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Studies on Promising Restorer Lines for Yield and Yield Components in Rice (*Oryza sativa* L.)

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Abstract

The present investigation was carried out at Regional Agricultural Research Station, Maruteru with a set of 30 experimental hybrids developed by crossing three male sterile lines with 10 testers in Line × Tester mating design during *kharif*, 2022. The resultant 30 hybrids were evaluated in Randomized Block Design with two replications along with the parents and hybrid check, HRI-174 during *rabi*, 2022-23. Analysis of variance for yield and yield components revealed significant differences among the genotypes, parents, hybrids and parents vs. crosses for most traits, indicating significant differences among parents and hybrids, in addition to significant levels of heterosis for the traits studied. In general, the hybrids had recorded higher grain yield per plant, compared to the lines and were observed to be early and relatively tall with a more number of productive tillers per plant and increased panicle length compared to the parents. The hybrids, APMS 15A×RGL 5613, APMS 15A×MTU 1213, APMS 17A×RGL 5613 and APMS 17A ×MTU 2055had recorded significant and positive relative heterosis, heterobeltiosis and standard heterosis of more than 25 per cent for grain yield per plant and were identified as promising heterotic combinations for further evaluation and commercial exploitation.

Keywords: Rice, Hybrids, Heterosis, Grain yield, and Yield components.

Introduction

Rice (*Oryza sativa* L.) is a staple food crop that plays a crucial role in global food security, feeding nearly half of the world's population (Manoj *et al*., 2023). India is one of the top rice producers globally, with predominant area, production, and productivity (www.indiastat.com, 2018-19). Globally, rice is being cultivated in 162.06 million hectares with a production of about 500 million metric tonnes and average productivity of 5.0t ha^{-1} (FAO, 2021). India has been the largest producer after Chinawith a cultivated area of paddy is 46.3 million hectares and production and productivity of 129.5 million tonnes and 2798 kg ha^{-1}, respectively during 2021-22 (Ministry of Agriculture and Farmer Welfare, GOI, 2022). In Andhra Pradesh, it is grown in an area of 2.6 million ha with a production and productivity of 13.1 million tonnes and 5130 kg ha^{-1}, respectively (Ministry of Agriculture and Farmers Welfare, Directorate of Economics and Statistics, 2021-2022).

With the increasing global population, the demand for rice is expected to rise, and production needs to increase by almost two million tons per year to meet this demand (Buelah *et al*., 2021). To achieve this, adopting hybrid rice technology is a viable alternative (Buelah *et al*., 2021), which has the potential to yield significantly higher than traditional high-yielding varieties (HYVs) by exploiting the genetic expression of heterosis or hybrid vigor (Virmani, 1994). In India, first rice hybrids (APHR 1 and APHR 2) were released in 1993 (Vishnuvardhan *et al*., 2022). Gradually, hybrid rice technology has gained importance in India (Singh *et al.,* 2016). Hybrid rice varieties account for about 50 per cent of rice genotypes in China, producing 148.27 million tonnes of paddy annually (Kushal *et al.,* 2023). Thus, on an average, hybrid rice in China yields about 27 per cent (1.5 mt ha^{-1}) more than inbred high-yielding varieties. The potential of hybrid rice technology to enhance yield and contribute to global food security has been demonstrated by its success in China (Yuan, 2003). However, the poor adoption of hybrid rice outside China, particularly, in India is due to the absence of significant levels of heterosis (Peng *et al*., 2008). Twenty per cent of dietary protein, 3 per cent of dietary fat, and other essential nutrients are provided by rice (Bhargavi *et al*., 2022). Efforts to develop and promote high yielding, heterotic hybrids are therefore, essential to address the growing food demands of the world's population (Vennela *et al.,* 2022). In this context, the present investigation was undertaken to identify heterotic experimental rice hybrids for grain yield and yield component traits.

