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GENETIC DISSECTION OF HETEROSIS FOR YIELD AND QUALITY TRAITS IN RICE USING LINE × TESTER METHOD

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ABSTRACT
This study was conducted to assess the magnitude of heterosis for grain yield and associated agronomic and quality traits in rice (*Oryza sativa* L.) using a Line × Tester mating design. Three lines and eight testers were crossed to generate twenty-four F_1 hybrids, which were evaluated along with their parents and a standard check during Kharif 2023 in a randomized complete block design. Analysis of variance revealed significant differences among genotypes for most traits, indicating substantial genetic variability. Significant positive heterosis was observed for grain yield and its component traits in several crosses. Notably, the hybrids NVSR-3537 × NWGR-19208, NVSR-3461 × NVSR-687, and NVSR-3537 × NVSR-796 exhibited high per se performance along with significant standard heterosis for grain yield. Desirable heterotic effects were also recorded for traits such as grains per panicle, harvest index, protein content, and amylose content, while negative heterosis for days to 50% flowering indicated potential for early maturity. The findings demonstrate the effectiveness of heterosis breeding in rice, the identified superior hybrids and parental lines can be utilized in future breeding programs aimed at developing high-yielding and quality rice cultivars, although multi-environment evaluation is recommended to confirm stability and adaptability.

KEYWORDS: Heterosis; Line x Tester; Hybrids; Rice; Randomized complete block design

INTRODUCTION

Rice (*Oryza sativa* L.) is a foundational staple crop sustaining vast populations, especially across Asia, and remains central to agricultural productivity and food security in India, including regions like Gujarat. As researchers strive to meet ever-rising yield demands under diverse environmental challenges, genetic improvement leveraging heterosis and combining ability has emerged as a proven method in rice breeding programs. Heterosis, first recorded in rice by Jones (1926), describes the superior performance of F_1 hybrids over their parents, particularly for key yield attributes. Multiple studies have confirmed notable levels of positive heterosis for grain yield and its components, often expressed as mid-parent, better-parent (heterobeltiosis), and standard heterosis, the later being of greatest agricultural relevance. For instance, significant and positive standard heterosis in numerous hybrids, with many crosses surpassing both their parents and check varieties, underscoring the potential to exploit hybrid vigour for yield enhancement in practical breeding, was documented (1,2).

The mechanism for effectively harnessing heterosis in rice lies in the systematic use of combining ability analysis, specifically through the Line × Tester method established by Kempthorne (1957). This approach enables breeders to distinguish between general combining ability (GCA), reflecting additive genetic effects and specific combining ability (SCA), indicative of dominance and epistatic (non-additive) effects. Consistent evidence from Line × Tester studies reveals that SCA variance often surpasses GCA variance for grain yield and related traits, highlighting the predominance of non-additive gene action and validating the focus on hybrid development. (3)

Given these proven methodologies and research advances, the present investigation is undertaken with the objectives to comprehensively assess the magnitude of heterosis for grain yield and related agronomic traits in rice. By utilizing a diverse set of parental lines and their F_1 hybrids in a Line × Tester mating design, this research aims to identify hybrid crosses that can be targeted for future yield improvement and breeding efficiency in rice.

MATERIALS AND METHODS

Experimental Site and Materials

The present study was conducted during the Kharif 2023 season at the Main Rice Research Centre, NAU, Navsari.

The experimental materials comprised a set of diverse rice genotypes including three lines (NVSR-3461, NVSR-3537, GNR-3) and eight testers (NVSR-2965, NVSR-917, Mahisagar, Gurjari, NVSR-687, NVSR-796, NWGR-19208, NWGR-19222), all sourced from the Main Rice Research Centre, NAU, Navsari. Additionally, the hybrid GR-17 (Sardar) was included as a standard check to facilitate comparison of heterotic performance.

Experimental Design and Layout

A line × tester mating design was employed to generate hybrids for heterotic studies. The experimental material included all possible crosses between the selected lines and testers, as outlined in the study objectives. The experiment was laid out in a randomized complete block design (RCBD) with an appropriate number of replications to ensure statistical rigor and minimize environmental variability.

Crop Management

Standard agronomic practices for rice cultivation were followed throughout the experimental period, including land preparation, sowing, transplanting, irrigation, fertilization, and plant protection measures, ensuring optimal crop growth and uniformity across treatments.

Data Collection

Observations were systematically recorded on key agronomic traits related to grain yield and its components, both at the parental and hybrid levels. Data collection was performed in accordance with established protocols and covered parameters such as days to 50% flowering, plant height, panicle number, panicle length, and grain yield per plant, among others.

Statistical Analysis

The data were subjected to analysis of variance (ANOVA) using the formulae appropriate for line × tester designs to evaluate the significance of genetic variability among parents and hybrids. The estimation of heterosis was performed for mid-parent, better-parent (heterobeltiosis), and standard heterosis levels. The significance of observed heterosis values was tested using standard error and critical difference at 5% and 1% probability levels. All statistical analyses and procedures were performed in close reference to the methodologies outlined in previous research on rice genetics and breeding, ensuring comparability and methodological rigor.

RESULT AND DISCUSSION

A. Mean performance

For days to 50% flowering, line GNR -3 (88.67), tester Mahisagar (79.00) and cross GNR-3 x Mahisagar (79.00) were the earliest in flowering. Crosses NVSR-3461 x NVSR-917 (96.00 cm), followed by NVSR-3537 x NVSR-687 (96.40 cm), and NVSR-3537 x NVSR-917 (96.80 cm) had the least height among all crosses. Tester NVSR-2965 (14.00), line NVSR-3537 (14.00) had the maximum number of Productive tillers per plant. While cross NVSR-3461 x NVSR-796 (13.00) followed by cross NVSR-3537 x NVSR-796 (12.00), GNR-3 x NVSR-796 (12.00) and GNR-3 x NWGR-19222 (12.00) had the maximum number of productive tillers per plant. For panicle length (cm), tester NVSR-2965 and NWGR-19222 (22.80), and line NVSR-3537 (23.70) had the highest panicle length (cm). Among crosses, GNR-3 x NWGR-19208 (28.00) recorded maximum Panicle length (cm). Tester Mahisagar (261.40), line GNR-3 (163.60) and cross GNR-3 x NWGR-19222 (249.60) had maximum grains per panicle. For grain yield /plant, tester NVSR-917 (26.20 g) and line NVSR-3537 (27.80 g) exhibited maximum grain yield. While cross NVSR-3537 x NWGR-19208 exhibited the highest grain yield of 35.34 g, followed by crosses NVSR-3461 x NVSR-687 (32.79 g), NVSR-3537 x NVSR-796 (32.66 g). Tester NWGR-19222 (39.84 g), line NVSR-3537 (42.47 g) and cross NVSR-3537 x NVSR-796 (44.18 g) recorded the highest Straw yield per plant. In the case of Harvest index, tester NVSR-2965 (43.18 g), line NVSR-3461 (41.32 g), and cross NVSR-3537 x NWGR-19208 (48.21 g) exhibited the highest Harvest index. Tester Gurjari (6.46), line GNR-3 (6.97) and cross NVSR-3461 x Gurjari (6.81) observed the highest Kernel length (mm). In case of female parents, Kernel breadth (mm) was maximum of 2.87 mm (Gurjari) followed by 2.34 mm (NVSR-796), and tester GNR-3 (2.47 mm) recorded highest mean Kernel breadth (mm). Cross GNR-3 x NWGR-19222 (2.47 mm) recorded the highest mean upper half length among all crosses. Tester NVSR-2965 (3.36), line NVSR-3537 (3.12) and cross NVSR-3537 x NWGR-19208 (3.01) recorded the highest L/B ratio. Tester Gurjari (2.77), line NVSR-3461 (2.82) and cross GNR-3 x Gurjari (2.86) observed maximum 100-grain weight (g). The tester NVSR-917 (6.02), line GNR-3 (6.50) and cross NVSR-3461 x Gurjari (8.19) recorded the highest Protein content (%). Tester Gurjari (28.17), line NVSR-3537 (26.34). and cross GNR-3 x NVSR-796 (28.07) had maximum Amylose content (%) (Table 1).

