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Heterotic Analysis (*Oryza sativa* L.) in Drought Tolerant Rice Accessions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Water-deficit stress tolerance in rice is important for maintaining stable yield, especially under rain-fed ecosystem. After a thorough drought-tolerance screening of 200 rice genotypes from DBT, Network Rice Project in our previous study, 19 rice lines were selected for drought tolerance capacity. Six randomly chosen rice accessions out of these 19 rice accessions were further used for creation of F1 Hybrids for heterosis study. The study investigates the heterosis effects on key agronomic traits in rice hybrids, including days to 50% flowering, plant height, number of effective tillers per plant, spikelet fertility, grain yield per plant, and 100-grain weight. Analysis reveals

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diverse heterotic effects across hybrid combinations, with some hybrids exhibiting significant negative heterosis for traits like days to flowering and plant height, indicating potential for early maturation and dwarfism, respectively. Conversely, positive heterosis is observed in traits such as number of effective tillers, spikelet fertility, grain yield, and 100-grain weight, highlighting the potential for enhanced productivity. Notably, certain hybrids consistently display strong positive heterosis across multiple traits, suggesting their suitability for breeding programs aimed at improving overall yield and agronomic performance.

Keywords: Water deficit; standard heterosis; mid parent heterosis; heterobeltosis; line x tester, rice.

1. INTRODUCTION

Drought is the leading threat to agricultural food production, especially in the cultivation of rice, a semi-aquatic plant. Drought tolerance is a complex quantitative trait with a complicated phenotype that affects different developmental stages in plants. Furthermore, to feed the excess population in third-world countries like India, the development of hybrid rice technology might be an inventive genetic approach for narrowing the gap between rice production and demand, as well as augmentation of rice yield up to 15–20% over the current high yielding variety [1,2]. However, rice breeders are facing many challenges in increasing the production of rice [3] due to the decline in rice-growing areas, scarcity of water and labour, and impending intimidations of abiotic and biotic stresses.

In Asia, rice plays a central role in politics, society and culture, directly or indirectly employs more people than any other sector. Farmers must produce good yields without endangering the environment in order to earn a solid living and give the people who eat rice a nutritious, reasonably priced staple food. This is supported by the fact that a robust rice research industry can lower expenses, boost output, and guarantee environmental sustainability. It seems that the most practical and easily adjustable method for raising rice yield levels is hybrid rice technology. In India and outside, a great deal of study is being done on various facets of hybrid rice [4]. The success of the hybrid rice programme depends on the degree of heterosis, which also aids in the identification of possible cross combinations to be used in the conventional breeding programme to create a wide range of variability in the segregating generations [5]. Several pioneer hybrids have demonstrated a yield advantage of about 20% over current three-line hybrids on a commercial scale [4]. Hybrid rice technology has provided a significant contribution to food security and employment opportunities. Hybrid rice has superior grain yield to inbred rice cultivars and is one of the most significant applications of heterosis in crops [6].

The goal of this work was to find good performing F1 hybrids based on the performance of the estimates of heterosis [7], heterobeltiosis [8], and standard heterosis (comparison of F1 with the best commercial variety). Data from the replicated tests were analysed.

2. MATERIALS AND METHODS

Heterosis study six randomly chosen genotypes from the promising accessions found based on the drought tolerance were taken as testers and five commercial lines were mated in line into tester mating design, and simultaneously two drought tolerant standard checks were taken for the analysis of standard heterosis. Lists of lines testers and standard checks is mentioned in Table 1.

Table 1. List of accessions used under Line X Tester mating design

Lines	Testers	Standard checks
Swarna	IC458657	IGKV R2
RRF 140	IC206758	DRR DHAN 42
Dagad desi	IC516693	
IR 64	IC460497	
Maheshwari	IC463878	
	IC514866	

2.1 Statistical Analysis

Heterosis was calculated using the overall average of each hybrid over the replication for each trait. The percent of heterosis for each trait in F_1 was worked out by applying the method proposed by Liang et al. [9] in relation to mid parent (average heterosis), better parent (heterobeltiosis) and standard checks (standard heterosis).

2.2 Average/Mid-parent Heterosis

It was estimated as percent deviation of a mean value of F_1 from its mid-parental value.

$$\text{Average heterosis} = \frac{\overline{F1} - \overline{MP}}{\overline{MP}} \text{X } 100$$

Where,

$\overline{F1}$ = Mean performance of hybrid
$\overline{MP}$ = Mean performance of both parent involved in the crosses

2.3 Heterobeltiosis

It was estimated as the deviation of hybrid mean from the mean of better parent.

$$\text{Heterobeltiosis} = \frac{\overline{F1} - \overline{BP}}{\overline{BP}} \text{X } 100$$

Where,

$\overline{BP}$ = Mean performance of better parent

2.4 Standard Heterosis

It is also known as useful heterosis and was estimated as the percent deviation of hybrid mean from the mean of standard check.

$$\text{Average heterosis} = \frac{\overline{F1} - \overline{SC}}{\overline{SC}} \text{X } 100$$

Where,

$\overline{SC}$ = Mean performance of the standard check

The significance of different types of heterosis was assessed by adopting 't' test as suggested by Snedecor and Cochran [10]:

't cal' for mid-parent heterosis = $\frac{(F1 - MP}{\sqrt{(3EMS/r)}}$

't cal' for heterobeltiosis = $\frac{F1 - BP}{\sqrt{(2EMS/r)}}$

't cal' for standard heterosis = $\frac{F1 - SC}{\sqrt{(2EMS/r)}}$

Where,

EMS = Error mean sum of squares in the ANOVA table
r = Number of replications

After finding the 't' calculated value it was compared to the tabulated 't' value at corresponding error degrees of freedom for each trait.

The significance of estimated heterosis levels were evaluated using the t test as described by Turner [11]. Estimated t values were compared with two tailed tabular t values with corresponding error degrees of freedom at the 95 and 99% confidence intervals [3,12].

Gramaje [3] Heterosis and combining ability analysis in CMS hybrid rice. *Euphytica*, *216*, 1-22.

Turner [11] a study of heterosis in Upland cotton II. Combining ability and inbreeding effects.

Kumar [12] Estimation of heterosis for earliness and certain growth characters in rice (Oryza sativa L.). *Plant Archives*, *20*(2), 1429-1432.