Materials and Methods

The study was undertaken at Regional Agricultural Research Station (RARS), Maruteru, West Godavari District of Andhra Pradesh. The experimental site is situated at 26°38'N latitude, 81° 44'E longitude and 5 m above mean sea level with semi-humid climate with black alluvial clayey soils. The experimental material for the present study comprised of three male sterile lines *viz.,* APMS 15A, APMS 17A and APMS 18A and 10 restorer lines *viz*., RGL 5613, MTU 2716, MTU 1224, RM 409-26-1-1-1, MTU 2055, MTU 2347-158-3-1-1, RM 67-60-1-1-1, UTR 76, MTU 2846-34-1-1and MTU 1213. The salient features of parents and the check are summarized in **(Table 1)**. Thirty rice hybrids were developed by crossing the three male sterile lines with the ten testers in Line × Tester mating design during *kharif*, 2022. Healthy male sterile plants of the female male sterile lines with just emerged panicles were uprooted and potted in the evening hours of the day in plastic buckets filled with mud and were transferred to the net house **(Plate 1)**. Productive tillers of these plants with healthy panicles were selected and leaf sheaths were removed carefully. Further, florets that had completed anthesis (at the top) and young florets at the bottom of the panicle were also removed. Florets due to flower on the next day alone were used for crossing. Top 1/3rd of each floret was clipped with scissors and the clipped florets were covered with butter paper bags and labelled properly. On the next day morning, panicles ready for anthesis were selected from healthy male parents and were brought to the crossing chamber, in which temperature relative humidity and light conducive for anthesis were maintained. When the male parent was ready for dehiscence, the female parent was brought inside the crossing chamber and butter paper bags covering clipped panicles of the female parents were removed. Further, the panicles of the female parent were gently shaken so that the sterile extruded anthers fell off. Later, panicles of male parents were gently shaken over the female parents (CMS lines) until adequate pollen was deposited on stigmas of the clipped spikelets. The pollinated spikelets were then covered with fresh butter paper bags, duly labelled and fixed against the support of bamboo stakes. The process of pollination was continued upto 11 AM in the morning. Crossed seeds were collected after four weeks from the plant maintained in the buckets in the net house. The hybrid seeds were then sun dried, dehusked, counted and placed in small envelops and stored under ideal conditions for use in the next season for evaluation along with parents.

Table 1: Salient features of experimental material

S. No	Genotype	Source	Salient features
	Lines		
1	APMS 15A	RARS, Maruteru	Medium duration, medium slender, straw glume, moderately tolerant to BPH
2	APMS 17A	RARS, Maruteru	Medium duration, medium slender, straw glume, fine
3	APMA 18A	RARS, Maruteru	Medium duration, medium slender, straw glume, tolerant to leaf blast
	Testers		
1	RGL 5613	ARS, Ragolu	Medium duration, long slender, straw glume, moderately tolerant to leaf blast
2	MTU 2716	RARS, Maruteru	Medium duration, medium slender, straw glume
3	MTU 1224	RARS, Maruteru	Medium duration, medium slender, straw glume
4	RM 409-26-1-1-1	RARS, Maruteru	Medium duration, medium bold, straw glume
5	MTU 2055	RARS, Maruteru	Medium duration, long slender, straw glume
6	MTU 2347-158-3-1-1	RARS, Maruteru	Medium duration, medium bold, straw glume, moderately tolerant to leaf blast
7	RM 67-60-1-1-1	RARS, Maruteru	Medium duration, medium slender, bold grain
8	UTR 76	ARS, Utukuru	Medium duration, long slender, straw glume, moderately tolerant to leaf blast
9	MTU 2846-34-1-1	RARS, Maruteru	Medium duration, medium slender, straw glume
10	MTU 1213	RARS, Maruteru	Early duration, medium slender, straw glume
	Check		
1	HRI-174	Bayer Bioscience, Hyderabad	Early duration, long bold, straw glume

Evaluation of the 30 hybrids along with their parents, *i.e.,* three CMS lines and 10 restorers and the hybrid check, HRI-174 was carried out in a randomized block design with two replications during *Rabi*, 2022-2023 at Regional Agricultural Research Station, Maruteru. The seedlings were transplanted into the main field 21 days after sowing in the nursery. Normal, healthy and vigorous seedlings of each genotype were selected and transplanted in two rows plot of 4.5 m length with a spacing of 20 x 15 cm. All the recommended package of practices were adopted throughout the crop growth period to raise a healthy crop. Observations were recorded for grain yield per plant and yield attributing characters, namely, plant height, productive tillers per plant, panicle length spikelet fertility and grain density, measured as grain number divided by panicle length, by randomly choosing five plants from each entry in each replication and their means were used for the statistical analysis. The plants were selected from the middle rows to minimize the error due to border effect. However, days to 50 per cent flowering was recorded on plot basis. In contrast, observations for test weight were obtained from a random grain sample drawn from each plot in each genotype and replication using standard procedures. Further, the observations for yield and yield component traits were recorded on maintainer (B) lines of the respective male sterile lines, while panicle exertion and duration of floret opening were recorded on the male sterile lines. The data collected were subjected to standard statistical procedures (Panse and Sukhatme, 1967).

