4 Genetic advance (GA) : The genetic advance was computed according to the following formula :

$$\text{GA} = K\sigma^2 pH$$

where,

K = Selection differential in standard units, which is 2.06 for 5 per cent selection intensity

σ^2p = Phenotypic standard deviation

H = Heritability in broad sense

The genetic gain was expressed as a percentage of the respective mean, for comparison of the estimates for different characters.

$$\text{Genetic gain (\%)} = \frac{\text{GA}}{\text{Grand Mean}} \text{ X } 100$$

For categorizing the magnitude of different parameters, the following limits were used:

PCV and GCV	> 20%	High
	10-20%	Moderate
	< 10%	Low
Heritability	> 80%	High
	50-80%	Moderate
	< 50%	Low
Genetic advance	> 30%	High
	20-30%	Moderate
	< 20%	Low

3.6 Combining ability analysis

Data pertaining to parents and F_1's of 9 x 9 diallel set were subjected to this analysis. The combining ability analysis were carried out as per the procedure given by Griffing (1956) Method 2 and Model 1, was considered most appropriate for the material under study.

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

$$X_{ij} = \mu + g_i + g_j + S_{ij} + \frac{1}{rc} \Sigma_K \Sigma_1 e_{ijkl}$$

where,

ij = 1……………………,n

K = i……………………,r

I = I……………………,c

n = Number of parents

r = Number of replications

c = Number of observations for each of the plots

μ = Population mean

g_i = General combining ability of i^{th} parent

g_j = General combining ability of j^{th} parent

S_{ij} = Specific combining ability effect such that $S_{ij} = S_{ji}$

e_{ijkl} = Environmental effect peculiar to the $ijkl^{th}$ observation

The restriction imposed on this model are:

$\Sigma g_i = 0$ and $\Sigma S_{ij} + S_{ii} = 0$ (for each i)

The sum of squares were calculated as follows

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

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

where,

S_g = Sum of squares due to general combining ability

S_s = Sum of squares due to specific combining ability

n = Number of parents

$x_{i.}$ = Total of the array of i^{th} parent

X_{ii} = Mean value of i^{th} parent

$x_{..}$ = Grand total of ½ n(n–1) progenies and n parental values

x_{ij} = Mean values of the diallel table

Analysis of variance for combining ability

	Source	d.f.	M.S.	Expectation of mean values
1.	gca	(n–1)	Mg	$\sigma^2e + (n+2)\frac{1}{(n-1)}\sum_i g_i^2$
2.	sca	$\frac{n(n-1)}{2}$	Ms	$\sigma^2e + \frac{2}{n(n-1)}\sum_i \sum_j S_{ij.}^2$
3.	Error	(r–1)	(t-1)Me′	σ^2e

The mean sum of squares due to gca and sca were obtained by dividing their sum of squares by respective degrees of freedom. The EMS for combining ability analysis was obtained by dividing error mean square obtained from simple R.B.D. analysis of variance for the experiment in the number of replication. For 'F' test each mean square was tested against Me′. In addition σ^2 gca and σ^2 sca were also calculated assuming random model.

Where $\sigma^2 \text{ gca} = \frac{Mg - Ms}{(n-2)}$ and $\sigma^2 \text{ sca} = Ms - Me'$

3.6.1 Estimates of gca and sca effects

gca = Effect of i^{th} parent

$$g_i = \frac{1}{(n+2)} (x_{i.} + x_{ii}) - 2/n \; x_{..})$$

sca = Effect of ij^{th} cross

$$S_{ij} = x_{ij} - \frac{1}{(n+2)} (x_{i.} + x_{ii} + x_{jj}) + \frac{2}{(n+1)\,(n+2)}$$

where,

n, $x_{i.}$, x_{ii} and $x_{..}$ are the same as explained above.

3.6.2 Standard error of estimates

Standard error of each estimate was calculated as the square root of the variance of the estimate. The variance of estimate was computed as follows:

$$\text{Var}\,(x_{ij}) = \sigma^2 e = Me'$$

$$\text{Var}\,(\mu) = \frac{2}{n(n+1)} \sigma^2 e$$

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

$$\text{Var}\,(S_{ij}) = \frac{n^2 + n + 2}{(n+1)\,(n+2)} \sigma^2 e$$

Each gca and sca value was tested against zero for its significance by 't' test

$$t = \frac{g_i - 0}{SE\,(g_i)} \quad \text{and} \quad \frac{S_{ij} - 0}{SE\,(S_{ij})}$$

3.7 Genetic component analysis

The following genetic components of variation were calculated, following the method given by Hayman (1954) and Askel and Johnson (1963).

D = Component of variation due to the additive effects of genes

H_1 = Component of variation due to the dominance effect of genes

H_2 = H_1 [$1-(u-v)^2$] where u and v are the proportion of positive and negative genes in the parents

F = Mean of Fr over the arrays

h^2 = Dominance effect (as algebric sum of all loci in heterozygous phase in all crosses).

The estimates of these components of genetic variation were determined by using the following relations suggested by Hayman (1954).

$\hat{D} = V_OL_O - \hat{E}$

$\hat{F} = 2V_OL_O - 4W_OL_OI - 2(n\text{-}2)\ \hat{E}/n$

$\hat{H}_1 = V_OL_O - 4W_OL_OI + 4V_IL_I - (3n\text{-}2)\ \hat{E}/n$

$\hat{H}_2 = 4V_IL_I - 4V_OL_I - 2\ \hat{E}$

$\hat{h}^2 = 4\ (ML_I - ML_O)^2 - 4\ (n\text{-}1)\ \hat{E}/n^2$

$\hat{Fr} = 2(V_OL_O - W_OL_O + V_1L_1 - Vr) - 2\ (n\text{-}2)\ \hat{E}/n$

The statistics in the above formulae may be explained as follows:

V_OL_O = Variance of parent

Vr = Variance of rth array

V_1L_1 = Mean variance of the arrays

Wr = Covariance between parents and their offspring in the rth array

W_OL_OI = Mean covariance between the parents and the arrays

V_OL_I = Variance of means of the array

$(ML_1\text{-}ML_O)$= Difference between the means of the parents and the *mean of* n^2 *progenies*

E = Expected environmental component of variance

3.7.1 Testing the validity of assumptions made by Hayman (1954) was done by testing the uniformity of Wr, Vr

The testing was done by using the following formula.

$$t^2 = \frac{(n-4)}{2}\left[\frac{(Var.Vr - Var.Wr)^2}{Var.Vr \times Var.Wr - COV\ (Vr.Wr)}\right]$$

Which is an F with (n-2) d.f., significant value indicates failure of hypothesis.

The presence of genic interactions was detected and interpreted by calculating the regression coefficient of Vr and Wr values.

$$b = \frac{COV\ (Wr.Vr)}{Var.Vr}$$

The standard error of regression coefficient was calculated by the following formula (Smith, 1954):

$$SE(b) = \pm\sqrt{\frac{Var.Wr - b\ COV.Vr.Wr}{Var.Vr\ (n-2)}}$$

The significance of difference of b was tested both from zero and unity 't' value of (b–0)/SE(b) and 1–b/SE(b) with (n–2) d.f.

3.8 Estimation of components of variation in F_2 generation

The components of variation of F_2's were estimated by formulae given by Jinks (1956). The expected statistics for F_2 are of the same form as those of F_1 except that contribution of 'h' is reduced to half by one generation of inbreeding. The coefficients of H_1 and H_2 are ¼ of those of F_1 statistics, while the coefficient of F is halved being second and first degree of statistics in 'h', respectively (Jinks, 1956; Hayman, 1958 and Mather and Jinks, 1971).

Components of F_2 variances were computed as follows:

$\overline{Vr} = V_1L_2 = (¼D + 1/16H_1 + 1/8F + E_2)$

$\overline{Wr} = W_0L_{02} = (½D - 1/8F + 1/n\ E_2)$

$Vm = V_0L_2 = (¼D + 1/16H_1 - 1/16H_2 - 1/8F + 1/n\ E_2)$

$\overline{VP} = V_0L_0 = D + E$

where,

E_2 = M'e of F_2

n = Number of parents

$\hat{D}_1 = V_0L_0 - E$

$$\hat{H}_1 = 16V_1L_2 - 16W_0L_{02} + 4V_1L_0 - \frac{4\ (5n-4)}{n} E_2$$

$$\hat{H}_2 = 16V_1L_2 - 16V_0L_{02} - \frac{16\ (n-1)}{n} E_2$$

$$\hat{F} = 4V_0L_0 - 8V_0L_0 - \frac{4\ (n-2)}{n} E_2$$

3.8.1 Estimation of standard errors

The standard errors, to test the significance of genetic components were calculated as follows:

$$SE(\hat{D}) = \pm\sqrt{\frac{S^2(n^5 + n^4)}{n^5}}$$

$$SE(\hat{H}_1) = \pm\sqrt{\frac{S^2(16n^5 + 65n^4 - 192n^3 + 64n^2)}{n^5}}$$

$$SE(\hat{H}_2) = \pm\sqrt{\frac{S^2(576n^4)}{n^5}}$$

$$SE(\hat{F}) = \pm\sqrt{\frac{S^2(16n^5 + 80n^4 - 64n^3 + 64n^2)}{n^5}}$$

$$SE(\hat{h}^2) = \pm\sqrt{\frac{S^2(256n^4 + 256n^2 - 512n + 256)}{n^5}}$$

$$SE(\hat{E}) = \pm\sqrt{\frac{S^2(n^4)}{n^5}}$$

where,

n = number of parents and

S^2 = ½ var. (Wr – Vr)

The significance of the various statistics is tested by 't' test at (n-2) degree of freedom as:

't' = Parameter/S.E. of parameter

3.9 Estimation Of Heterosis

3.9.1 Estimation of heterosis over better parent (H_1)

This was expressed as per cent increase or decrease in the mean value of F_1 hybrid over better parent.

$$H_1 = \bar{F}_1 - \overline{BP}$$

$$H_1(\%) = \frac{\bar{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

$$SE(H_1) = \pm\ (2Me/r)^{1/2}$$

where,

$\bar{F}_1$ = Mean value of hybrid

$\overline{BP}$ = Mean value of the better parent involved in that cross

r = Number of replications

Me = Error mean squares

3.9.2 Heterosis over the standard check

Expressed as per cent increase or decrease in the mean value of F_1 hybrid over the best variety for that particular character in the material.

$$H_2 = \bar{F}_1 - \overline{SC}$$

$$H_2(\%) = \frac{\overline{F}_1 - \overline{SC}}{\overline{SC}} \times 100$$

$$SE(H_2) = \pm\ (2Me/r)^{1/2}$$

where,

r = Number of replications

$\overline{SC}$ = Mean value of the standard check among parents for that particular trait

Me = Error mean square

3.9.3 Test of significance for heterosis

Significance of heterosis was tested by 't' test. Heterosis over respective parent is divided by respective standard error and thus calculated value of 't' was compared with tabulated value of 't' at error degree of freedom as follows:

$$'t'\ Cal\ (H_1) = (\overline{F} - \overline{BP}) / SE\ (H_1)$$

$$'t'\ Cal\ (H_2) = (\overline{F} - \overline{SC}) / SE\ (H_2)$$

3.9.4 Inbreeding depression in F_2

This was expressed as per cent increase or decrease in the mean value of F_2 generation over that of F_1 generation.

$$\text{Inbreeding depression (I)} = \overline{F}_2 - \overline{F}_1$$

$$(I\%) = \frac{\overline{F}_2 - \overline{F}_1}{\overline{F}_1} \times 100$$

$$SE\ (I.D) = \sqrt{(V\ \overline{F}_1 + V\ \overline{F}_2)}$$

3.10 Correlation coefficients

For computing phenotypic and genotypic correlation coefficients, analysis of covariance were performed in all possible paired combinations of various traits studied. The analysis of covariance table was set up as follows:

Source	d.f.	Mean sum of products	Expected mean sum of products
Replications	(r-1)	Mr_{xy}	$\sigma e_{xy} + g\sigma r_{xy}$
Genotypes	(g-1)	Mg_{xy}	$\sigma e_{xy} + r\sigma g_{xy}$
Error	(r-1)(g-1)	Me_{xy}	σe_{xy}

where,

g = Number of genotypes

Genetic covariance $(\sigma g_{xy}) = (Mg_{xy} - Me_{xy})/r$

Phenotypic covariance $\sigma p_{xy} = \sigma g_{xy} + \sigma e_{xy}$

The phenotypic and genotypic coefficients of correlation were computed as suggested by Al-Jibouri *et al.* (1958).

Phenotypic coefficient of correlation:

$$rp_{xy} = \frac{\sigma p_{xy}}{(\sigma^2 p_x + \sigma^2 p_y)^{1/2}}$$

where,

σp_{xy} = Phenotypic covariance between two characters x and y

$\sigma^2 p_x$ = Phenotypic variance of character x

$\sigma^2 p_y$ = Phenotypic variance of character y

Genotypic coefficient of correlation:

$$rg_{xy} = \frac{\sigma g_{xy}}{(\sigma^2 g_x + \sigma^2 g_y)^{1/2}}$$

where,

σg_{xy} = Genotypic covariance between character x and y

$\sigma^2 g_x$ = Genotypic variance of character x

$\sigma^2 g_y$ = Genotypic variance of character y

The significance of phenotypic coefficients of correlation was tested against 'r' values as given by Fisher and Yates (1963) at (n-2) degree of freedom.

3.10.1 Estimation of direct and indirect effects

Path coefficient, a standardized partial regression coefficient permits the partitioning of coefficient of correlation into direct and indirect effects. The path coefficient analysis of various traits was done following Dewey and Lu (1959) as under:

$$Py_1 + Py_2r_{12} + Py_3r_{13} + \dots\dots + Py_nr_n = ry_1$$

$$Py_1r_{12} + Py_2 + Py_3r_{23} + \dots\dots + Py_nr_{2n} = ry_2$$

$$Py_1r_{13} + Py_2r_{23} + Py_3 + \dots\dots + Py_nr_{3n} = ry_3$$

:

:

:

$$Py_1r_{n1} + Py_2r_{n2} + Py_3r_{n3} + \dots\dots + Py_n = ry_n$$

where,

Py_1, Py_2, Py_3, ..., Py_n are the direct path effects of 1, 2, 3 ...., n variables on the dependent variable 'y'; r_{12}, r_{13}, ... r $(n-1)^n$ are the possible coefficients of correlation between various independent variables and ry_1, ry_2, ..., ry_n are the coefficient of correlation of independent variables with dependent variable 'y'.

The variation in the dependent variable which remained undetermined by including the given variables was assumed to be due to variables not included in the present investigation. The degrees of determination of such variable(s) on the dependent variable was calculated as follows:

Residual effect = $(1 - R^2)^{1/2}$

where,

$R^2 = Py_1ry_1 + Py_2ry_2 + \ldots\ldots + Py_nry_n$

where,

R^2 is the square multiple correlation coefficient and is the amount of variation in yield that can be accounted for the yield component characters which were included in the present study.

Results

Chapter IV

RESULTS

Data collected on various traits in the present investigation were subjected to the following analyses.

4.1 Analysis of variance for the experimental design

4.2 Diallel analysis

4.2.1 Combining ability analysis

4.2.2 Genetic component analysis

4.3 Heterosis and inbreeding depression

4.4 Correlation coefficients and path analysis

4.5 Disease

4.1 Analysis of variance for the experimental design

Analysis of variance exhibited significant mean squares due to treatments including nine parents, thirty six hybrids and their thirty six F_2's for all the characters viz., days to 50 per cent flowering, plant height, leaf area index, dry matter, net-assimilation rate, panicle length, days to maturity, grain yield/plant, biological yield/plant, harvest index, 100-grain weight, grain length, length-breadth ratio, amylose content, grain breadth and protein content are presented in the Table 4.1.

Table 4.1 Analysis of variance for the experimental design

Character	Mean sum of square due to		
source	Replication	Treatment	Error
df	2	80	160
Days to 50 per cent flowering	6.02	145.04*	6.65
Plant height	21.82	309.61*	22.06
Leaf area index	0.06	0.85*	0.02
Dry matter	82.27*	120.49*	1.99
Net assimilation rate	0.16*	15.67*	0.50
Length of panicle	2.56	11.98*	3.39
Days to maturity	4.62	132.10*	6.58
Grain yield per plant	1.46	43.26*	2.30
Biological yield per plant	6.76	269.61*	20.81
Harvest index	16.49	122.23*	17.26
100-grain weight	0.025	0.27*	0.02
Grain length	0.15	0.57*	0.13
Grain breadth	0.10	0.13*	0.03
Length breadth ratio	0.02	0.21*	0.02
Amylose content	0.08	2.25*	0.03
Protein content	0.003	1.99*	0.14

* Significant at 5 per cent level of probability

4.2 Diallel analysis

4.2.1 Combining ability analysis

The combining ability analysis for yield, its components and grain quality traits as carried out following Method II and Model I of Griffing (1956) in F_1 and F_2 generations are presented in Table 4.2 and 4.3, respectively and described below.

The mean sum of squares due to gca in F_1 and F_2 generations were significant for all the traits except for net-assimilation rate in F_2. Likewise in F_1 and F_2 generation, mean sum of squares due to sca were also significant for all the traits.

The magnitude of gca variance was higher than the corresponding sca variances for all the traits except biological yield, length of panicle and grain length in F_1 generation however in F_2, magnitude of gca variance was higher than the corresponding sca variance except plant-height, biological yield/plant, harvest index, net-assimilation rate, and protein content.

4.2.1.1 Estimation of general combining ability (gca) effects

The estimates of gca effects associated with parental lines were significant in F_1 and F_2 generation for all the characters except grain breadth in F_1 and net-assimilation rate in F_2 generation are presented in Table 4.4 and 4.5, respectively and are described below.

Table 4.2 Analysis of variance for combining ability for yield, its components and grain quality traits in F_1 generation

Character	Mean sum of square due to		
Source	GCA	SCA	Error
df	8	36	160
Days to 50 per cent flowering	81.01**	53.51**	2.22
Plant height	150.58**	92.13*	7.35
Leaf area index	0.40*	0.36*	0.008
Dry matter	77.79**	42.91**	0.66
Net assimilation rate	10.92**	6.07**	0.003
Length of panicle	3.60**	4.67**	1.13
Days to maturity	68.17**	45.77**	2.19
Grain yield per plant	20.05**	19.48**	0.76
Biological yield per plant	126.84**	127.86**	6.96
Harvest index	62.88**	43.81**	5.75
100-grain weight	0.13*	0.10*	0.006
Grain length	0.13*	0.26*	0.04
Grain breadth	0.02	0.13	0.03
Length breadth ratio	0.08*	0.07*	0.008

* significant at 5 per cent
** significant at 1 per cent

Table 4.3 Analysis of variance for combining ability for yield, its components and grain quality traits in F_2 generation

Characters	Mean sum of square due to		
Source	GCA	SCA	Error
df	8	36	160
Days to 50 per cent flowering	77.73**	50.28**	1.51
Plant height	80.69**	91.63**	4.08
Leaf area index	0.46**	0.30**	0.0004
Dry matter	20.70**	12.43**	3.99
Net assimilation rate	1.41	4.02*	0.88
Length of panicle	4.86**	4.03**	0.47
Days to maturity	67.04**	47.45**.	1.25
Grain yield per plant	7.95**	3.55**	2.24
Biological yield per plant	111.95**	139.70**	3.88
Harvest index	39.54**	53.96**	5.52
100-grain weight	0.21**	0.08**	0.004
Grain length	0.40**	0.19**	0.020
Grain breadth	0.50**	0.008**	0.0007
L/B ratio	0.21**	0.05**	6.21
Amylose content	3.85**	0.06**	0.01
Protein content	0.33**	0.73**	0.04

* Significant at 5 per cent probability
** Significant at 1 percent probability

Table 4.4 Estimates of general combining ability effects for yield, its components and grain quality traits in F_1 generation

Traits / Genotypes	Plant height	Days to 50% flowering	Grain yield	Biological yield	Harvest index	Days to maturity	LAI	DM	PL	100grain weight	NAR	GL	L/B ratio
HPR 1164	-3.83**	-0.92*	-0.14	-2.09**	-1.09	-0.57	0.02	-2.34**	-1.07**	-0.10**	-1.32**	0.01	-0.03
HPR2047	4.12**	1.99**	0.49*	0.66	-1.35*	1.70**	0.16**	-1.19**	0.23	-0.12**	-0.83**	-0.03	0.08**
China 988	-3.86**	1.73**	-1.13**	-0.69	1.37*	1.47**	-0.01	-3.06**	-0.11	-0.16**	-0.54**	-0.16**	0.00
VL91-1754	2.73**	4.20**	0.10	-0.89	-0.84	3.92*	0.37**	0.52**	0.69**	0.12**	0.55**	0.02	-0.13**
VL93-3613	-4.64**	1.92**	2.69**	-6.38**	4.81**	1.64**	-0.06**	5.10**	0.41	0.05**	2.13**	0.08	-0.06*
VL 93-6052	4.22**	0.22	-0.23	-0.56	1.21	0.38	0.09**	3.37**	0.42	0.16**	0.30**	0.12*	0.02*
IR-57893-08	0.16	-2.07**	-0.55*	0.63	1.20	-2.17**	-0.17**	-1.38**	-0.21	0.04*	0.29**	-0.12*	-0.04*
VL-Dhan221	3.34**	-3.08**	-2.14**	0.92	-2.58**	-2.44**	-0.25**	-0.84**	0.31	0.03	-0.26	-0.07	-0.01
JD-8	-2.24**	-3.99**	0.92**	6.63**	-2.72**	-3.91**	-0.16**	-0.17	-0.67**	-0.03	-0.32**	0.15*	0.17**
S.E (gi)	0.77	0.42	0.24	0.74	0.67	0.42	0.02	0.23	0.30	0.02	0.015	0.06	0.02
S.E (gi-gj)	1.15	0.63	0.13	1.12	1.02	0.63	0.03	0.34	0.45	0.07	-0.023	0.09	0.039
C.D. (gi) at5%	1.50	0.82	0.47	1.45	1.31	0.82	0.04	0.45	0.58	0.03	0.029	0.11	0.03

* Significant at 5 per cent probability
** Significant at 1 percent probability

LAI – leaf area index DM – dry matter GL – grain length GB – grain breadth NAR – net assimilation ratePL – panicle length

Table 4.5 Estimates of general combining ability effects for yield, its components and grain quality traits in F_2 generation

Traits / Genotypes	Plant height	Days to 50% flowering	Grain yield	Biological yield	Harvest index	Days to maturity	LAI	DM	PL	100 grain weight	NAR	GL	GB	L/B ratio	AC	PC
HPR 1164	3.70**	0.52	0.35	2.42**	-2.93**	0.38	0.11**	2.56**	-0.27	0.02*	-0.22	0.12**	0.06**	-0.03	0.37**	0.14*
HPR2047	-1.70**	0.80*	1.37**	1.00	0.02	0.67*	-0.20**	-0.45	-0.16	-0.25**	-0.26	-0.25**	-0.12**	0.11**	-0.41**	-0.19**
China 988	-1.89**	3.99**	0.09	-3.71**	1.25	3.84**	0.08**	-1.72**	-0.27	0.05**	0.07	-0.06	0.09**	-0.20**	-0.80**	-0.13*
VL91-1754	4.82**	1.80**	0.34	-1.39*	1.21	1.66**	0.16**	0.80	1.49**	0.16**	0.49**	0.07	0.01**	0.00	0.38**	0.05
VL93-3613	-1.35*	-3.10**	0.72	6.13**	1.73**	-3.25**	-0.21**	-0.67	-0.30	-0.04**	0.65*	-0.25**	-0.01**	-0.11**	-0.14**	-0.14*
VL 93-6052	0.23	-0.71*	-0.68	-2.36**	1.49*	-0.86**	0.36**	1.30*	0.28	0.13**	-0.30	0.19**	0.02**	0.07**	0.83**	0.13*
IR-57893-08	-2.12**	2.69**	-1.33**	-2.95**	1.16	2.54**	0.03**	-1.58**	0.43*	0.13**	0.10	0.06	0.04**	-0.06**	-0.75**	-0.16**
VL-Dhan221	1.10	-3.76**	-0.94*	-1.40*	-3.18**	-2.97**	-0.28**	-0.16	-0.44**	-0.04**	-0.33	-0.17**	-0.03**	-0.05*	0.65**	-0.02
JD-8	-2.78**	-2.23**	0.09	2.25**	-0.72	-2.01**	-0.05**	-0.08	-0.77**	-0.17**	-0.19	0.28**	-0.06**	0.28**	-0.13**	0.32**
S.E (gi)	0.57	0.34	0.42	0.55	0.66	0.31	0.0006	0.56	0.17	0.01	0.26	0.04	0.0007	0.02	0.03	0.06
S.E (gi-gj)	0.86	0.52	0.63	0.83	0.31	0.46	0.0009	0.84	0.28	0.02	0.40	0.06	0.01	0.03	0.04	0.09
C.D.(gi) at5%	1.12	0.66	0.82	1.08	1.29	0.60	0.0001	1.09	0.33	0.02	0.50	0.08	0.0001	0.04	0.05	0.11

* Significant at 5 per cent probability
** significant at 1 percent probability

LAI – leaf area index DM – dry matter GL – grain length GB – grain breadth NAR – net assimilation rate PL – panicle length

Days to flowering

In F_1 generation, the parents JD-8, VLDhan 221, IR57893-08 and HPR-1164 were good general combiners for early flowering, remaining parents except VL93-6052 showed significant positive gca effects, whereas in F_2 generation, VL93-3613, VL93-6052, VLDhan 221 and JD-8 were good general combiners for early flowering, however remaining traits exhibited positive effects.

Plant height

Parents VL91-1754, VLDhan 221 and VL93-6052 exhibited good general combining ability in F_1 generation whereas in F_2, HPR-1164 and VL91-1754 showed good general combining ability and the remaining parents were significant negative general combiners.

Leaf area index

Parents VL91-1754, VL93-6052 and HPR-2047 were good general combiners, while remaining parents except HPR-1164 and China-988 did not exhibit~~s~~ good general combining ability in F_1 generation. In F_2, HPR-1164, China-988, VL91-1754, VL93-6052 and IR57893-08 were good general combiners and the remaining parents did not exhibits good general combining ability.

Dry matter

VL93-3613, VL93-6052 and VL91-1754 showed positive gca effects for dry matter, whereas the remaining parents exhibited negative gca effects in F_1 generation however in F_2, HPR-1164 and VL93-6052 showed positive gca effects and the remaining parents did not exhibit~~s~~ positive gca effects.

Net-assimilation rate

The parents VL93-3613, VL91-1754, VL93-6052 and IR57893-08 showed positive gca effects and the remaining parents did not exhibit good general combining ability in F_1 generation however in F_2, China-988 and VL91-1754 exhibit~~s~~ed positive gca effects.

Panicle length

In F_1 generation, only one parent i.e. VL91-1754 exhibited positive gca effects, whereas HPR-1164 and JD-8 showed negative gca effects. However in F_2, China-988 and IR57893-08 exhibited positive gca effects and the remaining parents except HPR-1164, HPR-2047, China-988, VL91-1754 and VL93-3613 showed negative gca effects.

Days to maturity

JD-8, VLDhan 221 and IR57893-08 were good general combiners for early maturity and VL91-1754, HPR-2047, VL93-3613 and China-988 showed highly positive gca effects in F_1 generation however in F_2 generation, VL91-1754, VL93-3613, VLDhan 221 and JD-8 were good general combiners and remaining parents showed positive gca effects.

Grain yield

The parents VL93-3613, JD-8 and HPR-2047 were good general combiners and the remaining parents VLDhan 221, China-988 and IR57893-08 had negative gca effects in F_1 generation. However in F_2, only HPR-2047 showed positive gca effect and IR57893-08 and VLDhan 221 showed negative gca effects.

Biological yield

Only parent JD-8 showed high gca effect, whereas VL93-3613 and HPR-1164 exhibited negative gca effects in F_1 generation however in F_2, HPR-1164, VL93-3613 and JD-8 showed high gca effects and remaining parents exhibited high negative gca effects.

Harvest index

The parents VL93-3613 and China-988 exhibited gca effects in positive direction, whereas JD-8, VLDhan 221 and HPR-2047 showed negative gca in F_1 generation however in F_2 generation, VL93-3613 and VL93-6052 exhibited positive gca effects, HPR-1164 and VLDhan 221 showed negative gca effects.

100-grain weight

VL93-6052, VL91-1754, VL93-3613 and IR57893-08 were the best general combiners, whereas China-988, HPR-2047 and HPR-1164 were poor combiners in F_1 generation. In F_2, excluding HPR-2047, VL91-1754, VLDhan 221 and JD-8 all were good general combiners.

Grain length

The parents JD-8 and VL93-6052 showed positive gca effects, whereas China-988 and IR57893-08 showed negative gca effects in F_1 generation however in F_2 generation, HPR-1164, VL93-6052 and JD-8 were good general combiners and HPR-2047, VL93-3613 and VLDhan 221 were poor general combiners.

Grain breadth

In F_2 generation, HPR-2047, VL93-3613, VLDhan 221 and JD-8 showed negative gca effects, whereas HPR-1164, China-988, VL91-1754, VL93-6052 and IR57893-08 exhibited positive gca effects.

Length-breadth ratio

Parents JD-8, HPR-2047 and VL93-6052 were good general combiners and VL91-1754, VL93-3613 and IR57893-08 were poor general combiners in F_1 generation however in F_2 generation, HPR-2047, IR57893-08 and JD-8 showed positive gca effects and the remaining parents except VL91-1754 showed negative gca effects.