3. RESULTS AND DISCUSSION

3.1 Heterosis Studies

Investigations on heterosis provides fundamental information regarding the utility of the cross combinations and its use for commercial exploitation. The magnitude of heterosis for grain yield, yield components and quality traits depends to a large extent on genetic variation, genetic base and adaptability of parents. The presence of significant amount of non-additive gene action is a prerequisite for the commercial exploitation of heterosis in rice [13].

A program to produce hybrid population may be initiated for a number of reasons. A partial listing of these would include existence of a significant amount of dominance variance, a requirement for high degree of uniformity in the harvested product, a need for flexibility in the program and the availability of cytoplasmic sterility. The demonstration of heterosis in crop is not adequate justification for the establishment of a program to produce hybrids. The existence of heterosis shows two things, some degree of genetic diversity between parents and some degree of dominance. Heterosis can arise when many loci are involved, if for each locus, the heterozygote is slightly super to the mid-parental value [14]. The existence of therefore, provides no guide as to the degree of dominance. Such information must be derived from specifically designed experiments.

The Heterosis over mid parent (Relative heterosis), over better parent (heterobeltiosis) and over standard check (standard heterosis/ useful heterosis) was estimated for all the characters under study. The estimates of mid parent, better parent and standard heterosis are given in Table 2.

Table 2. Mid parent heterosis, heterobeltiosis and standard heterosis

a. Days to 50 % flowering

F1 Cross	Mid	Better	IGKV R2	DRR DHAN 42
Swarna X IC458657	5.53	-1.48	17.11	16.09
Swarna X IC206758	7.04	6.81	10.09	9.13
Swarna X IC516693	20.43 *	19.15 *	22.81 *	21.74 *
Swarna X IC460497	4.58	2.45	10.09	9.13
Swarna X IC463878	-1.22	-5.45	6.58	5.65
Swarna X IC514866	-4.72	-7.94	1.75	0.87
RRF 140 X IC458657	-21.33 **	-25.25 **	-1.32	-2.17
RRF 140 X IC206758	-6.17	-16.61 *	10.09	9.13
RRF 140 X IC516693	-10.73	-21.26 **	3.95	3.04
RRF 140 X IC460497	-9.89	-18.27 *	7.89	6.96
RRF 140 X IC463878	-10.75	-17.28 *	9.21	8.26
RRF 140 X IC514866	-15.37 *	-22.26 **	2.63	1.74
Dagad desi X IC458657	-10.17	-13.65	2.63	1.74
Dagad desi X IC206758	0.83	-2.40	7.02	6.09
Dagad desi X IC516693	2.92	-1.20	8.33	7.39
Dagad desi X IC460497	-1.01	-2.00	7.46	6.52
Dagad desi X IC463878	-8.88	-10.12	1.32	0.43
Dagad desi X IC514866	1.99	1.59	12.28	11.30
IR64 X IC458657	-0.57	-4.06	14.04	13.04
IR64 X IC206758	10.29	6.35	17.54	16.52
IR64 X IC516693	-4.56	-8.73	0.88	0.00
IR64 X IC460497	-0.60	-1.98	8.33	7.39
IR64 X IC463878	1.38	0.39	13.16	12.17
IR64 X IC514866	5.16	5.16	16.23	15.22
Maheshwari X IC458657	-6.00	-10.33	6.58	5.65
Maheshwari X IC206758	5.83	3.25	11.40	10.43
Maheshwari X IC516693	4.20	0.81	8.77	7.83
Maheshwari X IC460497	-5.09	-5.28	2.19	1.30
Maheshwari X IC463878	4.97	2.72	15.79	14.78
Maheshwari X IC514866	2.81	1.59	12.28	11.30

**Significant at p=0.05% level, **Significant at p=0.01% level*

b. Plant height

F1 Cross	Mid	Better	IGKV R2	DRR DHAN 42
Swarna X IC458657	9.58	8.46	4.29	22.64 **
Swarna X IC206758	6.57	5.82	1.10	18.89 *
Swarna X IC516693	15.13 *	11.94	5.44	23.99 **
Swarna X IC460497	10.22	5.99	-0.16	17.40 *
Swarna X IC463878	4.73	0.01	-5.81	10.77
Swarna X IC514866	1.48	-3.48	0.78	18.51 *
RRF 140 X IC458657	-12.13 *	-19.70 **	-6.70	9.71
RRF 140 X IC206758	-19.25 **	-26.43 **	-14.51 *	0.53
RRF 140 X IC516693	3.23	-8.87	5.89	24.52 **
RRF 140 X IC460497	-2.39	-14.67 *	-0.86	16.59 *
RRF 140 X IC463878	-4.29	-16.85 **	-3.39	13.61
RRF 140 X IC514866	-19.42 **	-23.50 **	-11.12	4.52
Dagad desi X IC458657	-4.92	-9.59	-3.60	13.37

b. Plant height

F1 Cross	Mid	Better	IGKV R2	DRR DHAN 42
Dagad desi X IC206758	8.63	2.99	9.81	29.13 **
Dagad desi X IC516693	11.96	2.68	9.48	28.75 **
Dagad desi X IC460497	11.30	1.04	7.73	26.68 **
Dagad desi X IC463878	35.50 **	22.20 **	30.29 **	53.22 **
Dagad desi X IC514866	4.65	3.57	10.43	29.86 **
IR64 X IC458657	5.26	3.32	3.15	21.30 *
IR64 X IC206758	-13.20 *	-15.07 *	-15.21 *	-0.29
IR64 X IC516693	12.08	5.98	5.81	24.42 **
IR64 X IC460497	-4.01	-10.20	-10.34	5.43
IR64 X IC463878	1.45	-5.73	-5.89	10.67
IR64 X IC514866	-5.04	-7.13	-3.03	14.04
Maheshwari X IC458657	13.37 *	3.06	21.14 **	42.45 **
Maheshwari X IC206758	1.50	-8.00	8.14	27.16 **
Maheshwari X IC516693	-3.70	-15.41 *	-0.57	16.92 *
Maheshwari X IC460497	6.92	-6.99	9.32	28.56 **
Maheshwari X IC463878	5.33	-8.94	7.03	25.87 **
Maheshwari X IC514866	-15.05 **	-19.79 **	-5.72	10.87

