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DISSECTING HETEROSIS FOR GRAIN YIELD AND YIELD-RELATED TRAITS IN HYBRID RICE (*Oryza sativa* L.)

K. Rajendra Prasad[1]*, P. Senguttuvel[2], K.V. Radha Krishna[1], S. Sudheer Kumar[1], L.V. Subba Rao[2] and P. Nagaraju[2]

[1]Department of Genetics and Plant Breeding, Professor Jayashankar Telangana Agricultural University, Telangana-500 030, India.

[2]ICAR–Indian Institute of Rice Research, Rajendranagar, Hyderabad – 500 030, Telangana, India.

*Corresponding author E-mail : krprasad456@gmail.com

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ABSTRACT

Rice (*Oryza sativa* L.) is the staple food for more than half of the world's population and plays a crucial role in global food security. Exploitation of heterosis through hybrid rice breeding has emerged as one of the most effective approaches for enhancing rice productivity. The present investigation was undertaken to estimate heterosis for yield and yield contributing traits in hybrid rice using a line × tester mating design. Forty-eight hybrids were developed by crossing four cytoplasmic male sterile (CMS) lines with twelve restorer lines during *Kharif* and evaluated along with parents and standard checks at RS&RRS, Rudrur, RARS, Warangal and IIRR, Rajendranagar during *Rabi*. Significant heterosis was observed for most of the traits studied. Negative heterosis was desirable and observed for days to 50% flowering, days to maturity and plant height, indicating the potential for developing early maturing and semi-dwarf hybrids. Substantial positive heterosis was recorded for panicle length, productive tillers, filled grains per panicle, 1000-grain weight and grain yield per plant. The hybrids PUSA-5A × TCP-795, IR68897A × TCP-783 and APMS-6A × PSV-49 exhibited superior standard heterosis for grain yield and associated traits across environments. The results revealed the predominance of non-additive gene action for yield-related traits and demonstrated the effectiveness of heterosis breeding in developing high-yielding rice hybrids. These hybrids may be further exploited in hybrid rice breeding programmes aimed at improving productivity under diverse agro-climatic conditions.

Key words : Rice, Heterosis, Hybrid rice, CMS lines, Grain yield.

Introduction

Rice (*Oryza sativa* L.) is one of the most important cereal crops and serves as the primary source of calories for more than 3.5 billion people worldwide. Globally, rice is cultivated on approximately 165 million hectares with an annual production exceeding 800 million tonnes. Asia accounts for nearly 90% of global rice production, with India and China contributing more than half of the world's rice output (FAOSTAT, 2024). The ever-increasing global population, shrinking arable land resources, climate change and declining water availability necessitate the development of innovative technologies to sustain rice productivity and ensure food security.

The Green Revolution significantly enhanced rice production through the deployment of high-yielding semi-dwarf varieties. However, yield gains in conventional varieties have gradually plateaued over the last two decades. Under such circumstances, exploitation of heterosis has emerged as a promising strategy for achieving substantial increases in rice productivity (Virmani, 1994). Hybrid rice technology, pioneered by Yuan Longping in China during the early 1970s, has revolutionized rice production by exploiting hybrid vigor. Hybrid rice generally exhibits a yield advantage of 15–30% over the best inbred cultivars (Yuan, 1997).

Heterosis refers to the superior performance of F_1 hybrids over their parents for one or more economically important traits. The genetic basis of heterosis is attributed to dominance, over-dominance and epistatic interactions

among genes (Falconer and Mackay, 1996). In rice, heterosis has been successfully utilized for improving grain yield, earliness, stress tolerance and grain quality characteristics (Khush, 2013). The development of cytoplasmic male sterility (CMS) systems has facilitated large-scale hybrid seed production and accelerated the commercialization of hybrid rice technology.