B. Analysis of variance

The analysis of variance for Line x Tester for different characters of rice genotypes as depicted in the Table 1 indicated that significant variations were present among the genotypes for the characters *i.e.* Days to 50 per cent flowering, Panicle length (cm), Productive tillers per plant, Grains per panicle, 100 grain weight (g), Grain yield per plant (g), Straw yield per plant (g), Kernel length (mm), Kernel breadth (mm), L/B ratio, Harvest index (%), Protein content (%), Amylose content (%) except for Plant height (cm) revealing sufficient amount of wide genetic diversity as indicated by the significance of the mean squares. The differences between parents were highly significant for all the characters except plant height and panicle length.

The twenty-four cross combinations obtained by crossing three lines and eight testers were subjected to line x tester (L x T) analysis. The analysis revealed significant differences among lines for all parameters under investigation except Days to 50 per cent flowering, Plant height (cm), Panicle length (cm) and Kernel length (mm) (Table 1). The significant differences were also observed among the testers for all traits except for Plant height (cm). Line x tester interactions were significant for Productive tillers per plant, Grains per panicle, Grain yield per plant (g), Straw yield per plant (g), Kernel length (mm), Kernel breadth (mm), L/B ratio, Harvest index (%), Protein content (%), Amylose content (%) and 100-grain weight (g).

C. Heterosis

Early maturing hybrids are desirable in rice to fit well in multiple cropping. So, negative heterosis is desirable for days to 50 percent flowering. The hybrid NVSR-3537 x NWGR-1922, GNR-3 x NVSR-917 showed significant negative heterosis over mid parent, better parent and standard check. Heterosis for earliness was also reported (1,4,5,6,7,8).

In the case of plant height, negative heterosis is desirable for developing semi dwarf and dwarf varieties of rice. None of the crosses showed significant negative heterosis for standard and relative heterosis as well as heterobeltiosis. Similar results were mentioned (1,4,5,9,10,11).

Grain yield per plant depends on the number of tillers. So, significant positive heterosis for tillers per plant gives higher grain yield. For number of tillers per plant, hybrid NVSR-3461 x NVSR-796 showed significant positive heterosis over mid-parent. Similar results were also reported (4,12).

For panicle length, significant positive heterosis is desirable. In the case of panicle length, hybrid GNR-3 x NWGR-19208 (26.92%) showed significant positive heterosis over check Sardar. This is in agreement with the results (4,6,13).

For grains per panicle, positive heterosis is desirable. In the present study, hybrid NVSR-3537 x NVSR-796 (58.14 per cent) showed significantly positive relative heterosis. 12 out of 24 crosses showed significantly positive relative heterosis. Hybrid GNR-3 x NVSR-2965 (53.79 and 54.49 per cent respectively) showed significantly positive heterobeltiosis and standard heterosis. A total of seven crosses exhibited positive and significant heterobeltiosis, and a total of 13 crosses exhibited significant and positive standard heterosis for this trait. These findings are in close conformity with the results mentioned (4,5,11).

For 100-grain weight, positive heterosis is desirable. In the present study, hybrid NVSR-3537 x NWGR-19222 showed significant positive relative heterosis and heterobeltiosis. However, none of the crosses showed significant positive standard heterosis. Present results are in close agreement with earlier reports of several workers (1,8,13,14).

Grain yield per plant is a complex trait; its expression depends on multiple effects of several syndicated traits. Hybrids NVSR-3461 x NVSR-687 (42.13%), NVSR-3537 x NWGR-19208 (40.74%) and NVSR-3537 x NVSR-796 (40.23%) are top ranked for relative heterosis, and for heterobeltiosis total of four crosses exhibited significant positive heterobeltiosis, of which the hybrids NVSR-3537 x NWGR-19208 (27.12%) and NVSR-3461 x NVSR-687 (24.77%) are most heterotic for this trait. A total of eight hybrids exhibited positive standard heterosis, of which three top-ranking cross combinations are NVSR-3537 x NWGR-19208 (50.23%), NVSR-3461 x NVSR-687 (39.41%) and NVSR-3537 x NVSR-796 (38.84%). Present results are in close agreement with earlier reports of several workers (4,5,6,11).

The hybrid NVSR-3461 x NVSR-796 showed significant positive relative heterosis (19.85%) and heterobeltiosis (17.62%) for straw yield per plant (g), and the hybrid NVSR-3537 x NVSR-796 (24.44%) showed significant positive standard heterosis for the same trait. Similar results were also documented (2,10,15).

Positive heterosis is desirable as high harvest index will result in high economic yield. In the present study, hybrid NVSR-3537 x NWGR-19208 showed significant positive relative heterosis (26.88%), heterobeltiosis (21.87%) and standard heterosis (20.97%). These results are in conformity with the findings (7,16).

In the case of kernel length, none of the crosses was significant for any kind of heterosis in the positive direction. These results are in accordance with the results reported (8,12,17).

For Kernel breadth (mm), positive heterosis is desirable. In the present study, hybrid NVSR-3537 x NWGR-19222 showed significant positive relative heterosis (20.72%) and heterobeltiosis (9.26%) and standard heterosis showed significant and positive heterosis for hybrid GNR-3 x NWGR-19222 (7.25%). Similar results were also reported (4,8,17).

The L/B ratio is an important trait as it has a greater contribution towards seed quality. Relative heterosis was significantly positive for hybrid NVSR-3461 x Gurjari (5.74%), None of the hybrids was positively significant for either heterobeltiosis or standard heterosis. Similar findings have also been reported (4,12,17).

In Rice, protein content is an important quality trait, which determines the nutritional value of the produce. For protein content, hybrid NVSR-3461 x Gurjari showed significant positive relative heterosis (44.44%), heterobeltiosis (39.29%) and standard heterosis (32.95%). Comparable result for this character was also reported (18).

For Amylose content (%) positive heterosis is desirable. In the present study, hybrid NVSR-3461 x NVSR-796 showed significant positive relative heterosis (31.66%) and heterobeltiosis (28.66%) and standard heterosis showed significant and positive for hybrid GNR-3 x NVSR-796 (12.26%). Similar results were reported (12) (Table 2 and Figure 1, 2 and 3).

