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Heterosis studies for yield and yield contributing traits in aerobic rice (*Oryza sativa* L.)

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Abstract
The investigation on "Heterosis Studies for Yield and Yield Contributing Traits in Aerobic Rice (*Oryza sativa* L.)" was conducted during Rabi 2024-25 at the Regional Agricultural Research Station, Karjat, Dist. Raigad. Line × Tester mating design involving 3 lines (female) and 5 testers (male) were used to generate 15 hybrids. The experimental material, including parents, hybrids, and two checks, was evaluated in a randomized block design with three replications for 16 yield and quality-related traits. Analysis of variance revealed significant differences among genotypes for all traits, except straw yield per plant and protein content, indicating the presence of substantial genetic variability. The cross Ratnagiri 2 × Sahbhagi Dhan recorded the highest grain yield per plant (66.9 g), followed by (Ratnagiri 2 × Siri 1253) and (Karjat 3 × CR Dhan 202). These hybrids also exhibited high harvest index values, indicating efficient resource partitioning. The cross Karjat 5 × CR Dhan 202 exhibited the highest protein content (7.19%), while Ratnagiri 2 × Sahbhagi Dhan recorded the highest amylose content (25.13%). Combining ability analysis revealed that Ratnagiri 2 was the best general combiner among lines for grain yield and its components, while Siri 1253 and Sahbhagi Dhan were superior among testers. The hybrid Ratnagiri 2 × Sahbhagi Dhan showed the highest specific combining ability effects for grain yield and root biomass. Traits like plant height, productive tillers per plant, and grain yield per plant were governed predominantly by non-additive gene action (SCA > GCA), suggesting the suitability of heterosis breeding for these traits. High heritability in narrow sense was recorded for days to 50% flowering (89.87%), followed by test weight and harvest index, indicating scope for selection-based improvement. The study identified Karjat 3 × CR Dhan 202, Ratnagiri 2 × Sahbhagi Dhan, and Karjat 3 × Sahbhagi Dhan as promising hybrids with significant standard and economic heterosis for yield and associated traits. These results highlight their potential in the development of early maturing, high-yielding aerobic rice hybrids suitable for water-limited conditions.

Keywords: Aerobic rice, combining ability, heterosis, Line × Tester analysis, gene action, grain yield, heritability, additive effects

Introduction
Rice (*Oryza sativa* L.) is a staple food crop of global importance and is cultivated extensively across diverse agro-ecological regions. In India, rice occupies a prominent position both in terms of area and production. However, conventional transplanted rice cultivation is highly resource-intensive, demanding substantial quantities of water and labor. With the growing threat of climate change and shrinking water resources, there is an urgent need to adopt sustainable rice production technologies. Aerobic rice cultivation, a resource-conserving technology, has emerged as an alternative to traditional puddled transplanting. It involves growing rice under non-puddled and non-saturated soil conditions with minimal water use. Although it saves irrigation water and reduces methane emissions, yields under aerobic conditions are often lower due to sub-optimal root development, reduced tillering, and abiotic stress exposure. Hence, improving the genetic potential of rice genotypes for aerobic conditions is critical to ensure food security and sustainability. Hybrid breeding offers a viable solution to improve yield potential under such conditions. Combining ability analysis using Line × Tester mating design helps in identifying superior parents and hybrid combinations. General combining ability (GCA) reflects additive gene effects, whereas specific combining ability (SCA) denotes non-additive gene effects. Heterosis or hybrid vigor is another important genetic phenomenon that can be exploited to enhance productivity

in aerobic rice. The present investigation was undertaken to evaluate the extent of genetic variability, combining ability, gene action, and heterosis for yield and yield-contributing traits in aerobic rice using a Line × Tester analysis involving 3 lines and 5 testers. The aim was to identify promising hybrids and parental lines for further breeding programs under water-limited conditions.

Materials and Methods

The investigation entitled "Heterosis Studies for Yield and Yield Contributing Traits in Aerobic Rice (*Oryza sativa* L.)" was carried out during Rabi 2024-25 at the Regional Agricultural Research Station (RARS), Karjat, District Raigad, Maharashtra. The experimental site is characterized by lateritic soil with a moderately acidic pH of 5.7. Karjat is located in the western part of Maharashtra at coordinates between 17°95′ and 20°20′ N latitude and 73°48′ E longitude, with an elevation of 51.75 meters above sea level. The area experiences a warm and humid climate, with average annual rainfall ranging from 2500 to 3500 mm, mostly occurring between June and November. The experimental material comprised eight genotypes (parents) including three lines (Karjat 3, Karjat 5, Ratnagiri 2) and five testers (CR Dhan 202, Sahbhagi Dhan, DRR Dhan 55, Siri 1253, and Ratnagiri 1). These were crossed using a Line × Tester mating design during *Kharif* 2024-25 resulting the 15 crosses, along with the parents and two check varieties (Sabita and CR Dhan 204) formed the 25 entries were evaluated during Rabi 2024-25. The experiment was laid out in a Randomized Block Design (RBD) with three replications. Each genotype was sown on 30th December 2024 in a plot of 1.2 m^2 (1 m × 1.2 m) with 30 × 10 cm spacing. Each entry was planted in four rows with ten plants per row. All recommended agronomic practices for aerobic rice cultivation were followed uniformly across treatments to ensure a healthy crop. Observations were recorded on five randomly selected competitive plants per plot for the following 16 traits days to 50% flowering, plant height, panicle length, productive tillers per plant, number of grains per panicle, spikelet fertility, length-to-breadth ratio of grain, grain yield per plant, straw yield per plant, test weight (1000-grain weight), harvest index, root biomass, protein content, amylose content, milling percentage, and head rice recovery. Standard procedures were followed for measurement of quality traits. Protein content was determined using the Kjeldahl method (N × 6.25), and amylose content was estimated following the Juliano method (1971) [8]. The data were subjected to statistical analysis using Windostat software. Analysis of Variance (ANOVA) was carried out for all traits to detect significant differences among genotypes. Combining ability analysis was performed using Kempthorne's (1957) [9] Line × Tester method to estimate general combining ability (GCA) and specific combining ability (SCA) effects. Heterosis was estimated over the mid-parent, better parent, and standard check varieties. Additionally, genetic parameters such as genotypic and phenotypic coefficients of variation (GCV and PCV), heritability, and genetic advance were calculated to assess the nature and magnitude of variability present in the material.