APMS 15A

APMS 17A

APMS 18A

Male sterile lines studied

Panicle of male parents in crossing chamber

Pollen dusting

Bagging after pollination

Plate 1: Hybridization techniques

Results and Discussion

Commercial exploitation of heterosis in crop plants is regarded a major breakthrough in the realm of plant breeding. Heterosis in rice was first reported by Jones (1926). Later on, several workers had reported considerable heterosis for yield and other important economic characters. The aim of heterosis analysis in the present study was to identify the best combination of parents giving high degree of useful heterosis. In this direction, hybrid vigour over mid parent, better parent and the standard hybrid check, HRI-174 was studied for the 30 hybrids obtained by crossing of three male sterile lines with ten restorers in a Line ×Tester fashion for grain yield and yield component characters. The results obtained are presented in **Tables 2-5**.

Days to 50 per cent flowering and maturity

Negative heterosis is desirable for the trait as earliness is preferred over delayed and late flowering. Relative heterosis for the trait ranged from -9.31 (APMS 18A × MTU 1224) to 4.06 per cent (APMS 17A x UTR 76), while heterobeltiosis was noticed to range from -10.29 (APMS 17A × MTU 1224) to 4.06 per cent (APMS17A ×UTR 76). However, standard heterosis for the trait ranged from -2.67(APMS 15A ×MTU 2055, APMS 17A ×MTU 2055) to 9.63 per cent (APMS 17A ×UTR 76). Further, significant and desirable heterosis over mid parent was observed for 15 hybrids,16 hybrids over better parent and none of the hybrids over the standard check, HRI-174 **(Figure 1 and 2)**.

Heterosis over mid-parent for days to maturity ranged from -6.43 (APMS 17A × MTU 1224) to 3.61 per cent (APMS 17A × MTU 2347-158-3-1-1), while heterosis over better parent ranged from -8.40 (APMS 17A × MTU 1224) to 2.79 per cent (APMS 17A × MTU 2347-158-3-1-1). Further, standard heterosis for the trait ranged from-3.23 (APMS 17A × MTU 1224) to 4.03 per cent (APMS 17A × MTU 1224, APMS 17A × UTR 76). Significant and desirable heterosis was recorded for six hybrids over mid-parent; nine hybrids over better parent and none of the hybrids over the standard check, HRI-174. Among these, six hybrids had recorded significant and desirable heterosis over mid-parent and better parent.

Devi *et al.,* (2014) and Dar *et al.,* (2015) had reported lack of hybrids with significant and negative heterosis over standard hybrid check, similar to the findings of the present investigation.

Table 2: Analysisof variance (mean squares) for yield and yield components in rice

Source of variation	Degrees of freedom	Days to 50% flowering	Days to maturity	Plant height (cm)	Productive tillers per plant	Panicle length (cm)	Filled grains per panicle	Un-filled grains per panicle	Spikelet fertility (%)	1000 grain weight (g)	Grain density	Grain yield per plant (g)
Replications	1	1.14	8.28	0.0290	0.25	0.57	44.25	6.88	10.64	0.1020	0.04	0.76
Genotypes	43	18.92**	15.91*	153.57**	3.66**	5.23**	9995.21**	3326.67**	482.57**	10.14**	8.87**	147.59**
Parents	12	6.51	10.32	181.91**	2.06 **	8.77 **	6543.70**	721.06 **	26.15 *	13.17 **	12.87 **	109.78 **
Hybrids	29	18.15**	14.88	102.79 **	4.18 **	3.54 **	10603.41**	3597.75**	571.15 **	5.06 **	7.09 **	170.58 **
Parent vs. Crosses	1	193.41 **	126.40**	1303.56**	7.99 **	10.76 **	7832.81 **	27980.15**	3472.69**	5.01 **	2.95 **	44.16*
Error	43	6.02	8.98	24.46	0.15	1.38	130.93	8.14	11.70	0.56	0.18	14.35

Table 3: *Per se* performance of parents and hybrids for grain yield and yield component characters in rice