CONCLUSION

Analysis of variance for parents and hybrids revealed that mean squares due to parents for all the characters except plant height and panicle length were found highly significant, indicating a considerable amount of variability among the parents for various traits. The mean squares due to hybrids were found highly significant for all the characters except plant height. Parents *vs*. Hybrids comparison was found significant for all the characters except kernel length and amylose content, indicating a substantial amount of heterosis among hybrids. An examination of *per se* performance of parents and hybrids revealed that genotypes NVSR-3537, NVSR-3461 and NVSR-917 among parents and hybrids, NVSR-3537 x NWGR-19208, NVSR-3461 x NVSR-687 and NVSR-3537 x NVSR-796 exhibited higher mean performance for grain yield per plant and some of the yield attributing characters. Significantly high magnitude of heterobeltiosis, relative and standard heterosis in desired direction was observed for all the characters except for productive tillers per plant, plant height and kernel length. The higher estimates of heterobeltiosis for grain yield per plant were registered by the crosses NVSR-3537 x NWGR-19208, NVSR-3461 x NVSR-687 and NVSR-3537 x NVSR-796. Total nine crosses manifested significant positive mid-parental heterosis, highest among them was shown by NVSR-3461 x NVSR-687, NVSR-3537 x NWGR-19208 and NVSR-3537 x NVSR-796. Eight crosses showed significant positive standard heterosis over the standard check for grain yield per plant. The highest standard heterosis for grain yield per plant was registered by the cross NVSR-3537 x NWGR-19208, NVSR-3461 x NVSR-687 and NVSR-3537 x NVSR-796. Overall, the results identify several promising parental lines and hybrids with early maturity, high yield potential, and favourable quality attributes, suitable for advancing rice breeding programs targeting multi-trait improvement and heterotic gain. Further multi-environment validation is recommended to confirm stability and to select elite combinations for release.

Table 1: Analysis of variance of Line x Tester for experimental design for various characters

Source of variation	**df**	**Days to 50 % flowering**	**Plant height (cm)**	**Productive tillers/plant**	**Panicle length (cm)**	**Grains/panicle**	**Grain yield/plant (g)**	**Straw yield/plant (g)**
Replications	**2**	7.69	66.15	0.14	16.35	152.97	0.98	20.93
Genotypes	**34**	47.28**	119.16	10.83**	13.41**	4171.04**	72.67**	82.61**
Parents	**10**	51.94**	67.96	7.09**	1.18	4752.47**	30.01**	38.75**
Males	**7**	73.21**	51.42	5.79**	0.74	5122.96**	18.57*	38.45*
Females	**2**	0.11	141.64	1.00	1.69	390.24	3.60	22.23
Males vs Females	**1**	6.74	36.42	28.42**	3.25	10883.51**	162.92**	73.87*
Hybrids	**23**	31.03*	80.87	9.05**	12.51*	3959.85**	90.61**	102.48**
Parent vs Hybrid	**1**	374.57**	1511.86**	89.15**	156.42**	3214.02**	86.58**	64.19*
Error	**68**	15.09	118.59	0.56	6.76	182.89	7.21	13.39
Source of variation	**df**	**Harvest index (%)**	**Kernel length (mm)**	**Kernel breadth (mm)**	**L/B ratio**	**100 grain weight (g)**	**Protein content (%)**	**Amylose content (%)**
Replications	**2**	6.39	0.02	0.01	0.02	0.02	0.06	0.17
Genotypes	**34**	46.88**	0.67**	0.13**	0.15**	0.54**	1.40**	25.42**
Parents	**10**	31.13**	0.96**	0.27**	0.16**	0.82**	1.04**	22.05**
Males	**7**	36.34**	0.57**	0.27**	0.20**	0.71**	0.42**	25.21**
Females	**2**	2.44	0.19	0.07**	0.10**	0.10**	3.70**	19.34**
Males vs Females	**1**	52.08**	5.25**	0.59**	0.01	3.05**	0.06	5.36*
Hybrids	**23**	48.83**	0.57**	0.05**	0.10**	0.40**	1.58**	27.83**
Parent vs Hybrid	**1**	159.40**	0.01	0.52**	0.94**	1.02**	0.86**	3.71
Error	**68**	2.85	0.06	0.01	0.01	0.01	0.04	1.32

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

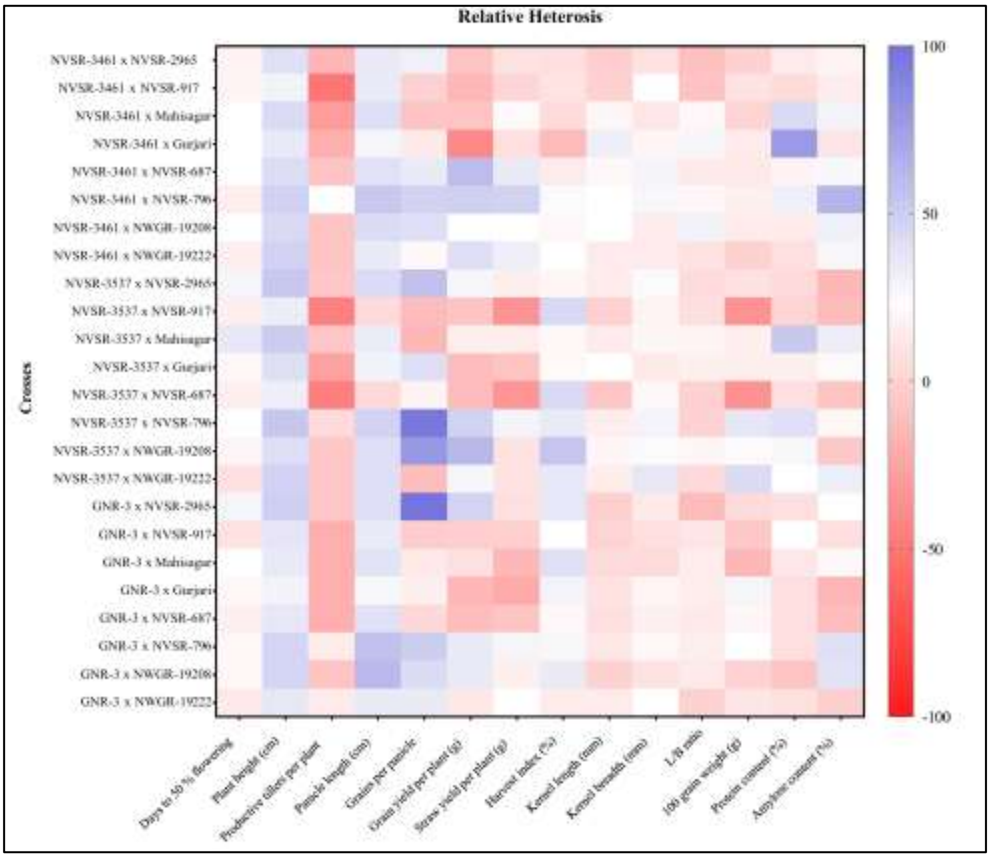

Figure 1. Heat map showing relative heterosis values for grain yield and its component traits in hybrids.

