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Heterosis analysis for yield and its contributing traits in rice hybrids of different CMS sources

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Abstract
The present investigation was carried out at Regional Rice Research Station, NAU, Vyara. The study involved two female lines with Wild Abortive (WA) and Gambiaca CMS sources crossed with 165 male parents. Total 284 F_1s were evaluated in *Kharif*-2020 to identify the potential restorers and maintainers. Out of those, 61 F_1s with identified restorers were further evaluated. The *per se* performance and heterosis was estimated for the characters *viz.*, days to 50 % flowering, plant height (cm), productive tillers per plant, panicle length (cm), grains per panicle, grain yield per plant (g), straw yield per plant (g) and harvest index (%). The *per se* performance reported huge variation among the cross combinations. It was observed that the means for yield and yield components were higher for the cross combinations of RTN13A comparative to IR58025A. Therefore, mostly the crosses of RTN13A were found to be superior than the crosses of IR58025A, except for days to 50 % flowering and plant height. The male parent NVSR 2309 gave highest yield 32.14 g and 33.33 g with both the CMS lines IR58025A and RTN13A, respectively. The magnitude of heterosis for yield and its related traits was found to be higher for the crosses of female IR58025A than the crosses of RTN13A. For IR58025A, the pollen parents NVSR 2247 and NVSR 2529 registered highest positive value of mid parent heterosis (34.77 %) and heterobeltiosis (28.35 %), respectively. While, for the female RTN13A, NVSR 2927 registered the highest positive value of 28.61 and 17.89 % for both mid parent heterosis and heterobeltiosis, respectively.

Keywords: CMS, WA, Gambiaca, restorers, maintainers, relative heterosis, heterobeltiosis

Introduction

Rice (*Oryza sativa* L.) princess among the cereals is self-pollinated crop have 24 recognized species belonging to genus *Oryza* and tribe Oryzeae in the family Poaceae of which 22 are wild and two *viz.*, *Oryza sativa* (2n = 24, AA) and *Oryza glaberrima* (2n = 24, AA) are cultivated. The number of chromosomes of the cultivated rice and its related species varies from 24 to 48, with the basic chromosome number equals to 12. *Oryza sativa* is the most widely grown of the two cultivated species, believed to have originated in Asia. However, the greatest diversity is observed in Assam and Meghalaya area and southwest China. *Oryza glaberrima* Steud. is believed to have originated on the swampy upper Niger river basin in Africa and *Oryza barthii* as progenitor (Chatterjee, 1948) [9].

"Rice is life" was the famous theme for the International Year of Rice, 2004 denoting its overwhelming importance as an item of food and commerce. Globally, rice is the most important food grain from nutritional, food security or economic perspective (Smith and Dilday, 2003) [30]. Asia is considered to be 'rice bowl' of the world and it produces and consumes more than 90% of world rice. Rice is staple food of 65 % of the total population in India. India is first in terms of area and second in terms of production. Rice is widely grown in most Indian states, covering approximately 43.78 Mha and producing 118.43 MT with a yield of 2705 kg/ha. West Bengal produces the most rice in India, with a yield of 2851 kg/ha and a total production of 15.57 MT. The state with the highest area under rice cultivation in India is Uttar Pradesh, with 5.74 Mha. Punjab has the highest productivity in India with 4035 kg/ha. (Anon[a], 2021) [1]. The majority of the rice-growing land in Gujarat is concentrated in the middle and south Gujarat, covering roughly 0.91 Mha with a production of 2.14 MT and productivity of 2367 kg/ha (Anon[b], 2021) [2].

Since the 1990s, however, rice production has failed to keep pace with population growth. The continued population increase in Asia at the rate of 1.8% per year requires 70 % more rice production in 2025 than that in 1995 (Sharma *et al.*, 2013) [28]. Hybrid rice technology has the potential to start to bridge the yield gap and to meet the challenge of increasing rice production while sustaining the natural resource base.