Amylose content

Out of nine parents, VL93-6052, VLDhan 221, VL91-1754 and HPR-2047 showed positive gca effects, whereas the remaining parents showed negative gca effects.

Protein content

Parents JD-8, HPR-1164 and VL93-6052 exhibited positive gca effects however, excluding VL91-1754 all the remaining parents showed negative gca effects.

4.2.1.2 Estimates of specific combining ability (sca) effects in the hybrids

The estimates of specific combining ability (sca) effects for yield, its components and grain quality traits in the F_1 and F_2 generations are presented in Table 4.6 and 4.7, respectively. The significant sca effects are described below.

Table 4.6 Estimates of specific combining ability effects for yield, its components and grain quality traits in F_1 generation

Traits / Genotypes (1)	Plant height (2)	Days to 50% flowering (3)	Grain yield (4)	Biological yield (5)	Harvest index (6)	Days to maturity (7)	LAI (8)	DM (9)	PL (10)	100-grain weight (11)	NAR (12)	GL (13)	L/B ratio (14)
HPR 1164xHPR 2047	9.22**	11.06**	4.78**	1.79	0.86	10.68**	1.32**	6.27**	4.15**	0.22**	2.62**	0.01	-0.10
HPR 1164xChina 988	-8.75**	-0.42	-2.91**	-3.69	9.23**	-0.82	-0.76**	-1.83*	-0.78	-0.11	1.04**	-0.30	-0.16*
HPR 1164xVL91-1754	8.10**	1.43	2.58**	-3.35	2.12	1.05	0.19**	-0.22	0.81	0.22**	0.11*	0.29	0.19*
HPR 1164xVL93-3613	-10.44**	5.70**	1.66*	-1.62	2.93	5.32**	0.18**	7.19**	-1.63	-0.37**	-0.22**	-0.52**	-0.10
HPR 1164xVL93-6052	-0.68	-15.81**	-4.57**	-7.73**	-4.85*	-11.64**	-0.96**	-6.15**	-1.19	-0.40**	-3.07**	-0.47*	0.04
HPR 1164xIR57893-08	-12.65**	-10.01**	4.51**	0.64	-6.52**	-8.57**	-0.10	2.25**	-2.61**	-0.32**	-1.21**	0.79**	0.68**
HPR 1164xVL Dhan 221	3.10	-0.95	1.54	19.88**	-2.29	-2.26	0.02	-0.36	1.41	0.17*	-1.17**	0.05	0.05
HPR 1164xJD-8	8.41**	2.30	-4.58**	-11.68**	0.79	1.55	-0.42**	-4.18**	2.74**	0.20**	-2.39**	-0.08	-0.29**
HPR 2047xChina 988	10.78**	-8.20**	-0.31	12.17**	-5.88**	-7.96**	-0.11	-2.24**	0.51	0.15*	-1.52**	0.17	-0.03
HPR 2047xVL91-1754	-0.88	-8.50**	-1.89*	17.35**	-5.33*	-8.24**	0.41**	-8.88**	0.17	0.06	-1.78**	-0.23	-0.23**
HPR 2047xVL93-3613	9.28**	8.24**	-4.66**	-5.97*	-2.80	8.50**	1.12**	-7.76*	-0.43	0.04	-5.13**	1.08**	0.52**
HPR 2047xVL93-6052	-3.31	-3.54**	5.45**	2.43	5.27*	-3.74**	-0.54**	6.48**	2.53**	0.34**	0.16**	0.37	-0.13
HPR 2047xIR57893-08	2.71	-4.32**	-1.16	2.45	-5.62*	-4.24**	-0.20*	-1.18**	-1.98*	0.16*	-0.07	-0.37	-0.22**
HPR 2047xVL Dhan 221	1.29	9.47**	-4.95**	-9.32**	2.73	8.80**	-0.11	0.69	0.57	0.04	0.83**	0.52**	0.12
HPR 2047xJD-8	-12.28**	4.54**	8.55**	-17.61**	14.62**	4.44**	-0.13	10.15**	1.18*	-0.22**	5.29**	-1.40**	-0.49**
China 988xVL91-1754	-10.87**	-5.47**	5.14**	-4.54	0.62	-5.23**	-0.74**	4.68**	-0.13	-0.43**	-0.94**	-0.62**	-0.09
China 988xVL93-3613	-6.47**	-1.05	-2.46**	-5.01*	5.83**	-0.81	-0.47**	-0.70	-0.05	-0.23**	-2.30**	-0.52**	-0.24**
China 988xVL93-6052	-7.60**	-0.66	-1.68*	19.62**	-7.38**	-0.88	0.44**	-1.45	1.95*	0.38**	1.42**	0.36	0.35**
China 988xIR57893-08	17.13**	3.38*	0.65	3.63	-9.61**	3.43*	1.05**	-1.11	1.41*	0.36**	0.35**	0.55**	-0.02
China 988xVL Dhan 221	1.37	-1.55	2.68**	-11.48**	-3.79	-2.04	-0.28**	-2.47**	1.07	-0.13	-0.67**	-0.32	0.15
China 988xJD-8	14.53**	7.45**	-0.80	3.34	11.52**	7.33**	-0.33**	4.83**	-0.22	-0.27**	0.94**	0.43*	0.01
VL91-1754xVL93-3613	9.02**	-1.58	-0.59	6.87**	3.17	-1.32	-0.17*	2.29**	-2.33*	0.29**	3.70**	0.52**	0.18*

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
VL91-1754xVL93-6052	-3.40	0.85	-7.37**	-5.31*	2.60	0.65	0.03	4.59**	-1.29*	0.10	0.49**	0.06	0.09
VL91-1754xIR57893-08	-1.33	-7.91**	-0.22	-13.51**	6.75**	-7.83**	-0.71**	6.60**	0.19	0.02	0.61**	-0.35	-0.29**
VL91-1754xVL Dhan 221	-9.97**	8.96**	0.76	3.41	-3.97	8.29**	-0.12	3.65**	-2.35*	-0.14	1.46**	-0.22	-0.25**
VL91-1754xJD-8	1.24	4.78**	2.70**	1.94	-6.16**	4.68**	-0.40**	-7.09**	1.10*	0.33**	-2.02**	0.64**	-0.01
VL93-3613xVL93-6052	2.25	6.93**	1.21	1.55	-2.84	6.73**	0.51**	9.47**	1.28*	-0.17*	3.77**	0.04	-0.35**
VL93-3613xIR57893-08	5.83*	-12.39**	6.85**	1.98	3.18	-12.31**	-0.48**	12.59**	3.52*	0.07	1.51**	-0.34	-0.02
VL93-3613xVL Dhan 221	2.31	3.16**	4.08**	-6.64**	-8.91**	2.49	0.24**	8.99**	2.92*	0.50**	1.79**	0.45*	0.15
VL93-3613xJD-8	2.55	-2.12	3.02**	-3.74	-0.34	-2.22	0.36**	3.32**	2.28*	0.81**	-4.37**	0.56**	0.01
VL91-1754xIR57893-08	-1.33	-7.91**	-0.22	-13.51**	6.75**	-7.83**	-0.71**	6.60*	0.19	0.02	0.61**	-0.35	-0.29**
VL91-1754xVL Dhan 221	-9.97**	8.96**	0.76	3.41	-3.97	8.29**	-0.12	3.65*	-2.35*	-0.14	1.46**	-0.22	-0.25**
VL91-1754xJD-8	1.24	4.78**	2.70**	1.94	-6.16**	4.68**	-0.40**	-7.09*	1.10*	0.33**	-2.02**	0.64**	-0.01
VL93-3613xVL93-6052	2.25	6.93**	1.21	1.55	-2.84	6.73**	0.51**	9.47*	1.28*	-0.17*	3.77**	0.04	-0.35**
VL93-3613xIR57893-08	5.83**	-12.39**	6.85**	1.98	3.18	-12.31**	-0.48**	12.59*	3.52*	0.07	1.51**	-0.34	-0.02
VL93-3613xVL Dhan 221	2.31	3.16**	4.08**	-6.64**	-8.91**	2.49	0.24**	8.99*	2.92*	0.50**	1.79**	0.45*	0.15
VL93-3613xJD-8	2.55	-2.12	3.02**	-3.74	-0.34	-2.22	0.36**	3.32*	2.28*	0.81**	-4.37**	0.56**	0.01
VL93-6052xIR57893-08	1.45	3.63**	-2.56**	-8.10**	4.42**	3.25*	-0.10	-2.48**	-0.05	0.20**	-0.22**	-0.16	0.03
VL93-6052xVL Dhan 221	15.48**	8.54**	10.44**	2.10	6.41**	7.42**	0.10	1.73*	1.37*	0.02	-1.24**	0.37	0.24**
VL93-6052xJD-8	-1.31	-8.48**	1.69*	2.28	0.83	-9.04**	-0.28**	5.13**	-3.76*	-0.33**	1.52**	-0.70**	-0.27**
IR57893-08xVL Dhan 221	7.57**	-1.27	-8.28**	4.22	13.59**	-2.13	-0.27**	-5.34**	0.70	0.36**	-0.12**	0.09	-0.17*
IR57893-08xJD-8	17.73**	7.22*	2.21**	31.38**	-14.70**	6.93**	-0.16*	-2.25**	2.57*	0.14	1.65**	0.20	-0.01
VL Dhan 221xJD-8	-7.22**	-5.67**	-3.28**	22.26**	-4.62*	-6.70**	1.13**	3.26**	-0.78	-0.03	5.32**	-0.40*	-0.08
S.E.(Sij)	2.47	1.36	0.80	2.40	2.19	1.35	0.08	0.74	0.97	0.07	0.05	0.19	0.08
S.E (Sij-Sik)	3.65	2.00	1.17	3.55	3.23	1.99	0.12	1.09	1.43	0.11	0.07	0.28	0.12
S.E (Sij-SkL	3.46	1.90	1.11	3.36	3.06	1.89	0.11	1.04	1.36	0.10	0.07	0.27	0.11
C.D (Sij) at 5 %	4.84	2.66	1.56	4.07	4.29	2.64	0.15	1.08	1.08	0.14	0.09	0.37	0.15

* Significant at 5 per cent probability

** Significant at 1 percent probability

LAI = Leaf area index; DM = Dry matter; PL = Panicle length; NAR = Net-assimilation rate; GL = Grain length;
GB = Grain breadth; AC = Amylose content; PC = Protein content

Table 4.7 Estimates of specific combining ability effects for yield, its components and grain quality traits in F_2 generation

Crosses	Plant height	Days to 50% flowering	Grain yield	Biological yield	Harvest index	Days to maturity	LAI	DM	PL	100 grain weight	NAR	GL	GB	L/B ratio	AC	PC
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
HPR 1164xHPR 2047	0.69	-6.04**	2.17*	15.26**	-3.22	-5.93**	-0.14**	-0.57	0.91	0.31**	-0.30	0.00	0.08**	-0.08	0.12	0.44**
HPR 1164xChina 988	0.61	-6.90**	-0.90	-5.87**	-1.54	-6.77**	-0.77**	0.54	1.37*	-0.02	-0.22	-0.01	-0.05*	0.08	0.04	0.19
HPR 1164xVL91-1754	2.61	-6.57**	-0.42	11.08**	-4.35*	-6.44**	-0.24**	2.50	-0.77	-0.34**	0.76	-0.24*	-0.11**	0.08	-0.38**	-0.66**
HPR 1164xVL93-3613	3.71*	0.50	1.44	10.33**	-6.52**	0.63	1.03**	6.55**	1.49*	0.06	0.04	-0.13	0.04*	-0.14*	0.54**	0.20
HPR 1164xVL93-6052	4.93**	12.57**	0.67	-11.77**	1.90	12.70**	0.75**	0.70	0.03	-0.21	-1.22	0.79**	0.05*	0.50**	-0.10	-0.08
HPR 1164xIR57893-08	3.54**	-4.32**	-1.08	3.03	6.69**	-4.19**	-0.44**	0.99	2.85**	0.21	0.27	0.25*	-0.04*	0.05	-0.17	-0.30
HPR 1164xVL Dhan 221	2.28	-0.94	2.41*	2.70	0.14	-1.73	-0.05**	3.77**	-1.43**	0.07	0.40	-0.49**	-0.08**	-0.11	-0.03	0.62**
HPR 1164xJD-8	7.92**	10.31**	-2.42	-12.43**	2.24	10.08**	-0.27**	0.55	1.98**	0.08	1.06	0.00	0.01	-0.06	-0.07	-0.61**
HPR 2047xChina 988	-6.72**	-2.02	-2.66	-7.64**	9.12**	-1.90	0.08**	4.00*	1.00	-0.19**	-0.94	-0.99**	-0.23**	-0.16*	-0.09	0.31
HPR 2047xVL91-1754	-15.01**	-1.90	-1.33	-3.98*	-0.25	-1.79	-0.36**	-4.27*	-1.05	-0.41	-1.75*	-0.61**	-0.01	-0.34**	0.24**	0.88**
HPR 2047xVL93-3613	-11.83**	5.14**	0.41	-19.24**	10.11**	5.26**	-0.15**	-5.43**	0.54	-0.09	-1.29	-0.13	0.11**	-0.30**	0.01	1.06**
HPR 2047xVL93-6052	-5.68**	1.43	0.64	19.70**	-6.47**	1.55	0.34**	-3.93*	1.98**	0.46**	-1.45	0.36**	0.01	0.18*	-0.03	0.27
HPR 2047xIR57893-08	17.34**	-0.21	0.43	5.48**	-8.39**	-0.10	1.02**	2.54	0.65	0.32**	3.03**	0.43**	0.06**	0.09	-0.20*	-0.66**
HPR 2047xVL Dhan 221	1.54	0.29	0.67	-10.87**	-2.01	-0.33	-0.07**	1.87	1.70**	0.00	2.80**	-0.15	0.05**	-0.20**	0.43**	-0.80**
HPR 2047xJD-8	13.01**	6.86**	5.91**	6.00**	10.70**	6.61**	-0.26**	3.69*	-0.23	-0.07	3.25**	0.37**	-0.08**	0.41**	-0.09	-0.23
China 988xVL91-1754	4.28*	-1.01	2.63*	6.46**	4.48*	-0.88	-0.11**	-4.26*	-2.62**	0.22**	-1.06	0.58**	0.06**	0.19*	0.55**	0.62**
China 988xVL93-3613	6.88**	4.61**	-0.06	7.43**	-0.21	4.74**	0.60**	-6.35**	0.23	0.34**	-2.87**	0.49**	-0.02	0.29**	-0.06	-0.22
China 988xVL93-6052	3.31	-8.82**	1.74	-5.95**	4.17	-8.69**	-0.97**	-0.92	0.49	-0.03	2.11*	-0.61**	0.02	-0.34**	-0.07	-0.30**
China 988xIR57893-08	0.21	3.63**	-0.37	11.86**	-10.00**	3.76**	-0.12**	-0.49	-1.67**	-0.19**	2.13*	-0.29**	0.00	-0.13	0.11	1.37**
China 988xVL Dhan 221	2.62	4.99**	0.92	14.55**	-8.00**	4.20**	0.00	2.68	1.67**	0.38**	1.68*	1.02**	0.13**	0.28**	-0.33**	1.17**
China 988xJD-8	6.60**	7.54**	0.77	-3.96**	2.44	7.30**	0.49**	2.28	2.98**	0.14**	0.63	0.01	0.27**	-0.47**	0.02	-0.21
VL91-1754xVL93-3613	-2.03	-11.00**	-0.40	-8.53**	6.05**	-10.87**	-0.68**	5.09**	2.36**	0.00	2.55*	-0.22	-0.05*	-0.02	0.12	-0.04
VL91-1754xVL93-6052	- 3.94*	1.14	-1.38	-8.37**	-9.58**	1.27	-0.60**	2.37	1.70**	0.27**	0.97	0.18	0.04*	0.02	0.15	-0.14

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
VL91-1754xIR57893-08	-6.93**	-8.45**	-0.74	0.83	-0.83	-8.32**	-0.06**	-2.44	-0.06	0.51**	-0.73	0.64**	0.09**	0.17*	-0.61**	-0.91
VL91-1754xVL Dhan 221	0.01	3.96**	1.23	-5.27**	8.59**	3.16**	-0.08**	-0.45	-1.07	0.25**	0.79	-0.07	-0.04*	0.05	0.06	1.58
VL91-1754xJD-8	21.09**	6.33**	-0.63	1.58	4.34*	6.10**	-0.18**	0.59	1.21	0.20**	0.54	0.06	0.03	-0.03	0.01	0.19
VL93-3613xVL93-6052	2.62	4.99**	0.92	14.55**	-8.00**	4.20**	0.00	2.68	1.67**	0.38**	1.68*	1.02**	0.13**	0.28**	-0.33**	1.17**
VL93-3613xIR57893-08	6.60**	7.54**	0.77	-3.96**	2.44	7.30**	0.49**	2.28	2.98**	0.14**	0.63	0.01	0.27**	-0.47**	0.02	-0.21
VL93-3613xVL Dhan 221	-2.03	-11.00**	-0.40	-8.53**	6.05**	-10.87**	-0.68**	5.09**	2.36**	0.00	2.55*	-0.22	-0.05*	-0.02	0.12	-0.04
VL93-3613xJD-8	- 3.94*	1.14	-1.38	-8.37**	-9.58**	1.27	-0.60**	2.37	1.70**	0.27**	0.97	0.18	0.04*	0.02	0.15	-0.14
VL91-1754xIR57893-08	-6.93**	-8.45**	-0.74	0.83	-0.83	-8.32**	-0.06**	-2.44	-0.6	0.51**	-0.73	0.64**	0.09**	0.17*	-0.61**	-0.91
VL91-1754xVL Dhan 221	0.01	3.96**	1.23	-5.27**	8.59**	3.16**	-0.08**	-0.45	-1.07	0.25**	0.79	-0.07	-0.04*	0.05	0.06	1.58
VL91-1754xJD-8	21.09**	6.33**	-0.63	1.58	4.34*	6.10**	-0.18**	0.59	1.21	0.20**	0.54	0.06	0.03	-0.03	0.01	0.19
VL93-3613xVL93-6052	1.87	-8.21**	-2.74*	4.55*	-4.10	-8.08**	-0.52**	-2.85	-4.14**	-0.32**	-0.78	-0.38**	-0.09**	-0.04	-0.07	1.10*
VL93-3613xIR57893-08	14.63**	-5.78**	-0.24	2.56	9.12**	-5.65**	-0.53**	5.03**	0.51	0.30**	-1.27	0.67	0.06**	0.06	0.08	-0.01
VL93-3613xVL Dhan 221	15.99**	8.25**	0.31	33.88**	-14.98**	7.46**	-0.01	0.34	2.27**	0.20**	-1.80*	0.63**	0.03	0.28**	-0.14	-0.85**
VL93-3613xJD-8	-1.91	-7.18**	-0.64	21.40**	-11.15**	-7.41**	0.96**	2.35	-0.23	0.16**	-1.11	-0.36**	-0.06**	-0.08	-0.34**	1.26**
VL93-6052xIR57893-08	1.12	-5.20**	-1.84	-2.65	-2.56	-5.06**	0.09**	0.70	0.34	0.19**	0.51	0.11	0.02	0.02	0.42**	0.07
VL93-6052xVL Dhan 221	-5.08**	2.64*	-1.28	4.12**	18.71**	1.84	0.89**	2.88	0.76	-0.01	0.43	-0.39**	0.11**	-0.40**	-0.06	-1.12**
VL93-6052xJD-8	-9.80**	-8.29**	1.85	0.07	3.90	-8.52**	0.32**	2.49	-0.57	-0.27**	0.50	0.11	-0.11**	0.29**	0.13	0.64**
IR57893-08xVL Dhan 221	1.12	7.27**	0.91	-17.32**	-2.71	6.47**	0.29**	-3.22	1.23*	-0.06	0.77	-0.08	-0.02	0.00	-0.14	1.62**
IR57893-08xJD-8	-1.88	9.93**	-1.29	4.62**	0.44	9.70**	-0.38**	-3.42	2.80**	-0.13*	-0.77	0.04	0.00	-0.01	0.33**	0.22
VL Dhan 221xJD-8	-13.70**	-8.92**	-0.48	-6.58**	-2.57	-10.08**	-0.36**	-2.57	-2.88**	-0.27**	3.03	-0.44**	-0.06**	-0.13	0.22*	-0.03
S.E.(Sij)	1.85	1.12	1.00	1.80	2.14	1.01	0.02	1.82	0.62	0.05	0.85	0.12	0.02	0.07	0.09	0.20
S.E (Sij-Sik)	2.72	1.65	2.01	2.65	3.17	1.50	0.03	2.69	0.92	0.08	1.26	0.18	0.03	0.12	0.14	0.29
S.E (Sij-SkL	2.58	1.57	1.91	2.51	3.00	1.43	0.03	2.55	0.87	0.07	1.20	0.18	0.03	0.11	0.13	0.28
C.D (Sij) at 5 %	3.63	2.19	1.96	3.53	4.19	1.97	0.04	3.56	1.21	0.09	0.92	0.23	0.04	0.13	0.17	0.39

* Significant at 5 per cent probability

** Significant at 1 percent probability

LAI = Leaf area index; DM = Dry matter; PL = Panicle length; NAR = Net-assimilation rate; GL = Grain length;
GB = Grain breadth; AC = Amylose content; PC = Protein content

Days to 50 per cent flowering

Out of 36 hybrids, eleven hybrids showed negative sca effects, these were HPR-1164xVL93-6052, VL93-3613xIR57893-08, HPR-1164xIR57893-08, HPR-2047xVL91-1754, VL93-6052xJD-8, HPR-2047xChina-988, VL91-1754x IR57893-08, VLDhan 221xJD-8, China-988xVL91-1754, HPR-2047xIR57893-08 and HPR-1164xVL93-6052. Ten hybrids exhibited positive sca effects in F_1 generation.

In F_2 generation, 12 hybrids showed negative sca effects, whereas fourteen hybrids exhibited positive sca effects.

Plant height

Hybrids, HPR-1164xIR57893-08, HPR-2047xJD-8, China-988xVL91-1754, HPR-1164xVL93-3613, VL91-1754xVLDhan 221, HPR-1164xChina-988, China-988xVL93-6052, VLDhan 221xJD-8 and China-988xVL93-3613 exhibited negative sca effects, whereas IR57893-08xJD-8, China-988xIR57893-08, VL93-6052xVLDhan 221, China-988xJD-8, HPR-2047xChina-988, HPR-2047xVL93-3613, HPR-1164xHPR-2047, VL91-1754xVL93-3613, HPR-1164xJD-8, HPR-1164xVL91-1754, IR57893-08xVLDhan 221 and VL93-3613xIR57893-08 exhibited positive sca effects, however in F_2 generation, out of thirty six hybrids, only nine hybrids showed negative sca effects, whereas eleven crosses showed positive sca.

Leaf area index

The cross combinations showed positive sca effects in F_1 generation and these were HPR-1164xHPR-2047, VLDhan 221xJD-8, HPR-2047xVL93-3613, China-988xIR57893-08, VL93-3613xVL93-6052, China-988xVL93-6052, HPR-2047xVL91-1754, VL93-3613xJD-8, VL93-3613xVLDhan 221, HPR-1164xVL91-1754 and HPR-1164xVL93-3613 showed significant positive sca effect, whereas sixteen hybrids exhibited negative sca effects in F_1 generation.

In F_2, only 12 combinations showed positive sca effects, while twenty two exhibited negative sca effects.

Dry matter

Out of 36 hybrids, VL93-3613xIR57893-08, HPR-2047xJD-8, VL93-3613xVL93-6052, VL93-3613xVLDhan 221, HPR-1164xVL93-3613, VL91-1754xIR57893-08, HPR-2047xVL93-6052, HPR-1164xHPR-2047, VL93-6052xJD-8, China-988xJD-8, China-988xDl, VL91-1754xVL93-6052, VL91-1754xVLDhan 221, VL93-3613xJD-8, VLDhan 221xJD-8, VL91-1754xVL93-3613, HPR-1164xIR57893-08 and VL93-6052xVLDhan 221 exhibited positive sca effects, whereas fourteen hybrids showed negative sca effects in F_1 generation. In F_2, only ten cross combinations showed positive sca effects, whereas thirteen exhibited negative sca effects.

Net-assimilation rate

In F_1 generation, positive sca effects were observed for VLDhan 221xJD-8, HPR-2047xJD-8, VL93-3613xVL93-6052, VL91-1754xVL93-3613, HPR-1164xHPR-2047, VL93-3613xVLDhan 221, IR57893-08xJD-8, VL93-6052xJD-8, HPR-2047xVLDhan 221, VL91-1754xIR57893-08, VL91-1754xVL93-

6052, China-988xIR57893-08, HPR-2047xVL93-6052 and HPR-1164xVL91-1754, whereas sixteen cross combinations showed negative sca effects however in F_2 generation, only seven showed positive sca effects, whereas only three cross combinations exhibit~~s~~ed negative sca effects.

Panicle length

Out of 36 hybrids, HPR-1164xHPR-2047, VL93-3613xIR57893-08, VL93-3613xVLDhan 221, HPR-1164xJD-8, IR57893-08xJD-8, HPR-2047xVL93-6052, VL93-3613xJD-8, China-988xVL93-6052, HPR-1164xVLDhan 221, China-988xVL93-6052, HPR-1164xVLDhan 221, China-988xIR57893-08, VL93-6052xVLDhan 221, VL93-3613xVL93-6052, HPR-2047xJD-8 and VL91-1754xJD-8 exhibited significant positive sca effects, whereas negative sca effects were showed by VL93-6052xJD-8, HPR-1164xIR57893-08, VL91-1754xVLDhan 221, VL91-1754xVL93-3613, HPR-2047xIR57893-08, HPR-1164xVL93-3613, VL91-1754xVL93-6052 and HPR-1164xVL93-6052 in F_1 generation.

In F_2 generation, thirteen cross combinations showed positive sca effects while five showed negative sca effects.

Days to maturity

The cross combinations exhibiting significant negative sca effects were VL93-3613xIR57893-08, HPR-1164xVL93-6052, VL93-6052xJD-8, HPR-1164xIR57893-08, HPR-2047xVL91-1754, HPR-2047xChina-988, VL91-1754xIR57893-08, VLDhan 221xJD-8, China-988xVL91-1754, HPR-2047x IR57893-08 and HPR-2047xVL93-6052, whereas thirteen hybrids showed positive sca effects in F_1 generation. However in F_2, thirteen crosses showed early maturity, while thirteen showed positive sca effects.

Grain yield per plant

The estimates of sca effects revealed that the hybrids (F_1's), VL93-6052xVLDhan 221, HPR-2047xJD-8, VL93-3613xIR57893-08, HPR-2047xVL93-6052, China-988xVL91-1754, HPR-1164xHPR-2047, HPR-1164xIR57893-08, VL93-3613xVLDhan 221, VL93-3613xJD-8, VL91-1754xJD-8, China-988xVLDhan 221, HPR-1164xVL91-1754, IR57893-08xJD-8, VL93-6052xJD-8 and HPR-1164xVL93-3613, exhibited positive sca effects, whereas twelve crosses showed negative sca effects however in F_2 generation, only single cross HPR-2047xJD-8 showed positive sca effect, while VL93-3613xVL93-6052 showed negative sca effects.

Biological yield per plant

Out of 36 crosses, only seven crosses showed positive sca effects and these were IR57893-08xJD-8, VLDhan 221xJD-8, HPR-1164xVLDhan 221, China-988xVL93-6052, HPR-2047xVL91-1754, HPR-2047xChina-988 and VL91-1754xVL93-3613, while eleven hybrids showed negative sca effects however in F_2 generation, only fifteen cross combinations showed negative sca effects, whereas fourteen exhibited positive sca.

Harvest index

Estimates of sca effects for harvest index revealed that the cross combinations HPR-2047xJD-8, IR57893-08xVLDhan 221, China-988xJD-8, HPR-1164xChina-988, VL91-1754xIR57893-08, VL93-6052xVLDhan 221, China-988xVL93-3613, HPR-2047xVL93-6052 and VL93-6052xIR57893-08 showed positive sca effects, whereas eleven crosses exhibited negative sca effects.

In F_2 generation, ten cross combinations showed positive sca effects, while seven showed negative sca effects.

100-grain weight

Positive sca effects were observed for VL93-3613xJD-8, VL93-3613xVLDhan 221, China-988xVL93-6052, China-988xIR57893-08, IR57893-08xVLDhan 221, HPR-2047xVL93-6052, VL91-1754xJD-8, VL91-1754xVL93-3613, HPR-1164xHPR-2047, HPR-1164xVL91-1754, HPR-1164xJD-8, VL93-3613xIR57893-08, HPR-1164xVLDhan 221, HPR-2047xIR57893-08 and HPR-2047xChina-988, whereas negative sca effects observed for China-988xVL93-3613, HPR-1164xVL93-6052, HPR-1164xVL93-3613, VL93-6052xJD-8, HPR-1164xIR57893-08, China-988xJD-8, China-988xVL93-3613, HPR-2047xJD-8 and VL93-3613xVL93-6052. However in F_2 generation, sixteen cross combinations showed positive sca effects, while seven exhibited negative sca effects.

Grain length

Highly significant positive sca effects were observed for HPR-2047xVL93-3613, HPR-1164xIR57893-08, VL91-1754xJD-8, VL93-3613xJD-8, China-988xVLDhan 221, HPR-2047xVLDhan 221, VL91-1754xe, VL93-3613xVLDhan 221 and China-988xJD-8 crosses, whereas negative sca effects were observed only for seven crosses in F_1 generation .however in F_2 generation, only ten cross combinations showed positive sca effects, while ten showed negative sca effects.