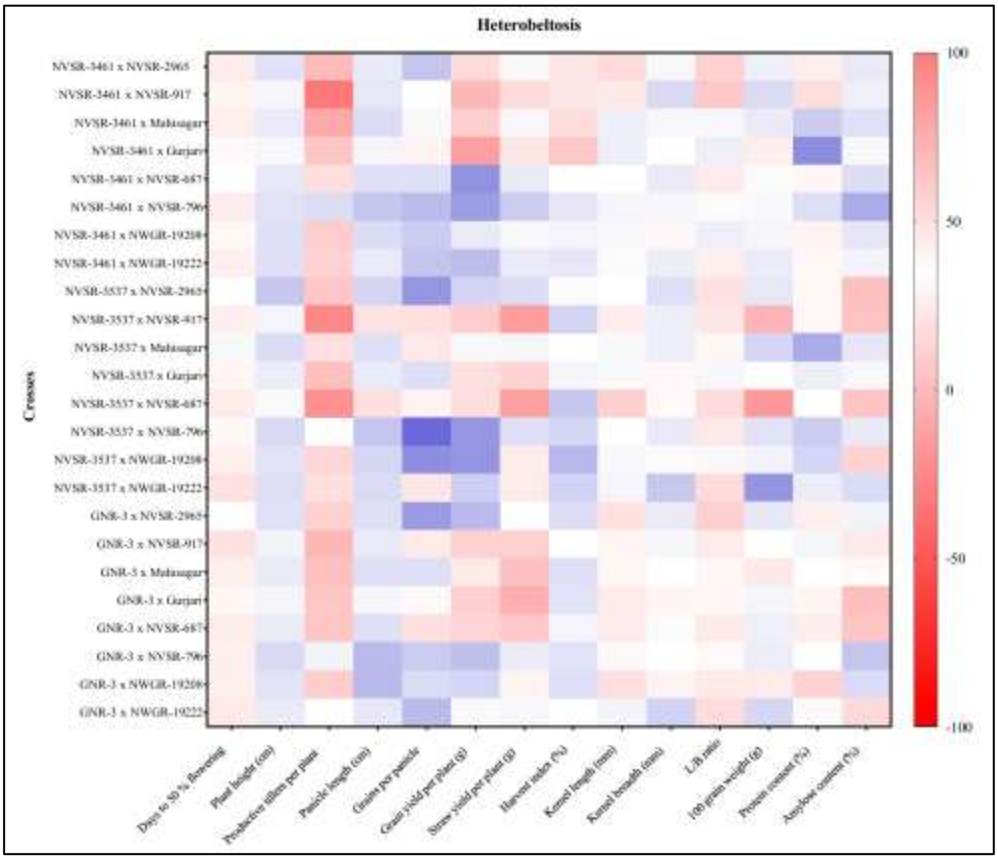

Figure 2. Heat map showing Heterobeltiosis values for grain yield and its component traits in hybrids.

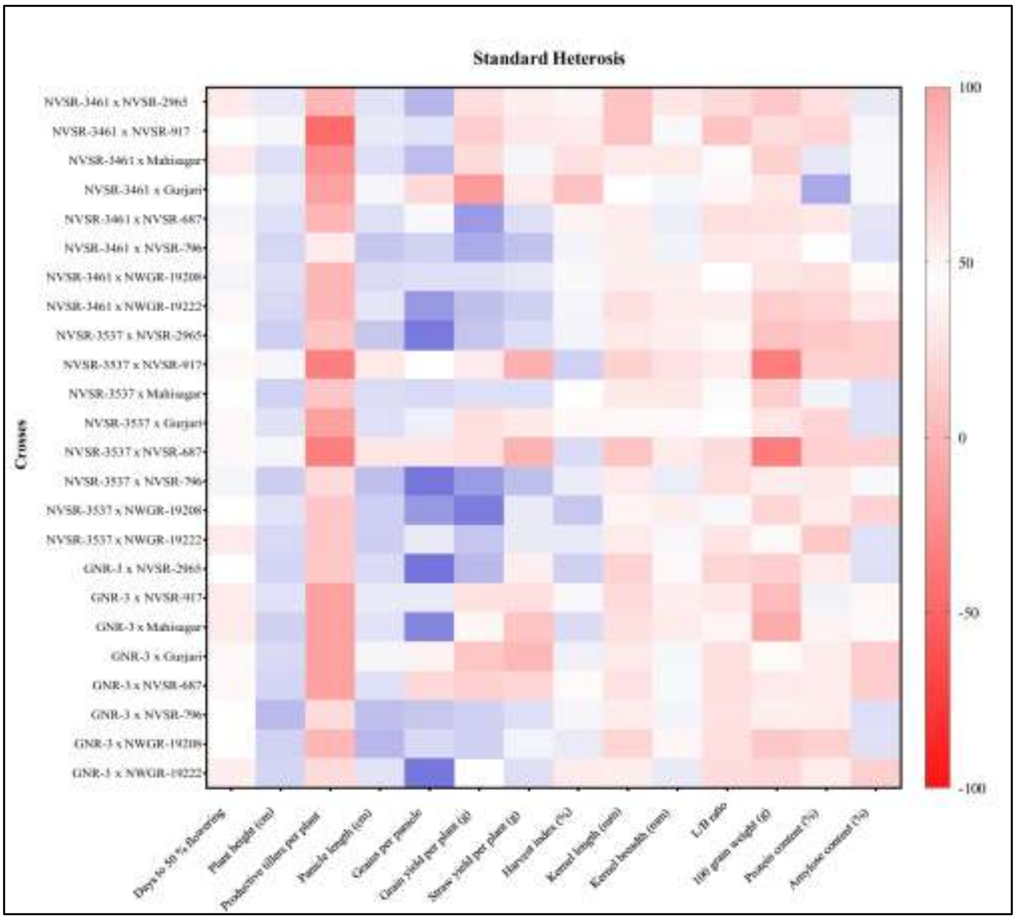

Figure 3. Heat map showing standard heterosis values for grain yield and its component traits in hybrids.

Table 2: Per cent relative heterosis, heterobeltiosis and standard heterosis for different characters