Character	Mean			Range			Best genotype		
	Lines	Testers	Hybrids	Lines	Testers	Hybrids	Lines	Testers	Hybrids
Grain yield Per plant	24.90	29.16	26.61	21.70 to 27.00	19.00 to 38.50	17.50 to 46.50	APMS 18A	MTU 2846-34-1-1	APMS 17A × MTU 2055
Days to 50% flowering	99.83	98.25	95.35	98.50 to102.00	96.00 to 102.00	91.00 to 102.50	APMS 17A	MTU 1213	APMS 15A × MTU 2055, APMS 17A × MTU 2055
Days to maturity	127.83	126.65	124.28	125.50 to 130.00	123.00 to 131.00	120.00 to 129.00	APMS 17A	MTU 1213	APMS 15A × MTU 2055
Plant Height	113.81	107.74	117.62	111.05 to 115.75	88.50 to 119.70	101.00 to 133.80	APMS 15A	MTU 1224	APMS 15A × MTU 1224
Productive tillers per plant	8.41	9.32	9.78	7.75 to 8.90	7.90 to 10.50	6.65 to 12.85	APMS 18A	MTU 1224	APMS 17A × RGL 5613
Panicle length	25.80	24.90	25.88	25.30 to 26.15	21.15 to 28.90	23.45 to 30.10	APMS 18A	MTU 2716	APMS 18A × MTU 2055
Filled grains per panicle	315.05	221.25	212.12	289.00 to 365.25	164.60 to 289.05	49.50 to 419.15	APMS 17A	UTR 76	APMS 18A × MTU 2055
Un-filled grains per panicle	67.80	27.45	76.04	61.00 to 75.85	17.20 to 39.00	26.50 to 192.00	APMS 18A	RM 409-26-1-1-1	APMS 17A × MTU 2055
Spikelet fertility	82.18	88.94	73.54	79.35 to 84.65	85.05 to 92.45	20.50 to 91.50	APMS 17A	RM 409-26-1-1-1	APMS 17A × RGL 5613
1000-grain weight	14.31	17.02	16.92	12.90 to 17.05	13.35 to 21.00	13.45 to 19.30	APMS 15A	MTU 2347-158-3-1-1	APMS 15A × MTU 1213
Grain density (grain numbercm^{-1})	14.88	9.95	11.49	13.50 to 17.10	7.60 to 12.15	7.55 to 15.85	APMS 17A	UTR 76	APMS 17A × MTU 2055

Table 4: Relative heterosis, heterobeltiosis and standard heterosis for grain yield and yield component character

Character	Relative heterosis			Heterobeltiosis			Standard heterosis		
	Range	No. of desirable & significant heterotic hybrids	Best hybrid combination	Range	No. of desirable & significant heterotic hybrids	Best hybrid combination	Range	No. of desirable & significant heterotic hybrids	Best hybrid combination
Grain yield Per plant	-45.74 to 118.45	7	APMS 17A × RGL 5613	-54.55 to 107.37	6	APMS 17A × RGL 5613	-44.44 to 47.62	5	APMS 17A ×MTU 2055
Days to 50% flowering	-9.31 to 4.06	15	APMS 18A × MTU 1224	-10.29 to 4.06	15	APMS 17A × MTU 1224	-2.67 to 9.63	-	-
Days to maturity	-6.43 to 3.61	6	APMS 17A × MTU 1224	-8.40 to 2.79	9	APMS 17A × MTU 1224	-3.23 to 4.03	-	-
Plant Height	-7.64 to 16.17	-	-	-9.05 to 12.15	-	-	-18.15 to 8.43	7	APMS 15A ×MTU 1224
Productive tillers per plant	-20.83 to 52.98	15	APMS 17A × RGL 5613	-25.28 to 49.42	10	APMS 17A × RGL 5613	-19.39 to 55.76	21	APMS 17A × RGL 5613
Panicle length	-6.81 to 17.35	2	APMS 18A × MTU 2055	-11.25 to 15.11	2	APMS 18A × MTU 2055	-14.57 to 9.65	1	APMS 18A ×MTU 2055
Filled grains per panicle	-82.79 to 67.19	2	APMS 18A × MTU 2055	-82.79 to	1	APMS 18A × MTU 2055	-86.40 to 15.15	1	APMS 18A ×MTU 2055
Un-filled grains per panicle	-48.44 to 270.40	7	APMS 17A × RGL 5613	-69.05 to 163.26	13	APMS 17A × MTU 2055	-34.71 to 508.56	1	APMS 17A ×MTU 2055
Spikelet fertility	-75.93 to 8.34	2	APMS 17A × MTU 2055	-77.47 to 7.58	-	-	-71.70 to 1.63	-	-
1000-grain weight	-13.86 to 45.73	16	APMS 17A × MTU 2055	-30.48 to 43.82	5	APMS 17A × MTU 2055	-45.77 to 22.18	-	-
Grain density (grain number. cm^{-1})	-34.49 to 19.17	6	APMS 17A × MTU 2055	-44.74 to 3.33	-	-	-47.75 to 9.69	1	APMS 17A × MTU 2055