*Significant at p=0.05% level, **Significant at p=0.01% level

c. Number of effective tillers per plant

F1 Cross	Mid	Better	IGKV R2	DRR DHAN 42
Swarna X IC458657	10.64	8.33	-16.13	-21.21 *
Swarna X IC206758	84.31 **	74.07 **	51.61 **	42.42 **
Swarna X IC516693	-11.11	-16.67	-35.48 **	-39.39 **
Swarna X IC460497	26.83 *	8.33	-16.13	-21.21 *
Swarna X IC463878	35.14 *	4.17	-19.35 *	-24.24 **
Swarna X IC514866	19.05	4.17	-19.35 *	-24.24 **
RRF 140 X IC458657	22.45 *	15.38	-3.23	-9.09
RRF 140 X IC206758	-1.89	-3.70	-16.13	-21.21 *
RRF 140 X IC516693	10.64	0.01	-16.13	-21.21 *
RRF 140 X IC460497	-6.98	-23.08 *	-35.48 **	-39.39 **
RRF 140 X IC463878	79.49 **	34.62 **	12.90	6.06
RRF 140 X IC514866	36.36 **	15.38	-3.23	-9.09
Dagad desi X IC458657	11.86	-8.33	6.45	0.01
Dagad desi X IC206758	55.56 **	36.11 **	58.06 **	48.48 **
Dagad desi X IC516693	-22.81 *	-38.89 **	-29.03 **	-33.33 **
Dagad desi X IC460497	13.21	-16.67 *	-3.23	-9.09
Dagad desi X IC463878	46.94 **	0.01	16.13	9.09
Dagad desi X IC514866	-33.33 **	-50.00 **	-41.94 **	-45.45 **
IR64 X IC458657	-9.80	-17.86	-25.81 **	-30.30 **
IR64 X IC206758	20.00 *	17.86	6.45	0.02
IR64 X IC516693	-6.12	-17.86	-25.81 **	-30.30 **
IR64 X IC460497	-15.56	-32.14 **	-38.71 **	-42.42 **
IR64 X IC463878	75.61 **	28.57 **	16.13	9.09
IR64 X IC514866	30.43 **	7.14	-3.23	-9.09
Maheshwari X IC458657	-4.00	-11.11	-22.58 *	-27.27 **
Maheshwari X IC206758	-7.41	-7.41	-19.35 *	-24.24 **
Maheshwari X IC516693	-29.17 **	-37.04 **	-45.16 **	-48.48 **
Maheshwari X IC460497	-31.82 **	-44.44 **	-51.61 **	-54.55 **
Maheshwari X IC463878	-5.00	-29.63 **	-38.71 **	-42.42 **
Maheshwari X IC514866	-15.56	-29.63 **	-38.71 **	-42.42 **

d. Number of filled grains per panicle				
F1 Cross	**Mid**	**Better**	**IGKV R2**	**DRR DHAN 42**
Swarna X IC458657	-27.64 **	-28.95 **	-22.02 *	-27.03 **
Swarna X IC206758	17.04 *	3.95	14.08	6.76
Swarna X IC516693	-12.62	-23.68 **	-16.25	-21.62 *
Swarna X IC460497	-28.73 **	-37.17 **	-31.05 **	-35.47 **
Swarna X IC463878	-28.32 **	-40.46 **	-34.66 **	-38.85 **
Swarna X IC514866	-0.97	-15.79	-7.58	-13.51
RRF 140 X IC458657	-33.77 **	-36.28 **	-27.08 **	-31.76 **
RRF 140 X IC206758	-11.75	-23.03 **	-11.91	-17.57 *
RRF 140 X IC516693	-25.74 **	-36.28 **	-27.08 **	-31.76 **
RRF 140 X IC460497	-23.13 **	-33.44 **	-23.83 *	-28.72 **
RRF 140 X IC463878	3.86	-15.14	-2.89	-9.12
RRF 140 X IC514866	4.91	-12.30	0.36	-6.08
Dagad desi X IC458657	-9.57	-12.97	-7.94	-13.85
Dagad desi X IC206758	-43.59 **	-47.23 **	-48.38 **	-51.69 **
Dagad desi X IC516693	-10.04	-17.34	-19.13 *	-24.32 **
Dagad desi X IC460497	-4.97	-11.81	-13.72	-19.26 *
Dagad desi X IC463878	4.66	-8.86	-10.83	-16.55
Dagad desi X IC514866	18.60 *	5.90	3.61	-3.04
IR64 X IC458657	-9.02	-15.70	-10.83	-16.55
IR64 X IC206758	4.53	1.60	-8.30	-14.19
IR64 X IC516693	0.21	-4.40	-13.72	-19.26 *
IR64 X IC460497	-3.32	-6.80	-15.88	-21.28 *
IR64 X IC463878	25.50 **	13.20	2.17	-4.39
IR64 X IC514866	42.12 **	31.60 **	18.77 *	11.15
Maheshwari X IC458657	-16.06 *	-17.06 *	-12.27	-17.91 *
Maheshwari X IC206758	-6.90	-15.03	-12.27	-17.91 *
Maheshwari X IC516693	3.31	-7.34	-4.33	-10.47
Maheshwari X IC460497	4.63	-5.24	-2.17	-8.45
Maheshwari X IC463878	8.01	-8.04	-5.05	-11.15
Maheshwari X IC514866	-10.22	-21.68 *	-19.13 *	-24.32 **