Sr. No.	Crosses	Days to 50 % flowering			Plant height (cm)			Productive tillers per plant			Panicle length (cm)		
		RH	HB	SH	RH	RH	RH	RH	HB	SH	RH	HB	SH
1	**NVSR-3461 x NVSR-2965**	-8.14*	-4.82	-8.14*	10.72	11.21	8.36	-25.92**	-28.56**	-28.55**	8.42	7.47	9.87
2	**NVSR-3461 x NVSR-917**	-4.49	-4.49	-1.16	3.23	4.58	2.79	-52.01**	-53.86**	-57.14**	9.08	7.13	7.61
3	**NVSR-3461 x Mahisagar**	-5.96	0.00	-8.14*	7.96	13.73	11.78	-33.34**	-38.48**	-42.86**	13.54	11.61	12.11
4	**NVSR-3461 x Gurjari**	-1.72	0.00	0.00	2.68	8.50	6.64	-21.78**	-30.81**	-35.74**	3.68	3.21	3.68
5	**NVSR-3461 x NVSR-687**	-1.11	0.00	3.49	8.69	13.07	11.14	-13.07**	-23.10**	-28.57**	11.99	10.73	11.23
6	**NVSR-3461 x NVSR-796**	-7.69*	-5.62	-2.32	10.90	17.07	15.06	13.06**	0.00	-7.12	22.44**	20.54*	21.08*
7	**NVSR-3461 x NWGR-19208**	-2.20	0.00	3.49	12.30	14.38	12.43	-19.98**	-23.07**	-28.55**	13.39	13.39	13.90
8	**NVSR-3461 x NWGR-19222**	-5.62	-5.62	-2.32	12.35	16.63	14.64	-16.68**	-23.10**	-28.57**	7.98	7.03	9.43
9	**NVSR-3537 x NVSR-2965**	0.00	3.61	0.00	21.36*	21.00*	18.64	-21.44**	-21.45**	-21.43**	15.72	13.52	20.64*
10	**NVSR-3537 x NVSR-917**	-5.62	-5.62	-2.32	4.20	5.68	3.65	-46.13**	-49.98**	-49.98**	-10.38	-14.35	-8.97
11	**NVSR-3537 x Mahisagar**	2.38	8.86*	0.00	13.46	19.65*	17.35	-12.00**	-21.43**	-21.43**	11.46	6.61	13.30
12	**NVSR-3537 x Gurjari**	-4.00	-2.32	-2.32	6.09	12.22	10.06	-25.00**	-35.71**	-35.71**	8.06	4.64	11.21
13	**NVSR-3537 x NVSR-687**	-6.67*	-5.62	-2.32	1.05	5.24	3.22	-41.67**	-50.00**	-50.00**	-11.84	-15.19	-9.87
14	**NVSR-3537 x NVSR-796**	-2.19	0.00	3.50	14.66	21.18*	18.84	0.00	-14.29**	-14.29**	22.46**	17.30	24.66*
15	**NVSR-3537 x NWGR-19208**	-5.49	-3.37	0.00	10.06	12.23	10.07	-15.36**	-21.40**	-21.40**	14.95	11.80	18.82
16	**NVSR-3537 x NWGR-19222**	-11.24**	-11.24**	-8.14*	12.61	17.03	14.78	-12.00**	-21.43**	-21.43**	13.99	11.83	18.85
17	**GNR-3 x NVSR-2965**	0.19	3.61	0.00	11.00	18.68	15.64	-18.53**	-21.45**	-21.43**	12.40	11.42	13.90
18	**GNR-3 x NVSR-917**	-11.07**	-10.90**	-8.14*	4.35	9.55	10.50	-27.97**	-30.74**	-35.69**	8.62	6.68	7.16
19	**GNR-3 x Mahisagar**	-5.77	0.00	-8.14*	7.22	8.27	17.78	-25.00**	-30.77**	-35.71**	11.82	9.91	10.40
20	**GNR-3 x Gurjari**	-3.82	-2.33	-2.32	3.79	4.50	14.35	-21.74**	-30.77**	-35.71**	3.14	2.68	3.14
21	**GNR-3 x NVSR-687**	-6.49*	-5.26	-2.32	6.31	8.67	15.42	-21.75**	-30.77**	-35.71**	11.96	10.70	11.20
22	**GNR-3 x NVSR-796**	-5.32	-3.01	0.00	14.59	15.49	26.13**	4.38	-7.67**	-14.26	26.07**	24.11*	24.66*
23	**GNR-3 x NWGR-19208**	-5.32	-3.01	0.00	10.46	15.34	17.56	-20.00**	-23.08**	-28.57**	26.35**	26.35**	26.92**
24	**GNR-3 x NWGR-19222**	-8.82**	-8.65*	-5.81	6.72	9.31	15.64	0.00	-7.69**	-14.29	8.85	7.89	10.31
	S.Em. ±	2.75	3.17	3.17	7.70	8.89	8.89	0.53	0.61	0.61	1.84	2.12	2.12

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

Table 2: Conti…

Sr. No.	Crosses	Grains per panicle			Grain yield per plant (g)			Straw yield per plant (g)			Harvest index (%)		
		RH	HB	SH	RH	RH	RH	RH	HB	SH	RH	HB	SH
1	NVSR-3461 x NVSR-2965	22.69**	4.83	27.85**	-14.39	-22.15**	-13.02	1.46	-10.78	-6.20	-9.93**	-11.87**	-4.51
2	NVSR-3461 x NVSR-917	0.00	-17.77**	10.28	-27.84**	-27.94**	-19.50*	-14.49*	-15.45	-9.07	-9.84**	-10.52**	-7.23*
3	NVSR-3461 x Mahisagar	1.34	-22.04**	25.14**	-19.38*	-23.06**	-14.04	2.10	-1.24	3.83	-13.56**	-14.27**	-11.12**
4	NVSR-3461 x Gurjari	-5.06	-8.44	-14.77*	-37.78**	-45.74**	-39.38**	-10.12	-12.17	-7.66	-21.02**	-26.64**	-23.94**
5	NVSR-3461 x NVSR-687	11.92	6.99	1.44	42.13**	24.77**	39.41**	8.34	6.86	12.35	-0.77	-8.00*	-4.62
6	NVSR-3461 x NVSR-796	25.43**	16.42*	17.53*	38.14**	18.43*	32.31**	19.85**	17.62*	23.66**	9.69**	0.40	4.09
7	NVSR-3461 x NWGR-19208	19.90**	11.80	11.76	8.24	0.29	12.04	1.62	-0.72	9.41	3.99	-2.16	1.44
8	NVSR-3461 x NWGR-19222	21.62**	-2.57	39.88**	25.17**	11.50	24.57**	8.54	5.11	17.97*	9.28**	-0.37	3.30
9	NVSR-3537 x NVSR-2965	40.24**	24.07**	51.30**	15.98*	2.88	21.58*	13.58	-5.34	13.25	0.48	-3.73	4.31
10	NVSR-3537 x NVSR-917	-12.39*	-25.55**	-0.15	-19.86**	-22.16**	-8.01	-38.59**	-41.69**	-30.24**	16.23**	14.60**	17.03**
11	NVSR-3537 x Mahisagar	-9.74*	-28.49**	14.79*	1.86	-5.32	11.89	3.18	-6.04	12.40	-0.88	-2.20	-0.27
12	NVSR-3537 x Gurjari	12.09	11.65	4.76	-12.58	-25.54**	-12.00	-16.61*	-23.33**	-8.28	3.64	-1.75	-2.48
13	NVSR-3537 x NVSR-687	-4.56	-5.05	-9.98	-13.20	-25.60**	-12.07	-36.57**	-41.17**	-29.62**	21.01**	14.49**	13.65**
14	NVSR-3537 x NVSR-796	58.14**	52.56**	54.01**	40.23**	17.48*	38.84**	12.69	4.02	24.44**	15.07**	7.45*	6.66
15	NVSR-3537 x NWGR-19208	44.36**	39.93**	39.88**	40.74**	27.12**	50.23**	-6.96	-10.63	6.92	26.88**	21.87**	20.97**
16	NVSR-3537 x NWGR-19222	-9.57	-25.24**	7.34	18.49*	3.02	21.75*	-7.76	-10.61	6.94	16.89**	8.70*	7.90*
17	GNR-3 x NVSR-2965	38.93**	53.79**	54.49**	26.12**	15.92	26.51**	0.36	-12.77	-5.75	13.06**	9.02**	18.12**
18	GNR-3 x NVSR-917	-8.27	-19.78**	7.58	-18.58*	-19.40*	-10.22	-18.59**	-18.78*	-12.23	0.00	-0.74	1.36
19	GNR-3 x Mahisagar	12.38**	-8.65*	46.64**	-8.54	-11.74	-3.67	-25.07**	-28.47**	-22.70**	12.05**	11.29**	13.49**
20	GNR-3 x Gurjari	-1.52	-5.13	-4.70	-18.64*	-28.33**	-21.78*	-30.63**	-33.11**	-27.72**	10.57**	4.16	4.78
21	GNR-3 x NVSR-687	-12.58*	-15.04*	-14.65*	-15.93	-25.45**	-18.63*	-20.49**	-22.63**	-16.39	4.01	-2.21	-1.62
22	GNR-3 x NVSR-796	19.88**	19.59**	20.72**	24.52**	7.80	17.66	6.55	3.18	11.49	10.60**	2.64	3.25
23	GNR-3 x NWGR-19208	13.97*	13.69*	14.21*	15.51	8.19	18.08	-4.54	-5.47	4.17	12.11**	6.99*	7.64*
24	GNR-3 x NWGR-19222	25.62**	6.76	53.27**	0.93	-9.15	-0.85	2.24	0.33	12.61	-0.58	-8.11*	-7.55*
	S.Em. ±	9.56	11.04	11.04	1.88	2.17	2.17	2.59	2.99	2.99	1.19	1.38	1.38