Table 5: Details of Promising hybrids identified

Hybrids	Characterization of parents with respect to *per se* performance	Grain yield per plant (g)	Relative heterosis (%)	Heterobeltiosis (%)	Standard heterosis (%)	Significant and positive standard heterosis recorded for other characters	Grain type
APMS 17A × MTU 2055	Low × High	46.50	58.43**	25.68**	47.62**	Un-filled grains per panicle, grain density, grain yield per plant	Medium slender, Straw glume
APMS 17A × RGL 5613	Low × Low	45.00	118.45**	107.37**	42.86**	Productive tillers per plant, grain yield perplant	Medium slender, Straw glume
APMS 15A × MTU 1213	High × Low	42.50	70.00**	63.46**	34.92**	Grain yield per plant	Medium bold, Straw glume
APMS 15A × RGL 5613	High × Low	42.00	84.62**	61.54**	33.33**	Productive tillers per plant, grain yield perplant	Medium slender, Straw glume
APMS 15A × MTU 2055	High × High	41.50	31.75**	12.16**	31.75**	Productivetillers per plant, grain yield perplant	Medium bold, Straw glume

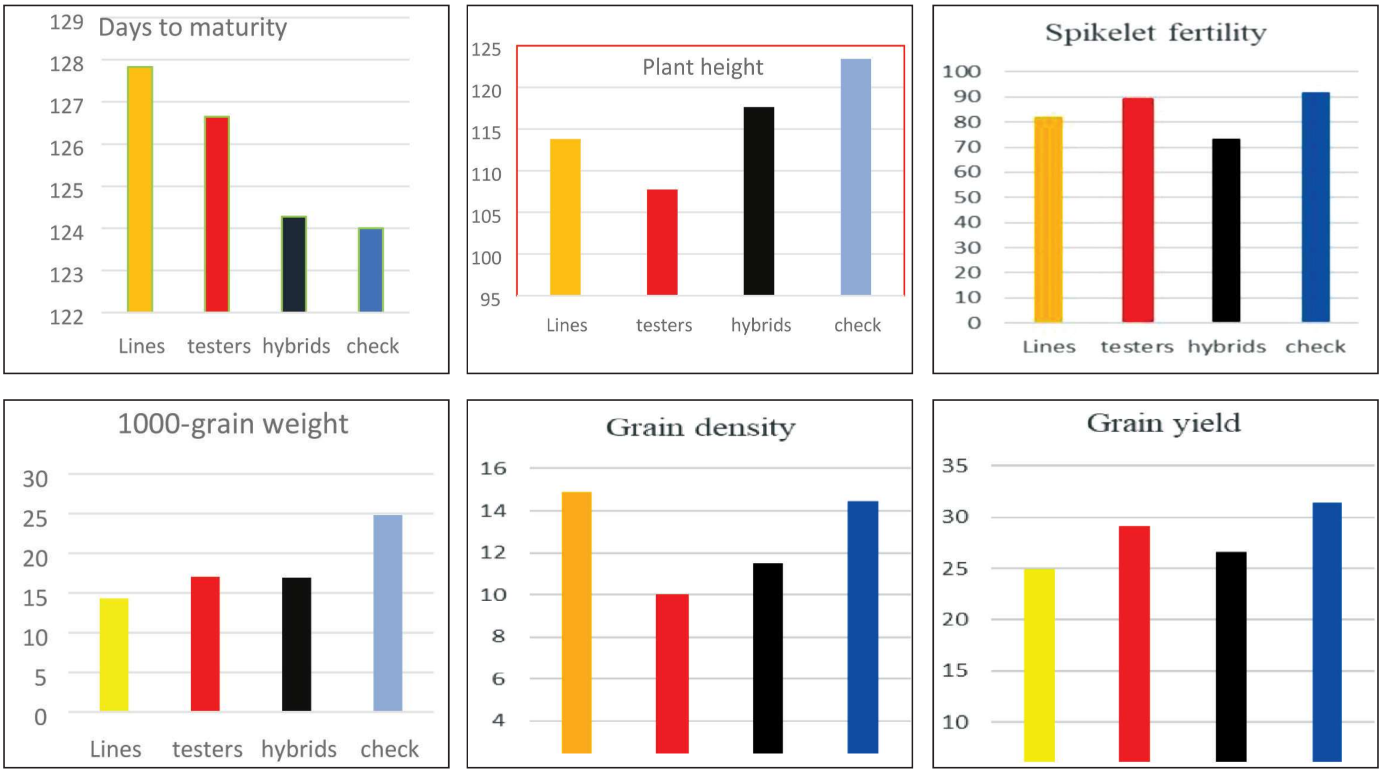

Figure 1: Mean performance of grain yield per plant and important yield attributes