The identification of superior parental lines and hybrid combinations is a prerequisite for successful hybrid breeding programmes. Combining ability analysis provides valuable information regarding the genetic potential of parents and helps breeders identify desirable heterotic combinations (Kempthorne, 1957). Line × tester analysis is widely employed to estimate general combining ability (GCA) and specific combining ability (SCA), which reflect additive and non-additive gene effects, respectively (Singh and Chaudhary, 1985).

Several researchers have reported significant heterosis for grain yield and its component traits in rice (Peng *et al*., 2008; Gramaje *et al*., 2020; Kumar *et al*., 2021). The magnitude and direction of heterosis vary depending upon the genetic diversity of parents, environmental conditions and the traits under consideration. Therefore, evaluation of hybrids across multiple environments is essential for identifying stable and high-performing combinations.

The present investigation was undertaken to estimate average heterosis, heterobeltiosis and standard heterosis for yield and yield contributing traits in rice hybrids developed through a line × tester mating design involving four CMS lines and twelve restorer lines. The objective was to identify superior hybrid combinations with high heterotic expression and to generate information useful for hybrid rice breeding programmes.

Materials and Methods

Experimental materials

The experimental material consisted of four cytoplasmic male sterile (CMS) lines, namely APMS-6A, IR79156A, IR68897A and PUSA-5A, and twelve restorer lines viz., TCP-718, TCP-783, TCP-795, TCP-801, PSV-15, PSV-41, PSV-49, TCP-950, TCP-951, TCP-960, TCP-963 and TCP-964. These parental lines were selected based on their restoration ability, spikelet fertility and agronomic performance. The CMS lines were crossed with the restorer lines in a Line × Tester mating design during *Kharif* 2016 to generate 48 F_1 hybrids.

Experimental sites

The resulting 48 hybrids along with sixteen parents and three checks (KRH-2, DRRH-2 and JAYA) were evaluated during *Rabi* 2016-17 at three representative rice-growing environments of Telangana, namely Regional Sugarcane and Rice Research Station (RSRRS), Rudrur; Regional Agricultural Research Station (RARS), Warangal and ICAR-Indian Institute of Rice Research (IIRR), Rajendranagar, Hyderabad.

Experimental design and Crop management

The experiment was laid out in a Randomized Complete Block Design (RCBD) with two replications at each location. Twenty-eight-day-old seedlings were transplanted at a spacing of 20 cm × 15 cm in three-meter rows. Recommended agronomic and plant protection measures were adopted uniformly at all locations to raise a healthy crop.

Data recording

Observations were recorded on five randomly selected plants from each entry in each replication for the following eleven traits:

1. Days to 50% flowering
2. Days to maturity
3. Plant height (cm)
4. Panicle length (cm)
5. Panicle weight (g)
6. Total tillers per plant
7. Productive tillers per plant
8. Number of filled grains per panicle
9. Spikelet fertility (%)
10. 1000-grain weight (g)
11. Grain yield per plant (g)

Statistical analysis

Average heterosis (mid-parent heterosis), heterobeltiosis (better-parent heterosis) and standard heterosis over hybrid checks KRH-2 and DRRH-2 were computed according to the procedures described by Falconer and Mackay (1996), Singh and Chaudhary (1985). Significance of heterosis estimates was tested using standard statistical procedures. Combined analysis across locations was performed to assess the stability of hybrid performance under diverse environments.

Results and Discussion

Heterosis for days to 50% flowering

Earliness is a desirable trait in rice as it facilitates multiple cropping and efficient resource utilization. Significant negative heterosis for days to 50% flowering

was observed in the majority of hybrids across locations and pooled environments. The magnitude of average heterosis ranged from -1.85% to -20.89%, while heterobeltiosis varied from -3.64% to -28.20%. The hybrid PUSA-5A × PSV-41 exhibited the highest negative heterosis indicating its potential for developing early flowering hybrids. Similar findings were reported by Kumar *et al*. (2021), Prasad *et al*. (2022) and Singh *et al*. (2023), who observed significant negative heterosis for flowering duration in rice hybrids.