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

Table 2: Conti…

Sr. No.	Crosses	Kernel length (mm)			Kernel breadth (mm)			L/B ratio		
		RH	HB	SH	RH	RH	RH	RH	HB	SH
1	NVSR-3461 x NVSR-2965	-14.33**	-18.90**	-22.83**	2.72	-10.73**	-9.57**	-17.72**	-24.83**	-14.66**
2	NVSR-3461 x NVSR-917	-9.24**	-18.02**	-22.00**	14.22**	0.00	1.30	-20.95**	-23.69**	-23.00**
3	NVSR-3461 x Mahisagar	5.23	-3.14	-7.84*	2.27	-9.59**	-8.41**	2.06	-2.41	0.45
4	NVSR-3461 x Gurjari	5.33	5.25	0.15	-0.42	-3.24	3.91	5.74*	2.76	-3.49
5	NVSR-3461 x NVSR-687	0.00	-2.06	-6.81*	7.76**	4.29	5.65*	-7.17**	-8.31**	-11.72**
6	NVSR-3461 x NVSR-796	3.34	-0.51	-5.34	2.85	2.56	4.49	0.56	-3.36	-9.24**
7	NVSR-3461 x NWGR-19208	2.17	-0.77	-5.59	-2.97	-6.58*	-5.36*	5.24*	4.37	-0.34
8	NVSR-3461 x NWGR-19222	0.48	-7.62*	-12.10**	5.56*	-7.58**	-6.38*	-5.44*	-10.42**	-5.98*
9	NVSR-3537 x NVSR-2965	-0.35	-7.38*	-8.33**	11.86**	0.46	-5.65*	-11.27**	-14.40**	-2.82
10	NVSR-3537 x NVSR-917	-6.64*	-17.13**	-17.98**	5.54*	-4.48	-10.29**	-10.10**	-12.07**	-7.22*
11	NVSR-3537 x Mahisagar	2.11	-7.67*	-8.62**	5.82*	-3.24	-9.13**	-3.41	-4.59	0.68
12	NVSR-3537 x Gurjari	1.39	-0.64	-1.67	-2.38	-8.50**	-1.74	3.14	-5.13	0.11
13	NVSR-3537 x NVSR-687	-18.55**	-21.73**	-22.54**	-1.84	-2.29	-7.39**	-14.30**	-18.05**	-13.53**
14	NVSR-3537 x NVSR-796	-0.60	-6.09*	-7.06*	8.36**	4.13	6.09*	-8.80**	-16.99**	-12.40**
15	NVSR-3537 x NWGR-19208	1.61	-3.17	-4.16	0.54	0.46	-5.65*	1.18	-3.63	1.69
16	NVSR-3537 x NWGR-19222	3.37	-6.63*	-7.59*	20.72**	9.26**	2.61	-14.41**	-14.64**	-9.92**
17	GNR-3 x NVSR-2965	-11.24**	-18.79**	-16.81**	7.40**	-8.91**	-2.17	-19.09**	-25.52**	-15.45**
18	GNR-3 x NVSR-917	-4.29	-16.31**	-14.26**	2.84	-12.15**	-5.65*	-7.46**	-9.94**	-9.13**
19	GNR-3 x Mahisagar	-3.22	-13.82**	-11.71**	-0.47	-14.17**	-7.83**	-3.41	-6.90*	-4.17
20	GNR-3 x Gurjari	-7.20**	-10.57**	-8.38**	-4.05	-4.05	3.04	-3.37	-6.85*	-11.05**
21	GNR-3 x NVSR-687	-7.67**	-12.72**	-10.58**	0.65	-5.26*	1.74	-8.29**	-8.67**	-12.06**
22	GNR-3 x NVSR-796	-2.37	-9.23**	-7.01*	-0.55	-3.10	4.06	-1.67	-6.26*	-10.48**
23	GNR-3 x NWGR-19208	-12.37**	-17.84**	-15.83**	-4.47	-10.53**	-3.91	-8.26**	-8.26**	-12.40**
24	GNR-3 x NWGR-19222	3.98	-7.51*	-5.24	16.90**	-0.13	7.25**	-13.72**	-17.62**	-13.53**
	S.Em. ±	0.18	0.20	0.20	0.05	0.06	0.06	0.07	0.08	0.08

