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|Research Article|

Genetic Architecture of Hybrid Vigour and Inbreeding Depression for Yield, Grain Quality and Biofortification Traits in Rice *(Oryza sativa L.)*

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Abstract- The present investigation was conducted to estimate heterosis, heterobeltiosis, and inbreeding depression for yield, grain quality, and micronutrient traits in the rice cross 'RPBio-226 × Madhukar'. The experimental material comprising parents, F_1, and F_2 generations was evaluated during kharif season under irrigated conditions in a randomized block design with two replications. Observations were recorded for important agronomic, grain quality, and micronutrient traits. Significant positive heterosis was observed for productive tillers per plant, filled grains per panicle, grain yield per plant, and certain grain quality traits. Grain yield per plant exhibited high heterosis over both mid parent and better parent along with high inbreeding depression, indicating the predominance of non-additive gene action. Grain quality traits showed favorable heterotic responses, whereas iron content exhibited positive mid-parent heterosis with low inbreeding depression. The results revealed the involvement of both additive and non-additive gene effects in the inheritance of different traits. The cross 'RPBio-226 × Madhukar' showed promising potential for utilization in rice improvement and heterosis breeding programmes.

Keywords: Rice; Heterosis; Heterobeltiosis; Inbreeding depression; Grain yield; Grain quality; Iron; Zinc; Biofortification; Oryza sativa L.

Introduction

Rice (Oryza sativa L.) is one of the most important cereal crops cultivated worldwide and serves as the primary source of food and dietary energy for a major segment of the global population. In India, rice plays a crucial role not only in ensuring food and nutritional security but also in supporting rural livelihoods and agricultural economies. However, sustaining rice productivity has become increasingly challenging due to rapid population growth, climate variability, shrinking natural resources, and evolving consumer preferences. Under these circumstances, the development of high-yielding rice cultivars with superior grain quality and nutritional value has become a major objective of contemporary rice breeding programmes. Recent studies have highlighted

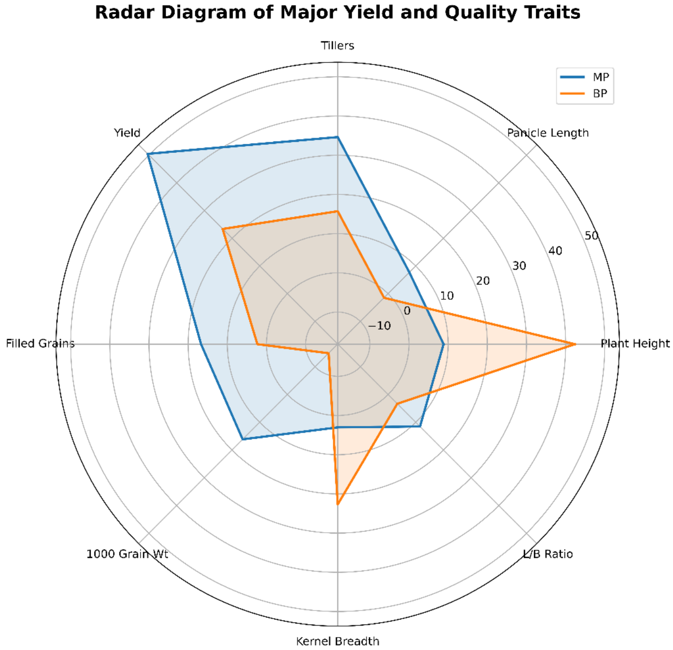

Fig. 1. Radar diagram showing the magnitude of heterotic response for important agronomic and grain quality traits in the rice cross 'RPBio-226 × Madhukar'