Hybrid rice technology exploits the phenomenon of hybrid vigour (heterosis) to increase the yield potential of rice varieties by 15 to 20 % over current commercial cultivars (Hwa and Yang, 2008) [16]. The commercial success of hybrid rice in China has clearly demonstrated the potential of this technology (Matthayatthaworn *et al*., 2011) [22]. Recent research in India (Mishra *et al*., 2003) [23], Vietnam (Hoan and Nghia, 2003) [15] and Philippines (Redona *et al*., 2003) [25] confirms that growing hybrid rice is an economically viable option to increase yields beyond the level of high yielding semi-dwarf inbred rice varieties.

Heterosis or hybrid vigour refers to the phenomenon in which hybrids outperform their inbred parents in yield, biomass, biotic and abiotic stress tolerance or other traits. Heterosis in rice was first reported by Jones (1926) [17]. In rice, the role of cytoplasm causing male sterility was first reported by Sampath and Mohanty (1954) [26]. China opened research on hybrid rice in 1964 and the first rice hybrid credit is to Chinese scientist Yuan Long Ping, who developed in 1976 using three-line breeding method (Yuan, 1977 and Cheng *et al*., 2007) [33, 10, 11].

The International Rice Research Institute (IRRI) had initially conducted studies on hybrid rice during 1970 to 1972 when a CMS line, derived from TN-1 cytoplasm and in the genetic background of an Indian variety, Pankhari-203 was developed. Encouraged by the success of hybrid rice technology in enhancing the rice production and productivity in China, the Indian Council of Agricultural Research (ICAR) initiated a national program for development and large scale adoption of hybrid rice in the country in December 1989. From the initial level of 10,000 hectares in 1995, area under hybrid rice reached 1 Mha in 2006, exceeded 2.5 Mha during 2014, which is about 5.6 % of the total rice area in the country. It has picked up during the last eleven years, mainly because of increasing popularity of hybrid rice in Uttar Pradesh, Bihar, Jharkhand, Madhya Pradesh and Chhattisgarh. So far, 117 rice hybrids (36 from public organization and 81 from private sector) were developed, suitable for different ecology and duration ranging from 115 to 150 days, covering 3.0 Mha, which accounted for ~7.0% of the total rice acreage in India (Anon^{d}, 2019) [3].

Availability of efficient male sterility systems is a prerequisite for the development of hybrids in rice. The breeding system CGMS using three lines developed in 1973 and a two-line hybrid rice system by means of PGMS and TGMS was established in the 1980s (Cheng *et al*., 2007) [10, 11]. Among all the male sterility system in rice, the three-line system of seed production is being commonly used for large scale hybrid rice seed production in the world. CMS combined with a fertility restoration system has been found to be the most efficient genetic tool in commercializing this technology in rice (Virmani and Wan, 1988) [32]. CMS is a maternally inherited trait characterized by the inability of a plant to produce functional pollen that is associated with abnormal ORFs found in mitochondrial genomes and, in many cases, male fertility can be restored by fertility restorer (*Rf*) genes associated with nuclear genes encoding pentatricopeptide repeat (PPR) proteins (Chase and Gabay-Laughnan, 2004) [8].

In rice, several CMS/*Rf* systems defined by different CMS cytoplasm with distinct genetic features have been identified. These include wild abortive (WA), Dissi, Gambiaca, Boro type II (BT), and Hong-lian (HL) CMS systems. WA (indica), Dissi (an *indica* variety, DS 97A, from Senegal), and Gambiaca (an *indica* variety from West Africa) belong to the sporophytic CMS system and all these possess typical aborted pollens, whereas HL (*indica*) and BT (japonica) CMS systems are categorized as gametophytic types (Rao, 1988) [24]. Pollen grains of CMS lines derived from sporophytic CMS systems abort at the uninucleate stage; hence, they are more stable than CMS lines derived from a gametophytic system in which pollen grains abort at the binucleate and trinucleate stages (Lin and Yuan, 1980) [20].

Though 20 independent types of CMS cytoplasms have been reported in rice, only three *viz.*, Wild Abortive (WA), Boro Tai (BT) and Honglian (HL) are mostly deployed for commercial hybrid seed production (Li and Yuan, 2000; Fujii and Toriyama, 2009) [19, 20, 14]. The WA system is widely used CMS source for *indica* rice accounting for about 90 % of the rice hybrids produced in China and approximately 98 % of the hybrids developed outside China (Sattari *et al.*, 2008) [27]. It is most stable over environment and reasonably easy to restore (Yuan and Virmani, 1988) [34]. Therefore, it is being transferred to various genotypes to develop suitable CMS lines for other environments.