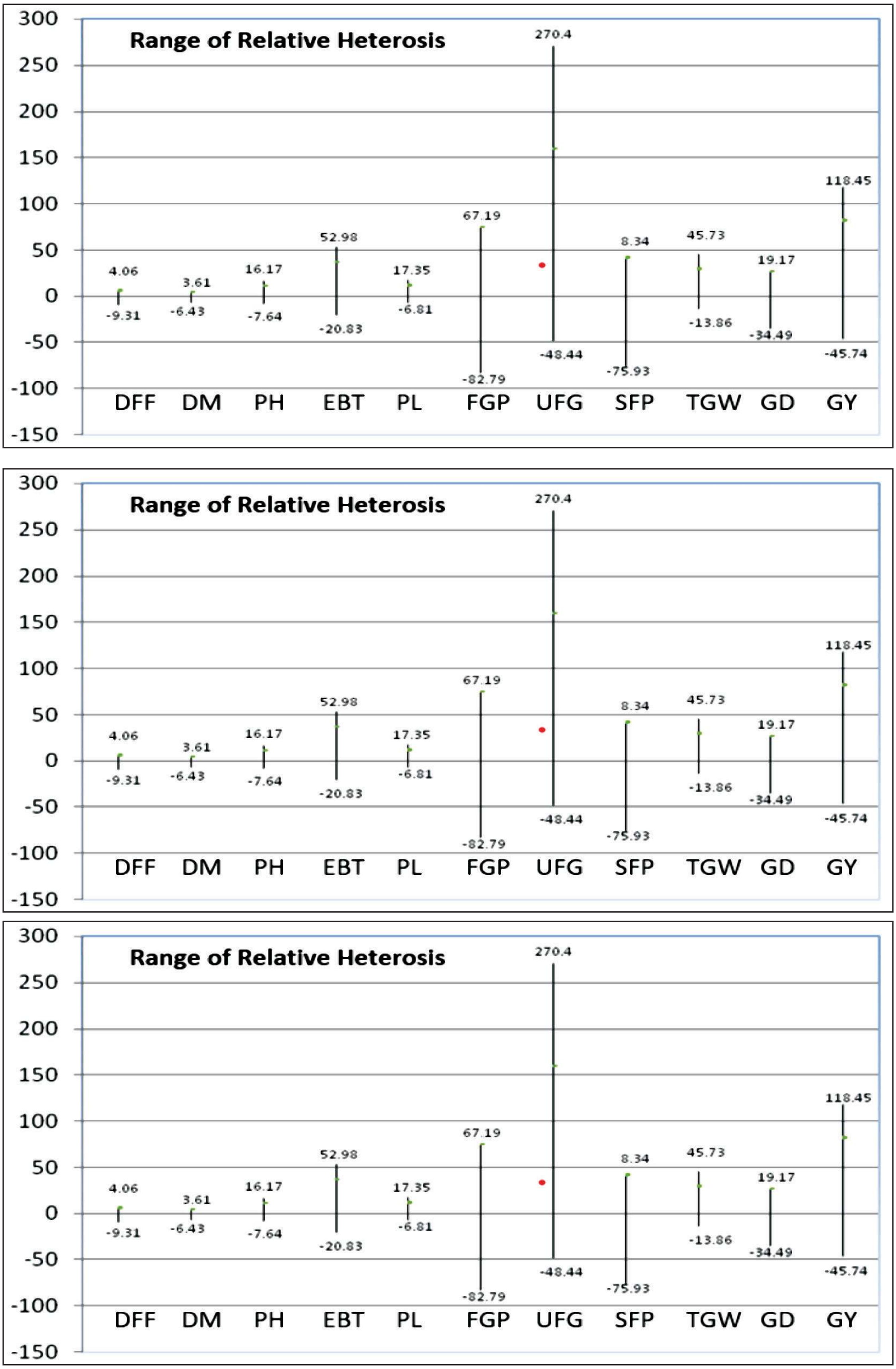

Figure 2: Range of relative heterosis, heterobeltiosis and standard heterosis for yield and yield component traits

Plant height

Negative heterosis is also desirable for the trait as dwarfness confers resistance to lodging. Relative heterosis was noticed to range from -7.64 (APMS 18A ×MTU 2347-158-3-1-1) to16.17 per cent (APMS 15A ×MTU 2055). However, heterobeltiosis ranged from -9.05 (APMS 15A ×MTU 1224) to 12.15 per cent (APMS 15A ×MTU 2055), while heterosis over the standard check ranged from -18.15 (APMS 15A ×MTU 1224) to 8.43 per cent (APMS 15A ×MTU 2055). Further, six crosses had recorded significant and desirable heterosis for the trait over the standard check, HRI-174. Similar results were reported by Bhati *et al.,* (2015) and Sri Lakshmi *et al.,* (2019). Of these, APMS15A× MTU 1224 had recorded more than 15 per cent significant and desirable heterosis over the standard check.