Results and Discussion

The analysis of variance (ANOVA) for 16 characters in aerobic rice revealed highly significant mean squares due to genotypes for all traits, except straw yield per plant and protein content, indicating the presence of considerable genetic variability among genotypes for most of the traits under study. The genotypic component was further partitioned into parents, hybrids, and parents vs. hybrids.

Among parents, mean squares due to lines were significant for all traits except number of grains per panicle, straw yield per plant, and protein content. In the case of testers, mean squares were significant for all traits except productive tillers per plant, panicle length, spikelet fertility, and root biomass, reflecting substantial genetic diversity among parental lines for most of the characters evaluated. The interaction component (lines vs. testers) exhibited significant differences for all traits except number of grains per panicle, spikelet fertility, straw yield per plant, and head rice recovery, suggesting that female and male parents differed significantly for most traits under investigation.

The parents vs. hybrids comparison showed significant mean squares for all traits except plant height, productive tillers per plant, spikelet fertility, root biomass, straw yield per plant, harvest index, and protein content, indicating a substantial magnitude of heterosis for the majority of characters. Similarly, check vs. hybrids comparison revealed significant differences for all traits except productive tillers per plant, number of grains per panicle, spikelet fertility, straw yield per plant, milling percentage, head rice recovery, and protein content, highlighting heterotic potential between checks and hybrids. Moreover, the check 1 vs. check 2 comparison recorded significant differences for panicle length, root biomass, grain yield per plant, test weight, harvest index, length-to-breadth ratio, amylose content, and protein content, indicating notable variation among the check varieties. Overall, the ANOVA results confirmed significant differences among genotypes for most of the traits, including days to 50% flowering, plant height, productive tillers per plant, panicle length, number of grains per panicle, spikelet fertility, root biomass, grain yield per plant, test weight, harvest index, length-to-breadth ratio, milling percentage, head rice recovery, and amylose content. These results point to the presence of considerable genetic variability in the experimental material, which can be effectively exploited for crop improvement. The significance of the parent vs. hybrid comparison for traits such as grain yield, amylose content, and root biomass further indicates the expression of heterosis for these characters. However, straw yield per plant and protein content exhibited non-significant variation across most comparisons, suggesting that these traits may be more influenced by environmental factors or that the genetic diversity for these traits is relatively low in the present material. These findings are in close agreement with earlier reports by Prasad *et al*. (2014) [14], who also observed significant genotypic differences for yield and related physiological traits in rice, thereby confirming the potential of utilizing genetic variability and heterosis through selection and hybridization strategies for crop improvement.

The estimation of general combining ability (GCA) variances for lines (s^2l) were highly significant for days to 50 percent flowering, plant height, no. of grains per panicle, grain yield plant-1, test weight, harvest index, length to breadth ratio Head rice recovery. While general combining ability (GCA) variance for testers (s^2t) was found significant for days to 50 percent flowering, Plant height, No. of grains per panicle, grain yield plant-1, Test weight and head rice recovery. The magnitude of SCA variance was higher than GCA variance for all characters except days to 50 percent flowering, plant height No. of grains per panicle, Spikelet fertility, Test weight, Length to breadth ratio and Protein content which indicated the predominance of non-additive gene action for these characters and less additive gene action. This was further supported by low magnitude of s^2 gca/s^2 sca ratios. suitability for both selection and hybrid development. In many traits, SCA variance was higher than GCA variance panicle length, straw yield and spikelet fertility), reflecting the predominance of dominance or epistatic gene effects, which are best exploited through hybridization. The significance of line × tester interaction for grain quality traits such as amylose content and head rice recovery also indicates the relevance of specific cross combinations. These results are consistent with the findings of Vadivel (2018) [21], who also emphasized the importance of both GCA and SCA in rice breeding under direct seeded and aerobic conditions. The analysis of variance revealed significant differences among genotypes for all traits except length to breadth ratio and protein content, indicating a wide range of genetic variability. Among the parental lines, Karjat-3 showed the earliest flowering (88 days), while among hybrids, Karjat-3 × Sahbhagi Dhan' exhibited the earliest flowering (91 days). Similarly, Karjat-5 × DRR Dhan 55 showed the maximum duration to 50% flowering (105 days). In terms of yield performance, hybrid Ratnagiri 2 × Sahbhagi Dhan recorded the highest grain yield plant^{-1} (66.9g), followed by Ratnagiri 2 × Siri 1253 and Karjat 3 × CR Dhan 202. These hybrids also showed high harvest index values, indicating efficient biomass partitioning. For quality parameters hybrid Karjat 5 × CR Dhan 202' exhibited the highest protein content (7.19%), while Ratnagiri 2 × Sahbhagi Dhan showed the highest amylose content (25.13%).