*Significant at p=0.05% level, **Significant at p=0.01% level

e. Spikelet fertility %				
F1 Cross	**Mid**	**Better**	**IGKV R2**	**DRR DHAN 42**
Swarna X IC458657	-4.27	-13.95 **	-7.74	-8.09 *
Swarna X IC206758	-17.41 **	-25.64 **	-20.27 **	-20.58 **
Swarna X IC516693	-17.21 **	-24.97 **	-19.55 **	-19.86 **
Swarna X IC460497	-13.90 **	-19.56 **	-13.75 **	-14.08 **
Swarna X IC463878	-18.71 **	-28.54 **	-23.37 **	-23.67 **
Swarna X IC514866	-0.96	-10.83 **	-4.40	-4.76
RRF 140 X IC458657	4.74	-6.32	1.56	1.17
RRF 140 X IC206758	8.11 *	-3.14	5.00	4.60
RRF 140 X IC516693	-5.51	-14.78 **	-7.62	-7.97 *
RRF 140 X IC460497	5.10	-2.31	5.90	5.50
RRF 140 X IC463878	15.62 **	1.17	9.67 *	9.25 *
RRF 140 X IC514866	15.28 **	3.28	11.97 **	11.54 **
Dagad desi X IC458657	6.47	-4.65	3.06	2.67
Dagad desi X IC206758	-52.89 **	-57.74 **	-54.32 **	-54.49 **
Dagad desi X IC516693	-9.05 *	-17.86 **	-11.22 **	-11.56 **
Dagad desi X IC460497	-4.62	-11.22 **	-4.04	-4.41
Dagad desi X IC463878	6.76	-6.47	1.10	0.71
Dagad desi X IC514866	9.83 **	-1.47	6.50	6.09
IR64 X IC458657	-2.16	-10.55 **	-7.68	-8.03 *
IR64 X IC206758	12.49 **	3.03	6.33	5.92
IR64 X IC516693	14.23 **	5.34	8.71 *	8.29 *

e. Spikelet fertility %				
F1 Cross	**Mid**	**Better**	**IGKV R2**	**DRR DHAN 42**
IR64 X IC460497	1.29	-3.66	-0.57	-0.95
IR64 X IC463878	1.86	-8.95 *	-6.03	-6.39
IR64 X IC514866	12.05 **	2.63	5.92	5.51
Maheshwari X IC458657	10.00 **	-3.48	9.34 *	8.92 *
Maheshwari X IC206758	5.66	-7.14 *	5.20	4.79
Maheshwari X IC516693	5.78	-6.43	5.99	5.59
Maheshwari X IC460497	8.23 *	-1.40	11.70 **	11.27 **
Maheshwari X IC463878	3.29	-11.29 **	0.49	0.11
Maheshwari X IC514866	-18.35 **	-28.24 **	-18.70 **	-19.02 **

*Significant at p=0.05% level, **Significant at p=0.01% level

f. Grain yield/Plant				
F1 Cross	**Mid**	**Better**	**IGKV R2**	**DRR DHAN 42**
Swarna X IC458657	-64.63 **	-66.28 **	-60.81 **	-62.82 **
Swarna X IC206758	10.87 **	4.08	37.84 **	30.77 **
Swarna X IC516693	-31.87 **	-35.42 **	-16.22 **	-20.51 **
Swarna X IC460497	-9.76 *	-13.95 **	0.02	-5.13
Swarna X IC463878	-53.75 **	-56.98 **	-50.00 **	-52.56 **
Swarna X IC514866	-54.49 **	-55.81 **	-48.65 **	-51.28 **
RRF 140 X IC458657	-53.09 **	-54.76 **	-48.65 **	-51.28 **
RRF 140 X IC206758	-27.47 **	-32.65 **	-10.81 *	-15.38 **
RRF 140 X IC516693	-53.33 **	-56.25 **	-43.24 **	-46.15 **
RRF 140 X IC460497	-37.04 **	-39.29 **	-31.08 **	-34.62 **
RRF 140 X IC463878	17.72 **	10.71 *	25.68 **	19.23 **
RRF 140 X IC514866	-24.85 **	-26.19 **	-16.22 **	-20.51 **
Dagad desi X IC458657	2.60	1.28	6.76	1.28
Dagad desi X IC206758	-5.75	-16.33 **	10.81 *	5.13
Dagad desi X IC516693	0.02	-10.42 **	16.22 **	10.26 *
Dagad desi X IC460497	14.29 **	12.82 **	18.92 **	12.82 **
Dagad desi X IC463878	20.00 **	18.42 **	21.62 **	15.38 **
Dagad desi X IC514866	24.84 **	20.99 **	32.43 **	25.64 **
IR64 X IC458657	-9.59 *	-15.38 **	-10.81 *	-15.38 **
IR64 X IC206758	-8.43 *	-22.45 **	2.70	-2.56
IR64 X IC516693	3.66	-11.46 **	14.86 **	8.97 *
IR64 X IC460497	-42.47 **	-46.15 **	-43.24 **	-46.15 **
IR64 X IC463878	38.03 **	32.43 **	32.43 **	25.64 **
IR64 X IC514866	16.78 **	7.41	17.57 **	11.54 *
Maheshwari X IC458657	24.64 **	10.26 *	16.22 **	10.26 *
Maheshwari X IC206758	22.78 **	-1.02	31.08 **	24.36 **
Maheshwari X IC516693	19.23 **	-3.13	25.68 **	19.23 **
Maheshwari X IC460497	27.54 **	12.82 **	18.92 **	12.82 **
Maheshwari X IC463878	25.37 **	13.51 **	13.51 **	7.69
Maheshwari X IC514866	36.17 **	18.52 **	29.73 **	23.08 **

*Significant at p=0.05% level, **Significant at p=0.01% level

g. 100 seed weight				
F1 Cross	**Mid**	**Better**	**IGKV R2**	**DRR DHAN 42**
Swarna X IC458657	4.85	1.57	6.82	1.34
Swarna X IC206758	-6.94	-12.98 *	-8.47	-13.17 *
Swarna X IC516693	23.00 **	11.86 *	17.65 **	11.61 *
Swarna X IC460497	11.98 *	11.86 *	17.65 **	11.61 *
Swarna X IC463878	12.24 *	10.65	19.76 **	13.62 *
Swarna X IC514866	-2.88	-3.94	3.29	-2.01
RRF 140 X IC458657	7.12	1.72	11.53	5.80
RRF 140 X IC206758	-12.28 *	-19.53 **	-11.76	-16.29 **