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

Table 2: Conti…

Sr. No.	Crosses	100 grain weight (g)			Protein content (%)			Amylose content (%)		
		RH	HB	SH	RH	RH	RH	RH	HB	SH
1	NVSR-3461 x NVSR-2965	5.26	-18.32**	-20.48**	-5.94*	-7.09*	-11.31**	8.33*	-4.40	7.42
2	NVSR-3461 x NVSR-917	14.11**	-10.64**	-13.00**	-12.97**	-14.00**	-15.91**	5.42	-6.32	3.59
3	NVSR-3461 x Mahisagar	7.42*	-16.19**	-18.41**	19.64**	14.29**	9.09**	11.28**	4.27	2.55
4	NVSR-3461 x Gurjari	-6.26*	-7.09*	-9.55**	44.44**	39.29**	32.95**	2.21	-9.90**	1.49
5	NVSR-3461 x NVSR-687	0.78	-8.51**	-10.93**	-3.64	-4.82	-9.15**	12.98**	1.46	9.56*
6	NVSR-3461 x NVSR-796	1.53	-5.67*	-8.17**	12.79**	4.76	0.00	31.66**	28.66**	10.58**
7	NVSR-3461 x NWGR-19208	3.72	-7.68**	-10.13**	-4.88	-7.14*	-11.36**	9.58**	4.80	-1.31
8	NVSR-3461 x NWGR-19222	6.66*	-17.61**	-19.79**	-3.90	-11.90**	-15.91**	4.28	1.96	-8.28*
9	NVSR-3537 x NVSR-2965	9.09**	-11.17**	-24.05**	-2.78	-14.58**	-20.45**	-24.90**	-27.25**	-18.25**
10	NVSR-3537 x NVSR-917	-29.30**	-41.86**	-50.29**	-2.77	-16.33**	-18.18**	-23.94**	-25.74**	-17.89**
11	NVSR-3537 x Mahisagar	15.37**	-5.52	-19.22**	32.90**	20.36**	4.60	9.23**	5.61	11.24**
12	NVSR-3537 x Gurjari	0.00	-5.29	-9.44**	5.68	-5.13	-15.91**	1.78	-1.53	10.93**
13	NVSR-3537 x NVSR-687	-39.71**	-41.86**	-50.29**	0.00	-12.14**	-18.18**	-22.04**	-23.00**	-16.85**
14	NVSR-3537 x NVSR-796	10.42**	9.15**	-6.67*	19.32**	11.04**	-9.09**	8.32*	-3.66	1.48
15	NVSR-3537 x NWGR-19208	4.49	-1.35	-15.65**	15.45**	2.50	-6.82*	-16.64**	-21.06**	-16.85**
16	NVSR-3537 x NWGR-19222	40.53**	13.86**	-2.65	6.02	0.00	-20.45**	13.52**	5.24	10.85**
17	GNR-3 x NVSR-2965	9.01**	-14.49**	-19.22**	-6.13*	-11.64**	-6.76*	4.62	-0.72	11.56**
18	GNR-3 x NVSR-917	-0.31	-21.07**	-25.43**	2.85	-0.92	4.55	-8.62**	-12.62**	-3.39
19	GNR-3 x Mahisagar	-9.19**	-28.38**	-32.34**	-0.79	-9.54**	-4.55	-1.63	-2.87	-2.00
20	GNR-3 x Gurjari	3.87	3.25	-1.27	-4.01	-11.69**	-6.82*	-24.87**	-28.79**	-19.78**
21	GNR-3 x NVSR-687	4.96	-3.41	-8.75**	-6.24*	-11.74**	-6.87*	-22.78**	-25.32**	-19.35**
22	GNR-3 x NVSR-796	6.27*	0.12	-5.41*	-0.55	-11.69**	-6.82*	22.74**	11.27**	12.26**
23	GNR-3 x NWGR-19208	-7.49**	-16.57**	-21.17**	-16.69**	-22.46**	-18.18**	13.74**	9.95**	10.93**
24	GNR-3 x NWGR-19222	15.29**	-9.99**	-14.96**	0.70	-11.69**	-6.82*	-14.86**	-19.47**	-18.75**
	S.Em. ±	0.07	0.08	0.08	0.15	0.17	0.17	0.81	0.94	0.94

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

Table 3: Mean performance of parents and crosses for different characters

Genotypes	Days to 50 % flowering	Plant height (cm)	Productive tillers/plant	Panicle length (cm)	Grains/panicle	Grain yield /plant	Straw yield/plant
NVSR-3461 x NVSR-2965	79.00	101.20	10.00	24.50	208.20	20.46	33.30
NVSR-3461 x NVSR-917	85.00	96.00	6.00	24.00	179.60	18.94	32.28
NVSR-3461 x Mahisagar	79.00	104.40	8.00	25.00	203.80	20.22	36.86
NVSR-3461 x Gurjari	86.00	99.60	9.00	23.12	138.80	14.26	32.78
NVSR-3461 x NVSR-687	89.00	103.80	10.00	24.80	165.20	32.79	39.88
NVSR-3461 x NVSR-796	84.00	107.47	13.00	27.00	191.40	31.12	43.90
NVSR-3461 x NWGR-19208	89.00	105.00	10.00	25.40	182.00	26.36	38.84
NVSR-3461 x NWGR-19222	84.00	107.07	10.00	24.40	227.80	29.30	41.88
NVSR-3537 x NVSR-2965	86.00	110.80	11.00	26.90	246.40	28.60	40.20
NVSR-3537 x NVSR-917	84.00	96.80	7.00	20.30	162.60	21.64	24.76
NVSR-3537 x Mahisagar	86.00	109.60	11.00	25.27	186.93	26.32	39.90
NVSR-3537 x Gurjari	84.00	102.80	9.00	24.80	170.60	20.70	32.56
NVSR-3537 x NVSR-687	84.00	96.40	7.00	20.10	146.60	20.68	24.98
NVSR-3537 x NVSR-796	89.00	111.00	12.00	27.80	250.80	32.66	44.18
NVSR-3537 x NWGR-19208	86.00	102.80	11.00	26.50	227.80	35.34	37.96

Table 3 Conti…

Genotypes	Days to 50 % flowering	Plant height (cm)	Productive tillers/plant	Panicle length (cm)	Grains/panicle	Grain yield /plant	Straw yield/plant
NVSR-3537 x NWGR-19222	79.00	107.20	11.00	26.50	174.80	28.64	37.96
GNR-3 x NVSR-2965	86.00	108.00	11.00	25.40	251.60	29.76	33.46
GNR-3 x NVSR-917	79.00	103.20	9.00	23.90	175.20	21.12	31.16
GNR-3 x Mahisagar	79.00	110.00	9.00	24.62	238.80	22.66	27.44
GNR-3 x Gurjari	84.00	106.80	9.00	23.00	155.20	18.40	25.66
GNR-3 x NVSR-687	84.00	107.80	9.00	24.80	139.00	19.14	29.68
GNR-3 x NVSR-796	86.00	117.80	12.00	27.80	196.60	27.68	39.58
GNR-3 x NWGR-19208	86.00	109.80	10.00	28.30	186.00	27.78	36.98
GNR-3 x NWGR-19222	81.00	108.00	12.00	24.60	249.60	23.32	39.98
NVSR-3461	89.00	91.80	13.00	22.40	140.80	26.28	37.32
NVSR-3537	89.00	91.60	14.00	23.70	152.80	27.80	42.47
GNR-3	88.67	103.60	13.00	22.40	163.60	25.67	38.36
NVSR-2965	83.00	91.00	14.00	22.80	198.60	21.52	28.32
NVSR-917	89.00	94.20	12.00	21.60	218.40	26.20	38.18