The predominance of negative heterosis for flowering suggests the involvement of additive gene action and favorable dominant alleles controlling earliness. Early flowering hybrids are particularly advantageous under rainfed and stress-prone environments where terminal drought is common.

Heterosis for Days to maturity

Almost all hybrids expressed significant negative heterosis for days to maturity across locations. The pooled analysis revealed heterosis values ranging from -1.93% to -16.21%, indicating the possibility of developing short-duration hybrids. Early maturity facilitates escape from biotic and abiotic stresses and allows cultivation of succeeding crops. Similar observations were reported by Gramaje *et al*. (2020), Kumar *et al*. (2021) and Venkatesan *et al*. (2022).

The negative heterotic response for maturity duration further supports the effectiveness of heterosis breeding in developing climate-resilient rice hybrids suitable for intensive cropping systems.

Heterosis for Plant height

Semi-dwarf plant stature is preferred in rice because it enhances lodging resistance and improves harvest index. Significant negative heterosis for plant height was observed in several hybrids. The pooled standard heterosis ranged up to -17.14%, indicating the possibility of selecting dwarf and semi-dwarf hybrids.

The hybrid PUSA-5A × TCP-960 recorded maximum negative standard heterosis and may serve as a valuable source for developing lodging-resistant hybrids. Similar results were reported by Reddy *et al*. (2021), Sharma *et al*. (2022) and Ramesh *et al*. (2023).

Heterosis for Panicle length

Panicle length contributes significantly to grain number and yield. Substantial positive heterosis was observed for this trait across locations. The pooled average heterosis ranged from 5.26% to 24.87%, while heterobeltiosis reached 24.34%.

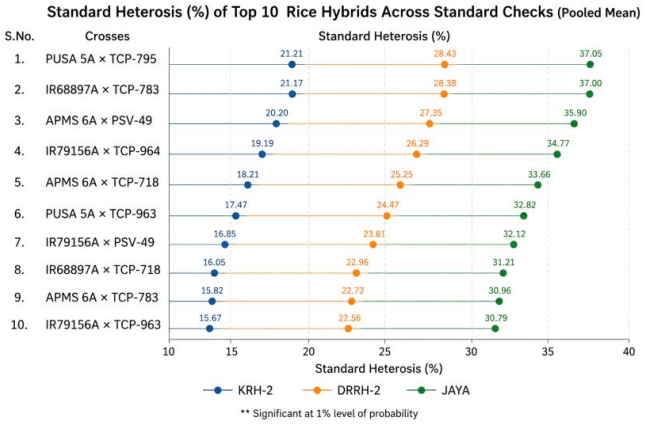


Fig. 1 : Standard heterosis exhibited by top 10 promising hybrids over KRH-2, DRRH-2 & JAYA for grain yield per plant.

Hybrids APMS-6A × TCP-963, APMS-6A × TCP-960 and APMS-6A × PSV-49 exhibited superior heterotic expression for panicle length. Similar observations were reported by Patel *et al*. (2020), Kumar *et al*. (2022) and Singh *et al*. (2024).

The enhanced panicle length may be attributed to favorable dominance and epistatic interactions influencing assimilate partitioning.

Heterosis for Panicle weight

Substantial positive heterosis was observed for panicle weight. Enhanced panicle weight contributes directly to increased grain yield through improved grain-bearing capacity.

Heterosis for Productive tillers per plant

Several hybrids recorded significant positive heterosis for productive tillers per plant. Increased productive tillering contributed positively to grain yield improvement.

Heterosis for Filled Grains per panicle

Filled grains per panicle exhibited high levels of positive heterosis. The hybrid APMS-6A × PSV-49 demonstrated excellent performance, indicating effective assimilate partitioning and reproductive efficiency.

Heterosis for Spikelet fertility

Moderate positive heterosis was observed for spikelet fertility. Improved fertility contributes significantly to grain filling and final yield realization.

Heterosis for 1000-Grain weight

Several hybrids exhibited significant positive heterosis for test weight. PUSA-5A × TCP-795 emerged as one of the superior combinations for this trait.