Grain breadth

Among 36 cross combinations, only thirteen showed significant positive sca effects, whereas twelve showed negative sca effects in F_1 generation.

Length-breadth ratio

Only six hybrids showed positive sca effects and these cross combinations were HPR-1164xIR57893-08, HPR-2047xVL93-3613, China-988xVL93-6052, VL93-6052xVLDhan 221, HPR-1164xVL91-1754 and VL91-1754xVL93-3613, whereas eleven hybrids showed negative sca effects in F_1 generation however in F_2, nine hybrids showed positive sca effects, while eight showed negative sca effects.

Amylose content

Out of 36 hybrids, only seven showed significant positive sca effects and these cross combinations were China-988xVL91-1754, HPR-1164xVL93-3613, HPR-2047xVLDhan 221, VL93-6052xIR57893-08, IR57893-08xJD-8, HPR-2047xVL91-1754 and IR57893-08xJD-8, whereas only five crosses viz., VL91-1754xIR57893-08, HPR-1164xVL91-1754, VL93-3613xJD-8, China-988xVLDhan 221 and HPR-2047xIR57893-08 showed negative sca effects.

Protein content

Eleven cross combinations showed positive sca effects and these cross combinations were IR57893-08xVLDhan 221, VL91-1754xVLDhan 221, China-988xIR57893-08, VL93-3613xJD-8, China-988xVLDhan 221, VL93-3613x

VL93-6052, HPR-2047xVL93-3613, HPR-2047xVL91-1754, VL93-6052xJD-8, HPR-1164xVLDhan 221, China-988xVL91-1754 and HPR-1164xHPR-2047, whereas seven crosses showed negative sca effects.

4.2.1.3 Estimation of mean degree of dominance

The mean degree of dominance was greater than unity in F_1 generation (Table 4.8 and 4.9) for plant height, days to 50 per cent flowering, grain yield, harvest index, days to maturity, leaf area index and net-assimilation rate whereas in F_2 generation, it was observed for days to 50 per cent flowering, grain yield, days to maturity, leaf area index, dry matter length of panicle, 100-grain weight and grain length indicated overdominance, however it was observed less than unity for grain breadth and amylose content indicated partial dominance.

4.2.2 Genetic component analysis

4.2.2.1 Hayman's (1954) approach

The analysis of components of variance was also carried out for yield, its components and grain quality traits as per Hayman's approach (1954) in the F_1 and F_2 generations. The estimates of components such as D, H_1, H_2, h^2 and E, ratio of dominant and recessive genes in the parents $[(H_1/D)^{1/2} + F] / [(H_1/D)^{1/2} - F]$, number of gene groups which control the character and exhibit dominance h^2/H_2, heritability in narrow sense, average degree of dominance $(H_1/D)^{1/2}$, coefficient of correlation r(Wr+Vr)/Yr, regression coefficient (bwr/vr) and value of t^2 for different characters in both the generations are given in Table 4.10 and 4.11. The components results are presented below.

Table 4.8 **Estimates of mean degree of dominance along with variance components of GCA and SCA for yield, its components and grain quality traits in F_1 generation**

Character	$\sigma^2 g$	$\sigma^2 s$	$\sqrt{\sigma^2 s / \sigma^2 g}$
Days to 50 per cent flowering	3.92	51.30	3.61
Plant height	8.35	84.78	3.18
Leaf area index	0.014	0.352	5.01
Dry matter	-	48.55	-
Net assimilation rate	14.74	6.06	0.64
Panicle length	-	0.50	-
Days to maturity	3.20	43.58	2.06
Grain yield per plant	0.07	18.72	15.90
Biological yield per plant	-	1271.07	-
Harvest index	2.72	38.06	3.74
100-grain weight	-	0.10	-
Grain length	-	0.21	-
Grain breadth	-	-	-
L/B ratio	-	0.07	-

- Not calculated

Table 4.9 **Estimate of mean degree of dominance along with variance components of gca and sca for yield, its components and grain quality traits in F_2 generation**

Character	σ^2g	σ^2s	$\sqrt{\sigma^2s/\sigma^2g}$
Days to 50 per cent flowering	3.92	48.77	3.53
Plant height	-	87.55	-
Leaf area index	0.02	0.30	3.87
Dry matter	1.18	8.44	2.67
Net assimilation rate	-	3.14	-
Length of panicle	0.12	3.56	5.45
Days to maturity	2.8	46.20	4.06
Grain yield per plant	0.63	1.31	1.44
Biological yield per plant	-	135.82	-
Harvest index	-	48.44	-
100-grain weight	0.02	0.08	1.95
Grain length	0.03	0.17	2.38
Grain breadth	0.07	0.01	0.32
L/B ratio	0.02	0.01	-
Amylose content	0.54	0.05	0.32
Protein content	-	0.69	-

- Not calculated

Table 4.10 Estimates of genetic components of variation for yield, its components and grain quality traits in F_1 generation

Traits Components	Plant height	Days to 50% flowering	Grain yield	Biological yield	Harvest index	Days to maturity	LAI	DM	PL	100grain weight	NAR	GL	GB	L/B ratio
E	7.35	2.22	0.77	6.94	5.76	2.19	0.01	0.66	1.13*	0.01	0.00	0.05	0.03	0.01
	±12.23	±6.60	±2.08	±22.24	±6.47	±5.04	±0.04	±3.89	±0.45	±0.01	±1.15	±0.04	±0.00	±0.01
D	105.69**	85.68**	2.51	11.72	24.10	61.07*	0.58*	4.35	3.86*	0.07	6.37	0.10	-0.02	0.08*
	±38.68	± 20.87	± 6.58	±70.32	±20.47	±15.93	±0.13	±12.31	± 1.41	± 0.04	±3.63	± 0.13	± 0.00	±0.03
F	121.04	119.02**	-5.37	15.78	4.00	81.01*	0.95**	5.64	5.81	0.10	6.63	0.15	-0.03*	0.11
	±90.23	± 48.69	±30.68	±164.04	±47.76	±37.16	± 0.30	±28.72	±3.30	±0.10	± 8.48	± 0.30	±0.01	±0.07
H_1	375.58**	247.57**±	304.64*	526.86*±	162.66*	205.81*	1.77*	181.01*	16.43 *	0.44*	26.9*±8	1.00*	-0.03*	0.31**
	±85.37	46.06	±58.01	155.20	±45.19	± 35.16	± 0.28	± 27.17	±3.12	±0.10	.02	±0.29	±0.01	±0.06
H_2	306.42**	186.91**	290.32**	458.75*	161.75*	161.81*	1.26*	138.63*	13.56 *	0.35*	22.3 9*	0.91*	0.01	0.27**±
	±73.39	± 39.60	± 49.90	±133.42	± 38.84	±30.22	±0.24	± 22.36	±2.68	±0.08	±6.89	±0.25	± 0.01	0.05
h^2	176.28**	-0.56	20.04*±	104.89	-2.06	1.66	0.02	142.99*	12.96 *±	0.26*	2.28	-0.01	-0.01	0.00
	±49.161	±26.53	8.36	± 89.38	±26.02	±20.25	±0.16	± 15.69	1.80	±0.06	±4.62	± 0.17	± 0.01	±0.04
$(H_1/D)^{1/2}$	1.89	1.70	11.01	6.71	2.60	1.84	1.75	6.45	2.06	2.59	2.06	3.19	1.27	1.93
$H_2/4H_1$	0.20	0.19	0.24	0.22	0.25	0.20	0.18	0.19	0.21	0.20	0.21	0.23	0.20	0.21
h^2(n.s)	27.12	38.40	2.97	2.13	11.71	31.37	40.57	2.38	20.32	15.08	23.87	8.71	-	26.01
K_D / K_R	1.87	2.38	0.82	1.22	1.06	2.13	2.76	1.10	2.15	1.80	1.67	1.62	0.24	1.55
h^2 / H_2	0.58	-	0.07	0.22	-0.01	0.01	0.01	1.03	0.96	0.74	0.10	-0.01	0.50	-
R	-0.52	-0.78	-0.67*	-0.44	0.28	-0.76**	0.32	-0.29	-0.38	-0.69*	0.56	-0.0028	-0.58	-0.13
b	0.0013	1.43*	0.16	-0.08	0.04	0.06	0.19	0.045	-0.20	-0.13	0.11	-0.070	0.40	0.38
	±0.33	±0.41	±0.13	±0.11	±0.19	± 0.44	± 0.32	±0.05	±0.18	±0.16	±0.29	±0.21	± 0.27	±0.34
1-b	3.00**	1.00*	6.13**	9.87**	4.87**	0.88	2.52**	20.16**	6.37**	6.76**	2.99**	4.93**	2.12**	1.76**
t^2	0.11	0.41	9.57**	17.20*	3.51	0.72	0.14	107.36*	3.54	5.45	0.36	2.34	0.26	-

* Significant at 5 per cent probability, ** Significant at 1 percent probability

LAI = Leaf area index; DM = Dry matter; PL = Panicle length; NAR = Net-assimilation rate; GL = Grain length;
GB = Grain breadth; AC = Amylose content; PC = Protein content

Table 4.11 Estimates of genetic components of variation for yield, its components and grain quality traits in F_2 generation

Components \ Traits	Plant height	Days to 50% flowering	Grain yield	Biological yield	Harvest index	Days to maturity	LAI	DM	PL	100-grain weight	NAR	GL	GB	L/B ratio	AC	PC
E	4.09 ±3.35	1.51 ±2.44	0.77 ±0.76	3.88 ±6.33	5.53 ±4.80	1.25 ±2.41	0.00 ±0.02	0.66 ±1.46	0.48 ±0.40	0.00 ±0.01	0.00 ±0.47	0.02 *±0.01	0.00 ±0.00	0.01 ±0.00	0.01 ±0.01	0.05 ±0.08
D	108.950* ±10.60	86.39* ±7.71	2.51 ±2.39	14.78 ±20.02	24.33 ±15.16	62.01** ±7.62	0.59** ±0.08	4.35 ±4.62	4.52** ±1.28	0.07** ±0.02	6.37** ±1.47	0.12 ±0.04	0.0 ±0.00	0.08 ±0.01	1.36* ±0.03	0.50 ±0.26
F	80.74* ±24.73	126.06** ±17.99	0.25 ±5.58	16.42 ±46.71	40.54 ±35.37	93.06** ±17.77	0.83** ±0.18	5.18 ±10.78	8.08** ±2.99	0.09** ±0.04	9.17* ±3.44	0.14 ±0.10	0.02* ±0.01	0.15* ±0.03	-0.08 ±0.13	1.48 ±1.22
H_1	113.71** ±23.40	140.47** ±17.02	20.67** ±5.28	151.92* ±44.20	103.86* ±33.47	123.88**± 16.82	1.03* ±0.17	91.44** ±10.20	12.18** ±2.82	0.23* ±0.04	20.15** ±3.25	0.42 *±0.10	0.02* ±0.01	0.19* ±0.02	0.91** ±0.24	10.99** ±2.30
H_2	81.77** ±20.12	87.12 ±14.64	20.18** ± 4.54	131.91** ±31.99	83.76* ±28.77	81.54** ±14.46	0.67** ±0.14	80.39* ±8.77	8.23* ±2.43	0.18** ±0.03	15.52** ±2.80	0.34* *±0.08	0.02* ±0.01	0.11* ±0.02	0.89** ±0.20	9.70** ±1.98
h^2	38.97** ±13.48	12.12 ±9.80	6.84* ±3.04	37.77 ±25.45	-1.45 ±19.27	22.72* ±9.68	0.16 ±0.10	58.90 *±5.88	14.06** ±1.63	0.17** ±0.02	3.64* ±1.87	0.00	0.00 ±0.00	0.00 ±0.01	0.02 ±0.03	2.65** ±0.33
$(H_1/D)^{1/2}$	0.25	0.32	0.71	0.80	0.51	0.35	0.33	1.14	0.41	0.45	0.44	0.46	0.32	0.37	0.21	1.17
$H_2/4H_1$	0.18	0.16	0.24	0.22	0.20	0.16	0.16	0.22	0.17	0.20	0.19	0.20	0.16	0.14	0.25	0.22
h^2(n.s)	68.83	-80.86	9.66	8.91	22.16	63.37	74.45	4.66	42.95	31.11	36.67	25.22	63.05	53.88	81.20	18.42
K_D/K_R	3.64	-14.83	1.07	2.10	9.34	-33.33	-26.33	1.70	-22.76	6.00	9.48	4.50	2.42	13.00	0.93	1.93
h^2/H_2	0.47	-0.13	0.33	0.28	-0.02	0.27	0.23	0.73	1.70	0.94	0.23	-	-	-	0.02	0.27
R	0.46	-0.04	-0.58	-0.66*	0.22	0.33	0.57	0.002	0.24	-0.60	0.44	-	-0.21	0.85*	-0.44	-0.81**
b	0.55 ±0.45	0.56 ±0.29	0.11 ±0.22	0.004 ±0.15	-0.37 ±0.27	0.37 ±0.22	0.54 ±0.30	0.25 ±0.15	-0.25 ±0.48	0.48* ±0.24	0.39 ±0.72	-0.04 ±0.27	0.28 ±0.39	0.54 ±0.21	0.94* ±0.17	0.18 ±0.20
1-b	1.00*	1.49	3.88**	6.46**	4.99**	2.84**	1.49**	4.66**	2.60**	2.13**	0.84	3.85**	1.84**	2.12**	0.31	4.05**
t^2	0.64	0.018	1.87	7.33**	0.34	1.39	0.005	5.65	0.51	6.51	3.74	0.76	0.034	0.77	0.08	2.83

* Significant at 5 per cent probability ** Significant at 1 percent probability

LAI = Leaf area index; DM = Dry matter; PL = Panicle length; NAR = Net-assimilation rate; GL = Grain length;
GB = Grain breadth; AC = Amylose content; PC = Protein content

E: Environmental component of variance was found to be non significant for all the traits except panicle length in F_1 generation.

D: Additive component of variance was found to be significant in F_1 for days to maturity, leaf area index, panicle length, plant height, days to 50 per cent flowering, length-breadth ratio and amylose content and was non-significant for the remaining traits.

However in F_2 generation, it was significant for plant height, days to 50 per cent flowering, days to maturity, leaf area index, panicle length, 100-grain weight, net-assimilation rate, length-breadth ratio, grain length and amylose content and non-significant for the remaining traits.

F: In F_1 generation, F value was significant for days to 50 per cent flowering, leaf area index, days to maturity, net-assimilation rate and grain breadth, whereas the remaining traits were non-significant.

In F_2 generation, it was significant for plant height, days to 50 per cent flowering, days to maturity, leaf area index, panicle length, 100-grain weight, net assimilation rate, length-breadth ratio and grain breadth, however the remaining traits was non-significant.

H_1 and H_2 : The dominance components (H_1) and (H_2) in F_1 generation were significant for all the traits. In F_2 generation, these components were also significant for all the traits under study.

$\sqrt{H_1/D}$: The mean degree of dominance in F_1 was greater than unity for days to 50 per cent flowering, plant height, leaf area index, dry matter, net-assimilation rate, panicle length, days to maturity, grain yield/plant, biological yield/plant, harvest index, 100-grain weight, length-breadth ratio, grain breadth, grain length and protein content, however it was less than unity for amylose content. In F_2 generation, it was less than unity for all the traits.

$H_2/4H_1$: The proportion of genes with positive and negative effects were almost equally distributed in the traits like harvest index, grain yield, biological yield, grain length and amylose content, whereas in the remaining traits negative effects were more as compared to the positive effects. In F_2 generation, proportion of genes with positive and negative effects was almost equally distributed in traits like grain yield/plant, biological yield/plant, dry matter, amylose content and protein content, however in the remaining traits negative effects were more as compared to the positive effects.

h^2(n.s.): Estimates of heritability in narrow sense, both in F_1 and F_2 generations were grouped in three categories i.e. low (<15%), medium (15-30%) and high (>30%). Estimates of heritability (ns) in F_1 were high for leaf area index, days to 50 per cent flowering, days to maturity, and amylose content. Medium heritability was observed for plant height, net-assimilation rate, panicle length, length-breadth ratio, amylose content and 100-grain weight, whereas it was low for harvest index, grain yield, dry matter, grain length and biological yield/plant.

In F_2 generation, high heritability was observed for amylose content, days to 50 per cent flowering, leaf area index, plant height, days to maturity, panicle length, net-assimilation rate, 100-grain weight, length-breadth ratio and grain breadth, whereas medium heritability was observed for harvest index, grain length and protein content. Low estimates of heritability was observed for grain yield/plant, biological yield/plant and dry matter.

K_D/K_R: The ratio exhibits, the relative frequencies of dominant and recessive alleles in the parents. It was observed to be greater than unity in F_1 for all the traits viz., plant height, days to 50 per cent flowering, biological yield/plant, harvest index, days to maturity, leaf area index, dry matter, panicle length, 100-grain weight, net-assimilation rate, length-breadth ratio, grain length and protein content, whereas it was less than unity for grain yield/plant, grain breadth and amylose content. In F_2 generation, it was observed to be greater than unity for plant height, grain yield/plant, biological yield/plant, harvest index, dry matter, 100-grain weight, net-assimilation rate, length-breadth ratio, grain length, grain breadth and protein content, whereas less than unity for days to 50 per cent flowering, days to maturity, leaf area index, panicle length and amylose content.

r: The coefficient of correlation between the parental order of dominance (Wr+Vr) and parental measurement in F_1 was found to be negative for grain yield/plant, days to maturity, days to 50 per cent flowering, 100-grain weight and protein content. In F_2 generation, it was found to be negative for biological yield/plant, 100-grain weight and protein content whereas positive significant for grain length-breadth ratio.

Considering the practical knowledge of the material under investigation, some of the assumptions like diploid segregation and homozygosity of parents were safely assumed to be fulfilled. For rest of the assumptions, Hayman (1954) proposed t^2-test to examine the independent distribution of genes among the parents and regression coefficient (b) as a test for non-allelic interaction.

t^2-test: In F_1 generation, t^2-test were non-significant for days to 50 per cent flowering, plant height, leaf area index, net-assimilation rate, panicle length, days to maturity, harvest index, 100-grain weight, grain length, grain breadth, amylose content and protein content.

b: Both the regression coefficient (b) and its deviation from unity (1-b) in F_1 were significant for days to 50 per cent flowering, plant height, net-assimilation rate, panicle length, grain yield/plant, biological yield/plant, harvest index, 100-grain weight, grain length, grain breadth, L/B ratio and protein content but its deviation from zero were significant for days to 50 per cent flowering and amylose content. In F_2 generation, regression coefficient and its deviation from unity were significant for days to 50 per cent flowering, plant height, panicle length, grain yield/plant, biological yield/plant, harvest index, 100-grain weight, grain length, grain breadth, L/B ratio and protein content but its deviation from zero were significant for 100-grain weight and amylose content.

4.3 Heterosis and inbreeding depression

Heterosis was studied for all the characters in F_1 and inbreeding depression in the F_2 generation. Extent of heterosis was estimated as per cent deviation of the F_1 from standard check (HPR-2047) and better parent. The extent of inbreeding effects were estimated as per cent deviation of the F_2 mean from the F_1 mean.

Days to 50 per cent flowering

Out of thirty six crosses studied, nine crosses exhibited significant negative heterosis over standard check (Table 4.12). These crosses were HPR1164xVL93-6052 (-18.31%), HPR1164xIR57893-08 (-14.31%), VLDhan 221xJD-8 (-14.03%), VL 93-3613xJR57893-08 (-13.79%), VL93-6052xJD-8 (-13.48%), JR57893-08xVLDhan 221 (-6.84%), VL91-1754xIR57893-08 (-6.10), HPR1164xVLDhan 221 (-5.17%), VL93-3613xJD-8 (-4.29%). The range of heterosis varied between -18.31 to 14.24 per cent. Eight crosses showed negative heterosis over superior parent and these were China 988xVL91-1754

Table 4.12 Mean performance, heterotic response and inbreeding depression for days to 50 per cent flowering

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	88.91	14.24**	14.24**	-15.50**
HPR 1164xChina 988	92.48	-1.24	0.90	-2.77
HPR 1164xVL 91-1754	95.17	3.54	5.81*	-17.37**
HPR 1164xVL 93-3613	89.31	7.10**	8.08**	-0.77
HPR 1164xVL 93-6052	91.46	-20.06**	-18.31**	37.12**
HPR 1164xIR57893-08	92.46	-16.14**	-14.31**	-2.83
HPR 1164xVL Dhan 221	80.85	16.09**	-5.17*	8.50**
HPR 1164xJD-8	82.61	13.77**	-2.51	8.96**
HPR 2047xChina 988	91.52	-4.62	-4.62	9.10**
HPR 2047xVL 91-1754	94.18	-2.17	-2.17	2.46
HPR 2047xVL 93-3613	88.35	14.26**	14.26**	-11.17**
HPR 2047xVL 93-6052	90.50	-1.06	-1.06	-8.41**
HPR 2047xIR57893-08	91.50	-4.54	-4.54	-7.07**
HPR 2047xVL Dhan 221	79.89	34.64**	9.98**	-11.21**
HPR 2047xJD-8	81.65	20.60**	3.34	-1.44
China 988xVL 91-1754	97.78	-6.59**	0.98	5.15
China 988xVL 93-3613	91.92	2.49	2.85	-1.35
China 988xVL 93-6052	94.07	-3.67	1.92	-2.64
China 988xIR57893-08	95.07	-3.85	3.92	-2.07
China 988xVL Dhan 221	83.46	18.94**	-2.84	-2.09
China 988xJD-8	85.22	24.13**	6.36**	-8.82**
VL 91-1754xVL 93-3613	94.61	4.67*	5.62**	-11.21**
VL 91-1754xVL 93-6052	96.77	0.60	6.44**	-14.18**
VL 91-1754xIR57893-08	97.77	-13.12**	-6.10**	8.75**
VL 91-1754xVL Dhan 221	86.16	37.01**	11.91**	-19.27**
VL 91-1754xJD-8	87.92	23.87**	6.13**	-16.78**
VL 93-3613xVL 93-6052	90.90	9.76**	10.76**	-20.63**
VL 93-3613xIR57893-08	91.90	-14.56**	-13.79**	13.72**
VL 93-3613xVL Dhan 221	80.29	25.76**	2.72	-5.74*
VL 93-3613xJD-8	82.05	11.69**	-4.29*	-3.31
VL 93-6052xIR57893-08	94.06	-3.14	2.47	-11.46**
VL 93-6052xVL Dhan 221	82.45	30.88**	6.91**	-10.86**
VL 93-6052xJD-8	84.21	0.96	-13.48**	15.67**
IR57893-08xVL Dhan 221	83.45	14.04**	-6.84**	12.48**
IR57893-08xJD-8	85.21	18.78**	1.78	-1.19
VL Dhan 221xJD-8	76.60	5.24	-14.03**	17.33**
S.E. ±	-	2.10	2.10	2.43

* Significant at 5 per cent probability

** Significant at 1 percent probability

(-17.71%), HPR1164xVL93-3613 (-12.33%), China 988xVL93-6052 (-11.98%), VL91-1754xVLDhan 221 (-11.04%), HPR1164xChina 988 (-10.00%), HPR1164x IR57893-08 (-9.89%), HPR2047xJD-8 (-9.16%) and VL91-1754xJD-8 (-6.41%). The inbreeding depression were showed by fifteen crosses.

Plant height

Only six cross combinations showed significant negative heterosis over standard check (HPR2047) in Table 4.13. The range of heterosis varied between -16.78 to 20.76 per cent. These crosses were HPR-1164xVL93-3613 (-16.78%), HPR-1164xChina-988 (-14.57%), HPR-1164xIR57893-08 (-14.26%), China-988xVL93-6052 (-13.26%), China-988xVL91-1754(-10.59%) and HPR-2047xJD-8 (-9.16%). Heterosis over better parent were exhibited by China-988xVL91-1754 (-17.71%), HPR-1164xVL93-3613 (-12.33%), China-988xVL93-6052 (-11.98%), VL91-1754xVLDhan 221 (-11.04%), HPR-1164xChina-988 (-10.00%), HPR-1164xIR57893-08 (-9.89%), HPR-2047xJD-8 (-9.16%) and VL91-1754xJD-8 (-6.41%). The range of heterosis varied between -17.71 to 33.46 per cent.

Twenty one crosses showed significant negative inbreeding depression and five observed inbreeding vigour. The range of inbreeding depression varied between -27.57 to 20.35 per cent.

Leaf area index

Twenty five crosses showed significant heterosis over standard check (Table 4.14). The range of heterosis lies between -22.93 to 192.66 per cent. The highest heterosis over standard check exhibited by cross HPR-1164x HPR-2047 (192.66%) and followed by HPR-2047xVL93-3613 (167.88%),

Table 4.13 Mean performance, heterotic response and inbreeding depression for plant height

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	108.84	8.65**	8.65*	-8.54**
HPR 1164xChina 988	102.54	-10.00**	-14.57**	13.20**
HPR 1164xVL 91-1754	113.68	-2.06	6.42	-16.36**
HPR 1164xVL 93-3613	100.70	-12.33**	-16.78**	20.35**
HPR 1164xVL 93-6052	112.43	-6.14	-0.11	-5.89
HPR 1164xIR57893-08	99.47	-9.89**	-14.46**	-5.89
HPR 1164xVL Dhan 221	108.78	2.59	2.47	-7.83**
HPR 1164xJD-8	100.76	7.70**	2.23	-26.66**
HPR 2047xChina 988	105.37	10.03**	10.03**	-12.21**
HPR 2047xVL 91-1754	116.51	-2.90	5.49	-16.71**
HPR 2047xVL 93-3613	103.53	7.99*	7.99*	-11.53**
HPR 2047xVL 93-6052	115.25	-1.66	4.64	-7.92**
HPR 2047xIR57893-08	102.30	6.40	6.40	-16.22*
HPR 2047xVL Dhan 221	111.61	7.97*	7.97*	-12.72**
HPR 2047xJD-8	103.60	-9.16*	-9.16**	-1.20
China 988xVL 91-1754	110.21	-17.71**	-10.59**	-5.52
China 988xVL 93-3613	97.23	-2.22	-13.26**	-1.72
China 988xVL 93-6052	108.96	-11.98**	-6.33	14.35**
China 988xIR57893-08	96.00	26.44**	12.16**	-12.60**
China 988xVL Dhan 221	105.31	1.02	0.90	-18.11**
China 988xJD-8	97.14	21.39**	7.69*	-27.57**
VL 91-1754xVL 93-3613	108.37	-1.96	6.51	-14.36**
VL 91-1754xVL 93-6052	120.10	-4.90	3.33	-7.82*
VL 91-1754xIR57893-08	107.14	-6.55	1.54	-8.81**
VL 91-1754xVL Dhan 221	116.45	-11.04**	-3.33	-11.69**
VL 91-1754xJD-8	108.43	-6.41*	1.69	-11.62**
VL 93-3613xVL 93-6052	107.12	-4.35	1.78	-3.35
VL 93-3613xIR57893-08	94.16	18.64**	1.35	5.22
VL 93-3613xVL Dhan 221	103.27	15.29	1.04	9.27**
VL 93-3613xJD-8	95.46	12.55**	-3.73	12.67**
VL 93-6052xIR57893-08	105.89	-0.99	5.36	-5.21
VL 93-6052xVL Dhan 221	115.20	13.47**	20.76**	-18.84**
VL 93-6052xJD-8	107.18	-5.34	0.73	-0.74
IR57893-08xVL Dhan 221	102.24	10.18**	10.05**	-10.61**
IR57893-08xJD-8	94.22	33.46**	14.15**	-16.46**
VL Dhan 221xJD-8	103.53	-5.23	5.34	-22.98
S.E.±	-	3.83	3.83	3.92

* Significant at 5 per cent probability

** Significant at 1 percent probability

Table 4.14 Mean performance, heterotic response and inbreeding depression for leaf area index

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	1.54	59.50**	192.66**	-31.66**
HPR 1164xChina 988	2.13	58.59**	-13.76	184.04**
HPR 1164xVL 91-1754	2.59	-28.84**	108.25**	3.08
HPR 1164xVL 93-3613	1.47	-8.50	67.88**	-4.91
HPR 1164xVL 93-6052	2.13	-62.99**	-22.93*	55.95**
HPR 1164xIR57893-08	1.91	-28.00	32.11**	-29.86**
HPR 1164xVL Dhan 221	1.42	-26.00	35.77**	28.37**
HPR 1164xJD-8	1.72	-43.50	3.66	39.82**
HPR 2047xChina 988	1.68	-23.34	59.63**	-8.62
HPR 2047xVL 91-1754	2.14	-17.24**	142.20**	-19.31**
HPR 2047xVL 93-3613	1.01	167.88**	167.88**	-42.46**
HPR 2047xVL 93-6052	1.68	-38.32**	28.44**	-22.80
HPR 2047xIR57893-08	1.46	-19.12**	35.77**	5.40
HPR 2047xVL Dhan 221	0.96	37.61**	37.61**	-9.45
HPR 2047xJD-8	1.26	15.97**	53.21**	-9.58
China 988xVL 91-1754	2.73	-58.93**	20.18	6.87
China 988xVL 93-3613	1.60	-48.89**	6.42	41.37**
China 988xVL 93-6052	2.27	-2.64	102.75**	-36.19
China 988xIR57893-08	2.05	12.77**	134.86**	-50.00
China 988xVL Dhan 221	1.55	-48.89**	6.42	14.65
China 988xJD-8	1.85	-47.13**	10.09	-18.33
VL 91-1754xVL 93-3613	2.06	-42.31**	68.80**	-28.26**
VL 91-1754xVL 93-6052	2.73	-31.66**	100.00**	-28.89
VL 91-1754xIR57893-08	2.51	-63.00**	8.25	-8.47*
VL 91-1754xVL Dhan 221	2.01	-47.02**	55.04**	-32.54*
VL 91-1754xJD-8	2.31	-52.66**	38.53**	-12.58
VL 93-3613xVL 93-6052	1.60	-1.76	104.58**	-38.11**
VL 93-3613xIR57893-08	1.38	-46.44**	-10.09	-4.08
VL 93-3613xVL Dhan 221	0.89	73.40**	49.54**	-20.24
VL 93-3613xJD-8	1.19	27.77**	68.80**	-21.19
VL 93-6052xIR57893-08	2.05	-33.48**	38.53**	-9.55**
VL 93-6052xVL Dhan 221	1.55	-27.75**	50.45**	-30.67
VL 93-6052xJD-8	1.85	-40.96**	22.93*	-24.62
IR57893-08xVL Dhan 221	1.33	-45.35**	-8.25	-2.00
IR57893-08xJD-8	1.63	-33.87**	11.00	8.26
VL Dhan 221xJD-8	1.14	67.36**	121.10**	-26.14**
S.E.±	-	0.12	0.12	0.17

* Significant at 5 per cent probability

** Significant at 1 percent probability

HPR-2047xVL91-1754 (142.20%), China-988xIR57893-08 (134.86%), HPR-1164xVL91-1754 (108.25%), VLDhan 221xJD-8 (121.10%), VL93-3613xVL93-6052 (104.58%), China-988xVL93-6052 (102.75%), VL91-1754xVL93-6052 (100.0%), VL91-1754xVL93-6052 (68.80%), VL93-3613xJD-8 (68.80%), HPR-1164xHPR-2047 (67.88%), HPR-2047xChina-988 (59.63%), VL91-1754x VLDhan 221 (55.04%), HPR-2047xJD-8 (53.21%), VL93-6052xVLDhan 221 (50.45%), VL93-3613xVLDhan 221 (49.54%), VL91-1754xJD-8 (38.53%), VL93-6052xIR57893-08 (38.53%), HPR-2047xVLDhan 221 (37.61%), HPR-2047xIR57893-08 (35.77%), HPR-1164xVLDhan 221 (35.77%), HPR-1164x IR57893-08 (32.11%) and VL93-3613xJD-8 (22.93%).