g. 100 seed weight				
F1 Cross	**Mid**	**Better**	**IGKV R2**	**DRR DHAN 42**
RRF 140 X IC516693	18.03 **	5.36	15.53 *	9.60
RRF 140 X IC460497	11.84 *	9.44	20.00 **	13.84 *
RRF 140 X IC463878	-5.40	-6.01	3.06	-2.23
RRF 140 X IC514866	3.79	2.79	12.71 *	6.92
Dagad desi X IC458657	15.93 **	13.79 *	16.47 **	10.49
Dagad desi X IC206758	15.78 **	9.66	12.24 *	6.47
Dagad desi X IC516693	24.84 **	14.94 *	17.65 **	11.61 *
Dagad desi X IC460497	6.24	4.93	10.12	4.46
Dagad desi X IC463878	1.68	-1.09	7.06	1.56
Dagad desi X IC514866	7.40	4.81	12.71 *	6.92
IR64 X IC458657	18.39 **	14.19 *	21.18 **	14.96 *
IR64 X IC206758	21.43 **	13.08 *	20.00 **	13.84 *
IR64 X IC516693	16.77 **	5.76	12.24 *	6.47
IR64 X IC460497	9.03	8.43	15.06 *	9.15
IR64 X IC463878	4.06	3.04	11.53	5.80
IR64 X IC514866	-4.19	-4.81	2.35	-2.90
Maheshwari X IC458657	6.59	0.21	12.24 *	6.47
Maheshwari X IC206758	16.30 **	5.67	18.35 **	12.28 *
Maheshwari X IC516693	12.35 *	-0.63	11.29	5.58
Maheshwari X IC460497	5.42	2.10	14.35 *	8.48
Maheshwari X IC463878	-4.49	-6.09	5.18	-0.22
Maheshwari X IC514866	-2.89	-4.83	6.59	1.12

**Significant at p=0.05% level, **Significant at p=0.01% level*

3.2 Days to 50% Flowering

The relative heterosis for this trait ranged from -21.33 % (RRF 140 X IC458657) to 20.43 % (Swarna X IC516693). The highest significant negative heterosis over mid parent recorded by cross RRF 140 X IC458657 (-21.33 %) followed by RRF 140 X IC514866 (-15.37 %). The heterobeltiosis ranged from –25.25 % (RRF 140 X IC458657) to 4.98% (Swarna X IC516693). The highest significant negative heterosis over better parent recorded by cross RRF 140 X IC458657 (-25.25 %) followed by RRF 140 X IC514866 (-22.26 %), RRF 140 X IC516693 (-21.26), RRF 140 X IC460497 (-18.27), RRF 140 X IC463878 (-17.28) and RRF 140 X IC206758 (-16.61). The standard heterosis (over DRR DHAN 42) ranged from -2.17% (RRF 140 X IC458657) to 21.74 % (Swarna X IC516693). Heterosis in both negative and positive direction for days to flowering has also been reported by by Premkumar et al. [15] and Awad-Allah, [16].

Negative heterosis is desirable for days to flowering because this will make the hybrids to mature earlier as compared to parents. Testers IC458657 showed highest significant negative estimates for mid and better parent heterosis. Tester IC458657 showed significant negative value for all heterotic estimates. IC458657 with IR 64 showed heterobeltiosis and relative heterosis in negative direction. It can also be used for developing early maturing hybrids.

The analysis of days to 50% flowering highlights a diverse range of heterosis values across hybrid combinations, indicating significant potential for influencing flowering time in breeding programs. Notably, hybrids involving RRF 140 consistently exhibited substantial negative heterosis, particularly notable in comparisons with both mid and better parent values. This suggests a genetic predisposition towards early flowering, making RRF 140 a promising candidate for developing early maturing hybrids. Tester IC458657 consistently demonstrated significant negative estimates across various heterotic measures, further underscoring its suitability for facilitating early maturation traits in hybrids. Additionally, the preference for negative heterosis aligns with the objective of achieving earlier maturity compared to parental lines.

3.3 Plant Height (cm)

The mid parent heterosis ranged from -19.42 % (RRF 140 X IC514866) to 35.50 % (Dagad desi X IC463878). Highest negative heterosis in plant height was obtained by cross RRF 140 X IC514866 (-19.42). The heterobeltiosis ranged from -26.43 % (RRF 140 X IC206758) to 22.20 % (Dagad desi X IC463878). Highest negative heterobeltosis in plant height was obtained by cross RRF 140 X IC206758 (-26.43). The standard heterosis (over IGKV R2) ranged from -15.21% (IR64 X IC206758) to 30.29 % (Dagad desi X IC463878). Highest negative standard heterosis in plant height was obtained by cross IR64 X IC206758 (-15.21). The standard heterosis (over DRR DHAN 42) ranged from -0.29 % (IR64 X IC206758) to 53.22 % (Dagad desi X IC463878). Among hybrids, none of them showed significant negative heterosis and nineteen hybrid showed significant positive heterosis for this trait.

Negative heterotic effects indicating that the hybrids were shorter than their mid parents and positive heterotic effects showed that hybrids were taller with their mid parents. Negative heterosis is desirable for plant height because this will make the hybrids to give more reproductive growth compared to parents. Testers IC514866 and IC206758 showed highest significant negative estimates for mid and better parent heterosis. Tester IC206758 showed significant negative value for all heterotic estimates over IGKV R2. Tester IC206758 with RRF 140 showed heterobeltiosis, relative heterosis and standard heterosis over IGKV R2 in negative direction. It can also be used for developing dwarf hybrid.

Similar results have also been reported by Sahu et al. [17], Borah et al. [18], Premkumar et al. [15], Thorat et al. [19], Kumar et al. [12], Awad-Allah, [16], El-Mowafi et al. [20] and Meena et al. [21]

A broad range of heterosis effects are shown by analysing plant height attributes across different hybrid combinations, with both positive and negative values affecting plant stature in comparison to parental lines. Notably, throughout several comparisons, hybrids including RRF 140 continuously showed significant negative heterosis, suggesting a tendency towards lower height in relation to the mid and higher parent values. This implies the possibility of producing dwarf hybrids, which would be especially interesting in crossings including the tests IC514866 and IC206758. Tester IC206758 is especially notable because it has the potential to be used in the breeding of dwarf varieties, as it consistently showed significant negative estimations across heterotic measurements. On the other hand, hybrids such as Dagad desi X IC463878 showed a strong positive heterosis, suggesting a tendency towards greater height in comparison to the parental lines. This might be useful for some breeding goals.