The heterosis estimates obtained for different traits revealed a wide range of variability in both positive and negative directions, indicating the presence of exploitable hybrid vigour among the studied crosses. Mid-parent heterosis values showed considerable variation, ranging from-25.85 (Karjat 5 × Ratnagiri 1) to as high as 43.19 (Ratnagiri 2 × Sahbhagi Dhan), while better-parent heterosis varied between-41.01 (Karjat 3 × Sahbhagi Dhan) and 25.81 (Ratnagiri 2 × Sahbhagi Dhan). Similarly, better check heterosis expressed a broad range from-21.41 (Ratnagiri 2 × DRR Dhan 55) to 68.98 (Karjat 5 × DRR Dhan 55), whereas poor check heterosis extended from-10.12 (Karjat 3 × CR Dhan 202) to an exceptionally high value of 148.35 (Karjat 5 × DRR Dhan 55). The occurrence of such wide heterotic effects across the checks suggests the potential of certain crosses for commercial exploitation. Among the promising crosses, Karjat 5 × DRR Dhan 55 exhibited the highest positive heterosis over poor check (148.35%) along with substantial better check heterosis (68.98%), highlighting its strong potential for yield improvement. Similarly, Ratnagiri 2 × Sahbhagi Dhan recorded remarkable heterosis over poor check (136.28%), coupled with consistently high heterotic values over mid-parent (43.19%) and better-parent (25.81%), signifying its superiority. In addition, Karjat 3 × SIRI 1253 showed notable positive heterosis with values of 36.99% (poor check) and 19.76% (better-parent), indicating its suitability for hybrid development. Ratnagiri 2 × SIRI 1253 also performed well with heterosis up to 43.80% over poor check and 12.71% over better check. Furthermore, crosses such as Karjat 5 × Ratnagiri 1, Karjat 5 × CR Dhan 202, and Karjat 5 × Sahbhagi Dhan displayed moderate but consistent heterotic responses, which may be useful in specific breeding objectives. Overall, the results demonstrated that while a few crosses showed negative heterosis, the magnitude of positive heterosis in several combinations was sufficiently high to identify them as superior hybrids. The outstanding performance of crosses like Karjat 5 × DRR Dhan 55, Ratnagiri 2 × Sahbhagi Dhan, Karjat 3 × SIRI 1253, and Ratnagiri 2 × SIRI 1253 indicates their potential utilization in aerobic rice improvement programmes for enhancing yield and yield-related traits.

Table 1: Details of experimental material used for study

Sr. No	Parents	Source	Characteristics
1	Karjat 3	RARS, Karjat	Early
2	Karjat 5	RARS, Karjat	Mid early
3	Ratnagiri 2	ARS, Shirgaon, Ratnagiri	Late
4	Ratnagiri 1	ARS, Shirgaon, Ratnagiri	Early
5	CR Dhan 202	CRRI, Cuttak	Aerobic situation
6	CR Dhan 204 (C)	CRRI, Cuttak	Aerobic situation
7	Sabita (C)	IIRR, Hyderabad	Lowland situation
8	Siri 1253	IIRR, Hyderabad	Lowland situation
9	Sahbhagi Dhan	IIRR, Hyderabad	Early, drought tolerant
10	DRR Dhan 55	IIRR, Hyderabad	Aerobic rice

Source and Characteristics of materials

Table 2: Analysis of variance of parents and hybrids in Line x Tester analysis for different characters in Aerobic rice.

Source of variation	DF	Characters							
		Days to 50% flowering	Plant height (cm)	Productive tillers per plant	Panicle length (cm)	Number of grains per panicle	Spikelet fertility (%)	Root biomass (g)	Grain yield plant-1 (g)
Replications	2	0.6182	69.224	1.1212	1.3926	229.895	0.7829	0.0609	8.508
Genotypes	22	68.0693**	47.3208**	3.2157*	3.9404**	148.2379**	9.5585**	0.4991**	81.1444**
Parents	7	131.6905**	41.7333**	5.1619**	3.82**	90.2543**	24.949**	0.388**	59.433**
Females/Lines	2	80.4445**	19.6934**	8.9645**	5.2578**	31.4134	80.0351**	0.3078**	122.2867**
Males/Tester	4	131.8333**	43.0227**	2.3107	1.5227	121.7893**	2.7347	0.0121	13.7106
Females *vs* Males(L *vs* T)	1	233.6111**	80.656**	8.9618*	10.1338**	81.796	3.6341	2.0524**	116.6154**
Hybrids	14	42.2246**	49.3413**	2.2033	3.5095**	85.8695**	3.202	0.5147**	55.7636**
Parents *vs* Hybrids	1	21.1019*	10.5245**	0.0696	4.8116**	1707.8029**	0.5092	0.0172	425.964**
Ch vs Hy		73.3497**	1.088	5.2941	6.0738**	20.384	0.0023	1.6708**	164.416**
Check1 vs Check2		5.6067	142.1067	4.86	9.6267**	0.54	9.385	0.368**	246.8107**
Error	44	3.0662	40.3307	1.4893	0.5981	28.5216	3.2195	0.0399	5.9408

Source of variation	DF	Characters							
		Test weight(g)	Straw yield per plant(g)	Harvest index(%)	Length to breadth ratio	Milling percent (%)	Head rice recovery (%)	Amylose content (%)	Protein content (%)
Replications	2	0.0213	23.9398	3.2843	0.0091	2.1493	3.9228	10.5581**	1.0216
Genotypes	22	2.8095**	10.4401	19.304**	0.1594**	15.1796**	21.2266**	10.668**	0.4899
Parents	7	3.588**	9.4402	24.9945**	0.2349**	25.9056**	5.8685*	10.9521**	0.4779
Females/Lines	2	0.7927*	6.9408	46.8513**	0.1028**	1.305	8.8334*	12.0678**	0.0669
Males/Tester	4	4.2305**	11.3589	8.7311	0.2636**	35.0731**	5.6029	12.5483**	0.0461
Females *vs* Males (L *vs* T)	1	6.6082**	6.7645	46.3345**	0.3841**	38.4369**	1.001	2.3361**	3.0272**
Hybrids	14	1.2006**	10.5199	8.0731	0.0745**	7.4906*	32.136**	11.4537**	0.3952
Parents *vs* Hybrids	1	5.7303**	18.7723	127.3785**	0.6304**	70.2439**	13.3677*	0.4721	0.0494
Ch vs Hy		2.089**	0.5154	33.3071*	0.1614**	7.9546	1.175	1.1595**	0.5099
Check1 vs Check2		18.8089**	15.7788	35.2451*	0.1768**	6.5396	1.62	17.0017**	2.2302*
Error	44	0.2493	21.7049	6.1081	0.0184	3.754	2.4329	0.1566	0.3495

* and ** indicates significance at 5 percent and 1 percent levels of probability, respectively.