Heterosis over better parent were exhibited by the following cross combinations. HPR-2047xVL93-3613 (167.88%), VL93-3613xVLDhan 221 (73.40%), VLDhan 221xJD-8 (67.36%), HPR-1164xHPR-2047 (59.50%), HPR-1164xChina-988 (58.59%), HPR-2047xVLDhan 221 (37.61%), VL93-3613xJD-8 (27.77%) and HPR-2047xJD-8 (15.97%).

Nine crosses revealed inbreeding depression whereas, five crosses showed inbreeding vigour.

Dry matter

Out of thirty six hybrids, twenty two exhibited positive heterosis over standard check (Table 4.15). The heterosis varied between -29.81 to 121.97 per cent. The highest heterosis exhibited by cross VL93-3613xVL93-6052 (121.97%) and lowest by HPR-1164xIR57893-08 (14.74%). Maximum heterosis over better parent was observed for the cross VL93-3613xIR57893-08 (157.75%) and minimum HPR-2047xVLDhan 221 (15.46%). Out of thirty six crosses, fifteen indicated inbreeding depression and four inbreeding vigour.

Table 4.15 Mean performance, heterotic response and inbreeding depression for dry matter

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	17.09	37.99**	37.99**	-24.60**
HPR 1164xChina 988	16.17	-7.68	-17.06**	41.54**
HPR 1164xVL 91-1754	18.28	-1.36	11.59	21.52
HPR 1164xVL 93-3613	15.42	100.24**	77.80**	-11.30
HPR 1164xVL 93-6052	18.21	-15.78**	-5.41	21.77
HPR 1164xIR57893-08	15.52	29.22**	14.74*	-1.10
HPR 1164xVL Dhan 221	15.79	16.35*	3.31	32.81**
HPR 1164xJD-8	15.70	-3.23	-14.08*	37.01**
HPR 2047xChina 988	17.19	-12.97*	-12.97*	17.82
HPR 2047xVL 91-1754	19.30	-37.96**	-29.81**	-0.94
HPR 2047xVL 93-3613	16.43	1.60	1.60	31.68**
HPR 2047xVL 93-6052	19.22	52.01**	70.73**	-46.47**
HPR 2047xIR57893-08	16.53	2.15	2.15	11.56
HPR 2047xVL Dhan 221	16.80	15.46*	15.46*	-11.23
HPR 2047xJD-8	16.71	71.39**	71.39**	-23.35**
China 988xVL 91-1754	18.38	19.08**	34.73**	-68.23**
China 988xVL 93-3613	15.51	44.99**	30.25**	-48.07**
China 988xVL 93-6052	18.30	3.83	16.62**	-19.08
China 988xIR57893-08	15.61	2.70	-7.73	-3.35
China 988xVL Dhan 221	15.88	-2.39	-12.31	17.19
China 988xJD-8	15.79	46.58**	31.69**	-13.66
VL 91-1754xVL 93-3613	17.62	47.19**	66.53**	-17.27**
VL 91-1754xVL 93-6052	20.41	50.02**	69.74**	-29.66**
VL 91-1754xIR57893-08	17.72	36.65**	54.61**	-54.96**
VL 91-1754xVL Dhan 221	17.99	24.84**	41.24**	-15.36
VL 91-1754xJD-8	17.90	-24.25**	-14.30*	18.75
VL 93-3613xVL 93-6052	17.55	97.64**	121.97**	-62.11**
VL 93-3613xIR57893-08	14.86	157.75**	112.92**	-36.11**
VL 93-3613xVL Dhan 221	15.04	99.08**	96.02**	-26.75**
VL 93-3613xJD-8	15.13	129.03**	68.41**	-26.75**
VL 93-6052xIR57893-08	17.65	7.03	20.20**	-21.31
VL 93-6052xVL Dhan 221	17.92	30.33**	46.38**	-4.60
VL 93-6052xJD-8	17.83	50.39**	68.91**	-30.79**
IR57893-08xVL Dhan 221	15.23	-5.22	-18.88**	-36.48*
IR57893-08xJD-8	15.14	20.43	1.87	-21.19
VL Dhan 221xJD-8	15.41	58.06**	35.28**	-32.73**
S.E.±	-	1.15	1.15	2.52

* Significant at 5 per cent probability

** Significant at 1 percent probability

Net-assimilation rate (NAR)

Heterosis estimates for net-assimilation rate over standard check (Table 4.16) were positive in twenty eight crosses. The range of heterosis lies between 352.56 to 2.99 per cent. Highest heterosis was exhibited by cross VL91-1754xVL93-3613 and lowest VL91-1754xJD-8. Heterosis over better parent varied in between 406.89 to -46.44 per cent. Maximum heterosis was exhibited by VLDhan 221xJD-8 and minimum VL91-1754xJD-8. Only five crosses observed inbreeding depression and 10 inbreeding vigour. The range lies between -49.86 to 184.00 Per cent.

Panicle length

Out of thirty six crosses, twenty five showed positive heterosis over standard check (Table 4.17). The heterosis varied between 15.58 to 33.77 per cent. VL93-3613xIR57893-08 observed highest heterotic 33.77 per cent, followed by VL93-3613xVLDhan 221 (33.41%), HPR-1164xHPR-2047 (31.68%), HPR-2047xVL93-6052 (31.06%), China-988xVL93-6052 (26.36%), VL93-3613xVL93-6052 (25.60%), VL93-6052xVLDhan 221 (25.54%), VL93-3613xJD-8 (25.14%, IR57893-08xJD-8 (23.45%), China-988xVLDhan 221 (21.30%), VL91-1754xJD-8 (20.54%), HPR-2047xVL93-3613 (20.49%), HPR-2047xVL91-1754 (20.33%), China-988xIR57893-08 (20.33%), HPR-1164xJD-8 (19.92%), IR57893-08xVLDhan 221 (18.90%), HPR-2047xJD-8 (18.59%), VL91-1754x IR57893-08 (18.19%), HPR-1164xVLDhan 221 (18.14%), HPR-2047xChina-988 (17.98%), China-988xVL91-1754 (17.11%), HPR-1164xVL91-1754 (17.01%), China-988xVL93-3613 (16.09%), HPR-2047xVL93-3613 (15.89%) and VL93-6052xIR57893-08 (15.58%).

Table 4.16 Mean performance, heterotic response and inbreeding depression for net-assimilation rate

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	3.02	26.21**	99.57**	-27.62
HPR 1164xChina 988	3.83	-14.64**	44.44**	35.20
HPR 1164xVL 91-1754	4.10	-21.33**	51.28**	67.79**
HPR 1164xVL 93-3613	6.40	-47.36**	104.70**	-3.75
HPR 1164xVL 93-6052	3.55	10.95**	-35.89**	23.33
HPR 1164xIR57893-08	3.61	-47.02**	-16.23**	211.22**
HPR 1164xVL Dhan 221	2.14	-60.81**	-38.03**	143.44**
HPR 1164xJD-8	2.14	-59.45**	-35.89**	294.00**
HPR 2047xChina 988	3.15	-66.91**	-44.01**	71.75**
HPR 2047xVL 91-1754	3.42	-52.44**	-8.54**	58.87
HPR 2047xVL 93-3613	5.72	-73.95**	1.28	56.11
HPR 2047xVL 93-6052	2.87	12.64**	63.67**	-49.86*
HPR 2047xIR57893-08	2.93	1.69	53.41**	184.00**
HPR 2047xVL Dhan 221	1.46	68.37	68.37**	27.66
HPR 2047xJD-8	1.46	256.41**	256.41**	0.47
China 988xVL 91-1754	4.23	-27.11**	40.17**	-42.07
China 988xVL 93-3613	6.53	-61.53**	49.57**	-24.57
China 988xVL 93-6052	3.68	35.85**	129.91**	54.08**
China 988xIR57893-08	3.74	8.58**	83.76**	42.55
China 988xVL Dhan 221	2.27	-31.06**	16.66**	109.89**
China 988xJD-8	2.27	8.08**	82.90**	13.08
VL 91-1754xVL 93-3613	6.80	16.37**	352.56**	-6.51
VL 91-1754xVL 93-6052	3.95	23.33	137.17**	-34.77*
VL 91-1754xIR57893-08	4.01	25.77**	141.88**	-15.19*
VL 91-1754xVL Dhan 221	2.54	35.22**	154.27**	-25.21
VL 91-1754xJD-8	2.54	-46.44**	2.99**	113.27**
VL 93-3613xVL 93-6052	6.25	14.39**	344.87**	-65.89**
VL 93-3613xIR57893-08	6.31	-10.65**	247.43**	47.72**
VL 93-3613xVL Dhan 221	4.84	-13.62**	235.89**	-69.08**
VL 93-3613xJD-8	4.84	-81.86**	29.48**	181.81**
VL 93-6052xIR57893-08	3.46	29.74**	95.72**	7.64
VL 93-6052xVL Dhan 221	1.99	-11.47**	28.63**	32.89
VL 93-6052xJD-8	1.99	67.64**	143.58**	-16.16
IR57893-08xVL Dhan 221	2.06	16.71**	76.06**	-24.42
IR57893-08xJD-8	2.06	64.87**	148.71**	-29.38
VL Dhan 221xJD-8	0.58	406.89**	25.64**	13.60
S.E.±	-	0.08	0.08	0.95

* Significant at 5 per cent probability

** Significant at 1 percent probability

Table 4.17 Mean performance, heterotic response and inbreeding depression for panicle length

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	19.23	31.68**	31.68**	-8.11**
HPR 1164xChina 988	19.63	0.68	4.80	13.26**
HPR 1164xVL 91-1754	22.33	-11.13	17.01**	-5.80
HPR 1164xVL 93-3613	19.70	-1.65	3.06	18.24**
HPR 1164xVL 93-6052	20.89	-9.91	5.41	24.39**
HPR 1164xIR57893-08	19.53	-7.93	-5.10	-0.16
HPR 1164xVL Dhan 221	19.59	12.06	18.14*	0.17
HPR 1164xJD-8	18.73	24.24**	19.92**	-13.16
HPR 2047xChina 988	19.97	13.35	17.98*	6.97*
HPR 2047xVL 91-1754	22.67	-8.61	20.33**	-7.81**
HPR 2047xVL 93-3613	20.04	10.58	15.89*	1.80
HPR 2047xVL 93-6052	21.23	12.00	31.06**	-12.67**
HPR 2047xIR57893-08	19.87	1.63	4.75	17.41**
HPR 2047xVL Dhan 221	20.10	14.29*	20.49**	-7.29**
HPR 2047xJD-8	19.07	18.59*	18.59*	-2.98**
China 988xVL 91-1754	23.07	-11.05	17.11*	1.43
China 988xVL 93-3613	20.44	10.77	16.09*	-10.21**
China 988xVL 93-6052	21.63	7.99	26.36**	-34.37**
China 988xIR57893-08	20.27	15.61*	20.33**	2.67
China 988xVL Dhan 221	20.50	15.07*	21.30**	-4.04
China 988xJD-8	19.47	5.40	9.74	5.63**
VL 91-1754xVL 93-3613	23.14	-17.61**	8.48	6.78
VL 91-1754xVL 93-6052	24.33	-13.50	13.89	-0.44
VL 91-1754xIR57893-08	22.97	-0.10	18.19*	-2.20
VL 91-1754xVL Dhan 221	23.20	-18.04**	7.92	4.07
VL 91-1754xJD-8	22.17	-8.45	20.54**	-8.73**
VL 93-3613xVL 93-6052	21.70	7.33	25.60**	-5.57**
VL 93-3613xIR57893-08	20.34	27.64**	33.77**	-3.47
VL 93-3613xVL Dhan 221	20.57	26.56**	33.41**	-0.72
VL 93-3613xJD-8	19.54	19.40**	25.14**	5.83*
VL 93-6052xIR57893-08	21.53	-1.22	15.58*	10.74**
VL 93-6052xVL Dhan 221	21.76	7.29	25.54**	-2.27
VL 93-6052xJD-8	20.73	-19.34**	-5.62	27.66**
IR57893-08xVL Dhan 221	20.40	12.79	18.90*	-0.12
IR57893-08xJD-8	19.37	19.78**	23.45**	-4.47
VL Dhan 221xJD-8	19.60	3.39	8.99	6.66
S.E.±	-	1.50	1.50	0.70

* *Significant at 5 per cent probability*

** Significant at 1 percent probability

Heterosis over better parent were exhibited by HPR-1164xHPR-2047 (31.68%), VL93-3613xIR57893-08 (27.64%), VL93-3613xVLDhan 221 (26.56%), HPR-1164xJD-8 (24.24%), IR57893-08xJD-8 (19.78%), VL93-3613xJD-8 (19.40%), HPR-2047xJD-8 (18.59%), China-988xIR57893-08 (15.61%), China-988xVLDhan 221 (15.07%) and HPR-2047xVLDhan 221 (14.29%). Only eight crosses observed inbreeding depression whereas nine inbreeding vigour.

Days to maturity

Out of thirty six crosses studied, eight crosses indicated negative heterosis over standard check (Table 4.18). The range of heterosis varied between -10.46 to 10.64 per cent. VLDhan 221xJD-8 (-10.46%), VL93-3613xIR57893-08 (-10.28%), VL93-6052xJD-8 (-10.05%), HPR-1164xVL93-6052 (-9.41%), HPR-1164xIR57893-08 (-8.97%), IR57893-08xVLDhan 221 (-5.10%), VL91-1754xIR57893-08 (-4.55) and HPR-1164xVLDhan 221 (-3.85%).

Only five crosses showed negative heterosis over better parent and these crosses were VL93-3613xIR57893-08 (-10.88%), HPR-1164xVL93-6052 (-10.87%), HPR-1164xIR57893-08 (-10.43%), VL91-1754xIR57893-08 (-9.97%) and China-988xVL91-1754 (-5.01%). Nine crosses observed positive inbreeding, however sixteen crosses exhibited inbreeding depression.

Grain yield per plant

Seventeen crosses indicated positive heterosis over standard check (Table 4.19). The range of heterosis was -49.61 to 65.32 per cent. These cross combinations showing high heterosis were VL93-3613xIR57893-08 (60.05%), VL93-6052xVLDhan 221 (54.94 %), VL93-3613xJD-8 (47.03 %), HPR-2047x

Table 4.18 Mean performance, heterotic response and inbreeding depression for days to maturity

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	118.91	10.62**	10.62**	-12.63**
HPR 1164xChina 988	122.48	-0.93	0.67	-2.07
HPR 1164xVL 91-1754	125.17	2.66	4.33*	-13.13**
HPR 1164xVL 93-3613	119.31	5.31**	6.02**	0.59
HPR 1164xVL 93-6052	121.46	-10.87**	-9.41**	20.28**
HPR 1164xIR57893-08	122.46	-10.43**	-8.97**	-3.85
HPR 1164xVL Dhan 221	113.35	6.14**	-3.85*	6.25**
HPR 1164xJD-8	113.61	7.80**	-1.87	6.64**
HPR 2047xChina 988	121.52	-3.45	-3.15	6.70**
HPR 2047xVL 91-1754	124.21	-1.61	-1.61	1.82
HPR 2047xVL 93-3613	118.35	10.64**	10.64**	-8.60**
HPR 2047xVL 93-6052	120.50	-0.79	-0.79	-6.25**
HPR 2047xIR57893-08	121.50	-3.39	-3.39	-5.21**
HPR 2047xVL Dhan 221	112.39	18.61**	7.44**	-8.7**
HPR 2047xJD-8	112.65	12.60**	2.49	-1.08
China 988xVL 91-1754	127.78	-5.01**	0.73	3.85
China 988xVL 93-3613	121.92	1.86	2.55	-1.01
China 988xVL 93-6052	124.07	-2.77	1.43	-1.98
China 988xIR57893-08	125.07	-2.92	2.92	-1.56
China 988xVL Dhan 221	115.96	8.24**	-1.94	-1.72*
China 988xJD-8	116.22	15.08**	4.74**	-6.68**
VL 91-1754xVL 93-3613	124.61	3.49*	4.19	-8.47**
VL 91-1754xVL 93-6052	126.77	0.45	4.80**	-10.74**
VL 91-1754xIR57893-08	127.77	-9.97**	-4.55**	6.42**
VL 91-1754xVL Dhan 221	118.66	20.20**	8.88**	-14.77**
VL 91-1754xJD-8	119.17	14.90**	4.57*	-12.70**
VL 93-3613xVL 93-6052	120.90	7.30**	8.02**	-15.77**
VL 93-3613xIR57893-08	121.90	-10.88**	-10.28**	9.83**
VL 93-3613xVL Dhan 221	112.79	12.64**	2.03	-4.31**
VL 93-3613xJD-8	113.05	6.34**	-3.20	-2.44
VL 93-6052xIR57893-08	124.06	-2.38	1.84	-8.51**
VL 93-6052xVL Dhan 221	114.95	16.08**	5.15**	-8.23**
VL 93-6052xJD-8	115.21	-1.18	-10.05**	11.24**
IR57893-08xVL Dhan 221	115.95	4.76**	-5.10**	7.22**
IR57893-08xJD-8	116.21	11.32**	1.33	-2.27
VL Dhan 221xJD-8	107.10	-1.15	-10.46**	10.89**
S.E.±	-	2.09	2.09	2.44

*Significant at 5 per cent probability

**Significant at 1 per cent probability

Table 4.19 Mean performance, heterotic response and inbreeding depression for grain yield

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	18.27	37.65**	38.79**	-19.00**
HPR 1164xChina 988	18.03	-13.07	-12.36	3.76
HPR 1164xVL 91-1754	19.06	14.66**	24.61**	-0.13
HPR 1164xVL 93-3613	19.66	16.11**	33.789*	-21.88**
HPR 1164xVL 93-6052	18.36	-17.25**	-16.48**	20.46**
HPR 1164xIR57893-08	18.18	30.51**	31.59**	-37.62**
HPR 1164xVL Dhan 221	16.34	5.66	6.53	18.15**
HPR 1164xJD-8	17.78	-10.95	-10.21	-6.73
HPR 2047xChina 988	17.95	5.38	5.38	-3.23
HPR 2047xVL 91-1754	18.99	-4.80	3.46	-0.26
HPR 2047xVL 93-3613	19.58	-11.06	2.47	10.24
HPR 2047xVL 93-6052	18.28	40.71**	42.03**	-17.33**
HPR 2047xIR57893-08	18.10	3.90	3.90	-4.17
HPR 2047xVL Dhan 221	16.27	-25.65**	-25.65**	-30.07**
HPR 2047xJD-8	17.70	65.32**	65.32**	-7.17
China 988xVL 91-1754	18.74	22.59**	33.24**	-13.93**
China 988xVL 93-3613	19.34	-8.29	5.65	-5.20
China 988xVL 93-6052	18.04	-6.96	-6.09	9.71
China 988xIR57893-08	17.876	6.05	4.94	-7.32
China 988xVL Dhan 221	16.02	10.33	7.36	-0.97
China 988xJD-8	17.46	7.96	5.05	-3.97
VL 91-1754xVL 93-3613	20.37	6.48	7.36	-15.13**
VL 91-1754xVL 93-6052	19.07	-36.09**	-30.54**	35.36**
VL 91-1754xIR57893-08	18.89	-1.56	6.97	-7.24
VL 91-1754xVL Dhan 221	17.06	-4.65	3.62**	-8.16
VL 91-1754xJD-8	18.49	20.62**	31.09**	-18.77**
VL 93-3613xVL 93-6052	19.67	13.94**	30.82**	-32.92**
VL 93-3613xIR57893-08	19.49	38.91**	60.05**	-38.55**
VL 93-3613xVL Dhan 221	17.65	18.12**	36.09**	-21.76**
VL 93-3613xJD-8	19.09	27.61**	47.03**	-34.71**
VL 93-6052xIR57893-08	18.19	-8.60	-7.74	-13.46
VL 93-6052xVL Dhan 221	16.35	53.51**	54.94**	-40.60**
VL 93-6052xJD-8	17.79	22.59**	23.73**	-8.61
IR57893-08xVL Dhan 221	16.17	-49.00**	-49.61**	50.59**
IR57893-08xJD-8	17.61	26.09**	24.78**	-21.88**
VL Dhan 221xJD-8	15.77	-9.18	-14.12**	1.15
S.E.±	-	1.23	1.23	1.36

* Significant at 5 per cent probability

** Significant at 1 percent probability

VL93-6052 (42.03%), HPR-1164xHPR-2047 (38.79%), VL93-3613xVLDhan 221 (36.09%), HPR-1164xVL93-3613 (33.79%), China-988xVL91-1754 (33.24%), HPR-1164xIR57893-08 (31.59%), VL91-1754xJD-8 (31.09%), VL93-3613x VL93-6052 (30.82%), IR57893-08xJD-8 (24.78%), HPR-1164xVL91-1754 (24.61%), VL93-6052xJD-8 (23.73%), VL91-1754xVL93-3613 (22.69%) and VL91-1754xVLDhan 221 (3.62%). Heterosis over better parent were exhibited by the crosses HPR-2047xJD-8 (65.32%), VL93-6052xVLDhan 221 (53.51%), HPR-2047xVL93-6052 (40.76%), VL93-3613xVLDhan 221 (38.91%), HPR-1164xHPR-2047 (37.65%), HPR-1164xIR57893-08 (30.51%), VL93-6052x IR57893-08 (27.61%), IR57893-08xJD-8 (26.09%), VL93-6052xJD-8 (22.59%), China-988xVL91-1754 (22.59%), VL93-3613xVL93-6052 (20.62%), VL93-3613x JD-8 (18.12%), HPR-1164xVL93-3613 (16.11%), HPR-1164xVL91-1754 (14.66%) and VL93-3613xIR57893-08 (13.94%). Out of thirty six crosses, 16 showed inbreeding depression whereas three inbreeding vigour.

Biological yield per plant

Heterosis estimates for biological yield/plant over standard check (Table 4.20) were positive in nine crosses. The extent of heterosis ranged from -26.61 to 88.95 per cent. These crosses were IR57893-08xJD-8 (88.95%), VLDhan 221xJD-8 (68.79%), HPR-2047xVL91-1754 (43.91%), HPR-1164xVLDhan 221 (43.46%), China-988xVL93-6052 (42.70%), HPR-2047x China-988 (28.46%), VL91-1754xJD-8 (22.36%), China-988xJD-8 (21.93%) and VL93-6052xJD-8 (19.83%).

Table 4.20 Mean performance, heterotic response and inbreeding depression for biological yield

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	43.12	1.57	1.57	-18.62**
HPR 1164xChina 988	39.28	-12.04	-14.01**	18.21
HPR 1164xVL 91-1754	43.66	-11.01	-9.60	11.43
HPR 1164xVL 93-3613	40.25	-20.40**	-22.25**	-33.94**
HPR 1164xVL 93-6052	41.21	-21.17*	-22.93**	42.44**
HPR 1164xIR57893-08	38.44	2.31	-1.11	-11.26
HPR 1164xVL Dhan 221	38.29	46.74**	43.46**	-43.13**
HPR 1164xJD-8	43.07	-15.54	-15.52**	-26.37**
HPR 2047xChina 988	39.77	28.46**	28.46**	-20.23**
HPR 2047xVL 91-1754	44.15	41.68**	43.91**	-42.60**
HPR 2047xVL 93-3613	40.74	-25.90**	-25.90**	26.18*
HPR 2047xVL 93-6052	41.70	6.52	6.52	-14.33
HPR 2047xIR57893-08	38.93	9.29	9.29	-4.01
HPR 2047xVL Dhan 221	38.78	-16.91*	-16.91	-2.25
HPR 2047xJD-8	43.56	-22.78**	-22.78**	5.37
China 988xVL 91-1754	40.12	-10.53	-9.13	5.97
China 988xVL 93-3613	36.70	-14.86	-26.79**	39.72**
China 988xVL 93-6052	37.67	57.87**	42.70**	-36.05**
China 988xIR57893-08	34.90	33.49**	8.90	-10.81
China 988xVL Dhan 221	34.75	-7.94	-24.90**	66.93**
China 988xJD-8	39.78	21.90**	21.93**	8.61
VL 91-1754xVL 93-3613	41.08	23.14	3.92	-14.05
VL 91-1754xVL 93-6052	42.05	-11.97	-10.59	8.83
VL 91-1754xIR57893-08	39.28	-27.75**	-26.61**	66.93**
VL 91-1754xVL Dhan 221	39.13	10.94	12.69	-23.88**
VL 91-1754xJD-8	43.91	20.47*	22.36**	-27.96**
VL 93-3613xVL 93-6052	38.63	-2.14	-11.54	-2.09
VL 93-3613xIR57893-08	35.86	7.19	-7.82**	-4.60
VL 93-3613xVL Dhan 221	35.71	-14.91	-26.84	36.38**
VL 93-3613xJD-8	40.74	-6.14	-7.19	12.17
VL 93-6052xIR57893-08	36.83	-8.81	-17.57*	15.97
VL 93-6052xVL Dhan 221	36.68	17.70	6.39	-12.50
VL 93-6052xJD-8	41.46	21.19**	19.83*	-33.46**
IR57893-08xVL Dhan 221	33.91	15.21**	13.92	-17.15*
IR57893-08xJD-8	38.69	91.08**	88.95**	-50.57**
VL Dhan 221xJD-8	38.54	70.70**	68.79**	-47.78**
S.E.±	-	3.72	3.72	3.90

* Significant at 5 per cent probability

** Significant at 1 per cent probability

Heterosis over better parent were exhibited by IR57893-08xJD-8 (91.08%), VLDhan 221xJD-8 (70.70%), China-988xVL93-6052 (57.87%), HPR-1164xVLDhan 221 (46.74%), HPR-2047xVL91-1754 (41.68%), China-988x IR57893-08 (33.49%), HPR-2047xChina-988 (28.46%), China-988xJD-8 (21.90%), VL93-6052xJD-8 (21.19%), VL91-1754xJD-8 (20.47%) and IR57893-08xVLDhan 221 (15.21%). Out of thirty six crosses, only thirteen observed inbreeding depression whereas six inbreeding vigour.

Harvest index

Out of thirty six crosses, twelve indicated positive heterosis over standard check (Table 4.21). Highest heterosis was exhibited by cross IR57893-08xVLDhan 221 (40.56%), followed by China-988xJD-8 (35.62%), HPR-1164xChina-988 (34.03%), VL93-3613xIR57893-08 (33.29%), VL91-1754 xVL93-3613 (28.35%), VL91-1754xIR57893-08 (28.28%), VL93-6052x IR57893-08 (27.60%), HPR-1164xVL93-3613 (27.17%), HPR-2047xVL93-6052 (23.51%), VL93-6052xVLDhan 221 (23.27%), VL93-3613xVL93-6052 (18.79%) and VL91-1754xVL93-6052 (18.28%). Heterosis over better parent were exhibited by these crosses HPR-2047xJD-8 (36.54%) and HPR-1164xChina-988 (14.46%). Only thirteen crosses showed inbreeding depression whereas thirteen also inbreeding vigour.