Productive tillers per plant

More number of productive tillers per plant resulting in higher number of panicles and ultimately more number of grains and grain yield per plant. Hence, positive heterosis is considered as desirable for the character. Heterosis over mid-parent range for this trait ranged from -20.83 (APMS 18A ×MTU 1213) to 52.98 per cent (APMS 17A ×RGL5613), while, heterobeltiosis was noticed to range from-25.28 (APMS 18A ×MTU 1213) to 49.42 per cent (APMS 17A ×RGL 5613). Standard heterosis ranged from -19.39 (APMS 18A ×MTU 1213) to 55.76 per cent (APMS 17A ×RGL 5613). Further, 15 crosses exhibited positive and significant heterosis over mid-parent, 10 hybrids over better parent and 21 over the standard hybrid check, HRI-174. Among these, 11 hybrids had recorded significant and desirable heterosis over mid-parent, better parent, and standard hybrid check, HRI-174. Of these, APMS17A×RGL 5613hadrecorded more than 45 per cent significant and desirable heterosis over the mid-parent, better parent and standard hybrid check. Similar levels of heterosis were reported by Rahman *et a*l., (2022).

Panicle length

Long panicles are a desirable trait and positive value has been considered as desirable for yield improvement. Relative heterosis for the trait ranged from -6.81 (APMS 18A × RGL 56133) to 17.35 per cent (APMS 18A × MTU 2055), while, heterobeltiosis ranged from -11.25 (APMS 18A × MTU 2716) to 15.11 per cent (APMS 18A × MTU 2055). However, standard heterosis was observed to range from -14.57 (APMS 15A × MTU 1224) to 9.65 per cent (APMS 18A × MTU 2055). Further, significant, and positive heterosis over mid parent and better parent was observed for two hybrids and one hybrid over the standard check, HRI-174. Among these, APMS 18A × MTU 2055 had recorded more than 10 per cent significant and desirable heterosis over mid-parent, better parent and the standard check. The findings agree with the reports of Ramakrishna *et al.,* (2023).

Filled grains per panicle

For this character, positive value has been considered desirable as it is directly associated with spikelet fertility percentage in rice. Relative heterosis estimates ranged from -82.79 (APMS 18A ×RGL 56133) to 67.19 per cent (APMS 18A ×MTU 2055). Two crosses exhibited positive and significant heterosis in the desired direction. On the other hand, heterobeltiosis ranged from-83.03 (APMS 17A × MTU 2716) to 44.09 per cent (APMS 18A × MTU 2055). Further, only one hybrid exhibited significant and positive heterosis over better parent. Heterosis over the standard check ranged from -6.40 (APMS 18A × MTU 2716) to15.15 per cent (APMS 18A × MTU 2055). One hybrid showed significant and positive standard heterosis. Among these, one hybrid APMS 18A × MTU 2055 had recorded more than 15 per cent significant and desirable heterosis over mid-parent, better parent and the standard check. These findings are in conformity with the results reported by Prasad *et al.,* (2019) and Vennela *et al*., (2022).

Un-filled grains per panicle

Heterosis in negative direction is desirable for this character. Relative heterosis for the trait ranged from -48.44 (APMS 17A × RGL 5613) to 270.40 per cent (APMS 17A × MTU 2716), respectively. Seven crosses showed significant and negative relative heterosis for the trait. Heterotic effects over better heterobeltiosis ranged from -11.25 (APMS 18A × MTU 2716) to 15.11 per cent (APMS 18A × MTU 2055). However, standard heterosis was observed to range from -14.57 (APMS 15A × MTU 1224) to 9.65 per cent (APMS 18A × MTU 2055). Further, significant, and positive heterosis over mid parent and better parent was observed for two hybrids and one hybrid over the standard check, HRI-174. Among these, APMS 18A × MTU 2055 had recorded more than 10 per cent significant and desirable heterosis over better parent and the standard check, indicating increased grain filling in the hybrid. These findings are in conformity with the results reported by Sri Lakshmi *et al.,* (2019).