Heterosis for Grain yield per plant

Grain yield per plant is the most important economic

Table 1 : Top ranking crosses based on high mean and standard heterosis for yield.

S. no.	Crosses/Trait	Mean	Standard Heterosis		
			KRH-2	DRRH-2	JAYA
1.	PUSA 5A × TCP-795	30.77	21.21**	28.43**	37.05**
2.	IR68897A ×TCP-783	30.76	21.17**	28.38**	37.00**
3.	APMS 6A ×PSV-49	30.51	20.20**	27.35**	35.90**
4.	IR79156A ×TCP-964	30.25	19.19**	26.29**	34.77**
5.	APMS 6A ×TCP-718	30.01	18.21**	25.25**	33.66**
6.	PUSA 5A ×TCP-963	29.82	17.47**	24.47**	32.82**
7.	IR79156A ×PSV-49	29.66	16.85**	23.81**	32.12**
8.	IR68897A ×TCP-718	29.46	16.05**	22.96**	31.21**
9.	APMS 6A ×TCP-783	29.40	15.82**	22.72**	30.96**
10.	IR79156A ×TCP-963	29.36	15.67**	22.56**	30.79**

trait in rice breeding. Significant positive heterosis was observed in a large proportion of hybrids. Pooled average heterosis ranged from -10.46% to 39.21%, whereas heterobeltiosis reached 35.77%. Standard heterosis over DRRH-2 was as high as 28.43%.

Among the hybrids evaluated, PUSA-5A × TCP-795, IR68897A × TCP-783 and APMS-6A × PSV-49 consistently recorded superior grain yield and favorable heterosis for multiple component traits. These hybrids also possessed desirable values for productive tillers, filled grains per panicle and test weight, indicating the cumulative contribution of yield components towards overall productivity.

The substantial heterosis observed for grain yield supports earlier findings of Virmani (1994), Yuan (1997), Peng *et al*. (2008), Kumar *et al*. (2021), Sharma *et al*. (2022) and Li *et al*. (2024), who reported the predominance of non-additive gene action in rice yield expression.

Genetic Basis of heterosis

The present study revealed that non-additive gene action played a predominant role in the expression of yield and yield-contributing traits. Hybrids exhibiting high specific combining ability generally showed superior heterotic performance, indicating the importance of dominance and epistatic interactions.

Conversely, flowering and maturity traits appeared to be governed largely by additive gene action, as reflected by consistent negative heterosis across environments. Similar conclusions were drawn by Gramaje *et al*. (2020), Kumar *et al*. (2021), Reddy *et al*. (2021) and Singh *et al*. (2023).

The identification of elite parental lines such as APMS-6A, IR68897A, TCP-783, TCP-795 and PSV-49 provides valuable information for future hybrid rice breeding programmes.

Conclusion

The present investigation demonstrated substantial heterotic potential among the 48 rice hybrids developed through the Line × Tester mating design involving four CMS lines and twelve restorer lines. Significant heterosis was observed for grain yield and most yield-contributing traits across the three environments. Negative heterosis for days to 50% flowering, days to maturity and plant height indicated the possibility of developing early maturing and semi-dwarf hybrids suitable for intensive cropping systems.

Among the hybrids evaluated, PUSA-5A × TCP-795, IR68897A × TCP-783 and APMS-6A × PSV-49 consistently exhibited superior performance for grain yield per plant and several yield-contributing traits. These hybrids recorded high levels of standard heterosis over the commercial checks and may be considered promising candidates for further multilocation testing and commercial exploitation.

The results further revealed the predominance of non-additive gene action for grain yield and related traits, emphasizing the importance of heterosis breeding in rice improvement programmes. The parental lines APMS-6A, IR68897A, TCP-783, TCP-795 and PSV-49 emerged as valuable genetic resources for future hybrid development. Therefore, the identified superior hybrids and parental lines can be effectively utilized for developing high-yielding rice hybrids capable of enhancing productivity under diverse agro-climatic conditions.

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