Table 3: Heterosis (%) over mid-parent, a better parent and check for different characters of 15 Aerobic rice hybrids.

Sr. No.	Hybrids	Days to 50% flowering				Plant height (cm)			
		MP	BP	BC	PC	MP	BP	BC	PC
1	Karjat 3 × SIRI 1253	0.6849	-0.6757	-5.4054**	-3.6066*	-1.5581	-5.3036	-6.8079	4.7619
2	Karjat 3 × DRR DHAN 55	0.1658	-4.127**	-2.8314*	-0.9836	-2.4058	-5.805	-7.9425	3.4864
3	Karjat 3 × SAHBHAGI DHAN	-1.61	-4.5139**	-11.5187**	-9.8361**	0.8471	-2.1143	-5.4463	6.2925
4	Karjat 3 × RATNAGIRI 1	0.722	-3.125*	-10.2317**	-8.5246**	-2.5682	-7.2235	-6.7322	4.8469
5	Karjat 3 × CR DHAN 202	1.0526	-2.654	-7.3359**	-5.5738**	-11.251	-12.0632	-20.045**	-10.119
6	Karjat 5 × SIRI 1253	0.8251	-1.4516	-1.7053	0.1639	2.4469	-1.8447	-3.4039	8.5884
7	Karjat 5 × DRR DHAN 55	1.44	0.6349	1.9949	3.9344**	0.6441	-3.2508	-5.4463	6.2925
8	Karjat 5 × SAHBHAGI DHAN	-0.1721	-6.4516**	-6.6924**	-4.918**	0.6885	-2.6625	-5.9758	5.6973
9	Karjat 5 × RATNAGIRI 1	0.8681	-6.2903**	-6.5315**	-4.7541**	-3.1337	-8.1264	-7.6399	3.8265
10	Karjat 5 × CR DHAN 202	1.0135	-3.5484*	-3.7967**	-1.9672	6.9983	6.4597	-4.0091	7.9082
11	RATNAGIRI 2 × SIRI 1253	-0.3257	-3.7736**	-1.5444	0.3279	-2.8081	-4.2275	5.7489	5.9524
12	RATNAGIRI 2 × DRR DHAN 55	-2.0537	-2.5157	-0.2574	1.6393	2.544	1.3932	-0.9077	11.3946
13	RATNAGIRI 2 × SAHBHAGI DHAN	-0.1698	-7.5472**	-5.4054**	-3.6066*	-4.5669	-5.0901	-8.3207	3.0612
14	RATNAGIRI 2 × RATNAGIRI 1	3.0822*	-5.3459**	-3.1532*	-1.3115	0.8488	-1.6554	-1.1346	11.1395
15	RATNAGIRI 2 × CR DHAN 202	1.2564	-5.6604**	-3.4749*	-1.6393	7.1633	3.6421	-0.9834	11.3095
	SE±	0.6849				1.5581			
	CD 5%	1.3986				3.1816			

* Significant at 5% LS and ** Significant at 1% LS. MP = Mid parent, BP = Better parent, BC = Better check, PC = Poor check,

Sr. No.	Hybrids	Productive tillers per plant				Panicle length (cm)			
		MP	BP	BC	PC	MP	BP	BC	PC
1	Karjat 3 × SIRI 1253	20.4819*	19.7605*	15.6069	36.9863**	-4.321	-10.6628**	-14.3646**	-4.321
2	Karjat 3 × DRR DHAN 55	2.6549	1.1628	0.578	19.1781	-2.8037	-8.5044**	-13.8122**	-3.7037
3	Karjat 3 × SAHBHAGI DHAN	5.3892	5.3892	1.7341	20.5479	-5.5728	-11.5942**	-15.7459**	-5.8642
4	Karjat 3 × RATNAGIRI 1	-6.8768	-10.7143	-6.0694	11.3014	-0.7974	-4.6012	-14.08**	-4.0123
5	Karjat 3 × CR DHAN 202	6.7093	3.2564	-3.4682	14.3836	-1.8293	-9.2958**	-11.049**	-0.6173
6	Karjat 5 × SIRI 1253	-2.6549	-5.1724	-4.6243	13.0137	-2.9674	-5.7637*	-9.6685**	0.9259
7	Karjat 5 × DRR DHAN 55	-14.450	-14.9425	-14.4509	1.3699	6.8862*	4.6921	-1.3812	10.1852**
8	Karjat 5 × SAHBHAGI DHAN	-0.2933	-2.2989	-1.7341	16.4384	-3.5714	-6.087*	-10.4972**	3.6547
9	Karjat 5 × RATNAGIRI 1	1.1236	-1.0989	4.0462	23.2877*	8.7289**	8.5627**	-1.9337	9.5679**
10	Karjat 5 × CR DHAN 202	6.875	-1.7241	-1.1561	17.1233	-3.2258	-7.0423*	-8.8398**	1.8519
11	RATNAGIRI 2 × SIRI 1253	-5.2632	-16.2791*	4.0462	23.2877*	-0.4367	-1.4409	-5.5249*	5.5556
12	RATNAGIRI 2 × DRR DHAN 55	-6.9767	-16.2791*	4.0462	23.2877*	0.4405	0.2933	-5.5249*	5.5556
13	RATNAGIRI 2 × SAHBHAGI DHAN	-1.5707	-12.5581	8.6705	28.7671**	-6.5693*	-7.2464*	-11.6022**	-1.2346
14	RATNAGIRI 2 × RATNAGIRI 1	-3.7783	-11.1628	10.4046	30.8219**	5.3254	-2.0588	-8.011**	2.7778
15	RATNAGIRI 2 × CR DHAN 202	-8.5873	-23.2558**	-4.6243	13.0137	-9.640**	-11.5493**	-13.2597**	-3.0864
	SE±	1.30				1.80			
	CD 5%	1.83				1.90			