CMS lines introduced from China are unsuitable to use as such in developing hybrid rice in India. Therefore, it is imperative to identify maintainers and restorers among the lines developed through conventional breeding procedures. Maintainers with high adaptability and restorers should have good combining ability. Development of genetically diverse restorer lines is important for broadening the genetic base of hybrid breeding programme and enhancing the heterosis potential of hybrids. Therefore, with the viewpoint of broadening the genetic base and diversifying the cytoplasm following study was undertaken.

Material and Method

The experimental material for present investigation comprised of two CMS lines IR58025A (WA) and RTN13A (Gambiaca) and 165 diverse male lines collected from Regional Rice Research Station, NAU, Vyara. Two staggers with the gap of 15 days of 165 male lines, each line having 16 plants were sown and 3 staggered for both the CMS lines were grown to ensure the synchronization and availability of male and female flower throughout the crossing programme. The F_1s were generated by crossing 165 lines as male to 2 CMS line as female during summer 2019-20. A row consists of 16 plants out of which 5 plants each of the P_1, P_2, and F_1 competitive plants were randomly selected and tagged excluding border plants to minimize border effects. All the characters studied were recorded on randomly selected competitive plants per line except days to flowering. For days to flowering, the observations were recorded on population basis. The characters studied were days to 50% flowering, plant height (cm), productive tillers per plant, panicle length (cm), grains per panicle, grain yield per plant (g), straw yield per plant (g) and harvest index (%). The mean performance of selected F_1s along with their parental lines were studied for both yield and components traits during *kharif*-2020 (Table 1). Due to the male sterile nature of CMS lines, their fertile counterpart maintainer lines, IR58025B and RTN13B were used for studying yield and components traits. Heterosis was estimated as per cent increase or decrease with respect to various traits over mid parent and better parent value for all the hybrids (Tables 2 and Table 3). Therefore, for calculating the mid parent value respective paired male plant row was used and for better parent value the mean value of following IR58025B and RTN13B were used.

Heterosis was estimated as per cent increase or decrease in the mean value of F_1s over the mid-parent, *i.e.*, relative heterosis (Briggle, 1963) [6] and over the better parent, *i.e.*, heterobeltiosis (Fonseca and Patterson, 1968) [13], for each character as under.

$$\text{Relative heterosis (\%)} = \frac{\overline{F}_1 - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Heterobeltiosis (\%)} = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

Where,

$\overline{F}_1$ = Mean performance of the F_1

$\overline{MP}$ = Mean value of the parents (P_1 and P_2) of F_1

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

Results and Discussion

Estimation of *per se* performance of hybrids

As the early flowering is desirable, the parent which flowered earlier was considered a better parent. For the female IR58025A, the mean values recorded by F_1s was 79.08. The cross combinations IR58025A × NVSR 3192 and IR58025A × NVSR 3306 registered the lowest (71 days) and the cross IR58025A × GR 104 (106 days) registered the highest number of days, respectively. However, for the crosses regarding female RTN13A, the mean of 81.31 days was observed. The cross RTN13A × IET 22584 recorded with highest (112 days) and the cross RTN13A × NVSR 3216 (68 days**)** registered the lowest number of days to 50% flowering, respectively.

Plants with shorter height are desirable in rice. For the cross combinations of the female IR58025A, plant height varied for different crosses with overall mean of 113.43 cm. The cross combination IR58025A × NVSR 2148 (97.40 cm) was the shortest in height and IR58025A × NVSR 3018 (134.50 cm) was the tallest among complete fertile F_1s. In case of F_1s of RTN13A, the mean value of 117.27 cm was observed. The cross RTN13A × NVSR 3280 (105.00 cm) observed with shortest and RTN13A × NVSR 3018 (135.40 cm) recorded maximum height.