3.4 Number of Effective Tillers per Plant

The mid parent heterosis ranged from -33.33 % (Dagad desi X IC514866) to 84.31 % (Swarna X IC206758). Highest positive heterosis in number of effective tillers per plant was obtained by cross Swarna X IC206758 (84.31). The heterobeltiosis ranged from -50.00 % (Dagad desi X IC514866) to 74.07 % (Swarna X IC206758). Highest positive heterosis in number of effective tillers per plant was obtained by cross Swarna X IC206758 (74.07). The standard heterosis (over IGKV R2) ranged from -51.61 % (Maheshwari X IC460497) to 58.06 (Dagad desi X IC206758). Highest positive heterosis in number of effective tillers per plant was obtained by cross Dagad desi X IC206758 (58.06). The standard heterosis (over DRR DHAN 42) ranged from -54.55 % (Maheshwari X IC460497) to 48.48 % (Dagad desi X IC206758). Highest positive heterosis in number of effective tillers per plant was obtained by cross Dagad desi X IC206758 (48.48).

There is considerable potential for altering tillering capacity in breeding programmes, as evidenced by the examination of the number of effective tillers per plant across various hybrid combinations, which demonstrates a wide variety of heterosis effects. Notably, relative to parental lines, a number of hybrids—most notably Swarna X IC206758—exhibited highly significant positive heterosis, indicating a notable increase in tillering. This points to a possible way to boost grain yield by producing more tillers. On the other hand, hybrids such as Dagad desi X IC514866 showed a notable decrease in tiller numbers in comparison to their parental lines, as evidenced by their strong negative heterosis. The preference for positive heterosis over better parent and standard checks aligns with the objective of maximizing tiller production for improved crop yield. Additionally, the consistent demonstration of significant heterosis effects across different comparison standards underscores the robustness of these findings, providing valuable insights for breeders aiming to optimize tillering traits in crop hybrids.

High heterosis for more number of panicles per plant has been reported by Karpagam and Kalaiyarasi, [22], Premkumar et al. [15], Thorat et al. [19], Venkatesan et al. [23], Kumar et al. [12] and El-Mowafi et al. [24].

3.5 Number of Filled Grains per Panicle

The mid parent heterosis ranged from -43.59 % (Dagad desi X IC206758) to 42.12 % (IR64 X IC514866. Highest positive heterosis in number of filled grains per panicle s was obtained by cross IR64 X IC514866 (42.12). The heterobeltiosis ranged from -47.23 % (Dagad desi X IC206758) to 31.60 % (IR64 X IC514866). Highest positive heterosis in number of filled grains per panicles was obtained by cross IR64 X IC514866 (31.60). The standard heterosis (over IGKV R2) ranged from -48.38 % (Dagad desi X IC206758) to 18.77 % (IR64 X IC514866). Highest positive heterosis in number of filled grains per panicle s was obtained by cross IR64 X IC514866 (18.77).

The number of number of filled grains per panicle directly contributes to grain yield hence positive heterotic effect would be highly desirable. In the present study, more number of number of filled grains per panicle is closely associated with high grain yield per plant resulting high productivity. Therefore, the main interest is to find out the cross combinations with more number of long and heavy panicle bearing tillers. The tester IC514866 with line IR 64 recorded higher values of heterotic expression for better parent, mid parent and check IGKV R2. Virmani et al. [25,26] reported that heterosis in grain yield was primarily due to increased number of spikelets per panicle further supported by Patel et al. (1994) and Reddy (1996) that confirms the present trend in these traits.

Analysing the amount of filled grains per panicle in a variety of hybrid combinations shows strong heterosis effects, indicating a great deal of potential for affecting grain output in breeding programmes. Some hybrids, like IR64 X IC514866, showed considerable positive heterosis, meaning that the number of filled grains was higher than in the parental lines. Other hybrids, like Dagad desi X IC206758, showed significant negative heterosis, indicating that the number of filled grains was lower. Given that they directly affect grain production and overall productivity, this emphasises the significance of choosing hybrid combinations with positive heterotic effects. IC514866 showed stronger heterotic expression across many comparative standards, especially when combined with line IR64, highlighting its potential for generating hybrids with better grain-filling traits. This is consistent with other research that suggests an increase in spikelets per panicle is the primary cause of heterosis in grain production. This emphasises the significance of choosing hybrids with improved panicle features in order to achieve higher productivity.

Significant positive heterosis for number of number of filled grains per panicle s per panicle was reported by Devi et al. [27], Premkumar et al. [15] and Ramesh et al. [28], Meena et al. [21] and El-Mowafi et al. [24].

3.6 Spikelet Fertility (%)

The mid parent heterosis ranged from -52.89 % (Dagad desi X IC206758) to 15.62 % (RRF 140 X IC463878. Highest positive heterosis in spikelet fertility per panicle was obtained by cross RRF 140 X IC463878 (15.62). The heterobeltiosis ranged from -57.74 % (Dagad desi X IC206758) to 5.34 % (IR64 X IC516693). The standard heterosis (over IGKV R2) ranged from -54.32 % (Dagad desi X IC206758) to 11.97 % (RRF 140 X IC514866). Highest positive heterosis in spikelet fertility per panicle was obtained by cross RRF 140 X IC514866 (11.97). The standard heterosis (over DRR DHAN 42) ranged from -54.49 % (Dagad desi X IC206758) to 11.54 % (RRF 140 X IC514866). Highest positive heterosis in spikelet fertility per panicle was obtained by cross RRF 140 X IC514866 (11.54).

The evaluation of spikelet fertility percentage in different hybrid combinations shows a broad range of heterosis effects, suggesting a substantial potential to affect the success of reproduction in breeding programmes. Significant negative heterosis was seen in some hybrids, such as Dagad desi X IC206758, indicating a drop in fertility, while significant positive heterosis was seen in some hybrids, such as RRF 140 X IC463878 and RRF 140 X IC514866, suggesting an increase in spikelet fertility relative to parental lines. This emphasises how crucial it is to choose hybrid combinations that have favourable heterotic effects because they have a direct impact on yield potential overall. Among the comparative standards, RRF 140 X IC514866 had the highest positive heterosis continuously, indicating that it may have the ability to increase spikelet fertility and ultimately crop productivity.