MP = Mid parent, BP = Better parent, BC = Better check, PC = Poor check,

Sr. No.	Hybrids	Number of grains per panicle				Spikelet fertility (%)			
		MP	BP	BC	PC	MP	BP	BC	PC
1	Karjat 3 × SIRI 1253	-7.8702	-8.8945*	0.0698	0.7022	0.3284	-0.7682	-0.836	2.2147
2	Karjat 3 × DRR DHAN 55	-2.3165	-4.892	4.4662	5.1264	-1.8441	-2.6762	-2.7428	0.2493
3	Karjat 3 × SAHBHAGI DHAN	-12.955**	-15.0572**	-6.6992	-6.1096	0.4051	0.0199	-0.0485	3.0264
4	Karjat 3 × RATNAGIRI 1	-19.319**	-21.4329**	-8.9323	-8.3567	-3.4447	-3.4778	-3.5438*	-0.5764
5	Karjat 3 × CR DHAN 202	-18.862**	-21.8032**	-7.3971	-6.8118	-1.6468	-1.9371	-1.4223	1.6104
6	Karjat 5 × SIRI 1253	-13.017**	-14.6849**	-8.374	-7.7949	-3.0858	-5.6564**	-2.6155	0.3805
7	Karjat 5 × DRR DHAN 55	-5.1498	-5.4997	-1.6748	-1.0534	-0.3996	-2.8051	0.3277	3.4142
8	Karjat 5 × SAHBHAGI DHAN	-8.0591	-8.6115	-4.4662	-3.8624	-2.0407	-3.9664*	-0.871	2.1786
9	Karjat 5 × RATNAGIRI 1	-14.167**	-18.8441**	-5.9316	-5.3371	-3.0716	-4.6492**	-1.5758	1.4521
10	Karjat 5 × CR DHAN 202	-13.818**	-19.3282**	-4.4662	-3.8624	-2.5127	-3.7869*	-0.6857	2.3696
11	RATNAGIRI 2 × SIRI 1253	5.4187	4.2885	12.0028*	12.7107**	5.6913**	2.2005	-0.1018	2.9715
12	RATNAGIRI 2 × DRR DHAN 55	-6.9069	-7.3705	-2.6518	-2.0365	4.1052*	0.4243	-1.3459	1.6891
13	RATNAGIRI 2 × SAHBHAGI DHAN	-8.8549*	-9.0969*	-4.4662	-3.8624	1.2167	-2.802	-3.6138*	-0.6486
14	RATNAGIRI 2 × RATNAGIRI 1	-8.4938*	-12.7634**	1.1165	1.7556	3.8006*	-0.6548	-0.7907	2.2614
15	RATNAGIRI 2 × CR DHAN 202	-8.8355*	-13.9658**	1.8842	2.5281	2.0308	-2.6557	-2.1446	0.8659
	SE±	1.9490				1.8920			
	CD 5%	3.9799				3.8635			

MP = Mid parent, BP = Better parent, BC = Better check, PC = Poor check,

Sr. No.	Hybrids	Root biomass (g)				Grain yield per plant (g)			
		MP	BP	BC	PC	MP	BP	BC	PC
1	Karjat 3 × SIRI 1253	-12.593	-21.3205**	5.0753	54.4248**	15.0734**	3.1427	-5.9497	20.5809**
2	Karjat 3 × DRR DHAN 55	-5.0551	-15.314	13.0968	66.2137**	18.467**	6.8753	-3.9577	23.1348**
3	Karjat 3 × SAHBHAGI DHAN	-15.07	-26.7633**	-2.1935	43.7421**	15.903**	5.1402	-6.6747	19.6514**
4	Karjat 3 × RATNAGIRI 1	36.01**	22.19**	63.1828**	139.823**	19.825**	4.9152	0.9525	29.430**
5	Karjat 3 × CR DHAN 202	-2.7116	-13.913	14.9677	68.9633**	12.896**	-1.3416	-4.6392	22.261**
6	Karjat 5 × SIRI 1253	-17.5989*	-32.289**	12.4731	65.2971**	7.8199*	6.555	-2.8382	24.570**
7	Karjat 5 × DRR DHAN 55	24.80**	1.7349	68.9892**	148.3565**	8.3142*	7.8207*	-3.1081	24.2241**
8	Karjat 5 × SAHBHAGI DHAN	-25.4581**	-41.015**	-2.0215	43.9949**	3.8671	3.7023	-7.6581*	18.390**
9	Karjat 5 × RATNAGIRI 1	-25.852**	-39.176**	1.0323	48.4829**	8.9824*	4.9176	0.9548	29.4331**
10	Karjat 5 × CR DHAN 202	15.3231	-6.6546	55.0538**	127.8761**	-3.444	-7.2462*	-10.3465**	14.9438**
11	RATNAGIRI 2 × SIRI 1253	-9.3842	-16.7957*	6.3226	56.2579**	21.8838**	20.7822**	12.1624**	43.8021**
12	RATNAGIRI 2 × DRR DHAN 55	-15.0046	-22.686**	-1.2043	45.196**	17.0462**	15.156**	6.9377*	37.1036**
13	RATNAGIRI 2 × SAHBHAGI DHAN	43.191**	25.8162**	60.7742**	136.2832**	26.401**	23.610**	14.789**	47.1697**
14	RATNAGIRI 2 × RATNAGIRI 1	-8.4665	-16.1225	7.1828	57.5221**	-2.309	-4.0144	-7.6398*	18.414**
15	RATNAGIRI 2 × CR DHAN 202	-12.1806	-20.7674*	1.2473	48.799**	0.6553	-1.3203	-4.6186	22.2874**
	SE±	0.9570				1.0310			
	CD 5%	1.9610				2.2313			