the significance of utilizing genetically diverse parental combinations for improving yield potential and grain quality traits in hybrid rice. Exploitation of heterosis has emerged as an effective breeding strategy for enhancing productivity in rice through the development of superior hybrids. The extent of heterosis expressed in a cross provides valuable insight into the genetic potential of parental lines and the inheritance pattern of economically important traits. Heterosis arises due to favorable interactions among alleles and is widely utilized for improving grain yield and its associated components. In addition, estimation of heterobeltiosis and inbreeding depression helps in understanding the relative contribution of additive and non-additive gene action governing quantitative traits (Falconer and Mackay, 1996). Traits exhibiting high heterosis coupled with high inbreeding depression are generally associated with dominance and over-dominance gene effects, whereas traits showing comparatively lower inbreeding depression are predominantly controlled by additive gene action and can be improved through selection in segregating generations. Earlier investigations by Ananda Kumar and Sreeranga Swamy (1986), Reddy and Nerkar (1995), and Ganeshan et al. (1997) reported substantial heterosis and inbreeding depression for productive tillers, grain yield per plant, filled grains per panicle, and panicle length, indicating the importance of non-additive gene action in rice improvement. Similar positive heterotic effects for yield and related traits were also documented by Elsy (1997), Bharathi (1998), Pandya and Tripathi (2006), Venkatesan et al. (2008), Borah and Barman (2010), and Gourishankar et al. (2010). Apart from grain yield, grain quality traits such as kernel length, kernel breadth, and length/breadth ratio are important determinants of market acceptability, cooking quality, and consumer preference. Significant heterosis for grain quality traits in rice hybrids has been reported by Raju et al. (2003) and Sanjeevkumar et al. (2010). Furthermore, increasing awareness regarding micronutrient malnutrition has intensified breeding efforts aimed at enhancing iron and zinc concentration in rice grains. Biofortification has therefore gained importance as a sustainable strategy to combat hidden hunger, particularly in developing countries where rice constitutes a major portion of the daily diet. In view of the above considerations, the present investigation involving the cross 'RPBio-226 × Madhukar' was undertaken to estimate heterosis, heterobeltiosis, and inbreeding depression for yield, yield-contributing traits, grain quality parameters, and micronutrient content. The study was aimed at identifying superior heterotic combinations and understanding the nature of gene action governing the inheritance of these traits for their effective utilization in rice breeding programmes.

Materials and Methods

Experimental Site

The present investigation was carried out during the kharif season at the experimental farm of the Directorate of Rice Research (DRR), ICRISAT, Patancheru, Hyderabad, Telangana, India. The experimental station is situated at 17.53°N latitude and 78.16°E longitude with an elevation of approximately 545 m above mean sea level. The region is characterized by a semi-arid tropical climate with irrigated rice cultivation facilities.

Plant Material and Crossing Programme

The experimental material comprised the rice cross 'Swarna × Madhukar'. The variety Swarna is widely cultivated for its high yield potential, adaptability, and stable agronomic performance, whereas Madhukar is recognized for desirable grain quality and nutritional characteristics. Hybridization between the two parents was carried out using standard emasculation and hand pollination techniques. The F_1 seeds obtained from successful crosses were raised during the succeeding season, and the F_2 generation was developed through selfing of F_1 plants.

Experimental Design and Crop Management

The parental lines along with F_1 and F_2 generations were evaluated in a randomized block design with two replications under irrigated conditions. Each genotype was transplanted in rows of 3 m length by maintaining a spacing of 20 cm between rows and 10 cm between plants within a row. Standard agronomic practices recommended for rice cultivation in the region were followed uniformly to ensure healthy crop growth. Necessary plant protection measures were adopted as and when required to minimize biotic stress.

Recording of Observations

Observations were recorded on five randomly selected competitive plants from each replication for important agronomic, grain quality, and micronutrient traits. The characters studied included days to 50 per cent flowering, plant height (cm), panicle length (cm), productive tillers per plant, filled grains per panicle, grain yield per plant (g), 1000-grain weight (g), kernel length (mm), kernel breadth (mm), and length/breadth ratio. Micronutrient traits such as iron and zinc content were estimated using Energy Dispersive X-ray Fluorescence (EDXRF) spectrometry.

Statistical Analysis

The mean data obtained for different characters were subjected to statistical analysis following standard biometrical procedures. Heterosis over mid parent and heterobeltiosis over better parent were estimated according to Turner (1953) and Hayes et al. (1956), respectively, while inbreeding depression was calculated following the method proposed by Wynne et al. (1970). The estimates were computed using the following expressions:

$$\text{Relative Heterosis (\%)} = \frac{F_1 - MP}{MP} \times 100$$

$$\text{Heterobeltiosis (\%)} = \frac{F_1 - BP}{BP} \times 100$$

$$\text{Inbreeding Depression (\%)} = \frac{F_1 - F_2}{F_1} \times 100$$

The significance of heterotic effects was tested using standard 't' tests at appropriate probability levels.