Most of the hybrids had negative heterosis due to the problem of spikelet sterility, as reported by Virmani et al. [26]. Standard heterosis of both positive and negative nature was observed by Panwar et al. [29] whereas; similar nature for heterobeltiosis was reported by and Belhekar et al. [30]. Positive heterosis over better parent and standard variety was reported by Virmani et al. [25] they concluded that heterosis in grain yield was primarily due to increased number of filled grains per panicle s per panicle. Similar result was also observed by Devi et al. [27], El-Mowafi et al. [24].

3.7 Grain Yield per Plant (g)

The mid parent heterosis ranged from -64.63 % (Swarna X IC458657) to 38.03 % (IR64 X IC463878). Highest positive heterosis in grain yield per plant was obtained by cross IR64 X IC463878 (38.03). The heterobeltiosis ranged from -66.28 % (Swarna X IC458657) to 32.43 % (IR64 X IC463878). Highest positive heterosis in grain yield per plant was obtained by cross IR64 X IC463878 (32.43). The standard heterosis (over IGKV R2) ranged from -60.81 % (Swarna X IC458657) to 37.84 % (Swarna X IC206758). Among hybrids, fifteen hybrids showed significant positive standard heterosis while eleven hybrids showed significant negative standard heterosis for this trait. Highest positive heterosis in grain yield per plant was obtained by cross Swarna X IC206758 (37.84). The standard heterosis (over DRR DHAN 42) ranged from -62.82 % (Swarna X IC458657) to 30.77 % (Swarna X IC206758). Highest positive heterosis in grain yield per plant was obtained by cross Swarna X IC206758 (30.77).

Grain yield is a complex trait that is multiplicative end product of several attributes of yield. Hybrid showing high heterosis for grain yield per plant, also manifested heterotic effects for productive tillers per plant, panicle length, fertile grains per panicle.

There is a great deal of opportunity for increasing yield in breeding programmes when the examination of grain yield per plant across various hybrid combinations shows a wide variety of heterosis effects. A significant increase in grain yield compared to parental lines was indicated by several hybrids that showed significant positive heterosis, including IR64 X IC463878 and Swarna X IC206758. In order to optimise yield potential, this emphasises how crucial it is to choose hybrid combinations with favourable heterotic effects. Hybrids such as Maheshwari X IC514866 have been seen to exhibit constant high positive heterosis when compared to different standards, indicating their potential for higher yield performance. Furthermore, the fact that other yield-related characteristics like as the number of productive tillers per plant and the number of viable grains per panicle are correlated with grain yield emphasises the multifactorial nature of grain production and the necessity of comprehensive breeding methods that target various yield components. For breeders hoping to create crop hybrids with improved agronomic performance and high yields, these results provide insightful information.

Increased grain yield in rice due to various component traits as observed in the present investigation is in close conformity the finding observed by the other workers Anis et al. [20], Devi et al. [24], Karpagam and Kalaiyarasi, [22], Thorat et al[19], Venkatesan et al. [23] and El-Mowafi et al. [24].

3.8 100 Grain Weight (g)

The mid parent heterosis ranged from -12.28 % (RRF 140 X IC206758) to 24.84 % (Dagad desi X IC516693). Highest positive heterosis in 100 seed weight was obtained by cross Dagad desi X IC516693 (24.84). The heterobeltiosis ranged from -19.53 % (RRF 140 X IC206758) to 14.94 % (Dagad desi X IC516693). Highest positive heterosis in 100 seed weight was obtained by cross Dagad desi X IC516693 (14.94). The standard heterosis (over IGKV R2) ranged from -11.76 % (RRF 140 X IC206758) to 21.18 % (IR64 X IC458657). Highest positive heterosis in 100 seed weight was obtained by cross IR64 X IC458657 (21.18). The standard heterosis (over DRR DHAN 42) ranged from -16.29 % (RRF 140 X IC206758) to 14.96 % (IR64 X IC458657). Highest positive heterosis in 100 seed weight was obtained by cross IR64 X IC458657 (14.96).

Significant heterosis effects are revealed when 100-grain weight is compared between different hybrid combinations, underscoring the possibility of improving this crucial yield factor in breeding programmes. Notably, a number of hybrids including IR64 X IC458657 and Dagad desi X IC516693 showed significant positive heterosis, suggesting a notable increase in seed weight in comparison to parental lines. Grain weight plays a major role in total yield, which emphasises how important it is to choose hybrid combinations with positive heterotic effects to maximise yield potential. The trait hundred grain weight is an important yield component in the final grain yield, as the bold grained varieties normally out grain yield the other types. In the present study positive significant values are reported which were in agreement with the earilier findings by Rahimi et al. [31], Krishna et al. (2011), Pratap et al. [32] and Latha et al. [33].