MP = Mid parent, BP = Better parent, BC = Better check, PC = Poor check,

Sr. No.	Hybrids	Test weight(g)				Straw yield per plant(g)			
		MP	BP	BC	PC	MP	BP	BC	PC
1	Karjat 3 × SIRI 1253	-6.339**	-6.5319**	-8.4099**	5.5225**	-9.3757	-9.527	-5.6846	0.0211
2	Karjat 3 × DRR DHAN 55	-3.4334*	-8.1429**	-9.9885**	3.7037*	-0.0069	-2.3237	1.4845	7.6239
3	Karjat 3 × SAHBHAGI DHAN	1.8187	-4.0715*	-5.9989**	8.3003**	-5.1463	-7.2578	-3.642	2.1873
4	Karjat 3 × RATNAGIRI 1	-3.9613*	-6.9713**	-8.8404**	5.0265**	-3.1427	-7.1134	-3.4919	2.3465
5	Karjat 3 × CR DHAN 202	-0.0447	-1.8453	-3.8175*	10.8135**	-3.0582	-6.5039	-2.8587	3.018
6	Karjat 5 × SIRI 1253	-3.5298*	-5.1471**	-7.434**	6.6468**	-5.4345	-7.5485	-3.6221	2.2085
7	Karjat 5 × DRR DHAN 55	0.4869	-2.6476	-8.1803**	5.787**	0.929	0.6747	0.258	6.3232
8	Karjat 5 × SAHBHAGI DHAN	2.268	-1.8868	-7.4627**	6.6138**	0.7459	0.5875	0.1712	6.2312
9	Karjat 5 × RATNAGIRI 1	-4.8104**	-6.056**	-11.3949**	2.0833	-4.0482	-6.0744	-6.4632	-0.8045
10	Karjat 5 × CR DHAN 202	-4.4245**	-4.4971**	-9.7876**	3.9352*	-2.8145	-4.3141	-4.7102	1.0545
11	RATNAGIRI 2 × SIRI 1253	-5.1064**	-6.2647**	-8.5247**	5.3902**	4.1648	1.5432	5.8558	12.2597
12	RATNAGIRI 2 × DRR DHAN 55	-6.2832**	-9.6171**	-13.9495**	-0.8598	-3.4333	-3.4745	-4.3584	1.4275
13	RATNAGIRI 2 × SAHBHAGI DHAN	-1.7045	-6.12**	-10.62**	2.9762	0.8037	0.665	-0.0668	5.9788
14	RATNAGIRI 2 × RATNAGIRI 1	-3.5753*	-5.2759**	-9.8163**	3.9021*	-2.6018	-4.3823	-5.3387	0.388
15	RATNAGIRI 2 × CR DHAN 202	-5.0242**	-5.3964**	-9.9311**	3.7698*	0.1625	-1.0956	-2.0848	3.8387
	SE±	0.9870				1.1280			
	CD 5%	2.0155				2.3034			

MP = Mid parent, BP = Better parent, BC = Better check, PC = Poor check,

Sr. No.	Hybrids	Harvest index(%)				Length to breadth ratio			
		MP	BP	BC	PC	MP	BP	BC	PC
1	Karjat 3 × SIRI 1253	13.568**	6.6842	-0.3146	10.2143*	-0.8798	-10.6026**	-16.6952**	-7.891*
2	Karjat 3 × DRR DHAN 55	9.5868*	2.1698	-2.9732	7.2749	12.561**	7.4382	-11.4659**	-2.109
3	Karjat 3 × SAHBHAGI DHAN	11.2543*	4.0481	-1.85	8.5167	0.0616	-12.1212**	-12.9876**	-3.7915
4	Karjat 3 × RATNAGIRI 1	11.807**	1.5604	2.1091	12.894**	3.7749	-1.5657	-17.80**	-9.1232**
5	Karjat 3 × CR DHAN 202	8.5837	-1.1511	-1.1009	9.3449*	13.333**	10.1215*	-12.558**	-3.3175
6	Karjat 5 × SIRI 1253	6.7636	6.2599	0.2347	10.8216*	10.754**	3.2659	-3.772	6.3981
7	Karjat 5 × DRR DHAN 55	3.6356	3.2883	-1.911	8.4493	14.6614**	13.394**	-6.5581*	3.3175
8	Karjat 5 × SAHBHAGI DHAN	1.5534	1.5526	-4.2041	5.914	1.79	-7.684*	-8.5941**	1.0664
9	Karjat 5 × RATNAGIRI 1	6.3523	3.0675	3.6244	14.5693**	7.628*	5.7495	-11.7017**	-2.3697
10	Karjat 5 × CR DHAN 202	-0.3927	-3.2406	-3.1914	7.0336	11.051**	10.239**	-11.1659**	-1.7773
11	RATNAGIRI 2 × SIRI 1253	8.0278	6.2677	2.6409	13.482**	5.9714	1.4259	-5.4865	4.5024
12	RATNAGIRI 2 × DRR DHAN 55	9.9981*	9.075*	5.3525	16.4799**	14.4501**	12.5786**	-4.0934	6.0427
13	RATNAGIRI 2 × SAHBHAGI DHAN	11.779**	10.4745*	6.7042	17.9745**	1.5707	-5.5195	-6.4509*	3.436
14	RATNAGIRI 2 × RATNAGIRI 1	0.0366	-1.93	-1.4002	9.014*	12.4381**	11.3208**	-5.165	4.8578
15	RATNAGIRI 2 × CR DHAN 202	0.4688	-1.2703	-1.2201	9.2131*	9.2448*	5.5346	-10.0943**	-0.5924
	SE±	0.1050				0.5860			
	CD 5%	0.2144				0.49			