100-grain weight

Out of thirty six crosses, thirty four revealed positive heterosis over standard check (Table 4.22). The range of heterosis varied between 12.56 to 71.01 per cent. Maximum heterosis was exhibited by cross VL93-3613xJD-8 (71.01%) and minimum by HPR-1164xVL93-3613 (10.62%). Highest heterosis

Table 4.21 Mean performance, heterotic response and inbreeding depression for harvest index

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	42.16	4.06	7.32	4.21
HPR 1164xChina 988	45.71	14.46*	34.03**	13.87**
HPR 1164xVL 91-1754	43.68	3.97	11.58	10.12
HPR 1164xVL 93-3613	44.56	-10.62**	27.17**	14.05
HPR 1164xVL 93-6052	49.22	-5.12	-0.26	-21.15*
HPR 1164xIR57893-08	47.80	-24.73**	-4.28	0.35
HPR 1164xVL Dhan 221	42.10	-6.16	-3.22	43.06**
HPR 1164xJD-8	41.27	0.70	3.85	39.48**
HPR 2047xChina 988	45.06	-17.15*	-2.98	26.14**
HPR 2047xVL 91-1754	43.03	-13.31	-6.96	37.59**
HPR 2047xVL 93-3613	48.57	-15.88**	12.74	-1.13
HPR 2047xVL 93-6052	43.91	10.68	23.51**	-24.16**
HPR 2047xIR57893-08	47.15	-23.52**	-2.74	24.59**
HPR 2047xVL Dhan 221	41.45	8.23	-5.82	-6.09
HPR 2047xJD-8	40.62	36.54**	-0.91	-26.49**
China 988xVL 91-1754	46.58	-27.15	13.92	-5.39
China 988xVL 93-3613	52.12	45.11	40.08	-20.20**
China 988xVL 93-6052	47.46	-14.95*	-0.40	32.054**
China 988xIR57893-08	50.70	-25.95**	-5.82	13.58*
China 988xVL Dhan 221	45.00	-15.38*	-0.91	-1.89
China 988xJD-8	44.17	15.81*	35.62**	-24.20**
VL 91-1754xVL 93-3613	50.09	-4.24	28.35**	-10.94*
VL 91-1754xVL 93-6052	45.43	6.00	18.28*	-10.48*
VL 91-1754xIR57893-08	48.67	0.87	28.28**	-17.87**
VL 91-1754xVL Dhan 221	42.97	-13.01	-6.64	28.23**
VL 91-1754xJD-8	42.14	-18.27**	-12.28	35.04**
VL 93-3613xVL 93-6052	50.98	-11.37	18.79*	0.16
VL 93-3613xIR57893-08	54.21	-0.55	33.29**	-17.18**
VL 93-3613xVL Dhan 221	48.52	-29.07**	-4.93	0.22
VL 93-3613xJD-8	47.68	-13.98**	15.36	-11.06*
VL 93-6052xIR57893-08	49.55	0.34	27.60**	-25.03**
VL 93-6052xVL Dhan 221	43.86	10.47	23.27**	-11.21*
VL 93-6052xJD-8	43.02	-1.87	9.49	12.01*
IR57893-08xVL Dhan 221	47.09	10.53	40.56**	-23.06**
IR57893-08xJD-8	46.26	-43.34**	-27.94**	48.44**
VL Dhan 221xJD-8	40.56	-12.56	-12.79	22.32**
S.E.±	-	3.39	3.39	2.57

* Significant at 5 per cent probability

** Significant at 1 percent probability

Table 4.22 Mean performance, heterotic response and inbreeding depression for 100 grain weight

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	2.38	0.74	30.91**	17.71**
HPR 1164xChina 988	2.60	-13.38**	12.56*	21.03**
HPR 1164xVL 91-1754	2.70	8.85*	42.51**	-17.96**
HPR 1164xVL 93-3613	2.51	-14.86**	10.62*	20.52**
HPR 1164xVL 93-6052	2.82	-19.66	14.49**	18.98**
HPR 1164xIR57893-08	2.49	-13.38**	12.56*	3.55
HPR 1164xVL Dhan 221	2.53	4.46	35.74**	-4.62
HPR 1164xJD-8	2.51	3.34	34.29**	-6.47
HPR 2047xChina 988	2.29	2.38	24.63**	11.62*
HPR 2047xVL 91-1754	2.39	2.21**	33.81**	-11.19*
HPR 2047xVL 93-3613	2.20	15.02	29.46**	2.61
HPR 2047xVL 93-6052	2.51	4.74**	49.27**	8.09
HPR 2047xIR57893-08	2.18	21.39**	34.29**	0.00
HPR 2047xVL Dhan 221	2.22	12.23**	28.50**	-13.90**
HPR 2047xJD-8	2.20	0.42	13.04*	-0.42
China 988xVL 91-1754	2.61	-17.34**	8.21	19.64**
China 988xVL 93-3613	2.42	-6.34	14.00**	-7.62
China 988xVL 93-6052	2.73	4.40	48.79**	-17.85**
China 988xIR57893-08	2.40	16.66**	42.02**	-16.32**
China 988xVL Dhan 221	2.44	-2.77	18.35**	-3.26
China 988xJD-8	2.42	-11.11*	8.21	13.83*
VL 91-1754xVL 93-3613	2.52	16.97**	53.14**	-12.93**
VL 91-1754xVL 93-6052	2.83	4.74	49.27**	-20.06**
VL 91-1754xIR57893-08	2.50	6.27	39.13**	-22.56**
VL 91-1754xVL Dhan 221	2.54	0.36	31.40**	-9.92
VL 91-1754xJD-8	2.52	15.12**	50.72**	-19.87**
VL 93-3613xVL 93-6052	2.64	-6.77	32.85**	-5.09
VL 93-3613xIR57893-08	2.31	22.74**	38.16**	-2.79
VL 93-3613xVL Dhan 221	2.35	38.81**	58.93**	-11.85**
VL 93-3613xJD-8	2.33	51.93**	71.01**	-13.84**
VL 93-6052xIR57893-08	2.62	5.08	49.75**	-18.06**
VL 93-6052xVL Dhan 221	2.66	-10.16	41.06**	-17.12**
VL 93-6052xJD-8	2.64	-14.91**	21.25**	0.00
IR57893-08xVL Dhan 221	2.33	32.06**	24.70**	-11.82**
IR57893-08xJD-8	2.31	22.74**	38.16**	-6.29
VL Dhan 221xJD-8	2.35	13.08**	29.46**	-6.71
S.E.±	-	0.11	0.11	0.14

* Significant at 5 per cent probability

** Significant at 1 percent probability

over better parent was indicated by cross VL91-1754xJD-8 (23.80%) and lowest HPR-1164xVL93-6052 (-19.66%). Only fourteen crosses exhibited inbreeding depression whereas inbreeding vigour by seven crosses.

Grain length

Seven crosses exhibited positive heterosis over standard check (Table 4.23). The range of heterosis varied between -17.79 to 19.17 peer cent. These cross combinations were HPR-2047xVL93-3613 (19.17%), VL91-1754x JD-8 (14.41%), VL93-3613xJD-8 (13.95%), HPR-1164xVLDhan 221 (12.26%), VL91-1754xVL93-3613 (11.34%), VL93-3613xVLDhan 221 (9.04%) and HPR-2047xVL93-6052 (9.04%). Only three crosses showed positive heterosis over better parent and these crosses were HPR-2047xVL93-3613 (19.17%), VL93-3613xVLDhan 221 (12.85%) and VL91-1754xVL93-3613 (9.33%). Out of thirty six crosses, thirteen crosses observed inbreeding depression whereas eleven crosses inbreeding vigour.

Grain breadth

Thirteen cross combinations showed heterosis over standard check (Table 4.24). The heterosis varied between 14.11 to 33.74 per cent. Highest heterosis was exhibited by VL93-3613xVL93-6052 (33.74%) followed by HPR-1164xJD-8 (26.99%), HPR-1164xVL93-3613 (25.15%), HPR-2047xVL93-6052 (23.92%), VL93-3613xJD-8 (19.63%), VL91-1754xIR57893-08 (23.31%), VL91-1754xVLDhan 221 (23.31%), HPR-1164xJD-8 (20.85%), HPR-2047xVL91-1754 (20.24%), VL93-3613xVLDhan 221 (19.63%), VL91-1754xVL93-6052 (19.01%), HPR-1164xVL91-1754 (19.01%) and VL93-6052xVLDhan 221 (14.11%).

Table 4.23 Mean performance, heterotic response and inbreeding depression for grain length

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	6.67	-2.78	1.84	5.87
HPR 1164xChina 988	6.64	-9.51*	-5.21	1.77
HPR 1164xVL 91-1754	6.73	1.90	6.74	4.02**
HPR 1164xVL 93-3613	6.50	-9.07	-4.75	4.18
HPR 1164xVL 93-6052	6.89	-9.48*	-3.37	1.14**
HPR 1164xIR57893-08	6.52	7.17	-3.06	-13.52**
HPR 1164xVL Dhan 221	6.56	-4.24	12.16**	2.90
HPR 1164xJD-8	7.07	-8.19*	0.30	-1.48
HPR 2047xChina 988	6.48	1.53	3.06	3.62
HPR 2047xVL 91-1754	6.58	-3.58	-1.68	6.86**
HPR 2047xVL 93-3613	6.35	19.17**	19.17**	-16.21**
HPR 2047xVL 93-6052	6.74	2.15	9.04**	-10.82**
HPR 2047xIR57893-08	6.36	-6.13	-6.13	12.58**
HPR 2047xVL Dhan 221	6.41	8.43	8.43	-2.26
HPR 2047xJD-8	6.92	-26.77**	-17.79**	27.79**
China 988xVL 91-1754	6.54	-11.44**	-9.81*	19.38**
China 988xVL 93-3613	6.31	-6.35	-7.36	10.76**
China 988xVL 93-6052	6.70	0.14	6.90	-20.22**
China 988xIR57893-08	6.33	7.13	5.98	-5.06*
China 988xVL Dhan 221	6.37	-5.58	-6.59	6.73**
China 988xJD-8	6.88	-3.55	8.28	-6.23**
VL 91-1754xVL 93-3613	6.41	9.33*	11.34*	-11.43**
VL 91-1754xVL 93-6052	6.80	-1.58	5.06	-10.36**
VL 91-1754xIR57893-08	6.42	-6.77	-5.06	9.53**
VL 91-1754xVL Dhan 221	6.47	-3.91	-2.14	-6.11*
VL 91-1754xJD-8	6.98	1.91	14.41**	-17.56**
VL 93-3613xVL 93-6052	6.57	-1.00	5.67	-6.53**
VL 93-3613xIR57893-08	6.19	0.96	-3.83	5.26
VL 93-3613xVL Dhan 221	6.24	12.85**	9.01*	-0.84
VL 93-3613xJD-8	6.75	1.50	13.95**	-1.88
VL 93-6052xIR57893-08	6.58	4.50	-0.46	-3.56
VL 93-6052xVL Dhan 221	6.63	1.58	8.43	-5.09
VL 93-6052xJD-8	7.14	-14.89**	-4.44	-5.61
IR57893-08xVL Dhan 221	6.25	3.96	0.46	-0.15
IR57893-08xJD-8	6.76	-6.01	5.52	-9.01**
VL Dhan 221xJD-8	6.81	-13.52**	-2.91	5.68**
S.E.±	-	0.29	0.29	0.18

[*] Significant at 5 per cent probability

[**] Significant at 1 percent probability

Table 4.24 Mean performance, heterotic response and inbreeding depression for grain breadth

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	1.84	-7.80	15.95	3.70
HPR 1164xChina 988	2.00	-10.73	12.26	1.02*
HPR 1164xVL 91-1754	1.97	-5.36	19.01*	-10.82**
HPR 1164xVL 93-3613	1.94	-10.24	12.88	1.63
HPR 1164xVL 93-6052	1.99	-14.14	7.97	5.68
HPR 1164xIR57893-08	1.94	-14.14	7.97	-1.70
HPR 1164xVL Dhan 221	1.90	-8.29	15.33	2.12
HPR 1164xJD-8	1.90	-3.90*	20.85*	-8.12*
HPR 2047xChina 988	1.79	-6.63*	12.26	3.82
HPR 2047xVL 91-1754	1.76	-3.57**	20.24*	-1.02
HPR 2047xVL 93-3613	1.73	3.82**	16.56	-0.52
HPR 2047xVL 93-6052	1.78	4.12**	23.92**	-3.46
HPR 2047xIR57893-08	1.73	-0.54*	12.26	1.09
HPR 2047xVL Dhan 221	1.69	-6.38	15.33	-11.17**
HPR 2047xJD-8	1.69	16.77	-1.22	5.59
China 988xVL 91-1754	1.92	-10.20	7.97	5.11
China 988xVL 93-3613	1.89	-5.61	13.49	-2.16
China 988xVL 93-6052	1.95	-9.18	9.20	41.57**
China 988xIR57893-08	1.90	-5.10	14.11	-2.68
China 988xVL Dhan 221	1.86	-10.20	9.20	-1.68
China 988xJD-8	1.86	-17.85	-1.22	19.25**
VL 91-1754xVL 93-3613	1.86	7.93*	25.15**	-3.43
VL 91-1754xVL 93-6052	1.91	0.00	19.01*	1.03
VL 91-1754xIR57893-08	1.86	6.34	23.31**	-7.79**
VL 91-1754xVL Dhan 221	1.82	6.34**	23.31**	-9.45**
VL 91-1754xJD-8	1.82	9.52**	26.99**	-9.66**
VL 93-3613xVL 93-6052	1.88	12.37*	33.74**	-11.46**
VL 93-3613xIR57893-08	1.83	-0.54	12.26	2.18
VL 93-3613xVL Dhan 221	1.79	6.55	19.63*	0.51
VL 93-3613xJD-8	1.79	10.38**	23.92**	-5.44
VL 93-6052xIR57893-08	1.89	-6.18	11.65	-2.74**
VL 93-6052xVL Dhan 221	1.85	-4.12	14.11*	-0.53
VL 93-6052xJD-8	1.85	-7.73	9.81	5.58
IR57893-08xVL Dhan 221	1.80	6.52*	20.24	-2.04
IR57893-08xJD-8	1.80	1.63	14.72	1.06
VL Dhan 221xJD-8	1.76	-1.13	6.74	15.51
S.E.±	-	0.14	0.14	0.06

* Significant at 5 per cent probability

** Significant at 1 percent probability

Eight crosses revealed positive heterosis over better parent VL93-3613xVL93-6052 (12.37%), VL93-3613xJD-8 (10.38%), VL91-1754xJD-8 (9.52%), VL91-1754xVL93-3613 (7.93%), IR57893-08xVLDhan 221 (6.52%), VL91-1754xVLDhan 221 (6.34%), HPR-2047xVL93-6052 (4.12%) and HPR-2047xVL93-3613 (3.82%). Out of 36 crosses, four crosses exhibited inbreeding vigour and eight inbreeding depression.

Length-breadth ratio

Out of thirty six crosses, only three crosses exhibited positive heterosis over standard check (Table 4.25). The range of heterosis varied between -22.25 to 7.52 per cent. China-988xJD-8 (9.952%) exhibited highest heterosis followed by HPR-1164 x IR57893-08 (4.26%) and HPR-2047xVL93-3613 (1.50%). Only three crosses showed positive heterosis over better parent. These were HPR-1164xIR57893-08 (23.44%), China-988xIR57893-08 (11.74%) and China-988xVL93-6052 (9.19%). Ten crosses combinations exhibited inbreeding depression whereas six inbreeding vigour.

4.4 Correlation coefficients and path analysis

4.4.1 Correlation coefficients

The phenotypic and genotypic correlation coefficients in F_1 and F_2 generation for yield, its components and grain quality traits are presented in Table 4.26 and 4.27, respectively. In general, the magnitude of genotypic correlations were higher than their corresponding phenotypic correlation coefficients. This indicated that genotypes were not super imposed by the

Table 4.25 Mean performance, heterotic response and inbreeding depression for grain length breadth ratio

Crosses	Mean	Better parent	Standard check	Inbreeding depression
HPR 1164xHPR 2047	3.66	-12.28**	-12.28**	-2.57
HPR 1164xChina 988	3.30	1.20	-15.53**	-5.93
HPR 1164xVL 91-1754	3.41	2.57	-10.02**	16.71**
HPR 1164xVL 93-3613	3.35	0.00	-15.53**	2.37
HPR 1164xVL 93-6052	3.46	-0.27	-10.27**	5.30
HPR 1164xIR57893-08	3.35	23.44**	4.26**	-12.25**
HPR 1164xVL Dhan 221	3.45	-0.55	-10.77**	-1.68
HPR 1164xJD-8	3.74	-18.02**	-14.53**	7.33
HPR 2047xChina 988	3.63	-9.77**	-9.77**	0.00
HPR 2047xVL 91-1754	3.74	-18.04**	-18.04**	7.95
HPR 2047xVL 93-3613	3.68	2.50	1.50**	-15.89**
HPR 2047xVL 93-6052	3.79	-11.77**	-11.77**	-7.67
HPR 2047xIR57893-08	3.68	-15.78**	-15.78**	10.41*
HPR 2047xVL Dhan 221	3.78	-6.01*	-6.01*	9.60**
HPR 2047xJD-8	4.07	-20.43**	-17.04**	-17.86**
China 988xVL 91-1754	3.39	-4.57	-16.29**	13.47**
China 988xVL 93-3613	3.32	-3.26	-18.29**	13.49**
China 988xVL 93-6052	3.43	9.19**	-1.75	-8.41*
China 988xIR57893-08	3.32	10.08**	-7.01*	-2.42
China 988xVL Dhan 221	3.39	2.56	-14.28**	8.47
China 988xJD-8	3.72	5.04	9.52**	-20.82**
VL 91-1754xVL 93-3613	3.43	1.42	-11.02**	-8.16
VL 91-1754xVL 93-6052	3.54	-1.67	-11.52**	-11.33**
VL 91-1754xIR57893-08	3.43	-11.71**	-22.55**	18.12**
VL 91-1754xVL Dhan 221	3.54	-19.20**	-11.52**	3.78
VL 91-1754xJD-8	3.83	-13.94**	-10.27**	-8.37*
VL 93-3613xVL 93-6052	3.48	-11.97**	-20.80**	5.69
VL 93-3613xIR57893-08	3.37	1.78	-14.03**	2.62
VL 93-3613xVL Dhan 221	3.47	1.95	-8.52**	-2.46
VL 93-3613xJD-8	3.76	-11.53**	-7.76*	3.53
VL 93-6052xIR57893-08	3.48	-0.83	-10.77**	6.74
VL 93-6052xVL Dhan 221	3.58	6.12	-4.51	-4.98
VL 93-6052xJD-8	3.87	-16.58**	-14.03**	-10.08*
IR57893-08xVL Dhan 221	3.47	-6.98*	-16.54**	2.40
IR57893-08xJD-8	3.76	-11.53**	-7.76*	-9.78**
VL Dhan 221xJD-8	3.87	-12.50**	-8.77*	-8.51*
S.E.±	-	0.12	0.12	0.15

* Significant at 5 per cent probability

** Significant at 1 percent probability

Table 4.26 Correlation coefficients for yield, yield components and grain quality traits in F_1 and F_2 at phenotypic level

		Days to 50% flowering	Grain yield	Biological yield	Harvest index	Days to maturity	L/B ratio	Leaf area index	Dry matter	Panicle length	Grain breadth	Grain length	100 grain weight	NAR	Amylose content	Protein content
Plant height	F_1	0.26	0.18	0.24	-0.13	0.26	0.16	0.04	0.06	0.21	0.22	0.35*	0.34*	0.01	-	-
	F_2	0.09	-0.20	-0.08	-0.15	-0.07	0.01	-0.09	0.003	0.50*	0.28	0.24	0.44*	0.008	0.10	-0.24
Days to 50% flowering	F_1		-0.21	-0.20	0.02	1.00*	0.09	0.21	-0.50*	0.23	0.26	0.33*	0.12	-0.46*	-	-
	F_2		0.05	0.05	0.03	0.95*	0.16	-0.06	0.009	-0.003	-0.03	0.18	-0.07	0.05	-0.10	-0.17
Grain yield	F_1			0.72*	0.26	-0.21	0.16	0.06	0.55*	-0.06	-0.010	0.04	0.01	0.24	-	-
	F_2			0.61*	0.35*	0.04	0.11	-0.03	0.16	0.07	0.03	0.16	-0.02	0.04	-0.02	-0.03
Biological yield	F_1				-0.45*	-0.20	0.17	0.09	0.49*	-0.06	-0.07	0.08	0.04	0.18	-	-
	F_2				-0.49*	0.06	0.13	-0.25	0.001	0.14	0.03	0.20	0.04	0.14	-0.14	-0.24
Harvest index	F_1					0.02	-0.09	-0.07	0.03	0.03	-0.03	-0.13	-0.05	0.01	-	-
	F_2					0.001	-0.03	0.27	0.20	-0.09	-0.03	-0.07	-0.08	-0.13	0.13	0.24
Days to maturity	F_1						0.09	0.21	-0.50*	0.23	0.26	0.33*	0.12	-0.47*	-	-
	F_2						0.16	-0.08	0.06	0.001	-0.02	0.19	-0.06	-0.05	-0.07	-0.18
L/B ratio	F_1							0.14	0.14	-0.05	-0.47	0.67*	-0.08	-0.08	-	-
	F_2							-0.02	0.05	-0.007	-0.61	0.77*	-0.11	0.03	0.09	-0.005
Leaf area index	F_1								0.008	0.01	0.16	0.29	0.17	-0.39*	-	-
	F_2								0.25	-0.11	0.18	0.09	-0.08	-0.37*	0.14	0.007
Dry matter	F_1									-0.12	-0.08	0.05	0.16	0.69*	-	-
	F_2									0.18	-0.02	0.03	-0.05	0.35*	0.25	-0.13
Panicle length	F_1										0.28	0.18	0.38*	-0.11	-	-
	F_2										0.18	0.15	0.38*	0.21	0.28	-0.14
Grain breadth	F_1											0.33	0.59*	-0.12	-	-
	F_2											0.01	0.40*	-0.16	-0.02	-0.004
Grain length	F_1												-0.42*	-0.03	-	-
	F_2												0.18	-0.06	0.10	-0.02
100 grain weight	F_1													0.03	-	-
	F_2													-0.14	0.05	-0.26
NAR	F_1														-	-
	F_2														-0.16	-0.17
Amylose content	F_1															-
	F_2															0.04
Protein content	F_1															
	F_2															

Table 4.27 Correlation coefficients for yield, yield components and grain quality traits in F_1 and F_2 at genotypic level

		Days to 50% flowering	Grain yield	Biological yield	Harvest index	Days to maturity	L/B ratio	Leaf area index	Dry matter	Panicle length	Grain breadth	Grain length	100 grain weight	NAR	Amylose content	Protein content
Plant height	F_1	0.28	0.18	0.24	-0.13	0.28	0.16	0.04	0.06	0.23	0.27	0.39*	0.36*	0.01	-	-
	F_2	-0.09	-0.32	-0.13	-0.26	-0.08	0.01	-0.09	-0.02	0.64*	0.33	0.32	0.52*	0.01	0.10	-0.28
Days to 50%flowering	F_1		-0.22	-0.21	0.02	1.00*	0.10	0.22	-0.52*	0.40*	0.31	0.38*	0.13	-0.48*	-	-
	F_2		0.14	0.11	0.07	1.01*	0.17	-0.08	-0.006	-0.05	-0.02	0.20	-0.06	-0.05	-0.12	-0.25
Grain yield	F_1			0.72*	0.27	-0.22	0.19	0.06	0.57*	-0.10	-0.13	0.04	0.02	0.24	-	-
	F_2			0.79*	0.07	0.09	0.14	-0.02	0.22	0.21	0.06	0.27	-0.10	0.05	-0.003	-0.10
Biological yield	F_1				-0.45*	-0.21	0.21	0.10	0.49*	-0.12	-0.11	0.09	0.05	0.19	-	-
	F_2				-0.55*	0.08	0.24	-0.30	0.007	0.21	0.01	0.33*	0.05	0.17	-0.18	-0.28
Harvest index	F_1					0.02	-0.11	-0.07	0.03	0.09	-0.02	-0.15	-0.05	0.02	-	-
	F_2					0.04	-0.17	0.45*	0.32	-0.12	0.03	-0.17	-0.23	-0.19	0.25	0.24
Days to maturity	F_1						0.10	0.21	-0.52*	0.39*	0.31	0.38*	0.14	-0.48*	-	-
	F_2						0.17	-0.09	-0.003	-0.06	-0.02	0.20	-0.03	-0.05	-0.09	-0.26
L/B ratio	F_1							0.19	0.17	-0.02	-0.42*	0.62*	-0.04	0.10	-	-
	F_2							-0.03	0.03	-0.03	-0.65*	0.73*	-0.15	0.04	0.13	0.05
Leaf area index	F_1								0.009	0.03	0.18	0.34*	0.19	-0.40*	-	-
	F_2								0.26	-0.13	0.19	0.11	-0.09	-0.37*	0.14	0.01
Dry matter	F_1									-0.15	-0.10	0.05	0.17	0.70	-	-
	F_2									0.23	-0.03	0.006	-0.03	0.37	0.29	-0.17
Panicle length	F_1										0.37*	0.33	0.57*	-0.15	-	-
	F_2										0.22	0.17	0.45*	0.24	0.33*	-0.21
Grain breadth	F_1											0.45*	0.68*	-0.14	-	-
	F_2											0.03	0.54*	0.17	-0.02	-0.04
Grain length	F_1												0.57*	-0.04	-	-
	F_2												0.31	-0.08	0.16	0.01
100 grain weight	F_1													0.03	-	-
	F_2													-0.16	0.04	-0.25
NAR	F_1														-	-
	F_2														-0.17	-0.20
Amylose content	F_1															-
	F_2															0.11
Protein content	F_1															
	F_2															

environment. Correlation studies indicated that at phenotypic level, plant height showed positive correlation with grain length, 100-grain weight and panicle length. Days to 50 per cent flowering showed positive correlation with days to maturity and grain length and negative correlation with dry matter and net-assimilation rate. Grain yield showed positive correlation with biological yield, harvest index and dry matter. Biological yield showed positive correlation with dry matter and negative correlation with harvest index. Days to maturity exhibited positive correlation with grain length and negative correlation with dry matter and net-assimilation rate. L/B ratio exhibited positive correlation with grain length and negative correlation with grain breadth. Leaf area index showed negative correlation with net-assimilation rate. Dry matter exhibited positive correlation with net-assimilation rate. Panicle length showed positive correlation with 100-grain weight. Grain breadth showed positive correlation with 100-grain weight and grain length. Grain length, showed negative correlation with 100-grain weight.

At the phenotypic level, the nature of correlations was generally similar to the observed phenotypic correlations for most of F_1 and F_2. However, the absolute values of the genotypic correlations were generally higher than the corresponding phenotypic estimates.

4.4.2 Path analysis

4.4.2.1 Estimates of direct and indirect effects at phenotypic level in both the generations

In order to understand, the casual factors of the correlations among the characters studied, the estimates of direct and indirect effects were computed through path coefficient analysis. These estimates of direct and indirect effects at phenotypic level were worked out with respect to different plant characters viz., yield, yield contributing and grain quality traits in Table 4.28. The results of these effects are presented below. A perusal of direct and indirect effects at phenotypic level in both the generations revealed low direct effect of plant height with grain yield. It was mainly due to indirect effects via days to maturity, L/B ratio, leaf area index and grain breadth.