4. CONCLUSION

In conclusion, the study underscores the importance of heterosis effects in shaping rice hybrid performance across various agronomic traits. The findings suggest avenues for targeted breeding efforts to enhance traits crucial for yield and productivity. Notably, hybrids exhibiting consistent positive heterosis across multiple traits hold promise for improving overall crop performance. Furthermore, the identification of hybrids with significant negative heterosis for specific traits presents opportunities for developing specialized varieties, such as early maturing or dwarf hybrids. Overall, the insights provided by this research offer valuable guidance for rice breeders seeking to optimize hybrid combinations for enhanced agronomic performance and yield potential.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kumar A, Singh VJ, Krishnan SG, Vinod KK, Bhowmick PK, Nagarajan M, Singh AK. WA-CMS-based iso-cytoplasmic restorers derived from commercial rice hybrids reveal distinct population structure and genetic divergence towards restorer diversification. 3 Biotech. 2019;9:1-15.
2. Azad AK, Sarker U, Ercisli S, Assouguem A, Ullah R, Almeer R, Peluso I. Evaluation of combining ability and heterosis of popular restorer and male sterile lines for the development of superior rice hybrids. Agronomy. 2022;12(4):965.
3. Gramaje LV, Caguiat JD, Enriquez JOS, dela Cruz QD, Millas RA, Carampatana JE, Tabanao, DAA. Heterosis and combining ability analysis in CMS hybrid rice. Euphytica, 2020;216:1-22.
4. Begum S, Reddy V, Srinivas B, Arunakumari CH. Heterosis studies for yield and physical quality traits in hybrid rice (*Oryza sativa* L.). Journal of Crop and Weed. 2020;16(1):38-50.
5. Ray SR, Islam AA, Rasul MG, Saikat MHA, Ahmed JU. Heterobeltiosis and economic heterosis for grain yield related traits of boro rice (*Oryza sativa* L.). International Journal of Applied Sciences and Biotechnology. 2021;9(1):45-53.
6. Liu J, Li M, Zhang Q, Wei X, Huang X. Exploring the molecular basis of heterosis for plant breeding. Journal of Integrative Plant Biology. 2020;62(3):287-298.
7. Matzinger DF, Mann TJ, Cockerham CC. Diallel crosses in Nicotiana tabacum; 1962.
8. Fonseca S, Patterson FL. Hybrid vigor in a seven-parent diallel cross in common winter wheat (*Triticum aestivum* L.) 1. Crop Science. 1968;8(1):85-88.
9. Liang GH, Reddy CR, Dayton AD. Heterosis, inbreeding depression, and heritability estimates in a systematic series of grain sorghum genotypes 1. Crop Science. 1972;12(4):409-411.
10. Snedecor GW, Cochran WG. Statistical Methods. Ames, IA; 1967.
11. Turner JJ. A study of heterosis in Upland cotton II. Combining Ability and Inbreeding Effects; 1953.
12. Kumar CPS, Sathiyabama R, Suji DB, Muraleedharan A. Estimation of heterosis for earliness and certain growth characters in rice (*Oryza sativa* L.). Plant Archives. 2020;20(2):1429-1432.
13. Lingaiah N, Raju CS, Sarla N, Radhika K, Venkanna V, & Reddy D. Genetic mechanism of heterosis and inbreeding depression for grain physical quality traits in elite rice (*Oryza sativa* L.) crosses. Journal of Eco-Friendly Agriculture. 2023;18(1):55-60.
14. Labroo MR, Studer AJ, Rutkoski JE. Heterosis and hybrid crop breeding: A multidisciplinary review. Frontiers in Genetics. 2021;12:643761.
15. Premkumar R, Gnanamalar RP, Anandakumar CR. Heterosis analysis for grain yield and yield component traits in rice (*Oryza sativa* L.). Journal of Pharmacognosy and Phytochemistry. 2017;6(6):881-884.
16. Awad-Allah MMA. Heterosis and combining ability estimates using line x tester analysis to develop wide compatibility and restorer lines in rice. Journal of Agricultural Chemistry and Biotechnology. 2020;11(12):383-393.
17. Sahu R, Singh SK, Singh DK, Vennela PR, Yerva SR, Kumar D, Rathan ND. Heterosis studies for yield & yield traits in rice (*Oryza Sativa* L.) under rainfed condition. International Journal of Agriculture,

Environment and Biotechnology. 2017; 10(1):1-10.

18. Borah PULIN, Sarma DEBOJIT, Hazarika GN. Magnitude of heterosis for yield and its components in hybrid rice (*Oryza sativa* L.). International Journal of Agricultural Science and Research. 2017;7(2):209-216.
19. Thorat BS, Kunkerkar RL, Bagkar TA. Studies on heterosis for yield and its contributing traits in hybrid rice (*Oryza sativa* L.). International Journal of Chemical Studies. 2017;5(5):07-12.
20. Anis G, El-Mowafi H, El-Sherif A, Freeg H, El-Sayed A, Sabagh AE. Utilizing two line system in hybrid rice (*Oryza sativa* L.) and potential yield advantage under Egyptian conditions. Agricultural Advances. 2017; 6(3):398-406.
21. Meena D, Karnwal MK, Chaudhary H, Kashyap S, Sachan N. Study of heterosis for yield and quality traits in rice (*Oryza sativa* L.) using line x tester mating system. Journal of Pharmacognosy and Phytochemistry. 2021;10(2):384-391.
22. Karpagam V, Kalaiyarasi R. Choice of parents for developing two line hybrids in rice (*Oryza sativa* L.). Journal of Applied and Natural Science. 2017;9(4):2047-2054.
23. Venkatesan M, Karthikeyan P, Mohan BV. Gene action and heterosis for yield and its component traits in rice (*Oryza sativa* L.) through line x tester analysis under saline condition. Plant Archives (09725210). 2019;19(2).
24. El-Mowafi HF, AlKahtani MD, Abdallah RM, Reda AM, Attia KA, El-Hity MA, El-Esawi MA. Combining ability and gene action for yield characteristics in novel aromatic cytoplasmic male sterile hybrid rice under water-stress conditions. Agriculture. 2021;11(3):226.
25. Virmani SS, Chaudhary RC, Khush GS. Current outlook on Hybrid Rice; 1981.
26. Virmani S, Aquino RC, Khush GS. Heterosis breeding in rice (*Oryza sativa* L.). Theoretical and Applied Genetics. 1982;63:373-380.
27. Devi KR, Venkanna V, Chandra BS, Hari Y. Gene action and combining ability for yield and quality traits in rice (*Oryza Sativa* L.) using diallel analysis. International Journal of Current Microbiology and Applied Sciences. 2018;7(1):2834-2843.
28. Ramesh C, Raju CD, Raju CS, Varma NR. Combining ability and gene action in hybrid rice. Int. J. Pure App. Biosci. 2018;6(1): 497-510.
29. Panwar DVS, Rakesh K, Singh A, Mehta BS. Studies on heterosis in hybrid rice. Oryza. 2002;39:54-55.
30. Belhekar PS, Meheta HD, Patil HM, Bhor TJ, Patil YJ, Lende NS. Heterosis and combining ability in aromatic hybrid rice (*Oryza sativa* L.). International Journal of Chemical Studies. 2017;5:1341-1345.
31. Rahimi M, Rabiei B, Samizadeh H, KAFI GA. Combining ability and heterosis in rice (*Oryza sativa* L.) Cultivars; 2010.
32. Pratap NARENDRA, Shekhar R, Singh PK, Soni SK. Combining ability, gene action and heterosis using cms lines in hybrid rice (*Oryza sativa* L.). The Bioscan. 2013;8(4): 1521-1528.
33. Latha S, Sharma D, SANGHERA GS. Combining ability and heterosis for grain yield and its component traits in rice (*Oryza sativa* L.). Notulae Scientia Biologicae. 2013;5(1):90-97.

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