MP = Mid parent, BP = Better parent, BC = Better check, PC = Poor check

Sr. No.	Hybrids	Milling percent (%)				Head rice recovery(%)			
		MP	BP	BC	PC	MP	BP	BC	PC
1	Karjat 3 × SIRI 1253	1.8969	-2.64	0.5167	3.4913	2.957	1.7507	-1.5748	-0.1833
2	Karjat 3 × DRR DHAN 55	4.7027*	1.3818	1.8061	4.8189*	2.5781	0.4294	-0.981	0.4189
3	Karjat 3 × SAHBHAGI DHAN	5.8002*	2.4188	2.9009	5.9462*	-0.0027	-0.9123	-4.6623**	-3.3145
4	Karjat 3 × RATNAGIRI 1	9.0281**	7.1663**	0.7883	3.771	-0.0054	-0.9334	-4.646**	-3.2988
5	Karjat 3 × CR DHAN 202	1.5289	-0.7402	-2.2796	0.6123	-3.4441	-6.3085**	-5.9118**	-4.5816*
6	Karjat 5 × SIRI 1253	-1.3131	-4.8988*	-1.8153	1.0904	5.6981**	4.588**	3.3406	4.8015**
7	Karjat 5 × DRR DHAN 55	3.4583	1.0482	1.4711	4.474	-3.7219*	-3.8251*	-4.9721**	-3.6287*
8	Karjat 5 × SAHBHAGI DHAN	-1.079	-3.408	-2.9532	-0.0813	-0.6301	-1.9334	-3.1031	-1.7332
9	Karjat 5 × RATNAGIRI 1	9.4583**	6.6553**	2.1117	5.1336*	4.2537*	2.9054	1.678	3.1155
10	Karjat 5 × CR DHAN 202	-0.5558	-1.924	-3.4451	-0.5877	4.2009*	3.3625	3.8001*	5.2676**
11	RATNAGIRI 2 × SIRI 1253	2.548	-1.3138	1.8859	4.9011*	8.2158**	7.537**	5.3439**	6.8332**
12	RATNAGIRI 2 × DRR DHAN 55	3.0209	0.4807	0.9012	3.8873	0.7854	0.4608	-0.95	0.4503
13	RATNAGIRI 2 × SAHBHAGI DHAN	0.1269	-2.3667	-1.907	0.9959	5.8232**	4.8806**	2.7416	4.1942*
14	RATNAGIRI 2 × RATNAGIRI 1	7.8988**	5.2824*	0.5093	3.4838	3.6608*	2.7565	0.6609	2.084
15	RATNAGIRI 2 × CR DHAN 202	6.5026**	4.8893*	3.2625	6.3184**	-9.970**	-11.0746**	-10.6981**	-9.4355**
	SE±	1.01				0.95			
	CD 5%	2.06				1.96			

MP = Mid parent, BP = Better parent, BC = Better check, PC = Poor check,

Sr. No.	Hybrids	Amylose content (%)				Protein content (%)			
		MP	BP	BC	PC	MP	BP	BC	PC
1	Karjat 3 × SIRI 1253	2.98*	1.052	-8.32**	6.32**	-7.27	-11.67	-20.59**	-5.08
2	Karjat 3 × DRR DHAN 55	6.52**	2.797*	0.272	16.29**	1.033	-2.83	-14.37*	2.36
3	Karjat 3 × SAHBHAGI DHAN	-4.30**	-8.120**	-16.64**	-3.32*	10.23	3.66	-4.218	14.49
4	Karjat 3 × RATNAGIRI 1	-0.14	-4.275**	-5.32**	9.81**	-0.217	-5.46	-14.03*	2.76
5	Karjat 3 × CR DHAN 202	2.63	-3.308*	-12.27**	1.74	4.52	-1.33	-9.57	8.09
6	Karjat 5 × SIRI 1253	15.46**	13.75**	-0.68	15.18**	5.94	1.53	-8.73	9.10
7	Karjat 5 × DRR DHAN 55	-12.42**	-18.18**	-20.19**	-7.43**	5.11	1.69	-10.375	7.13
8	Karjat 5 × SAHBHAGI DHAN	21.33**	20.45**	2.04	18.35**	-8.15	-13.12	-19.73**	-4.04
9	Karjat 5 × RATNAGIRI 1	-8.03**	-14.63**	-15.56**	-2.07	-3.28	-7.83	-16.18*	0.19
10	Karjat 5 × CR DHAN 202	11.49**	8.53**	-8.04**	6.64**	10.88	5.28	-3.50	15.35
11	RATNAGIRI 2 × SIRI 1253	1.44	-5.40**	-4.50**	10.75**	7.39	0.606	-9.56	8.10
12	RATNAGIRI 2 × DRR DHAN 55	-20.82**	-22.16**	-21.41**	-8.86**	4.08	-1.58	-13.26*	3.68
13	RATNAGIRI 2 × SAHBHAGI DHAN	11.53**	1.89	2.864*	19.30**	-0.716	-8.16	-15.14*	1.43
14	RATNAGIRI 2 × RATNAGIRI 1	-16.04**	-16.89**	-16.09**	-2.68	1.91	-5.03	-13.63*	3.23
15	RATNAGIRI 2 × CR DHAN 202	1.355	-9.05**	-8.18**	6.48**	3.33	-4.05	-12.06	5.11
	SE±	1.26				1.18			
	CD 5%	2.60				2.41			