Higher number of productive tillers are desirable in rice. Mean number of tillers per plant of complete fertile F_1s was 7.04 having female IR58025A. Minimum number of tillers per plant was 4.33 for IR58025A × NVSR 3192 and maximum number of tillers per plant was 9.13 for IR58025A × NVSR 3019. While, overall mean of 7.61 for F_1s with female RTN13A was recorded. The cross combinations RTN13A × NVSR 3019 and RTN13A × NVSR 2341 showed highest (9.25) and lowest (5.00) number of tillers per plant, respectively.

Higher panicle length is desirable to increase the grain count, which add to the overall yield in rice. The mean value for panicle length was 28.88 cm for F_1s of female IR58025A, the cross IR58025A × NVSR 3280 (24.30 cm) had the shortest panicle and IR58025A × NVSR 2817 (35.46 cm) had the longest panicle among fully fertile F_1s of IR58025A female parent. For the female RTN13A, the overall mean of 29.53 cm was recorded. The cross RTN13A × NVSR 2309 found with the shortest (23.38 cm) and RTN13A × Mahisagar had longest (33.62 cm) panicle length among the F_1s studied.

Higher grain numbers are desirable to increase the yield directly in rice. From the F_1s of female IR58025A, mean of 275.98 was recorded. Lowest number of grains were recorded by the cross IR58025A × NVSR 3306 (168.00) and highest was recorded by IR58025A × NVSR 3046 (398.00). The F_1s of female RTN13A recorded mean of 298.15, the cross RTN13A × NVSR 3046 showed maximum (411.00) and RTN13A × NVSR 2896 showed minimum (186.00) number of grains per plant.

Higher grain yield is the prime objective of hybrid rice breeding. The comparison of mean values of crosses revealed that from the F_1s of female IR58025A, overall mean of 25.88 g was recorded. The IR58025A × NVSR 2309 (32.14 g) reported maximum and IR58025A × WGL-14 (17.22 g) reported minimum yield. The hybrids of female RTN13A recorded overall mean value of 27.88 g. Cross RTN13A × NVSR 2309 (33.33 g) and RTN13A × IR-28 (22.23 g) reported with maximum and minimum yield, respectively.

Higher straw yield is a desirable trait in rice breeding as it used for feed purpose. The F1s of IR58025A recorded mean value of 32.23 g. The cross combinations IR58025A × WGL-14 (24.97 g) exhibited the lowest and IR58025A × NAUR-1 had the highest (43.10 g) straw yield. Similarly, the F_1s of RTN13A recorded overall mean of 33.94 g. The crosses RTN13A × NAUR-1 (46.22 g) and RTN13A × NVSR 3306 (25.54 g) observed with highest and lowest straw yield, respectively.

The higher harvest index is desirable in food crops like rice. The F_1s of female IR58025A recorded mean value of 44.62%. The highest harvesting index was recorded for the cross IR58025A × NVSR 2309 (54.32 %) and lowest for IR58025A × IET 22582 (38.46 %). The F_1s of female RTN13A observed with mean of 45.17%. Cross RTN13A × NVSR 3306 (53.48 %) and RTN13A × IET 22582 (38.46 %) reported with highest and lowest harvest index, respectively.

Estimation of heterosis

Negative heterosis is desirable for days to 50 % flowering because this makes the hybrids to flower earlier as compared to their parents. Considering the female IR58025A, the heterosis for days to 50 per cent flowering in F_1s ranged from -16.57 to 6.49 % over the respective mid parent and -16.09 to 21.28 % over better parent (Table 2). As compared to their better parent, earlier flowering was observed in 34 crosses, while 54 hybrids showed negative mid parent heterosis. Cross combination IR58025A × NVSR 3224 and IR58025A × NVSR-2247 showed highest desirable heterosis over mid parental (-16.57 %) and better parent (-16.09 %), respectively. For female RTN13A, the heterosis for days to 50% flowering in F_1s ranged from -21.27 to 29.11 and -15.56 to 36.59 % over mid parent and better parent, respectively (Table 3). As compared to their better parent, significantly earlier flowering was observed in 33 crosses, while 52 crosses showed negative mid parent heterosis. Cross combination RTN13A × NVSR 3384 (-21.27 %) showed highest desirable heterosis over mid parent and hybrid RTN13A × NVSR 3224 (-15.56 %) showed highest desirable better parent heterosis. A wide range of heterosis from negative to positive values have been reported by Kumar *et al.* (2017) [18], Singh *et al.* (2019) [29] and Begum *et al.* (2020) [5].