Results and Discussion

The estimates of heterosis, heterobeltiosis, and inbreeding depression for yield, grain quality, and micronutrient traits in the cross 'RPBio-226 × Madhukar' are presented in Table 4.3. Considerable variation was observed among the traits with respect to the magnitude and direction of heterotic expression, indicating the involvement of diverse genetic mechanisms in the inheritance of these characters. Days to 50 per cent flowering exhibited significant negative mid-parent heterosis (-5.77%) along with non-significant heterobeltiosis and low negative inbreeding depression (-1.02%). The occurrence of negative heterosis for flowering duration indicates earliness in the hybrid combination, which is considered desirable for the development of short-duration rice cultivars suitable for multiple cropping systems and stress-prone environments. Similar results for desirable negative heterosis in flowering duration. Plant height recorded positive heterosis over both mid parent (8.84%) and better parent (42.37%), whereas inbreeding depression was low and negative (-8.41%). The expression of positive heterosis accompanied by comparatively low inbreeding depression suggests partial dominance together with the possible involvement of additive gene effects in the inheritance of plant height. Similar findings were earlier reported by Verma et al. (2004), Saravanan et al. (2006b), and Deoraj et al. (2007). Increased plant height generally contributes to greater biomass production; however, excessively tall plants may increase susceptibility to lodging under intensive cultivation conditions. Panicle length exhibited significant positive mid-parent heterosis (7.69%) but negative heterobeltiosis (-1.46%) with comparatively low inbreeding depression (8.32%). The moderate heterotic response along with low inbreeding depression indicates the probable involvement of additive gene action in controlling this character. Similar observations were reported by Bharathi (1998), Pandya and Tripathi (2006), and Gourishankar et al. (2010). Since panicle length is directly associated with spikelet-bearing capacity, improvement in this trait may contribute positively toward grain productivity. Productive tillers per plant expressed highly significant positive heterosis over both mid parent (34.64%) and better parent (15.73%) together with high inbreeding depression (20.09%). Likewise, grain yield per plant exhibited remarkably high positive heterosis over mid parent (50.46%) and better parent (23.37%) accompanied by high inbreeding depression (37.90%). The occurrence of high heterosis associated with high inbreeding depression clearly indicates the predominance of non-additive gene action and over-dominance effects in the inheritance of these traits. Similar results were reported by Ananda Kumar and Sreeranga Swamy (1986), Ganeshan et al. (1997), Alam et al. (2004), and Venkatesan et al. (2008). Positive heterotic effects for productive tillers and grain yield were also reported by Borah and Barman (2010) and Panwar and Mashiat Ali (2010). These findings suggest that exploitation of heterosis breeding may be effective for improving grain yield in rice. Filled grains per panicle exhibited positive heterosis over both mid parent (16.71%) and better parent (2.33%) along with moderate inbreeding depression (14.63%). Positive heterosis for filled grains indicates the role of partial dominance in governing this trait. Similar observations were reported earlier by Elsy (1997), Raju et al. (2006), and Gourishankar et al. (2010). Since the number of filled grains is one of the major determinants of grain yield, improvement in this trait may substantially enhance productivity.

Table 1. Estimates of heterosis, heterobeltiosis and inbreeding depression in the cross 'Rpbio-226 X Madhukar'

S.No.	**Character**	**Heterosis percent over**		**Inbreeding Depression**
		MP	**BP**	
1	Days to 50% flowering	-5.77**	2.08	-1.02
2	Plant Height	8.84*	42.37**	-8.41*
3	Panicle Length	7.69**	-1.46**	8.32**
4	Productive Tillers	34.64**	15.73**	20.09**
5	Yield per plant	50.46**	23.37**	37.90**
6	Filled Grains	16.71	2.33	14.63
7	1000 Grain Weight	16.14**	-14.92**	9.59**
8	Kernel Length	3.33**	-4.29**	0.22
9	Kernel Breadth	3.03**	22.68**	-0.84**
10	Length/Breadth Ratio	11.52**	3.31**	11.83**
11	Iron	3.35**	-0.72**	-1.01**
12	Zinc	-2.95**	-11.67**	-8.24**

The trait 1000-grain weight exhibited significant positive mid-parent heterosis (16.14%) but negative heterobeltiosis (-14.92%) with comparatively low inbreeding depression (9.59%). The lower magnitude of inbreeding depression suggests relatively stable inheritance and the possible involvement of additive gene effects. Similar heterotic responses for test weight were reported by Banumathi (2001) and Borah and Barman (2010). Kernel length exhibited low positive mid-parent heterosis (3.33%) together