MP = Mid parent, BP = Better parent, BC = Better check, PC = Poor check,

Conclusion

The parental line Karjat-3 and the hybrid Karjat-3 × Sahbhagi Dhan were identified as early maturing genotypes, which is beneficial for aerobic rice cultivation under limited water availability. Notably, hybrid Ratnagiri 2 × Sahbhagi Dhan exhibited the highest grain yield plant^{-1} and harvest index, indicating its superiority and suitability for improving yield potential in aerobic rice. For grain quality traits, Karjat 5 × Sahbhagi Dhan recorded the highest protein content, while Ratnagiri 2 × Sahbhagi Dhan exhibited the intermediate amylose content, suggesting these hybrids are valuable for enhancing both nutritional and cooking quality attributes. Several hybrids including Karjat 3 × Ratnagiri 1 and Ratnagiri 2 × Sahbhagi Dhan showed significant positive heterosis for grain yield and harvest index, highlighting their potential for hybrid development. Heritability in the narrow sense was highest for days to 50% flowering (89.87%) and traits like root biomass, grain yield plant^{-1}and productive tillers per plant exhibited high genetic advance as a percentage of the mean. This indicates that these characters can be effectively improved through direct selection. The heterosis study revealed wide variability for mid-parent, better-parent and check comparisons, indicating sufficient genetic diversity for hybrid development in aerobic rice. Although some crosses expressed negative heterosis, several combinations exhibited exceptionally high positive heterosis for yield and related traits. Notably, Karjat 5 × DRR Dhan 55, Ratnagiri 2 × Sahbhagi Dhan, Karjat 3 × SIRI 1253, and Ratnagiri 2 × SIRI 1253 consistently showed superiority across different heterosis estimates, suggesting their strong potential for commercial exploitation and utilization in breeding programmes. These crosses may serve as promising candidates for developing high-yielding hybrids suited to aerobic rice cultivation Overall, the study identified promising parents and cross combinations that could be utilized for developing early maturing, high-yielding and quality-rich variety suitable for aerobic rice cultivation.

References

1. Al-Daej MI. Estimation of heterosis, heritability and genetic parameters for some agronomic traits of rice using the line × tester method. Journal of King Saud University-Science. 2022;34:101906. https://doi.org/10.1016/j.jksus.2022.101906.
2. Ambikabathy A, Banumathy S, Gnanamalar RP, Arunchalam P, Jeyaprakash P, Amutha R, *et al*. Heterosis and combining ability for yield and yield attributing traits in rice. Electronic Journal of Plant Breeding. 2019;10(3):1060-1066.
3. Arunachalam V. The fallacy behind the use of a modified line × tester design. Indian Journal of Genetics and Plant Breeding. 1974;34:280-287.
4. Cochran WG, Cox GM. Experimental designs. 2nd ed. New York: John Wiley and Sons; 1957.
5. Dwivedi DK, Pandey MP. Gene action and heterosis for yield associated traits in indica and tropical japonica crosses of rice (*Oryza sativa* L.). International Journal of Plant Breeding and Genetics. 2012;6:140-150.
6. Griffing B. Concept of general and specific combining ability in relation to diallel crossing systems. Australian Journal of Biological Sciences. 1956;9(4):463-493.
7. Islam MZ, Galib MAA, Akand MM, Lipi LF, Akter A, Matin MQI, *et al*. Combining ability and heterotic studies in aromatic rice through line × tester analysis. [Details incomplete-please provide journal, volume, and pages].
8. Juliano BO. A simplified assay for milled rice amylose. Cereal Science Today. 1971;16:334-336, 338, 360.
9. Kempthorne O. An introduction to genetic statistics. New York: John Wiley and Sons; 1957.
10. Manivelan K, Hepziba SJ, Suresh R, Theradimani M, Renuka R, Gnanamalar RP. Combining ability and heterosis for yield and grain quality characters in rice (*Oryza sativa* L.). Electronic Journal of Plant Breeding. 2022;13(2). https://doi.org/10.37992/2022.1302.213.
11. Nanditha RS, Pushpam R, Geetha S, Surendar KK, Ganesamurthy K. Assessment of combining ability, gene action and heterosis for yield and grain characters in rice (*Oryza sativa* L.). Electronic Journal of Plant Breeding. 2021;12(3):976-982.
12. Panse VC, Sukhatme PV. Statistical methods for agricultural workers. 3rd rev. ed. New Delhi: ICAR; 1978.

13. Patel AM. Genetic analysis of yield and its yield attributing traits in aerobic rice (*Oryza sativa* L.) [doctoral dissertation]. Navsari: Navsari Agricultural University, NM College of Agriculture; 2016.
14. Prasad KR. Genetic analysis of yield and yield components in hybrid rice (*Oryza sativa* L.) [doctoral dissertation]; 2017.
15. Pratap N, Shekhar R, Singh PK, Soni SK. Combining ability and gene action and heterosis using CMS lines in hybrid rice (*Oryza sativa* L.). The Bioscan. 2013;8(4):1521-1528.
16. Rathava KV, Patel PB, Patel A, Balat JR, Delvadiya IR. Heterosis for yield and its components traits of rice (*Oryza sativa* L.) in aerobic condition. Journal of Pharmacognosy and Phytochemistry. 2019;8(5):1605-1610.
17. Robinson HF. Quantitative genetics in relation to breeding on the central of Mendelism. Indian Journal of Genetics and Plant Breeding. 1966;26:171-187.
18. Shull GH. Duplicate genes for capsule form in *Bursa pasteris*. Zeitscher Inductive Abstammu Vererbunglehra. 1914;12:97-149. In: Gowen JW, editor. Heterosis. New York: Hafner Inc.; 1952. p. 50.
19. Singh Y, Singh PK, Pathak VN, Misra V, Mall AK. Combining ability and gene action for grain yield using line × tester technique in aerobic rice. [Details incomplete-please provide journal, volume, and pages].
20. Utharasu S, Anandakumar CR. Heterosis and combining ability analysis for grain yield and its component traits in aerobic rice (*Oryza sativa* L.) cultivars. Electronic Journal of Plant Breeding. 2013;4(4):1271-1279.
21. Vadivel K. Studies on combining ability and heterosis in rice (*Oryza sativa* L.). Electronic Journal of Plant Breeding. 2018;9(3):1115-1121.