Days to 50 per cent flowering contributed high negative direct effect with grain yield in F_1. It was due to negative indirect effects via biological yield, panicle length, grain length and net-assimilation rate. However in F_2 generation, days to 50 per cent flowering contributed positive effect with grain yield. It was mainly due to indirect effects via biological yield, harvest index, L/B ratio and leaf area index. Biological yield contributed high positive direct effect with grain yield. Its positive indirect effect via days to 50 per cent flowering and panicle length. Harvest index also contributed high positive direct effect with grain yield and indirect effects via grain length. Days to maturity also contributed high positive direct effect with grain yield and

Table 4.28 Estimates of direct and indirect effects for yield, its components and grain quality traits at phenotypic level in F_1 and F_2

		Plant height	Days to 50% flowering	Biological yield	Harvest index	Days to maturity	L/B ratio	Leaf area index	Dry matter	Panicle length	Grain breadth	Grain length	100 grain weight	NAR	Amylose content	Protein content
Plant height	F_1	**0.02**	-0.17	0.24	-0.09	0.16	0.04	0.001	-0.002	-0.006	0.04	-0.08	0.01	0.001	-	-
	F_2	**0.03**	-0.005	-0.09	-0.14	0.006	0.009	0.002	0.00	0.002	0.11	-0.11	-0.01	0.00	0.003	0.00
Days to 50%flowering	F_1	0.006	**-0.65**	-0.20	0.02	0.63	0.03	0.004	0.02	-0.007	0.05	-0.07	0.004	-0.02	-	-
	F_2	-0.002	**0.06**	0.05	0.02	-0.08	0.09	0.002	0.00	0.00	-0.01	-0.08	0.002	0.00	-0.003	0.00
Biological yield	F_1	0.005	0.13	**1.02**	-0.32	-0.102	-0.04	0.002	-0.01	0.002	-0.01	-0.01	.001	0.009	-	-
	F_2	-0.002	0.003	**1.07**	-0.45	-0.05	0.08	0.006	0.00	0.001	0.01	-0.09	-0.001	0.001	-0.004	0.00
Harvest index	F_1	-0.003	-0.02	-0.45	**0.72**	0.01	-0.02	-0.002	-0.001	-0.001	-0.005	0.03	-0.002	0.001	-	-
	F_2	-0.004	0.001	-0.53	**0.90**	0.00	-0.01	-0.006	-0.004	0.00	-0.01	0.03	0.002	0.00	0.003	0.00
Days to maturity	F_1	0.006	-0.66	-0.21	0.01	**0.63**	0.02	0.004	0.02	-0.007	0.05	-0.07	0.003	-0.02	-	-
	F_2	-0.002	0.06	0.07	0.001	**-0.09**	0.1	0.002	0.00	0.00	-0.009	-0.09	0.001	0.00	-0.002	0.00
L/B ratio	F_1	0.004	-0.06	0.17	-0.06	0.05	**0.29**	0.003	0.005	0.002	-0.08	-0.14	-0.002	0.004	-	-
	F_2	0.00	0.01	0.14	-0.03	-0.01	**0.59**	0.001	-0.001	0.00	-0.24	-0.40	0.003	0.00	0.002	0.00
Leaf area index	F_1	0.001	-0.13	0.10	-0.05	0.13	0.04	**0.02**	0.00	0.00	0.03	-0.06	0.005	-0.01	-	-
	F_2	-0.002	-0.0047	-0.27	0.25	0.007	-0.01	**-0.02**	-0.005	0.00	0.07	-0.04	0.002	-0.001	0.003	0.00
Dry matter	F_1	0.001	0.33	0.50	0.02	-0.31	0.04	0.00-	**-0.04**	0.004	-0.01	-0.01	0.005	0.03	-	-
	F_2	0.00	0.001	0.001	0.18	-0.001	0.03	0.006	**-0.02**	0.001	-0.01	-0.02	0.001	0.001	0.006	0.00
Panicle length	F_1	0.005	-0.15	-0.06	0.02	0.14	-0.01	0.00	0.005	**-0.03**	0.05	-0.03	0.01	-0.005	-	-
	F_2	0.01	0.00	-0.09	-0.09	0.00	-0.004	0.003	-0.004	**0.004**	0.07	-0.07	-0.009	0.001	0.007	0.00
Grain breadth	F_1	0.005	-0.17	-0.07	-0.01	0.16	-0.14	0.004	0.003	-0.008	**0.19**	-0.07	0.01	-0.006	-	-
	F_2	0.007	-0.002	0.04	-0.03	0.002	-0.36	-0.004	0.001	0.001	**-0.39**	-0.008	-0.01	-0.001	-0.001	0.00
Grain length	F_1	0.008	-0.22	0.08	-0.09	0.20	0.20	0.006	-0.002	-0.005	0.06	**-0.22**	0.01	-0.002	-	-
	F_2	0.007	0.01	0.22	-0.06	-0.02	0.45	-0.002	-0.001	0.001	0.007	**-0.46**	-0.05	0.00	0.003	0.00
100 grain weight	F_1	0.008	-0.07	0.054	-0.04	0.07	-0.02	0.004	-0.006	-0.01	0.11	-0.09	**0.03**	0.001	-	-
	F_2	0.01	-0.004	0.04	-0.07	0.005	-0.07	0.002	0.001	0.001	0.16	-0.08	**-0.03**	-0.001	0.01	0.00
NAR	F_1	0.00	0.31	0.18	0.01	-0.29	0.02	-0.009	-0.02	0.003	-0.02	0.008	0.001	**0.05**	-	-*
	F_2	0.00	-0.003	0.16	-0.12	0.004	0.02	0.009	-0.007	0.001	0.06	0.03	0.004	**0.004**	-0.004	0.00
Amylose content	F_1	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**	-
	F_2	0.003	-0.006	-0.16	0.12	-0.003	0.00	0.003	-0.001	-0.002	0.009	0.006	-0.001	0.001	**0.001**	-0.001
Protein content	F_1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	F_2	-0.007	-0.01	-0.26	0.22	0.02	-0.003	0.00	0.003	-0.001	-0.002	0.009	0.006	-0.001	0.001	**-0.001**

indirect effects via grain breadth and harvest index in F_1 however in F_2 generation, days to maturity contributed negative direct effect with grain yield and indirect effects via days to 50 per cent flowering and biological yield. L/B ratio exhibited direct positive effect with grain yield. It was mainly due to biological yield, leaf area index and net-assimilation rate. Leaf area index contributed direct effect with grain yield in F_1. It was mainly due to indirect effects via days to maturity and L/B ratio. However in F_2 generation, leaf area index contributed low negative direct effect with grain yield and indirect effects via plant height, days to 50 per cent flowering and biological yield. Dry matter contributed positive direct effect with grain yield and indirect effects via days to 50 per cent flowering, biological yield and harvest index. Panicle length contributed negative direct effect with grain yield. It was mainly indirect effects via days to 50 per cent flowering and biological yield. However in F_2 generation, panicle length contributed positive direct effect with grain yield and its negative indirect effects via biological yield and leaf area index. Grain breadth contributed positive direct effect with grain yield and indirect effects via plant height, days to maturity and dry matter. Grain length contributed positive direct effect with grain yield and indirect effects via plant height and biological yield. 100-grain weight contributed low positive direct effect with grain yield in F_1 generation. It was mainly due to indirect effects via plant height, biological yield, days to maturity and leaf area index. However in F_2 generation, 100-grain weight contributed negative direct effect with grain yield and indirect effects via days to 50 per cent flowering, harvest index and grain length. Net-assimilation rate contributed positive direct effect with grain yield and indirect effects via biological yield, L/B ratio and panicle length. Amylose content contributed low direct effect with grain yield. It was mainly due to indirect effects via plant height, harvest index and days to maturity.

Protein content contributed low negative direct effect with grain yield and indirect effects via plant height, days to 50 per cent flowering and biological yield.

At genotypic level (Table 4.29), plant height contributed low indirect effect with grain yield and indirect effect with grain yield and indirect effects via days to 50 per cent flowering and biological yield with grain yield and indirect effects via harvest index and panicle length. Biological yield contributed positive direct effect with grain yield. It also exhibited indirect effects via biological yield.

Harvest index also contributed positive direct effect with grain yield. It was due to indirect via days to 50 per cent flowering. Similar trends were observed for the other traits like phenotypic level except L/B ratio contributed positive direct effect with grain yield in F_1 and indirect effects via days to 50 per cent flowering and biological yield. However in F_2 generation, L/B ratio contributed negative direct effect with grain yield and indirect effects via days to 50 per cent flowering and biological yield.

Table 4.29 Estimates of direct and indirect effects for yield, its components and grain quality traits at genotypic level in F_1 and F_2

		Plant height	Days to 50% flowering	Biological yield	Harvest index	Days to maturity	L/B ratio	Leaf area index	Dry matter	Panicle length	Grain breadth	Grain length	100 grain weight	NAR	Amylose content	Protein content
Plant height	F_1	**0.01**	0.18	0.23	-0.09	-0.20	0.47	0.00	-0.005	-0.004	0.66	-1.16	0.07	0.00	-	-
	F_2	**0.18**	-0.01	-0.17	-0.17	0.006	-0.01	0.01	0.00	-0.05	-0.33	0.30	0.007	0.00	0.008	-0.05
Days to 50%flowering	F_1	0.003	**0.66**	-0.20	0.01	-0.70	0.31	0.00	0.04	-0.006	0.66	-1.14	0.03	0.00	-	-
	F_2	-0.02	**0.14**	0.14	0.04	-0.07	-0.25	-0.01	0.00	0.004	-0.33	-0.001	-0.001	0.00	-0.009	-0.04
Biological yield	F_1	0.002	-0.14	**0.95**	-0.30	0.15	0.65	0.00	-0.03	0.002	-0.27	-0.27	0.01	-0.003	-	-
	F_2	-0.02	0.01	**1.33**	-0.36	-0.007	-0.35	-0.04	0.00	-0.01	-0.01	0.32	0.001	0.003	-0.01	-0.05
Harvest index	F_1	-0.01	0.01	-0.43	**0.66**	-0.01	-0.35	0.00	-0.002	-0.001	-0.05	0.46	-0.01	0.00	-	-
	F_2	-0.04	0.01	-0.73	**0.66**	-0.003	0.25	0.05	0.003	0.01	-0.03	-0.16	-0.003	-0.004	0.02	0.04
Days to maturity	F_1	0.003	0.66	-0.20	0.01	**-0.70**	0.31	0.00	-0.01	0.00	0.45	-1.03	0.04	0.006	-	-
	F_2	-0.01	0.14	0.11	0.02	**-0.08**	-0.26	-0.01	0.00	0.005	0.02	0.19	0.00	-0.001	-0.007	-0.04
L/B ratio	F_1	0..002	0.07	0.20	-0.008	-0.07	**3.02**	0.00	-0.011	0.00	-1.05	-1.87	-0.008	-0.001	-	-
	F_2	0.002	0.02	0.32	-0.11	-0.01	**-1.47**	-0.004	0.00	0.003	0.67	0.70	-0.002	0.001	0.01	0.009
Leaf area index	F_1	0.00	0.14	0.09	-0.04	-0.15	0.56	**-0.001**	-0.001	0.00	0.45	-1.03	0.03	0.006	-	-
	F_2	-0.01	-0.01	-0.40	0.30	0.007	0.04	**0.13**	0.002	0.01	-0.20	-0.10	-0.001	-0.007	0.01	0.002
Dry matter	F_1	0.001	-0.34	0.47	0.01	0.36	0.51	0.00	**-0.07**	0.002	-0.24	-0.16	0.03	-0.01	-	-
	F_2	-0.003	-0.001	0.01	0.21	0.00	-0.04	0.03	**0.009**	-0.01	0.03	0.006	0.00	0.007	0.02	-0.03
Panicle length	F_1	0.022	0.26	-0.12	0.06	-0.28	-0.06	0.00	0.01	**-0.02**	0.93	-1.00	0.11	0.001	-	-
	F_2	0.11	-0.007	0.28	-0.08	0.005	0.05	-0.01	0.002	**0.002**	-0.03	0.17	0.006	0.004	0.02	-0.03
Grain breadth	F_1	0.003	0.20	-0.10	-0.01	-0.22	-1.27	0.00	0.008	-0.006	**2.49**	-1.34	0.13	0.002	-	-
	F_2	0.06	-0.003	0.02	0.022	0.97	0.03	0.00	-0.01	-1.03	**0.02**	0.007	-0.003	-0.001	-0.008	-0.02
Grain length	F_1	0.004	0.25	0.08	-0.01	-0.26	-1.87	-0.001	-0.04	-0.005	1.11	**3.02**	0.10	0.001	-	-
	F_2	0.05	0.02	0.44	-0.11	-0.01	-1.08	0.01	0.00	-0.01	-0.02	**0.96**	0.004	-0.001	0.01	0.002
100 grain weight	F_1	0.004	0.09	0.05	-0.03	-0.09	-0.12	0.00	-0.01	-0.009	1.69	-1.72	**0.18**	0.00	-	-
	F_2	0.09	-0.009	0.07	-0.15	0.003	0.22	-0.01	0.00	-0.03	-0.55	0.29	**0.01**	-0.003	0.003	-0.04
NAR	F_1	0.00	-0.31	0.18	0.01	0.34	0.30	0.001	-0.005	0.002	-0.34	0.13	0.006	**-0.02**	-	-
	F_2	0.003	-0.007	0.23	-0.13	0.004	-0.05	-0.04	0.003	-0.01	0.18	-0.07	-0.002	**0.01**	-0.01	-0.03
Amylose content	F_1	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**	-
	F_2	0.01	-0.01	-0.24	0.16	0.007	-0.19	0.01	0.003	-0.02	0.15	0.001	-0.003	0.07	**0.01**	0.01
Protein content	F_1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	F_2	-0.05	-0.03	-0.37	0.16	0.02	-0.07	0.001	-0.002	0.01	0.04	0.009	-0.003	-0.004	0.008	**0.14**

- Not calculated

Leaf area index contributed negative direct effect with grain yield in F_1 and indirect effects via harvest index and days to maturity. However in F_2 generation, leaf area index contributed positive direct effect with grain yield. It was mainly due to indirect effects via harvest index. Dry matter contributed negative direct effect with grain yield in F_1 and indirect effects via days to 50 per cent flowering and panicle length. However in F_2 generation, dry matter contributed positive direct effect with grain yield. It was mainly due to indirect effects via biological yield and harvest index.

4.5 Disease

The nine parents, thirty six hybrids and their thirty six F_2's were evaluated under field conditions for leaf blast and neck blast reaction at the experimental farm of Department of Plant Breeding and Genetics, during *Kharif* 2003.

Data on leaf blast and neck blast reactions are presented in Table 4.30. The results revealed that the two parents, viz., IR57893-08 and JD-8 showed resistant reaction against the leaf blast. China 988 showed susceptible reaction to the leaf blast and the remaining parents were moderately resistant.

Among the parents, IR57893-08, VLDhan 221 and JD-8 showed highly resistant reaction against neck blast. China-988 exhibited susceptible reaction and the remaining parents were moderately resistant.

Among the hybrids, the cross combinations showing high resistance to leaf blast were HPR-2047xIR57893-08, China-988xVLDhan 221, China-988x JD-8 and HPR-2047xVL93-6052 and remaining cross combinations were moderately resistant to leaf blast. The cross combinations showing high

Table 4.30 Reaction of rice genotypes to leaf blast and neck blast under field conditions

Parents/Hybrids	Normal fertility (90N:40P:40K)		Reaction	
	Leaf blast	Neck blast	Leaf blast	Neck blast
(1)	(2)	(3)	(4)	(5)
HPR 1164	2	4	MR	MR
HPR 2047	3	3	MR	MR
China 988	9	12	S	S
VL91-1754	3	0	MR	MR
VL93-3613	3	2	MR	HR
VL93-6052	4	3	MR	MR
IR57893-08	1	0	R	HR
VLDhan 221	2	1	MR	R
JD-8	0	1	HR	MR
HPR 1164xHPR 2047	3	2	MR	HR
HPR 1164xChina 988	4	0	MR	HR
HPR 1164xVL91-1754	5	2	MR	MR
HPR 1164xVL93-3613	6	0	MR	HR
HPR 1164xVL93-6052	3	5	MR	MR
HPR 1164xIR57893-08	4	2	MR	MR
HPR 1164xVLDhan221	4	0	MR	HR
HPR 1164xJD-8	3	6	MR	MR
HPR 2047xChina 988	2	4	MR	MR
HPR 2047xVL91-1754	4	6	MR	MR
HPR 2047xVL93-3613	3	1	MR	R
HPR 2047xVL93-6052	1	0	R	HR
HPR 2047xIR57893-08	0	0	HR	HR
HPR 2047xVLDhan 221	5	2	MR	MR
HPR 2047xJD-8	2	4	MR	MR
China 988xVL91-1754	5	0	MR	HR
China 988xVL93-3613	3	2	MR	MR
China 988xVL93-6052	3	0	MR	HR
China 988xIR57893-08	3	0	MR	HR
China 988xVLDhan 221	0	0	HR	HR
China 988xJD-8	0	0	HR	R
VL91-1754xVL93-3613	2	1	MR	HR
VL91-1754xVL93-6052	2	0	MR	R
VL91-1754xIR57893-08	3	1	MR	HR
VL91-1754xVLDhan221	3	0	MR	MR
VL91-1754xJD-8	3	7	MR	MR
VL93-3613xVL93-6052	3	4	MR	MR
VL93-3613xIR57893-08	3	6	MR	MR

Contd../-

(1)	(2)	(3)	(4)	(5)
VL93-3613xVLDhan 221	3	8	MR	MR
VL93-3613xJD-8	3	0	MR	HR
VL93-6052xIR57893-08	3	4	MR	MR
VL93-6052xVLDhan 221	5	2	MR	MR
VL93-6052xJD-8	6	4	MR	MR
IR57893-08xVLDhan 221	3	1	MR	R
IR57893-08xJD-8	4	0	MR	MR
VLDhan221xJD-8	0	0	HR	MR ?
HPR 1164xHPR 2047	1	0	R	HR
HPR 1164xChina 988	1	0	R	HR
HPR 1164xVL91-1754	1	0	R	HR
HPR 1164xVL93-3613	1	2	R	MR
HPR 1164xVL93-6052	2	1	MR	R
HPR 1164xIR57893-08	5	2	MR	MR
HPR 1164xVLDhan221	2	1	MR	R
HPR 1164xJD-8	2	1	MR	R
HPR 2047xChina 988	2	0	MR	HR
HPR 2047xVL91-1754	2	0	MR	HR
HPR 2047xVL93-3613	1	0	R	HR
HPR 2047xVL93-6052	2	1	MR	R
HPR 2047xIR57893-08	2	1	MR	R
HPR 2047xVLDhan 221	3	2	MR	MR
HPR 2047xJD-8	1	0	R	HR
China 988xVL91-1754	2	0	MR	HR
China 988xVL93-3613	1	1	R	R
China 988xVL93-6052	3	1	MR	R
China 988xIR57893-08	3	1	MR	R
China 988xVLDhan221	2	1	MR	R
China 988xJD-8	1	0	R	HR
VL91-1754xVL93-3613	2	3	MR	MR
VL91-1754xVL93-6052	2	4	MR	MR
VL91-1754xIR57893-08	3	2	MR	MR
VL91-1754xVLDhan221	2	0	MR	HR
VL91-1754xJD-8	1	0	R	HR
VL93-3613xVL93-6052	2	1	MR	R
VL93-3613xIR57893-08	2	1	MR	R
VL93-3613xVLDhan221	1	1	R	R
VL93-3613xJD-8	1	1	R	R
VL93-6052xHPR 1164	1	2	R	MR
VL93-6052xVLDhan221	2	5	MR	MR
VL93-6052xJD-8	1	3	R	MR
IR57893-08xVLDhan 221	1	0	R	HR
IR57893-08xJD-8	1	0	R	HR
VLDhan 221xJD-8	2	1	MR	R

MR-moderately resistant (2,3,4,5,6,1-5%)
R-resistant (1, <1%)

HR– highly resistant (0, 0%)
S – susceptible (9, 26-50%)

resistance against neck blast were HPR-1164xChina-988, HPR-1164xVL93-3613, HPR-1164xVLDhan 221, HPR-2047xVL93-6052, HPR-2047xIR57893-08, China-988xVL91-1754, China-988xVL93-6052, China-988xIR57893-08, China-988x VLDhan 221, VL91-1754xVL93-3613, VL91-1754xIR57893-08, VL93-3613xJD-8, IR57893-08xVLDhan 221, HPR-2047xVL93-3613, China-988xJD-8 and VL91-1754xVL93-6052 and the remaining cross combinations exhibited moderately resistant reaction against neck blast.

Among the 36 F_2's, the cross combinations exhibited resistant reaction against leaf blast and these were HPR-1164xHPR-2047, HPR-1164x China-988, HPR-1164xVL91-1754, HPR-1164xVL93-3613, HPR-2047xVL93-3613, HPR-2047xJD-8, China-988xVL93-3613, China-988xJD-8, VL91-1754xJD-8, VL93-3613xVLDhan 221, VL93-3613xJD-8, VL93-6052xIR57893-08, VL93-6052x JD-8 and IR57893-08xVLDhan 221.

Twenty one crosses showed moderately resistant reaction against leaf blast. Twelve crosses in F_2 generation were highly resistant against neck blast, fourteen crosses were resistant and nine cross combinations exhibited moderately resistant reaction against neck blast.

Discussion

Chapter V

DISCUSSION

Diallel approach (Jinks and Hayman, 1953 and Griffing, 1956[b]) was followed in the present study to understand the nature of gene actions involved in the rice (*Oryza sativa* L.) genotypes for yield, its components and grain quality traits. The importance of such analysis lies in the fact that it provides a systematic approach in formulating further breeding programmes in order to get maximum possible information. Johnson (1963) described diallel analysis experimentally as a systematic approach and analytically, it provides an overall genetic evaluation that would be useful in identifying the errors with best potential in early generations. The analysis of Griffing (1956[b]) is particularly useful to the breeders as gca are calculated for each parent and sca for each hybrids. From this analysis, the performance of each genotype can be evaluated. From the combining ability analysis we can also predict, the relative magnitude of additive and non-additive genetic variances. The variances due to gca contains additive genetic variance and epistatic interactions of similar type, while sca contains the dominance variance and all types of epistatic interactions including additive x additive types also (Griffing, 1956[a] and 1956[b], Arunachalam, 1976). High gca variance indicates mainly the importance of additive portion, while the high sca variance is an indication of the predominant role of non-additive or dominance portion of genetic variance.

Hayman's (1954) graphical approach is based on the estimation of components of variation. It was initially developed by Jinks and Hayman in 1953, and later elaborated independently by Jinks and Hayman (1953). The following six components of variation are estimated additive genetic variance (D), dominance component (H_1), $H_2=H_1[1-(u-v)^2]$ where u and v are the proportions of positive and negative genes in the parents, respectively expected environmental components of variance (E), preponderance of dominance variance (F) and dominance effect (h^2). From the above estimates, the following ratios are determined, average degree of dominance ($\sqrt{H_1/D}$), ratios of dominance and recessive genes in the parents $[(H_1/D)^{1/2} + F] / [(H_1/D)^{1/2}-F]$, number of gene groups (h^2/H_2) and the proportion of genes with positive and negative effects in the parents ($H_2/4H_1$).

The results obtained on combining ability, gene action, heterosis, inbreeding depression, correlation, path analysis and disease reaction (rice blast) are discussed hereunder in different heads.

5.1 Analysis of variance for yield, its components and grain quality traits

The analysis of variance revealed significant differences among the genotypes including nine parents, thirty six F_1's and their thirty six F_2's for all the traits under study viz., days to 50 per cent flowering, plant height, leaf area index, dry matter, net-assimilation rate, panicle length, days to maturity, grain yield/plant, biological yield/plant, harvest index, 100-grain weight, grain length, grain breadth, L/B ratio, amylose content and protein content. This showed that sufficient genetic variability existed in the material under study.

5.2 Diallel analysis

5.2.1 Combining ability analysis

It is important to consider the combining ability of parents and crosses for their exploitation in breeding approaches aimed particularly to breed for high yield. The combining ability analysis of Griffing (1956) has been extensively used to identify potential parents and cross combinations on the basis of their combining ability effects to obtain maximum genetic gain by their exploitation in breeding programme for desirable economic traits.

General combining ability effects being related to additive genetic effects represents the fixable components of genetic variance and are used to classify the parents for their breeding behaviour in hybrid combinations, whereas specific combining ability (sca) effects are related to non-fixable component of genetic variance (Hayman, 1960; Sprauge, 1966).

In the present study, significance of gca and sca variances revealed the presence of additive and non-additive gene actions in both the generations for all the traits except grain breadth in F_1 (both gca and sca) and only gca of net-assimilation rate in F_2. The differences due to gca and sca indicated the presence of sufficient genetic variability for combining ability in the material. These results are in agreement with the findings of Geetha *et al.* (1994) they had reported additive gene action for plant height, grain length, grain breadth and 100-grain weight and non-additive gene action for grain yield per plant. Lokaparkash *et al.* (1991) revealed non-additive gene action for plant height and harvest index. Ghosh (1993) indicated additive gene action for days to 50 per cent flowering, plant height, length of panicle, grain length, grain breadth and 100-grain weight and non-additive gene action for harvest index and grain yield/plant. Singh and Singh (1991) reported additive gene action for plant height, panicle length and harvest index.

The magnitude of gca variance was higher than the corresponding sca variance for all the traits except biological yield, length of panicle and grain length in F_1 generation, whereas in F_2, magnitude of gca variance was higher than the corresponding sca variance for all the traits except for plant height, biological yield/plant, harvest index, net-assimilation rate and protein content.

Predominance of additive gene action prevailed for plant height, days to 50 per cent flowering, grain yield, harvest index, days to maturity, leaf area index, dry matter, 100-grain weight, net-assimilation rate and length breadth ratio which might be due to high gca as compared to sca variances, whereas remaining traits showed predominance of non-additive gene-action due to high sca variances than gca. However in F_2 generation, non-additive gene action predominated for plant height, biological yield/plant, harvest index, net-assimilation rate and protein content while, remaining traits exhibited predominance of additive gene action. These results are in agreement with the findings of the following workers: Lokaparkash *et al.* (1991) and Singh and Singh (1991) reported additive gene action for plant height and non-additive gene action for panicle length. Ghosh (1993) reported additive gene action for days to 50 per cent flowering, plant height and 100-grain weight. Sardana and Borthakur (1987) reported additive gene action for grain yield/plant, plant height and 100-grain weight. Verma *et al.* (1995) reported additive gene action for grain yield/plant, days to 50 per cent flowering and non-additive gene action for biological yield/plant. Chakraborty *et al.* (1994) reported non-additive gene action for panicle length. Singh *et al.* (1993) revealed non-additive gene effects for kernel length and additive gene effects for L/B ratio. Kaushik and Sharma (1988) reported non-additive gene action for protein content. Geetha *et al.* (1994) reported both additive and non-additive gene action for yield contributing traits.

5.2.2 General combining ability effects

The gca effects are of direct utility to decide the next phase of the breeding programme i.e. to locate the parents which can be commercially exploited for development of suitable hybrids.

In the present study, the parents were classified as good, average and poor combiners based on gca effects. Parents with desirable gca effects significantly differing from zero were considered as good combiners, while those with non-significant estimates were called as average combiners. Poor combiners had significant but undesirable gca effects. It is revealed from the results that the parents HPR-2047, VL93-3613 and JD-8 were good general combiners for grain yield/plant in F_1 generation, whereas in F_2, HPR-2047 showed good general combining ability for grain yield/plant. These parents were also simultaneously better combiners for few other yield components. It would be interesting to find the behaviour of these good general combiners in various cross combinations exhibiting significant sca effects. In view of this, these parents appeared to be worthy of exploiting in practical plant breeding for utilizing the fixable component of variation.

For grain quality traits, the parent JD-8 was good general combiner for grain length, L/B ratio and protein content in both the generations, whereas HPR-1164, VL91-1754, VL93-3613 and VLDhan-221 were good general combiners for amylose content and VL93-6052 and HPR-1164 for both amylose content and protein content in F_2 generation. Many workers had also reported different parents as good, average and poor general combiners for grain yield, its components and quality traits in rice. Kaushik and Sharma (1988) had indicated that parent Himdhan was good general combiner for days to flowering, panicle length, 100-grain weight and yield per plant. Verma *et al.* (1995) reported parents PP72, Jaya and Sita were good general combiners for yield and most of its characters. Singh *et al.* (1980) revealed parent IET3618 was good general combiner for yield per plant and days to flower and parent Saket4 for plant height. Borgoham and Sarma (1998) reported parents DWR1, DWR2 and DWR5 were good general combiners for yield and most of its characters. Sharma and Mani (2001) reported parents Basmati 370, Haryana Basmati 1, Kasturi and Pusa Basmati 1 were good general combiners for grain yield per plant.

5.2.3 Specific combining ability effects

The sca effects arise due to dominance and epistatic components of variation i.e. mainly non-fixable components of variation. Non-significant sca mean squares indicates that the performance of single cross progeny can be predicted adequately on the basis of gca. Significant sca is the indication of relative importance of interactions in determining the performance of single cross. A comparison of the combining ability effects of the parents and their corresponding crosses indicated that in most of the cases gca effects of the parents were not reflected in the sca effects of the crosses for most of the traits studied. Thus, in most cases crossing the two good general combiners did not necessarily result in good specific combination and the same was true for poor combiners. In some cases, however, good hybrid combinations involved one good combiner, while in very few cases both good combiners could produce superior combinations. In some cases, when two poor combiners were crossed, best combinations were observed to be produced. This indicated wide diversity in nicking to produce hybrid vigour. In general, there was no generalized order of nicking among the parents to produce desirable combinations. Any sort of combinations among the parents could give hybrid vigour over the parents which might be due to favourable dominant genes, over dominance or epistatic action of genes (Matzinger and Kempthorne, 1956).

The cross-combinations VL93-6052xVLDhan-221, VL93-3613x IR57893-08, HPR-2047xJD-8, HPR-2047x VL93-6052 and HPR-1164xIR57893-08 in F_1 and HPR-2047xJD-8, China-988xVL91-1754, HPR-1164xVLDhan-221 and HPR-1164xHPR-2047 in F_2 generation showing high sca effects for grain yield. The cross combinations VL93-6052xVLDhan-221 in F_1 and HPR-2047xJD-8 in F_2 generations were superior for grain yield involving poor x poor and good x average parents, respectively.

The parents of hybrid combination HPR-2047xJD-8 were good general combiners for grain yield. Simultaneously high sca effects of this cross were also observed for harvest index, days to maturity, dry matter, length of panicle and net-assimilation rate (in F_1). Crosses HPR-1164xHPR-2047 and China-988xVL91-1754 involved the parents having good x poor and average x average containing parents for grain yield. SCA effects of these hybrids were also significant for leaf area index, plant height, dry matter, grain yield, net-assimilation rate and panicle length. Cross combination HPR-1164xIR57893-08 was found to be superior for grain quality traits like, grain length and length breadth ratio. The parents of the said cross were poor combiners. HPR-2047xVL93-3613 combination exhibited high sca for grain length and L/B ratio.

Common cross combinations (in F_1 and F_2) China-988xVL93-6052 and HPR-2047xVL91-1754 were found to be superior for amylose content and protein content. These results are also in agreement with the findings of Verma *et al.* (1995). They reported high sca for grain yield/plant, plant height and biological yield/plant. Kaushik and Sharma (1988) indicated the importance of sca for yield/plant. Ghosh (1993) reported high sca for harvest index and grain yield/plant. Geetha *et al.* (1994) reported that sca was more important than gca for grain yield per plant. Lokprakash *et al.* (1991) reported sca to be more important than gca for panicle length, 100-grain weight, yield/plant and harvest index.

A number of studies conducted earlier have also reported contradictory reports about the relative importance of parents for general and specific combining ability effects. Lokparkash *et al.* (1991) reported importance of sca for harvest index, grain yield/plant and 100-grain weight. Singh and

Singh (1991) concluded that gca was more important than sca for panicle length. Geetha *et al.* (1994) reported importance of gca for grain length and sca for grain yield/plant. Ghosh *et al.* (1993) reported importance of gca for grain length, harvest index and yield/plant. Sardana and Borthakur (1987) reported importance of sca for days to flowering. Singh *et al.* (1980) reported the importance of gca was more than that of sca for yield/plant, days to flowering and plant height.