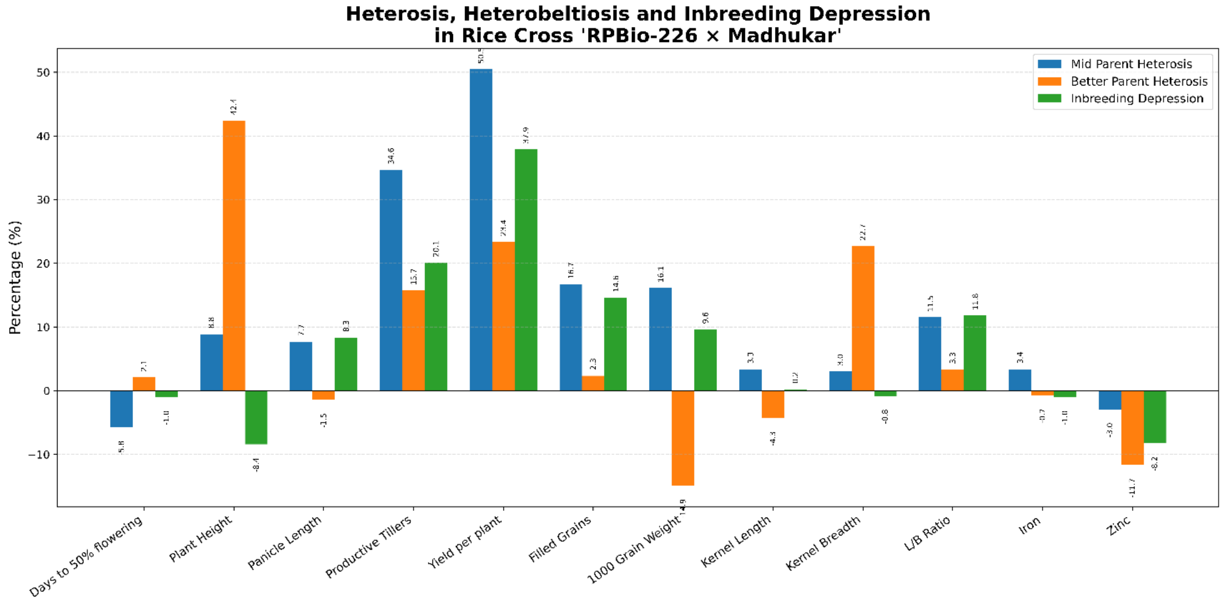

Fig. 2. Comparative estimates of heterosis, heterobeltiosis and inbreeding depression for yield, grain quality and micronutrient traits in the rice cross 'RPBio-226 × Madhukar'

with negative heterobeltiosis and negligible inbreeding depression (0.22%), indicating the predominance of additive gene action. Kernel breadth recorded significant positive heterosis over both mid parent (3.03%) and better parent (22.68%) with low negative inbreeding depression (-0.84%). Similar positive heterosis for grain breadth was reported by Raju et al. (2003) and Sanjeevkumar et al. (2010). Length/breadth ratio expressed positive heterosis over both mid parent (11.52%) and better parent (3.31%) accompanied by moderate inbreeding depression (11.83%). The occurrence of favorable heterosis for grain dimension traits indicates the possibility of improving grain appearance and market quality through hybridization programmes. Iron content exhibited significant positive mid-parent heterosis (3.35%) but slight negative heterobeltiosis (-0.72%) along with low negative inbreeding depression (-1.01%). The comparatively low magnitude of inbreeding depression suggests relative stability of iron concentration in segregating generations. In contrast, zinc content recorded negative heterosis over both mid parent (-2.95%) and better parent (-11.67%) with negative inbreeding depression (-8.24%). Similar negative relationships between grain yield and micronutrient concentration were reported, indicating the complexity involved in simultaneously improving productivity and micronutrient density in rice.

Overall, the cross 'RPBio-226 × Madhukar' exhibited substantial heterotic potential for productive tillers per plant, grain yield per plant, filled grains per panicle, and certain grain quality traits. The study revealed the involvement of both additive and non-additive gene effects in the inheritance of different characters. Traits predominantly governed by additive gene action may be effectively improved through selection in segregating generations, whereas characters showing high heterosis associated with high inbreeding depression may be better exploited through heterosis breeding strategies.

Conclusion

The present investigation on heterosis in the cross 'Rpbio-226 × Madhukar' revealed significant hybrid vigor for several economically important agronomic and grain quality traits. Productive tillers and grain yield per plant exhibited high positive heterosis along with substantial inbreeding depression, indicating the predominance of non-additive gene action and over-dominance effects. These traits may therefore be effectively exploited through hybrid breeding programmes. Filled grains, 1000-grain weight, and length/breadth ratio exhibited positive mid-parent heterosis indicating partial dominance for these characters. Traits such as panicle length, 1000-grain weight, and kernel length showed comparatively low inbreeding depression suggesting the involvement of additive gene effects and the possibility of effective selection in segregating generations. Iron content exhibited comparatively stable inheritance with low negative inbreeding depression, whereas zinc content recorded negative heterotic responses. Overall, the cross 'Rpbio-226 × Madhukar' may serve as a promising genetic resource for developing high-yielding rice hybrids with desirable grain quality traits.

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