Spikelet fertility

The estimates of heterosis over mid parent for spikelet fertility per centranged from -75.93 (APMS 18A × MTU 2716) to 8.34 per cent (APMS 17A × MTU 2055). Two crosses had exhibited significant and positive relative heterosis for this character. The estimates of heterobeltiosis ranged between -77.47 (APMS18A × MTU 2716) to 7.58 per cent (APMS 17A × RGL 5613). None of the crosses recorded significant and positive heterobeltiosis for the trait. On the other hand, economic heterosis ranged from -71.70 (APMS 17A × MTU 2716) to 1.63 per cent (APMS 17A ×MTU 2055). None of the crosses exhibited positive and significant standard heterosis for the character. Similar results were reported by Srivastava and Jaiswal (2016).

1000-Grain weight

Heterosis over mid parent ranged from -13.86 (APMS18A × MTU 2347-158-3-1-1) to 45.73 per cent (APMS 17A × MTU 2055). Sixteen crosses recorded positive and significant heterosis for the trait. Heterosis over better parent varied from -30.48 (APMS 18A × MTU 2347-158-3-1-1) to 43.82 per cent (APMS 17A × MTU 2055); and five crosses had recorded significant and positive heterobeltiosis for the trait. None of the crosses recorded significant and positive standard heterosis for the trait. Results of similar trend were also reported by Vanisree *et al*., (2011) and Prem kumar *et al.,* (2017).

Grain density

Heterosis over mid parent for grain density exhibited minimum and maximum values of -34.49 (APMS 15A × MTU 1224) to 19.17 per cent (APMS17A × MTU 2055) respectively. Six crosses exhibited significant and positive heterosis over mid parent. Estimates of heterosis over better parent varied between -44.74 (APMS17A× MTU 2716) to 3.32 per cent (APMS15A × UTR 76). None of the hybrids recorded significant and positive over better parent. On the other hand, standard heterosis ranged from -47.75 (APMS 15A ×MTU 1224) to 9.69 per cent (APMS 17A × MTU 2055). Of these, only one hybrid registered significant and positive heterosis over the check, HRI-174.

Grain yield per plant

Heterosis over mid parent for grain yield per plant ranged from -45.74 (APMS 15A × MTU 2846-34-1-1) to 118.45 per cent (APMS17A × RGL 5613). Similarly, high levels of relative heterosis for grain yield per plant were reported earlier (Buelah *et al.,* 2021). Seven crosses exhibited significant and positive heterosis over mid parent. Estimates of heterosis over better parent varied between -54.55 (APMS 15A × MTU 2846-34-1-1) to107.37 per cent (APMS 17A × RGL 5613). Similarly, high levels of heterobeltiosis for grain yield per plant were reported earlier (Vennela *et al*., 2022). Six crosses recorded positive and significant estimates of heterobeltiosis. On the other hand, standard heterosis ranged from -44.44 (APMS 15A × MTU 2846-34-1-1) to 47.62 per cent (APMS 17A

×MTU 2055). Similar levels of standard heterosis for grain yield per plant were reported earlier (Sudeepthi *et al.,* 2017). Further, Swaminathan *et al*., (1972) and Virmani (1996) had reported that about 20 to 30 per cent standard heterosis is sufficient to offset the extra cost of hybrid seed. In the present investigation, five crosses recorded significant and positive heterosis more than 30 per cent over the standard check, indicating their potential for commercial exploitation. Among these, APMS 17A × RGL 5613, APMS 15A × MTU 1213, APMS 15A × RGL 5613 and APMS 17A × MTU 2055 recorded significant and positive heterosis over mid and better parent also.

A perusal of the results on heterosis revealed several heterotic hybrids with significant and desirable heterosis for grain yield per plant and other yield attributes. Several workers have also reported similar significant and desirable heterosis for yield and yield components (Dar *et al*., 2015 and Srivastava and Jaiswal, 2016). Further, the hybrids, APMS 15A × RGL 5613, APMS 15A × MTU 1213, APMS 17A × RGL 5613 and APMS 17A × MTU 2055 were identified as promising and high yielding heterotic hybrids in the present study with significant and positive relative heterosis, heterobeltiosis and standard heterosis of more than 25 per cent for grain yield per plant. These hybrids had also recorded desirable levels of relative heterosis and heterobeltiosis for days to 50 per cent flowering.

Conclusion

The crosses, APMS 17A × MTU 2055, APMS 17A × RGL 5613, APMS 15 A × MTU 1213, APMS 15 A × RGL 5613 and APMS 15 A × MTU 2055are identified as promising heterotic combinations with potential for commercial exploitation and need to be tested over locations and years for their stability in performance, before utilization.

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