5.2.4 Genetic component analysis

Hayman's (1954) diallel analysis is carried out if the assumptions underlying the analysis are fulfilled to show the validity of additive-dominance model. To employ the validity of such assumptions the t^2-values are computed. The non-significant t^2-values for majority of the traits indicated the validity of most of the assumptions underlying diallel analysis, but, it is appropriate to consider the results from F_1 generation regarding genetic components of variation which are to be free from bias and also to avoid further contradictions. The non-allelic interactions were observed, as indicated by the significant values of (1-b) to be present for plant height, days to 50 per cent flowering, grain yield, biological yield, harvest index, leaf area index, dry matter, length of panicle, 100-grain weight, net-assimilation rate, grain length, grain breadth, L/B ratio and protein content. Significant regression coefficient values (b) coupled with significant values of (1-b) indicated the presence of probably complementary type of interactions for the trait days to 50 per cent flowering.

Estimates of components of variation (Hayman's approach, 1954) for yield and yield contributing traits indicated the significance of both additive (D) and dominant (H) components with the predominance of dominant component for plant height, days to 50 per cent flowering, days to maturity, leaf area index, length of panicle, grain length, grain breadth, L/B ratio. Dominance component (H_1) was observed to be significant for all the traits under study. A number of workers have earlier reported the type of gene action governing the inheritance of various characters. Kaushik and Sharma (1988) reported additive gene action for plant height and panicle length and non-additive gene action for grain yield/plant and days to 50 per cent flowering. Lokaparkash *et al.* (1991) revealed non-additive gene action for harvest index, grain yield/plant, 100-grain weight and panicle length and additive gene action for plant height. Chakraborty *et al.* (1994) observed additive gene action for days to 50 per cent flowering and 100-grain weight, whereas non-additive gene action for plant height, panicle length and yield per plant. Kumar and Rangaswamy (1984) concluded that non-additive gene action were important for panicle length, plant height and yield per plant. Borgohan and Sarma (1998) indicated additive gene action for plant height, days to 50 per cent flowering, whereas non additive gene action for length of panicle and 100-grain weight. Verma *et al.* (1995) reported additive action for days to 50 per cent flowering and plant height and non-additive gene action for 100- grain weight and harvest index. Sardana and Borthakur (1987) reported non-additive gene action for yield/plant and plant height, whereas additive gene action for days to 50 per cent flowering, plant height, panicle length and 100-grain weight. Ghosh *et al.* (1993) reported non additive gene action for grain yield/plant and harvest index and additive gene action for days to 50 per cent flowering, plant height and panicle length.

The relative distribution of dominant and recessive genes in the parents was recorded from the significant value of F and ratio of K_D/K_R. When the value of K_D/K_R is greater than unity, it shows the preponderance of dominant genes. In the present study, dominant genes, predominated for plant height, days to 50 per cent flowering, grain yield/plant, biological yield/plant, harvest index, days to maturity, leaf area index, dry matter, length of panicle, 100- grain weight, net-assimilation rate, grain length and length breadth ratio. Similar results were also reported by earlier workers, Sardana and Borthakur (1987) for yield per plant and plant height; Kaushik and Sharma (1988) for plant height, panicle length, 1000-grain weight; Verma *et al.* (1995) for grain yield/plant, days to flowering, plant height, 1000-grain weight, biological yield/plant and harvest index.

The positive and negative genes in the parents were distributed unequally for all the traits. It was evident from the ratio of $H_2/4H_1$, which was less than 0.25, except for harvest index where equal distribution of genes with positive and negative effects were noticed.

For the characters exhibiting significant additive (D) and dominance (H_1) component of variance, the average degree of dominance $(H_1/D)^{1/2}$ was greater than unity indicating over dominance for plant height, days to 50 per cent flowering, days to maturity, leaf area index, length of panicle, grain length, grain breadth, L/B ratio, protein content and partial dominance for amylose content. Earlier workers have also reported the varying levels of dominance for different characters studied. Kaushik and Sharma (1988) observed over dominance for 1000-grain weight, plant height and panicle length. Verma *et al.* (1995) reported over dominance for grain yield per plant, days to flower, plant height, 1000-grain weight, biological yield and harvest index. The magnitude of dominance variance is also higher for other traits like leaf area index and net assimilation rate so their average degree of dominance was greater than unity. Significant h^2 values for plant height, grain yield/plant, dry matter, panicle length, 100-grain weight, grain length, grain breadth and L/B ratio indicated that the dominance was unidirectional and since the progeny mean was more than the parental mean, the dominance was in the direction of higher manifestation of the characters. Significant influence of environmental component on variance components for length of panicle was observed. Significant value of F for days to 50 per cent flowering, days to maturity, leaf area index and grain breadth indicated asymmetrical distribution of dominant and recessive genes in the parents.

The correlation coefficient between the parental order of dominance and parental measurement indicated about the dominance of positive and negative genes. If the correlation coefficient is significant and positive, it indicates that negative genes are dominant and vice-versa. In the present study, the correlation coefficient was negative and significant indicating the dominance of positive genes for days to 50 per cent flowering, grain yield/plant, days to maturity and 100-grain weight.

Besides getting information on gene actions, the other advantage of Hayman (1954) approach over combining ability is that, one can get information on heritability estimates (narrow sense). In the present investigation, high heritability (>30%) was observed for days to flowering, days to maturity and leaf area index. Medium heritability (15-30%) was observed for plant height, length of panicle, 100-grain weight, net-assimilation rate, L/B ratio and low heritability (<15%) was observed for grain yield/plant, biological yield/plant, harvest index, grain length and dry matter. It may be concluded in the light of above discussion that the characters like days to 50 per cent flowering, days to maturity and leaf area index have high heritability. Consequently, any selection method adopted could lead to desirable improvement in the above mentioned traits. Earlier workers also reported the wide range of heritability for different characters studied. High heritability has been reported by Kaushik and Sharma (1988) for days to 50 per cent flowering. Nayeem (1994) for days to flowering and days to maturity. Sardana and Borthakur (1987) for days to flowering and medium heritability for plant height.

In order to facilitate a comparison of the results obtained by the Griffing (1956) and Hayman (1954) in the present study on genetic architecture of different characters, the conclusion drawn from these analyses are summarized in Table 4.31. According to Griffing (1956), ten characters out of thirteen viz., days to 50 per cent flowering, plant height, leaf area index, dry mater, net assimilation rate, days to maturity, grain yield, harvest index, 100-grain weight and L/B ratio showed both the additive and non-additive genetic variances with predominance of non-additive gene action and remaining traits i.e. panicle length, biological yield and grain length showed only dominant variance. Whereas in Hayman (1954) approach, traits like days to 50 per cent flowering, plant height, leaf area index, panicle length and L/B ratio exhibited both additive and non-additive gene actions coupled with non-allelic interaction with predominance of dominant gene action. Dry matter, net assimilation rate, grain yield, biological yield, harvest index, 100- grain weight and grain length showed only dominant gene action coupled with non-allelic interaction; only days to maturity exhibited both additive and non-additive gene actions with predominance of dominant gene action.

The degree of dominance in Griffing (1956) as well in Hayman (1954) showed over-dominance for traits like days to 50 per cent flowering, plant height, leaf area index, days to maturity, grain yield and harvest index. In combining ability analysis, the degree of dominance is computed on the assumption that genes are unidirectionally distributed among the parents. Therefore, asymmetry of the genes and the presence of non-allelic interaction as indicated by various component analysis, could be the reasons for the

Table 4.31 Comparison of the broad conclusions derived from different methods of genetic analysis of various characters

	Gene action		Degree of dominance	
Character	Griffing (1956)	Hayman (1954)	Griffing (1956)	Hayman (1954)
Days to 50% flowering	A+D(A>D)	A+D(D>A)+I	OD	OD
Plant height	A+D(A>D)	A+D(D>A)+I	OD	OD
Leaf area index	A+D(A>D)	(A +D(D>A)+I	OD	OD
Dry matter	A+D(A>D)	D+I	-	OD
Net assimilation rate	A+D(A>D)	D+I	PD	OD
Panicle length	D	A+D(D>A)+I	-	OD
Days to maturity	A+D(A>D)	A+D(D>A	OD	OD
Grain yield	AD+D(A>D)	D+I	OD	OD
Biological yield	D	D+I	-	OD
Harvest Index	A+D(A>D)	D+I	OD	OD
100 grain weight	AD+D(A>D)	D+I	-	OD
Grain Length	D	D+I	-	OD
L/B ratio	AD+D(A>D)	A+D(D>A)+I	-	OD

Where A= Additive variance
D=Dominance variance
A>D = Preponderance Additive variance
D>A =Preponderance Dominance variance
I=non allelic interaction
OD=Over dominance
PD=Partial dominance

inflated estimates of additive gene action, resulting in variation in the degree of dominance for net-assimilation rate by the methods viz., Griffing (1956) and Hayman (1954).

5.3 Heterosis and inbreeding depression

Heterosis will not only facilitate the easy creation of new and more productive (F_1) hybrids but also help the initial component of all plant breeding programmes, i.e. the creation of useful genetic variability prior to the evaluation of the different genotypes (through their phenotypes) and selection for superior ones (Tsaftaris, 1995).

Since the first attempt to explain heterosis as due to union of unlike gametes by Shull (1910) and due to heterozygosis by East and Hayes (1912), till today several theories have been proposed on different disciplines like genetics, physiology, biochemistry and molecular genetics for the manifestation of heterosis. The achievements made so far in heterosis breeding are mainly confined to cross pollination crops, but new hypotheses have emerged in recent years showing that even homozygosity may have advantage over heterozygosity leading to inbreeding depression.

The impact of progress in crop improvement programme through plant breeding was propelled by a better understanding of gene action and an appropriate exploitation of heterosis. The exploitation of heterosis in food crops will tend to continue because hybrids have shown their remarkable ability to increase production in a number of self pollinated and cross pollinated crops. In the present study, an attempt has been made to gather information.

5.3.1 Magnitude of heterosis with respect to various characters in thirty six cross combinations and inbreeding depression in F_2 generation

An appraisal of heterosis and inbreeding depression (Table 4.12 to 4.25) indicated that some of the cross combinations gave superior performance than the better parent and standard check. The cross combinations exhibiting the significant desirable heterosis over better parent and standard check and inbreeding vigour for yield, its components and quality traits have been summarized in Table 4.32.

For days to 50 per cent flowering, five crosses (HPR-1164xVL93-6052, HPR-1164xIR57893-08, VL91-1754xIR57893-08 and VL93-3613x IR57893-08) exhibited negative heterosis over better parent and nine over standard check. The negative heterosis for days to flowering can be desirable because this results in earlier maturity thereby enabling the hybrids to increase per day productivity. These results are in agreement with Virmani *et al.* (1981) and Kim and Rutger (1988), they have reported that earliness in maturity of rice hybrids increase per day productivity. Patnaik *et al.* (1990) has also reported negative heterosis for days to flowering. These same crosses exhibited inbreeding vigour for days to 50 per cent flowering, which may be due to the presence of complementary favourable genes largely with additive gene action in the parents. Jinks (1983) indicated that the heterosis in the F_2 hybrids may be due to complementary type of epistasis and dispersion of genes in the parents. Plant height is the important yield contributing traits and

Table 4.32 List of cross combinations with significant desirable heterosis over both better parent and standard check and inbreeding depression for yield, its components and grain quality traits

Character	No. of crosses with significant heterosis over BP and SC	Cross combination with significant heterosis over both BP and SC	Cross combination with significant positive inbreeding depression
(1)	(2)	(3)	(4)
Days to 50% flowering	BP-5 SC-9	HPR-1164xVL93-6052, HPR-1164xIR57893-08, VL91-1754x IR57893-08, VL93-3613xIR57893-08	Some crosses showed positive inbreeding depression
Plant height	BP-7 SC-7	HPR-1164xChina-988, HPR-1164xVL93-3613, HPR-1164x IR57893-08, HPR-2047xJD-8, China-988xVL91-1754	HPR-1164xChina-988, HPR-1164xVL93-3613
Leaf area index	BP-9 SC-25	HPR-1164xHPR-2047, HPR-2047xVL93-3613, HPR-2047xJD-8, China-988xVL91-1754, China-988xIR57893-08, VL93-3613xVLDhan-221, VL93-3613xJD-8, VLDhan-221xJD-8	-
Dry matter	BP-21 SC-22	HPR-1164xHPR-2047, HPR-1164xVL93-3613, HPR-1164x IR57893-08, HPR-2047xVL93-6052, HPR-2047xVLDhan-221, HPR-2047xJD-8, China-988xVL91-1754, China-988xVL93-3613, China-988xJD-8, VL91-1754xVL93-3613, VL91-1754x VL93-6052, VL91-1754xIR57893-08, VL91-1754xVLDhan-221, VL93-3613xVL93-6052, VL93-3613xIR57893-08, VL93-3613x VLDhan-221, VL93-3613xJD-8, VL93-6052xIR57893-08, VL93-6052xVLDhan-221, VL93-6052xJD-8, VLDhan-221xJD-8	HPR-1164xIR57893-08, China-988xVL93-3613
Net-assimilation rate	BP-15 SC-29	HPR-1164xHPR-2047, HPR-2047xVL93-6052, HPR-2047xJD-8, China-988xVL93-6052, China-988xIR57893-08, China-988x JD-8, VL91-1754xVL93-3613, VL91-1754xIR57893-08, VL91-1754xVLDhan-221, VL93-3613xVL93-6052, VL93-6052x IR57893-08, VL93-6052xJD-8, IR57893-08xVLDhan-221, VLDhan-221xJD-8	China-988xIR57893-08

Contd../-

(1)	(2)	(3)	(4)
Panicle length	BP-10 SC-25	HPR-1164xHPR-2047, HPR-1164xJD-8, HPR-2047xVLDhan-221, China-988xIR57893-08, China-988xVLDhan-221, VL93-3613xIR57893-08, VL93-3613xJD-8, IR57893-08xJD-8	VL93-3613xJD-8
Days to maturity	BP-5 SC-8	HPR-1164xVL93-6052, HPR-1164xIR57893-08, VL91-1754xIR57893-08, VL93-3613xVL93-6052	-
	BP-15 SC-17	HPR-1164xHPR-2047, HPR-1164xVL91-1754, HPR-1164xVL93-3613, HPR-1164xIR57893-08, HPR-2047xVL93-6052, HPR-2047xJD-8, China-988xVL91-1754, VL93-3613xVL93-6052, VL93-3613xIR57893-08, VL93-3613xJD-8, VL93-6052xVLDhan-221, VL93-6052xJD-8, IR57893-08xJD-8	HPR-1164xVL93-3613, HPR-1164xVLDhan-221, VL91-1754xVL93-6052 (excluding BP and SC)
Grain yield	BP-11 SC-7	HPR-1164xVLDhan-221, HPR-2047xChina-988, HPR-2047xVL91-1754, China-988xIR57893-08, China-988xJD-8, VL91-1754xJD-8, VL93-6052xJD-8, IR57893-08xJD-8, VLDhan-221xJD-8	-
Harvest index	BP-3 SC-12	HPR-1164xChina-988, China-988xJD-8	HPR-1164xChina-988
100-grain weight	BP-14 SC-34	HPR-1164xVL91-1754, HPR-2047xVL91-1754, HPR-2047xVL93-6052, HPR-2047xIR57893-08, HPR-2047xVLDhan-221, China-988xVLDhan-221, VL91-1754xVL93-3613, VL91-1754xJD-8, VL93-3613xIR57893-08, VL93-3613xVLDhan-221, VL93-3613xJD-8, IR57893-08xVLDhan-221, IR57893-08xJD-8, VLDhan-221xJD-8	-
Grain length	BP-3 SC-7	HPR-2047xVL93-3613, VL91-1754xVL93-3613, VL93-3613xVLDhan-221	-
Grain breadth	BP-8 SC-13	HPR-2047xVL93-3613, VL91-1754xVL93-3613, VL91-1754xVLDhan-221, VL93-3613xVL93-6052, VL91-1754xJD-8, VL93-6052xIR57893-08	-
L/B ratio	BP-3 SC-3	HPR-1164xIR57893-08	-

the negative heterosis over better parent and standard check were exhibited by seven crosses (HPR-1164xChina-988, HPR-1164xVL93-3613, HPR-1164xIR57893-08, HPR-2047xJD-8 and China-988xVL91-1754). Similar observations have been made by Singh *et al.* (1980). Among these crosses, only two crosses (HPR-1164xChina-988 and HPR-1164xVL93-3613) showed inbreeding vigour.

For leaf area index, nine crosses showed heterosis over better parent and 25 over standard check, over both better parent and standard check. The crosses (HPR-1164xHPR-2047, HPR-2047xVL93-3613, HPR-2047xJD-8, China-988xVL91-1754, China-988xIR57893-08, VL93-3613xVLDhan-221, VL93-3613x JD-8 and VLDhan-221xJD-8) showed desirable heterosis over both better parent and standard check. Significant positive heterosis for leaf area index has also been reported by Lin (1969) who reported considerable variation for heterosis for leaf area index in rice hybrids. Similar results were also reported by Yamauchi and Yoshida (1985), Murty and Pattanaik (1986) showed higher net-assimilate rate than the control.

Out of 36 crosses, 21 cross combinations showed positive heterosis over both better parent and standard check for dry matter. Positive inbreeding were exhibited by two crosses showing inbreeding vigour which may be due to the presence of complementary favourable genes largely with additive gene action in the parents. For net-assimilation rate, fifteen crosses showed positive heterosis over both better parent and standard check. One cross showed positive inbreeding depression. Since leaf area index and dry matter also showed positive heterosis over both better parent and standard check. Hence, resultant net-assimilation rate showed positive heterosis, because both the dry matter and leaf area index are pre-requisite for the determination of net-assimilation rate.

For panicle length, ten cross combinations (HPR-1164xHPR-2047, HPR-1164xJD-8, HPR-2047xVLDhan-221, HPR-2047xJD-8, China-988xIR57893-08, China-988xVLDhan-221, VL93-3613xIR57893-08, VL93-3613xVLDhan-221, VL93-3613xJD-8 and IR57893-08xJD-8) exhibited positive heterosis over both standard check and better parent. Positive inbreeding depression was observed for one cross. Janardhanam *et al.* (2001) also reported standard heterosis for panicle length. For days to maturity, five hybrids exhibited negative heterosis over better parent and eight over standard check. Four hybrids showed positive heterosis over both better parent and standard check and these were (HPR-1164xVL93-3613, HPR-1164xIR57893-08, VL91-1754xIR57893-08 and VL93-3613xIR57893-08). Breeding for early maturing varieties is an important objective in rice research in view of the increasing importance of intensive crop sequences. Early flowering and early maturity are an index of the general efficiency of a genotype in terms of giving maximum returns per unit time. Therefore, the cross combinations exhibiting negative heterosis are of special interest. Similar results were also reported by Cheema *et al.* (1988).

For grain yield/plant, out of 36 hybrids, 15 showed positive heterosis over better parent and 17 over standard check. Thirteen crosses: (HPR-1164xHPR-2047, HPR-1164xVL91-1754, HPR-1164xVL93-3613, HPR-1164x IR57893-08, HPR-2047xVL93-3613, HPR-2047xJD-8, China-988xVL91-1754, VL93-3613xVL93-6052, VL93-3613xIR57893-08, VL93-3613xVLDhan-221, VL93-6052xJD-8, VL93-6052xVLDhan-221, VL93-6052xJD-8 and IR57893-08xJD-8) were superior over better parent and standard check. Only three crosses, showed hybrid vigour in F_2 generation which may be due to the presence of complementary favourarble genes largely with additive gene action in the parents. These results are in agreement with the findings of Lokaprakash *et al.* (1992) and Singh *et al.* (1993) they reported heterosis for yield and yield contributing traits. Similar results were also reported by Janarahanam *et al.* (2001).

For biological yield, eleven hybrids exhibited positive heterosis over better parent and nine over standard check, out of them, nine showed heterosis over both better parent and standard check. These cross combinations were HPR-1164xVLDhan-221, HPR-2047xChina-988, HPR-2047xVL91-1754, China-988xIR57893-08, China-988xJD-8, VL91-1754xJD-8, VL93-6052xJD-8, IR57893-08xJD-8 and VLDhan-221xJD-8.

For harvest index, out of 36 hybrids, three showed heterosis over better parent and 12 over standard check. HPR-1164xChina-988 and China-988xJD-8 exhibited positive heterosis over both better parent and standard check. Positive inbreeding depression was exhibited by a single cross.

Out of 36 hybrids, 14 exhibited positive heterosis over better parent and 34 over standard check. Out of them, fourteen showed heterosis over both better parent and standard check. For grain length, three crosses showed positive heterosis over better parent and seven over standard check, whereas three exhibited over both better parent and standard check. These were HPR-2047xVL93-3613, VL91-1754xVL93-3613 and VL93-3613xVLDhan-221.

For grain breadth, eight hybrids showed positive heterosis over better parent and thirteen over standard check. Six hybrids (HPR-2047xVL93-6052, VL91-1754xVL93-3613, VL91-1754xVLDhan-221, VL93-3613xVL93-6052, VL91-1754xJD-8 and VL93-6052xIR57893-08) showed positive heterosis over both the better parent and standard check.

For L/B ratio, three hybrids exhibited positive heterosis over better parent and three over standard check. Only cross HPR-1164xIR57893-08 showed positive heterosis over both better parent and standard check.

There are numerous reports on heterosis for yield, its components and grain quality traits in the literature. Earlier workers have reported high heterosis in respect of different characters.

Significant positive standard heterosis for 100-grain weight has also been reported by Srivastava *et al.* (1982) and Rajesh and Maurya (1997). Singh *et al.* (1980) exhibited significant heterosis for yield components and days to maturity. Ponnuthurar and Virmani (1983) for grain yield due to simultaneous heterosis for plant height, early flowering and harvest index. Saravgi and Shrivastava (1988) reported heterosis for yield/plant and biological yield. Singh and Singh (1985) had reported significant heterosis for grain length, grain breadth and L/B ratio. These results are also in accordance with the findings of Sahai *et al.* (1986) who emphasized that hybrids with desirable grain quality can be produced by complementation of grain quality characters in the parents.

From the above discussion, it is quite obvious that there is sufficient exploitable magnitude of heterosis available in rice for yield, quality and physiological attributes. Heterosis *per se* had been of limited use in rice till Chinese demonstrated the commercial feasibility of hybrids in the crop since then intensive investigations are underway at International Rice Research Institute (IRRI), Manila Philippines and various national centres all over the world including India for exploiting of hybrid vigour in rice.

5.4 Correlation coefficient

Grain yield is a complex character and is the end product of various yield contributing traits. A few of these component trait may be directly or positively correlated with grain yield and often prove to be useful indicators while making selection for grain yield with other component character is valuable for understanding the correlated response to selection.

Correlation studies (Table 4.27) revealed that at phenotypic level grain yield showed positive correlation with biological yield, harvest index and dry matter. These results are in agreement with the findings of Reddy *et al.* (1994) they had reported positive correlation of grain yield with dry matter and harvest index. Singh *et al.* (1990) revealed positive correlation of grain yield with biological yield. Plant height exhibited positive correlation with panicle length, grain length and 100-grain weight which shows that increase in plant height would tend to increase panicle length and grain length. It indicates that plant would be vigorous, ultimately length of panicle, grain length and 100-grain weight would be more and showed positive correlation.

Days to 50 per cent flowering showed positive correlation with days to maturity and grain length, which shows that late flowering genotypes were also late in maturity. It also showed negative correlation with dry matter and net-assimilation rate which might be due to less amount of source converted into sink. Therefore, net-assimilation rate would be less because dry matter is directly used for the determination of net-assimilation rate.

Biological yield exhibited positive correlation with dry matter. This might be due to, biological yield which involves dry matter and is directly related with each other. It also showed negative correlation with harvest index which may be due to fact that the harvest index is inversely related with biological yield. Days to maturity exhibited positive correlation with grain length because late maturing genotypes allowed maximum translocation of source into sink. It also revealed negative correlation with net-assimilation rate which might be due to less amount of dry matter. Length-breadth ratio exhibited negative correlation with grain breadth and positive correlation with grain length.

Leaf area index showed negative correlation with net-assimilation rate. Similar result was also reported by Reddy *et al.* (1994). Dry matter exhibited positive correlation with net-assimilation rate. Positive correlation of net-assimilation rate with dry matter at flowering were also reported by Reddy *et al.* (1994).

Panicle length exhibited positive correlation with 100-grain weight, which might be due to sterility. Grain breadth revealed positive correlation with 100-grain weight and negative correlation with grain length. These results were also in agreement with the findings of Panwar *et al.* (1989).

In general, genotypic correlation coefficients in both the generations followed the same trend as observed for phenotypic correlation of coefficients. However, the values of genotypic correlation of coefficients were generally higher than the corresponding phenotypic one for most of the characters studied suggesting strong inherent relationship between the various characters. However, the phenotypic expression of the correlation seemed to be impended under the influence of environmental factors. These observations were in agreement with the results of Chauhan *et al.* (1986) and Bai *et al.* (1992).

5.5 Path coefficient analysis

Association of various plant characters with the traits of major interest and economic importance like grain yield is the consequence of their direct and indirect effects. It becomes, therefore essential to partition such associations into direct and indirect effects of component characters through path coefficient analysis.

At both, the phenotypic and genotypic levels in both the generations biological yield/plant showed high positive direct effect with grain yield/plant. It was mainly due to positive indirect effects via days to 50 per cent flowering and panicle length. It might be due to high positive correlation of grain yield with biological yield.

Harvest index contributed positive direct effect with grain yield and indirect effects via grain length and days to maturity. It was found to be due to positive correlation of grain yield with harvest index. Plant height contributed low direct effect with grain yield. It was mainly due to high positive indirect effects via days to maturity and L/B ratio high positive indirect effects were nullified by the negative indirect effects via plant height, days to 50 per cent flowering and harvest index. In F_2 generation, days to 50 per cent flowering contributed positive direct effect with grain yield which might be due to positive indirect effects via biological yield, harvest index, L/B ratio and leaf area index. However in F_1 generation, days to 50 per cent flowering contributed negative direct effect with grain yield. It was mainly due to high positive direct effects via days to maturity and these positive indirect effects were nullified by the corresponding negative indirect effects via biological yield, panicle length, grain length and net-assimilation rate.

Length-breadth ratio contributed positive direct effect with grain yield. It was mainly due to positive indirect effects via biological yield and leaf area index.

In F_1 generation, leaf area index contributed low positive direct effect with grain yield. It was mainly due to high positive indirect effects via biological yield and days to maturity. These positive indirect effects were counterbalanced by the indirect effects via days to 50 per cent flowering, harvest index and grain length. However in F_2 generation, leaf area index contributed low negative direct effect with grain yield. This might be due to high positive indirect effects via harvest index and grain breadth. These effects were counterbalanced by negative indirect effects via biological yield, dry matter and days to 50 per cent flowering.

Dry matter contributed low negative direct effect with grain yield. It was mainly due to high negative indirect effects via days to maturity, grain breadth and grain length. These negative indirect effects were nullified by their corresponding positive indirect effects via biological yield, harvest index and length-breadth ratio. Panicle length made less contribution with directly to grain yield in F_1 generation which might be due to high negative indirect effects via days to 50 per cent flowering, grain length and net-assimilation rate. These negative indirect effects were counterbalanced by high positive indirect effects via days to maturity, grain breadth and harvest index.

However in F_2 generation, panicle length contributed low positive direct effect with grain yield. It was mainly due to high positive indirect effects via biological yield, leaf area index and grain breadth. The positive indirect effects were nullified by the negative indirect effects via harvest index, L/B ratio, dry matter and grain length.

Grain breadth contributed positive direct effect with grain yield and indirect effects via plant height, days to maturity and dry matter. Grain length contributed negative direct effect with grain yield. It was mainly due to high negative indirect effects via harvest index and dry matter. 100-grain weight contributed low negative direct effect with grain yield. It was found to be due high negative indirect effects via harvest index and leaf area index. These negative indirect effects were counterbalanced by the positive indirect effects via biological yield and grain breadth. Net-assimilation rate contributed low positive direct effect with grain yield. It was mainly due to high positive indirect effects via biological yield, L/B ratio and grain length. These positive indirect effects were counterbalanced by the negative indirect effects via dry matter.

In F_2 generation, amylose content contributed low positive direct effect with grain yield and indirect effects via harvest index, days to maturity and leaf area index. It was found to be due to high positive indirect effects were counter-balanced by negative indirect effects via biological yield and harvest index. In F_2 generation, protein content contributed low negative direct effect with grain yield and indirect effects via biological yield. It was mainly due to high positive indirect effects via harvest index and days to maturity. These indirect effects were counterbalanced by negative indirect effects.

These results are in agreement with the findings of earlier workers. Amirthadevarathinam (1983) revealed days to 50 per cent flowering made positive direct contribution to grain yield. Reddy (1994) had reported harvest index to be the major determinant of grain yield in rice. Panwar *et al.* (1989) reported plant height and panicle length had positive direct effect with grain yield. Krishnaya *et al.* (1991) also reported positive direct effect of 100-grain weigh with grain yield. Biological yield as selection criterion for grain yield improvement Bhatt (1977) and Sharma *et al.* (1991). Meenakashi *et al.* (1999) revealed that dry matter production was the most important character influencing grain yield. Surek *et al.* (1998) reported that high positive direct effect of biological yield, harvest index and 100-grain weight with grain yield.