Table 3 Conti…

Genotypes	Days to 50 % flowering	Plant height (cm)	Productive tillers/plant	Panicle length (cm)	Grains/panicle	Grain yield /plant	Straw yield/plant
Mahisagar	79.00	101.60	11.00	21.64	261.40	23.88	34.88
Gurjari	86.00	102.20	10.00	22.20	151.60	19.56	35.62
NVSR-687	91.00	99.20	10.00	21.90	154.40	19.86	36.30
NVSR-796	93.00	102.00	10.00	21.70	164.40	18.78	35.94
NWGR-19208	93.00	95.20	12.00	22.40	162.80	22.42	39.12
NWGR-19222	89.00	98.80	11.00	22.80	233.80	20.54	39.84
GR-17 (Sardar)	86.00	93.40	14.00	22.30	162.85	23.52	35.50
mean of parents	88.15	97.38	11.82	22.32	182.05	22.96	36.94
mean of hybrids	84.08	105.56	9.83	24.95	193.97	24.91	35.26
Range of parents	79 to 93	91.00 to 103.60	10.00 to 14.00	21.60 to 23.70	140.80 to 261.40	18.78 to 27.80	28.32 to 42.47
Range of hybrids	79 to 89	96.00 to 117.80	6.00 to 13.00	20.10 to 28.30	138.80 to 251.60	14.26 to 35.34	24.76 to 44.18
S. Em. ±	2.29	6.32	0.43	1.51	7.75	1.54	2.13
C.D (0.05)	6.45	17.84	1.2	4.25	21.85	4.34	6
C.V. (%)	4.64	10.66	7.01	10.83	7.08	11.09	10.3

Table 3 Conti…

Genotypes	Harvest index (%)	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	100 grain weight (g)	Protein content (%)	Amylose content (%)
NVSR-3537 x NWGR-19222	43.00	6.29	2.36	2.66	2.82	4.90	27.72
GNR-3 x NVSR-2965	47.07	5.66	2.25	2.50	2.34	5.74	27.90
GNR-3 x NVSR-917	40.40	5.83	2.17	2.69	2.16	6.44	24.16
GNR-3 x Mahisagar	45.23	6.01	2.12	2.83	1.96	5.88	24.51
GNR-3 x Gurjari	41.76	6.23	2.37	2.63	2.86	5.74	20.06
GNR-3 x NVSR-687	39.21	6.08	2.34	2.60	2.64	5.74	20.17
GNR-3 x NVSR-796	41.15	6.33	2.39	2.65	2.74	5.74	28.07
GNR-3 x NWGR-19208	42.90	5.73	2.21	2.59	2.28	5.04	27.74
GNR-3 x NWGR-19222	36.84	6.45	2.47	2.56	2.46	5.74	20.32
NVSR-3461	41.32	6.47	2.33	2.78	2.82	5.88	21.49
NVSR-3537	39.56	6.73	2.16	3.12	2.48	4.34	26.34
GNR-3	40.09	6.97	2.47	2.82	2.74	6.50	25.23

Table 3 Conti…

Genotypes	Harvest index (%)	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	100 grain weight (g)	Protein content (%)	Amylose content (%)
NVSR-3461 x NVSR-2965	38.06	5.25	2.08	2.52	2.30	5.46	26.86
NVSR-3461 x NVSR-917	36.97	5.31	2.33	2.28	2.52	5.18	25.90
NVSR-3461 x Mahisagar	35.42	6.27	2.11	2.97	2.36	6.72	25.64
NVSR-3461 x Gurjari	30.31	6.81	2.39	2.85	2.62	8.19	25.38
NVSR-3461 x NVSR-687	38.01	6.34	2.43	2.61	2.58	5.60	27.40
NVSR-3461 x NVSR-796	41.48	6.44	2.40	2.68	2.66	6.16	27.65
NVSR-3461 x NWGR-19208	40.43	6.42	2.18	2.95	2.60	5.46	24.68
NVSR-3461 x NWGR-19222	41.17	5.98	2.15	2.78	2.32	5.18	22.94
NVSR-3537 x NVSR-2965	41.57	6.24	2.17	2.87	2.20	4.90	20.44
NVSR-3537 x NVSR-917	46.64	5.58	2.06	2.74	1.44	5.04	20.53
NVSR-3537 x Mahisagar	39.75	6.22	2.09	2.98	2.34	6.44	27.82
NVSR-3537 x Gurjari	38.87	6.69	2.26	2.96	2.62	5.18	27.74
NVSR-3537 x NVSR-687	45.29	5.27	2.13	2.56	1.44	5.04	20.79
NVSR-3537 x NVSR-796	42.51	6.32	2.44	2.59	2.70	5.60	25.38
NVSR-3537 x NWGR-19208	48.21	6.52	2.17	3.01	2.44	5.74	20.79

Table 3 Conti…

Genotypes	Harvest index (%)	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	100 grain weight (g)	Protein content (%)	Amylose content (%)
NVSR-2965	43.18	5.78	1.72	3.36	1.56	5.74	28.10
NVSR-917	40.70	5.22	1.75	2.98	1.60	6.02	27.65
Mahisagar	40.64	5.44	1.79	3.04	1.58	5.35	24.59
Gurjari	35.44	6.46	2.47	2.62	2.77	5.46	28.17
NVSR-687	35.30	6.21	2.18	2.85	2.30	5.74	27.00
NVSR-796	34.32	5.99	2.34	2.56	2.42	5.04	20.51
NWGR-19208	36.43	6.10	2.16	2.82	2.20	5.60	23.55
NWGR-19222	34.02	5.43	1.75	3.10	1.54	4.90	22.50
GR-17 (Sardar)	39.85	6.80	2.30	2.96	2.90	6.16	25.01
mean of parents	38.27	6.07	2.10	2.91	2.18	5.51	25.01
mean of hybrids	40.93	6.09	2.25	2.71	2.39	5.70	24.61
Range of parents	34.02 to 43.18	5.22 to 6.97	1.72 to 2.47	2.56 to 3.36	1.54 to 2.82	4.34 to 6.50	20.51 to 28.17
Range of hybrids	30.31 to 48.21	5.25 to 6.81	2.06 to 2.47	2.28 to3.01	1.44 to 2.86	4.90 to 8.19	20.06 to 28.07
S. Em. ±	0.98	0.14	0.04	0.06	0.06	0.12	0.65
C.D (0.05)	2.75	0.4	0.12	0.17	0.16	0.35	1.85
C.V. (%)	4.22	4.05	3.41	3.71	4.12	3.82	4.58

Table 4: Best heterotic crosses and their performance for grain yield per plant and related parameters

Best crosses (P1 x P2)	Mean yield per plant(g)	RH (%)	HB (%)	SH (%)	Significant standard heterosis of other traits in desired direction
NVSR-3537 x NWGR-19208	35.34	40.74**	27.12**	50.23**	GPP, HI
NVSR-3461 x NVSR-687	32.79	42.13**	24.77**	39.41**	KB, AC
NVSR-3537 x NVSR-796	32.66	40.23**	17.48*	38.84**	PL, GPP, SYP, KB,
NVSR-3461 x NVSR-796	31.12	38.14**	18.43*	32.31**	PL, GPP, SYP, AC
GNR-3 x NVSR-2965	29.76	26.12**	15.92	26.51**	GPP, HI, PC, AC

*** and ** indicates significance at 5% and 1% levels of probability, respectively.**
HB (%) = Heterobeltiosis (%), SH (%) = Standard Heterosis (%), RH (%) = Relative Heterosis (%)
GPP = Grains/panicle, **PL** = Panicle length, **SYP** = Straw yield/plant, **HI** = Harvest index, **KB** = Kernel breadth, **PC** = Protein content, **AC** = Amylose content

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