At the genotypic level, the direct and indirect effects were similar to those observed at phenotypic level for most of the characters under study in both the generations except for traits like days to 50 per cent flowering, days to maturity, L/B ratio, dry matter, panicle length and grain length.

Days to 50 per cent flowering contributed positive direct effect with grain yield and indirect effects via biological yield and grain length. These indirect effects were counterbalanced by the negative indirect effects via L/B ratio and plant height. Days to maturity contributed low negative direct effect with grain yield and indirect effects via L/B ratio, leaf area index and net-assimilation rate. These negative indirect effects were counterbalanced by high positive indirect effects via days to 50 per cent flowering and biological yield.

Length/Breadth ratio contributed negative direct effect with grain yield. It was mainly due to high positive indirect effects via biological yield, grain breadth and grain length and these positive indirect effects were counterbalanced by the high indirect effects via harvest index and length/breadth ratio.

In F_1 generation dry matter contributed negative direct effect with grain yield. It was found to be due to high positive indirect effects via biological yield, days to maturity and L/B ratio. These positive indirect effects were counterbalanced by the negative indirect effects via days to 50 per cent flowering, grain breadth and grain length. However in F_2, it contributed low positive direct effect with grain yield. Panicle length contributed, low negative direct effects with grain yield and indirect effects via biological yield, days to maturity and grain length. These effects were nullified by the positive indirect effects via grain breadth, days to 50 per cent flowering and 100-grain weight.

Grain length contributed high positive direct effect with grain yield. It was mainly due to high positive indirect effects via L/B ratio, grain breadth, 100- grain weight and days to 50 per cent flowering.

The contribution of residual factors (variable not included in the study), that influence grain yield was only 0.01 and 0.05 at genotypic level in F_1 and F_2 generations, respectively and 0.008 and 0.02 at phenotypic level in F_1 and F_2 generations, respectively indicating, thereby that the characters included in the present study were sufficient enough to account for the variability in the dependent character i.e. grain yield.

5.6 Evaluation of genotypes for rice blast disease

Five hybrids viz., HPR-2047xVL93-6052, HPR-2047xIR57893-08, China-988xVLDhan-221, China-988xJD-8 and VLDhan-221xJD-8 out of the thirty six hybrids developed by hybridization have been found giving resistant reactions for leaf blast and neck blast under field conditions. However, the parents for these hybrids gave susceptible and moderately resistant to resistant reactions to rice blast disease. The higher resistance to leaf blast and neck blast in the hybrids may be due to complementary interactions among the genes of the parents. Thus, the hybrids with high resistance to leaf blast and neck blast can be developed by complementation of resistant genes of the parents in hybrids.

These results are in consonance with the findings of Tabien *et al.* (1995), who reported that resistance to blast in rice hybrids might be due to gene interactions. These results are also in accordance with the findings of Yang (1987), who has reported that rice hybrids are more resistant to rice blast than the parents due to complementary interaction among the genes of the parents. Hedge *et al.* (2001) reported IET13549 and IET16332 showed resistance to leaf and neck blast. Chauhan *et al.* (2000) reported rice accessions Arrozoas Indios, CNA108-8-42, CNA4136, IRAT-267 and Akashi were resistant to leaf blast. Fifty seven accessions were moderately resistant, among indigenous accessions only pallavi. Nagaraju *et al.* (2001) revealed KAUM57-18-1-1, KAUM59-29-2-1 were highly resistant, 31 entries resistant, 33 moderately resistant, 22 moderately susceptible and 12 susceptible to leaf blast and neck blast.

In F_2 generation, above hybrids (i.e. HPR-2047xVL93-6052, HPR-2047xIR57893-08, China-988xVLDhan-221, China-988xJD-8 and VLDhan-221xJD-8) gave moderately resistant to resistant reactions, against leaf blast and neck blast under field conditions at normal fertility (90N:40P:40K).

The results of experiments conducted at experimental farm of Department of Plant breeding and Genetics indicates that cross combination such as HPR-2047xVL93-6052 which had high sca effect (5.45 per cent) and heterosis (42.03%) for grain yield can be utilized for further breeding programmes because of high sca effects, desirable heterosis for grain yield and high degree of resistance to leaf blast and neck blast.

Conclusion and implications

It can be concluded that sufficient genetic variability has been generated through hybridization in the present material. Significant differences among the parents, hybrids and F_2's have been observed for all the traits.

The combining ability analysis of variance indicated that gca and sca variances are significant except grain breadth for yield, its components and grain quality traits. The parent HPR-2047, have been adjudged to be good general combiner for grain yield and other characters like plant height, days to 50 per cent flowering, days to maturity and leaf area index. Other good general combiners for grain yield and other traits like plant height, days to 50 per cent flowering, biological yield, harvest index and net-assimilation rate was VL93-3613. Another good general combiner for grain yield is JD-8 and for other traits like early flowering, early maturity and plant height in F_1 generation. Whereas in F_2 generation, HPR-2047 have been adjudged to be good general combiner for grain yield and yield contributing traits, suggesting their use in further hybridization programmes. On the basis of high desirable sca effects, the cross combinations VL93-6052xVLDhan-221, HPR-2047xJD-8, VL93-3613xIR57893-08, HPR-1164xHPR-2047, HPR-2047x VL93-6052 and VL93-3613xVLDhan-221 have been emerged to be the best for grain yield.

The gene action studies revealed that both additive and non-additive genetic components are significant for most of the characters with the preponderance of former. The magnitude of additive variance has been found to be higher as compared to non-additive. In the Hayman's (1954) approach, genetic component analysis, average degree of dominance indicated over-dominance for almost all the characters, while (1-b) values indicated non-allelic interactions (epistatic) for grain yield, plant height, days to 50 per cent flowering, biological yield, harvest index, leaf area index, dry matter, panicle length, 100-grain weight and net-assimilation rate. The type of gene action observed in the present study can be best used by developing hybrids. Further, the potential cross combinations with high inbreeding vigour observed in the present study can be best utilized in later generations to isolate desirable segregants with respect to grain yield. An appraisal of the heterosis and inbreeding depression led to the identification of crosses: HPR-1164xHPR-2047, HPR-1164xVL91-1754, HPR-1164xVL93-3613, HPR-1164xIR57893-08, HPR-2047x VL93-6052, HPR-2047xJD-8, China-988xVL91-1754, VL93-3613x VL93-6052, VL93-3613xIR57893-08, VL93-3613xVLDhan-221, VL93-3613xJD-8, VL93-6052xVLDhan-221, VL93-6052xJD-8 and IR57893-08xJD-8 for exhibiting high superiority over better parent and standard check (HPR-2047). It is interesting to note that these crosses included moderately resistant x moderately resistant, moderately resistant x moderately resistant, moderately resistant x moderately resistant, moderately resistant x moderately resistant, moderately resistant x resistant, susceptible x moderately resistant, moderately resistant x moderately resistant, moderately resistant x moderately resistant, moderately resistant x moderately resistant, moderately resistant x moderately resistant, moderately resistant x highly resistant, moderately resistant x moderately resistant, moderately resistant x highly resistant and highly resistant x moderately resistant, suggesting that it is necessary for developing high yielding and disease resistant varieties to involving both tolerant parents.

On the basis of high inbreeding vigour crosses: HPR-1164xVL93-3613, HPR-1164xVLDhan-221, VL91-1754xVL93-6052 have emerged as potential crosses for the isolation of transgressive segregants with respect to grain yield in the later segregating generations.

On the basis of correlation and path analysis studies biological yield, harvest index, dry matter, days to 50 per cent flowering, L/B ratio, grain breadth, 100-grain weight and net-assimilation rate have emerged as important selection criteria for higher grain yield.

Summary

Chapter VI

SUMMARY

The present study was undertaken with the objectives to estimate the general and specific combining ability, gene action and information on heterosis and inbreeding depression for grain yield, its components and grain quality traits in rice *(Oryza sativa* L.). Correlation coefficients and path analysis were also studied.

Nine genotypes along with their 36 hybrids (F_1's) developed through diallel mating system (excluding reciprocals) and their 36 F_2's were evaluated in randomized block design (RBD) with three replications at the Experimental Farm of Department of Plant Breeding & Genetics, of CSK HPKV, Palampur (H.P.) during *kharif* 2003. The data were recorded on yield, yield contributing and grain quality traits viz., days to 50 per cent flowering, plant height, grain yield, biological yield, harvest index, days to maturity, length-breadth ratio, leaf area index, dry matter, panicle length, grain breadth, grain length, 100-grain weight, net-assimilation rate, amylose content and protein content. Reaction to leaf blast and neck blast were observed under field conditions. The data were analysed following the Griffing's (1956) Method II and Model I and Hayman's (1954) approaches. The combining ability analysis revealed significant gca and sca variances for yield, yield contributing and grain quality traits except grain breadth in F_1 and gca of net-assimilation rate in F_2 generation.

Estimates of general combining ability effects revealed that parents HPR-2047, VL93-3613 and JD-8 were good general combiners for grain yield in F_1 generation, whereas in F_2, only HPR-2047 was good general combiner. Parent JD-8 in F_1 and VL93-6052 in F_2 were good general combiners for grain quality traits. The top ranking ten cross combinations HPR-1164xHPR-2047, HPR-1164xVL91-1754, HPR-2047xJD-8, China-988xVL91-1754, VL91-1754x VL93-3613, VL93-3613xVL93-6052, VL93-3613xIR57894-08, VL93-6052x VLDhan-221, VL93-6052xJD-8 and IR57893-08xJD-8 showed high sca effects for grain yield, yield contributing and grain quality traits.

Combining ability approach (Griffing, 1956) indicated the preponderance of additive genetic variance for days to 50 per cent flowering, grain yield, days to maturity, leaf area index, dry matter, L/B ratio and 100-grain weight in both the generations, whereas preponderance of non-additive genetic variance for biological yield in both the generations.

Hayman's (1954) genetic component approach indicated significant dominance and additive components with preponderance of dominance for plant height, days to 50 per cent flowering, leaf area index, days to maturity, length of panicle and length-breadth ratio in F_1 generation; in F_2 generation, all the above traits in addition to 100-grain weight and grain length showed preponderance of dominant component. For the remaining traits like grain yield, biological yield, harvest index, dry matter, 100-grain weight, net-assimilation rate, grain breadth and grain length in both the generations and protein content in F_2 showed the significance of additive genetic component only.

The ratio of $H_2/4H_1$ indicated asymmetrical distribution of dominant and recessive genes among the parents for all the traits in both the F_1 and F_2 generations except harvest index in F_1.

Non-significant values of t^2, b and 1-b for majority of the traits indicated that the assumptions underlying the analysis are fulfilled, however significant b and 1-b for all the traits except days to maturity indicated the presence of epistasis. Low and medium heritability was found for all the traits under study.

The K_D/K_R showed high preponderance of dominant genes for all the traits except grain yield and grain breadth. Desirable and high heterosis was observed over the better parent and standard check (HPR-2047) for grain yield and grain quality traits in twelve crosses. The top ranking five crosses: HPR-2047xJD-8 (65.32%), VL93-3613xIR57893-08 (60.05%), VL93-6052xVLDhan-221 (54.94%), VL93-3613xJD-8 (47.03%) and VL93-3613xVLDhan-221 (36.09%) showed desirable heterosis over the better parent, *per se* performance and standard check. The cross HPR-1164xVL93-6052 for days to 50 per cent flowering, and days to maturity; HPR-2047xVL93-3613 for leaf area index, grain length and grain breadth; China-988xIR57893-08 for drymatter, net-assimilation rate, panicle length and biological yield were designated as the best cross.

Grain yield positively correlated with biological yield and harvest index. Grain length showed negative correlation with 100-grain weight, L/B ratio exhibited positive correlation with grain length and negative with grain breadth. These traits can be regarded as selection criteria for improving yield and quality traits of rice.

Days to 50 per cent flowering, biological yield, harvest index, length-breadth ratio and grain breadth exhibited high positive direct effect with grain yield, whereas grain length and days to maturity showed high negative direct effect with grain yield. The hybrids HPR-2047xVL93-6052, HPR-2047xIR57893-08, China-988xVLDhan-221, China-988xJD-8 and VLDhan-221xJD-8 to resistant reaction against both leaf blast and neck blast in F_1 generation. However in F_2 generation, cross combinations HPR-1164xHPR-2047, HPR-1164xChina-988, HPR-1164xVL91-1754, HPR-1164xVL93-3613, HPR-2047xVL93-3613, HPR-2047xJD-8, China-988xVL93-3613, China-988xJD-8, VL91-1754xJD-8, VL93-3613xVLDhan-221, VL93-3613xJD-8, VL93-6052x IR57893-08, VL93-6052xJD-8, IR57893-08xVLDhan-221 and IR57893-08xJD-8 showed the similar type of resistance.

CONCLUSIONS

- Based on general combining ability effects, parents HPR-2047, VL93-3613 and JD-8 were found to be good general combiners for yield, yield contributing and grain quality traits.

Cross combinations, HPR-1164xHPR-2047, HPR-1164xVL91-1754, HPR-1164xIR57893-08, HPR-2047xVL93-3613, HPR-2047xJD-8, China-988xVL91-1754, VL91-1754xVL93-3613, VL93-3613xVL93-6052, VL93-3613xIR57893-08, VL93-6052xVLDhan-221, VL93-6052xJD-8 and IR57893-08xJD-8 exhibited significant specific combining ability effects as well as desirable heterosis over better parent and standard check for yield and quality traits. Desirable segregants can be isolated and exploited commercially for further breeding programmes from these crosses.

Following Hayman's approach (1954), out of thirteen characters five viz., plant height, days to 50 per cent flowering, leaf area index, panicle length and days to maturity exhibited additive as well as dominant gene actions coupled with non-allelic interactions, seven characters viz., grain yield, biological yield, harvest index, dry matter, 100-grain weight, net-assimilation rate and grain length showed dominant and non-allelic interactions and days to maturity showed additive and dominant gene actions.

All the traits exhibited over-dominance.

Grain yield showed positive correlation with harvest index and biological yield.

L/B ratio exhibited positive correlation with grain length and negative correlation with grain breadth.

Highest direct effect on grain yield was exhibited by biological yield and was followed by harvest index; L/B ratio, grain breadth, plant height and net-assimilation rate.

Out of thirty six cross combinations, 20 exhibited resistant reaction against leaf and neck blast at Palampur. These cross combinations also gave better sca effects and desirable heterosis over better parent and standard check and therefore can be exploited commercially for breeding programmes.

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Appendices

APPENDIX-I

Mean monthly weather data during the period of experimentation

Month	Temperature (^{o}C)		Relative humidity (%)		Rainfall (mm)	No. of rainy days
	Maximum	Minimum	RH I	RH II		
June	32.7	20.0	59	50	238.4	3
July	27.5	19.7	85	80	457.8	5
August	27.6	19.0	88	80	858.2	6
September	26.8	17.7	80	75	245.6	4
October	26.5	12.5	62	45	0.0	0
November	21.9	8.5	65	50	30.9	2
December	18.5	6.8	66	49	20.6	2

APPENDIX - II

Mean values of grain yield, its components and grain quality traits

Genotypes/ hybrids		Plant height	Days to 50% flowering	Grain yield	Biological yield	Harvest index	Days to maturity	L/B ratio	Leaf area index	Dry matter	Panicle length	Grain breadth	Grain length	100-grain wt	NAR	Amylose content	Protein content
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
HPR 1164		106.01	87.87	18.35	42.83	42.81	119.87	3.33	2.00	16.08	18.89	2.05	6.83	2.69	3.70	25.86	8.58
HPR 2047		111.68	87.95	18.20	43.81	41.51	117.95	3.99	1.09	18.11	19.57	1.63	6.52	2.07	2.34	24.10	7.18
China 988		99.07	95.09	17.71	35.74	48.61	125.09	3.28	2.27	16.27	20.37	1.96	6.45	2.52	3.96	23.42	6.48
VL91-1754		121.35	100.48	19.78	44.50	44.55	130.48	3.50	3.19	20.49	25.77	1.89	6.64	2.71	4.50	25.80	7.53
VL93-3613		95.40	88.75	20.97	37.67	55.64	118.75	3.37	0.94	14.76	20.51	1.83	6.18	2.33	9.10	24.77	6.66
VL93-6052		118.85	93.06	18.37	39.60	46.32	123.06	3.59	2.27	20.34	22.90	1.94	6.96	2.95	3.40	26.57	8.23
IR57893-08		92.93	95.06	18.01	34.06	52.79	125.06	3.37	1.83	14.96	20.17	1.84	6.21	2.29	3.53	23.69	7.18
VLDhan 221		111.55	71.84	14.34	33.76	41.40	106.84	3.58	0.84	15.50	20.63	1.76	6.30	2.37	0.59	26.41	7.05
JD-8		95.52	75.36	17.21	43.32	39.73	107.36	4.16	1.44	15.32	18.57	1.76	7.32	2.33	0.58	24.74	8.23
HPR 1164x	F_1	121.35	100.48	25.26	44.50	44.55	130.48	3.50	3.19	24.99	25.77	1.89	6.64	2.71	4.67	-	-
HPR 2047	F_2	110.98	84.90	20.46	36.21	46.43	114.90	3.59	2.18	18.84	23.68	1.96	7.03	3.19	3.38	25.18	8.58
HPR 1164x	F_1	95.40	88.75	15.95	37.67	55.64	118.75	3.37	0.94	15.02	20.51	1.83	6.18	2.33	3.38	-	-
China-988	F_2	108.00	86.29	16.55	44.53	63.36	116.29	3.17	2.67	21.26	23.23	1.98	6.29	2.82	4.57	24.71	8.40
HPR 1164x	F_1	118.85	93.06	22.68	39.60	46.32	123.06	3.59	2.27	20.21	22.90	1.94	6.96	2.95	3.54	-	-
VL91-1754	F_2	99.40	76.89	22.65	44.13	51.01	106.89	4.19	2.34	24.56	21.57	1.73	7.24	2.42	5.94	25.47	7.72
HPR 1164x VL93-3613	F_1	92.93	95.06	24.35	34.06	52.79	125.06	3.37	1.83	32.20	20.17	1.84	6.21	2.29	4.79	-	-
	F_2	111.85	94.32	19.02	22.50	41.62	124.32	3.45	1.74	28.56	23.85	1.87	6.47	2.33	4.61	25.87	8.39
HPR-1164x VL93-6052	F_1	111.55	71.84	15.20	33.76	41.40	106.84	3.58	0.84	17.13	26.63	1.76	6.30	2.37	1.50	-	-
	F_2	104.97	98.51	18.31	48.09	47.22	128.51	3.77	1.31	20.86	25.09	1.86	7.04	2.68	1.85	26.20	8.38
HPR-1164x VL57893-08	F_1	95.52	75.36	23.95	43.32	39.73	107.36	4.16	1.44	20.78	18.57	1.76	7.32	2.33	1.96	-	-
	F_2	96.37	73.22	14.94	38.44	39.87	103.22	3.65	1.01	20.55	18.54	1.73	6.33	2.18	6.10	24.55	7.87
HPR-1164x VLDhan-221	F_1	114.44	83.40	19.39	62.85	40.17	113.40	3.56	1.48	18.71	23.12	1.88	6.54	2.81	1.45	-	-
	F_2	105.71	90.49	22.91	35.74	57.47	120.49	3.50	1.90	24.85	23.16	1.92	6.73	2.53	3.53	26.09	8.93
HPR-2047x China-988	F_1	114.18	85.74	16.34	37.01	43.11	115.74	3.41	1.13	15.56	23.47	1.97	6.72	2.78	1.50	-	-
	F_2	83.73	93.43	15.24	27.25	60.13	123.43	3.66	1.58	21.32	20.38	1.81	6.62	2.46	5.91	25.27	8.05

Contd../-

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
HPR-2047x China988	F_1	122.89	83.88	19.18	56.28	40.27	113.88	3.60	1.74	15.76	23.09	1.83	6.62	2.58	1.31	-	-
	F_2	107.88	91.52	18.56	44.89	50.80	121.52	3.60	1.59	18.57	24.70	1.90	6.86	2.75	2.25	23.80	8.18
HPR-2047x VL91-1754	F_1	117.82	86.04	18.83	63.05	38.62	116.04	3.27	2.64	12.71	23.55	1.96	6.41	2.77	2.14	-	-
	F_2	98.13	88.16	18.78	36.19	53.14	118.16	3.53	2.13	12.59	21.71	1.94	6.85	3.34	3.40	25.33	8.93
HPR-2047x VL93-3613	F_1	120.61	100.50	18.65	32.46	46.80	130.50	4.09	2.92	18.40	22.68	1.90	7.77	2.68	2.37	-	-
	F_2	106.70	89.27	20.56	40.96	46.27	119.27	3.44	1.68	12.57	23.09	1.89	6.51	2.78	3.70	24.57	8.92
HPR-2047x VL93-6052	F_1	116.87	87.01	25.85	46.67	51.27	117.01	3.52	1.40	30.92	25.65	2.02	7.11	3.09	3.83	-	-
	F_2	107.61	79.69	21.37	39.98	38.88	109.69	3.25	1.14	16.55	22.40	1.95	6.34	2.29	1.92	25.49	8.40
HPR-2047x IR57893-08	F_1	118.83	83.95	18.91	47.88	40.37	113.95	3.36	1.48	18.50	20.50	1.83	6.12	2.78	3.59	-	-
	F_2	99.55	78.01	18.12	45.96	50.30	108.01	3.71	1.56	20.64	24.07	1.85	6.89	2.33	10.21	23.74	7.18
HPR-2047x VLDhan-221	F_1	120.59	96.73	13.53	36.40	44.93	126.73	3.75	1.50	20.91	23.58	1.88	7.07	2.66	3.94	-	-
	F_2	105.25	85.88	19.35	37.22	42.19	115.86	4.11	1.34	18.56	21.86	1.67	6.91	2.68	5.03	25.78	7.18
HPR-2047x JD-8	F_1	101.44	90.89	30.09	33.83	56.68	120.89	3.31	1.67	31.04	23.21	1.61	5.36	2.34	8.34	-	-
	F_2	100.22	89.58	27.93	44.57	41.66	119.58	4.03	1.51	23.79	20.83	1.70	6.85	2.18	8.38	24.47	8.09
China-988x VL91-1754	F_1	99.85	88.82	24.25	39.81	47.29	118.82	3.34	1.31	24.40	22.92	1.76	5.88	2.24	3.28	-	-
	F_2	94.33	93.40	20.87	42.19	44.44	123.40	3.79	1.40	7.75	23.25	1.85	7.02	2.53	1.90	25.23	8.74
China-988x VL93-3613	F_1	96.87	90.96	19.23	32.07	58.15	120.96	3.26	1.16	23.59	22.72	1.85	6.04	2.36	3.50	-	-
	F_2	95.20	89.73	18.13	44.81	46.40	119.73	3.70	1.64	12.25	20.40	1.81	6.69	2.46	2.64	24.10	7.70
China-988x VL93-6052	F_1	104.60	89.64	17.09	62.52	41.34	119.64	3.92	2.21	21.12	24.73	1.78	6.97	3.08	5.38	-	-
	F_2	119.62	87.27	18.75	39.98	54.59	117.27	3.59	1.41	17.09	16.23	3.52	5.56	2.37	8.29	25.05	7.89
China-988x IR57893-08	F_1	125.37	91.40	19.10	47.71	39.09	121.40	3.71	2.56	16.71	23.55	1.86	6.91	2.94	4.30	-	-
	F_2	109.48	89.50	17.70	42.55	44.40	119.50	3.62	1.28	16.15	24.18	1.81	6.56	2.55	6.13	23.66	9.28
China-988x VLDhan-221	F_1	112.69	85.45	19.54	32.90	41.13	115.65	3.42	1.16	15.88	23.74	1.78	6.09	2.45	2.73	-	-
	F_2	92.28	83.66	19.35	54.92	40.35	113.66	3.71	1.33	18.61	22.78	1.75	6.50	2.76	5.73	24.62	9.22
China-988x JD-8	F_1	120.27	93.55	19.12	53.42	56.30	123.55	4.37	1.20	23.85	21.47	1.61	7.06	2.24	4.28	-	-
	F_2	87.10	85.29	18.36	58.02	42.67	115.29	3.46	0.98	20.59	22.68	1.92	6.62	2.47	4.84	24.19	8.18
VL91-1754x VL93-3613	F_1	118.96	92.90	22.33	45.53	53.28	122.90	3.55	1.84	30.16	21.23	2.04	7.26	3.17	10.59	-	-
	F_2	101.87	82.48	18.95	44.89	47.45	112.48	3.26	1.32	24.95	22.67	1.97	6.43	2.23	9.90	25.48	8.06
VL91-1754x VL93-6052	F_1	115.40	93.62	12.64	39.17	49.10	123.62	3.53	2.18	30.74	22.29	1.94	6.85	3.09	5.55	-	-
	F_2	106.37	80.34	17.11	42.63	43.95	110.34	3.13	1.55	21.62	22.19	1.96	6.14	2.45	3.62	26.46	8.23

Contd../-

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
VL91-1754x IR57893-08	F_1	113.40	82.58	19.47	32.15	53.25	112.58	3.09	1.18	28.00	23.13	2.01	6.19	2.88	5.66	-	-
	F_2	103.40	89.91	18.06	40.76	43.73	119.81	3.65	1.08	12.61	22.62	1.85	6.78	2.50	4.80	24.13	7.18
VL91-1754x VLDhan-221	F_1	107.95	93.43	18.86	49.37	38.75	128.43	3.17	1.69	25.58	21.12	2.01	6.38	2.72	5.95	-	-
	F_2	95.32	79.46	17.32	37.58	49.69	109.46	3.29	1.14	21.65	21.98	1.82	5.99	2.61	5.80	26.20	9.80
VL91-1754x JD-8	F_1	113.57	93.35	23.86	53.61	36.41	123.35	3.58	1.51	15.52	23.59	2.07	7.46	3.12	2.41	-	-
	F_2	100.37	77.68	19.38	38.62	49.17	107.68	3.28	1.32	18.43	21.53	1.87	6.15	2.78	5.14	25.37	8.75
VL93-3613x VL93-6052	F_1	113.67	97.42	23.81	38.75	49.31	127.42	3.16	2.23	40.20	24.58	2.18	6.89	2.75	10.41	-	-
	F_2	109.86	77.32	15.97	37.94	49.39	107.32	3.34	1.38	15.23	23.21	1.93	6.44	2.90	3.55	25.72	9.28
VL93-3613x IR57893-08	F_1	113.19	75.82	29.13	40.38	55.31	105.82	3.43	0.98	38.56	26.18	1.83	6.27	2.86	8.13	-	-
	F_2	119.10	86.23	17.90	38.52	45.82	116.23	3.52	0.94	24.56	25.27	1.87	6.60	3.05	4.25	24.29	7.88
VL93-3613x VLDhan-221	F_1	112.85	90.35	24.77	32.05	39.46	120.35	3.65	1.63	35.50	26.11	1.95	7.11	3.29	7.86	-	-
	F_2	123.32	85.16	19.38	43.71	39.55	115.16	3.56	1.30	14.63	25.92	1.96	7.05	2.54	2.43	25.48	7.18
VL93-3613x JD-8	F_1	107.51	84.17	26.76	40.66	47.89	114.17	3.68	1.84	30.50	24.49	2.02	7.43	3.54	1.65	-	-
	F_2	121.14	81.38	17.47	45.61	42.59	111.38	3.81	1.45	22.34	25.92	1.91	7.29	2.42	4.65	24.49	9.63
VL93-6052x IR57893-08	F_1	117.67	90.13	16.79	36.11	52.97	120.13	3.56	1.51	21.77	22.62	1.82	6.49	3.10	4.58	-	-
	F_2	111.53	79.80	14.53	41.88	39.71	109.90	3.80	1.40	17.13	25.05	1.77	6.73	2.51	4.93	25.60	8.23
VL93-6052x VLDhan-221	F_1	134.87	94.03	28.20	46.61	51.17	124.03	3.81	1.64	26.51	24.57	1.86	7.07	2.92	3.01	-	-
	F_2	109.45	83.81	16.75	40.78	45.43	113.81	3.62	1.13	25.29	24.01	1.85	6.71	2.76	4.00	26.52	7.18
VL93-6052x JD-8	F_1	112.50	76.09	22.52	52.50	45.45	106.09	3.47	1.34	30.59	18.47	1.79	6.23	2.51	5.70	-	-
	F_2	111.66	88.02	20.58	34.93	50.91	118.02	3.12	1.01	21.17	23.58	1.89	5.88	2.68	4.75	25.93	9.28
IR57893-08x VLDhan-221	F_1	122.91	81.93	9.17	49.91	58.35	111.93	3.33	1.00	14.69	23.27	1.96	6.55	3.13	4.12	-	-
	F_2	109.86	92.16	13.81	41.35	44.89	120.02	3.41	0.98	9.33	23.24	1.92	6.54	2.50	2.99	24.86	9.63
IR57893-08x JD-8	F_1	127.49	89.52	22.71	82.78	29.91	119.52	3.68	1.21	18.45	24.16	1.87	6.88	2.86	5.82	-	-
	F_2	106.50	88.45	17.74	40.91	44.40	122.24	3.32	1.31	14.54	23.08	1.89	6.26	2.68	4.11	24.55	8.58
VLDhan-221x JD-8	F_1	105.71	75.61	15.63	73.95	36.20	105.61	3.64	2.41	24.50	21.33	1.74	6.33	2.68	2.94	-	-
	F_2	103.28	88.72	15.81	38.61	44.28	117.12	3.33	1.78	16.48	22.75	2.01	6.69	2.50	3.24	25.85	8.46