Semi-dwarf plant height and hence negative value of heterosis is desirable for high yield in rice as vigour in plant height may lead to unfavorable grain/straw ratio and below optimum yield due to lodging. Therefore, optimum plant height which increases the paddy yield but prevents the crop logging is preferred by farmers. total four crosses showed the negative value of heterosis over mid parent and only one cross combination exhibited considerable desirable negative value of heterobeltiosis. The range observed for mid parent and better parent heterosis was -7.40 to 21.27 and 6.60 to 47.20 %, respectively. The F_1 IR58025A × NVSR 2148 recorded most negative value for mid parent heterosis (-7.40 %) and lowest value for better parent heterosis (6.60 %) (Table 2). The F_1s of female RTN13A showed the mid parents heterosis and heterobeltiosis ranged from 1.96 to 22.33 and 7.49 to 38.61%, respectively. As it was observed none of the crosses recorded with negative heterosis. But lowest heterosis over better parent and mid parent were recorded by cross combinations, RTN13A × NVSR 3280 (7.49 %) and RTN13A × NVSR 2778 (0.37 %), respectively. Results were in line with Devi *et al.* (2017) [12], Kumar *et al.* (2017) [18], Singh *et al.* (2019) [29], Begum *et al*. (2020) [5] and Azad *et al.* (2022) [4].

Positive heterosis is desirable for number of effective tillers per plant as a greater number of panicles bearing tillers is believed to be closely associated with higher grain yield. Considering the F_1s of IR58025A, heterotic value for number of effective tillers per plant ranged from -27.85 to 65.81 and -38.17 to 23.80 % over mid parent and better parent, respectively (Table 2). Also 43 cross combinations recorded positive value of mid parent heterosis and 31 crosses showed positive heterobeltiosis. Cross combination, IR58025A × NVSR 2876 registered the highest positive heterosis for mid parent (67.81 %) and also for better parent heterosis (23.80%). Considering the F_1s of female RTN13A, heterotic values ranged from -28.62 to 42.39 and -36.88 to 16.76 % over mid parent and better parent, respectively (Table 3). Also 47 hybrids showed positive mid parent heterosis and 23 cross combinations recorded positive value of heterobeltiosis. Cross combination, RTN13A × NVSR 2876, registered the highest positive heterosis for mid parent (42.39 %) and RTN13A × NVSR 3019 over better parent (16.76 %). Significant positive heterosis for number of effective tillers has been reported by Borah *et al.* (2017) [7], Devi *et al.* (2017) [12], Begum *et al.* (2020) [5] and Azad *et al.* (2022) [4].

Positive value of heterosis is desirable for panicle length. For the crosses of female IR58025A, the heterotic values for panicle length ranged and -1.65 to 26.40 and from -7.62 to 25.32 % over mid parent and better parent, respectively (Table 2). Total, 59 crosses showed positive mid-parent heterosis, while 50 cross combinations recorded positive heterobeltiosis Cross combination IR58025A × NVSR 3384, registered the highest positive heterosis for both mid parent (26.40%) and better parent heterosis (25.32 %). Similarly, F_1s for RTN13A showed heterotic values from -9.39 to 27.05 % and -17.77 to 16.86% over mid parent and better parent, respectively (Table 3). Also 52 crosses showed positive mid parent heterosis and 40 cross combinations recorded positive value of heterobeltiosis. Cross combination, RTN13A × Mahisagar, registered the highest positive heterosis over better parent (17.15 %) and RTN13A × NVSR 2817 observed with highest mid parent heterosis (27.05 %). Significant positive heterosis for this trait was also reported by Devi *et al.* (2017) [12], Kumar *et al.* (2017) [18], Thorat *et al*. (2017) [31], Singh *et al.* (2019) [29], Begum *et al*. (2020) [5] and Azad *et al.* (2022) [4].

Positive value of heterosis is desirable for number of grains per panicle. For the crosses of female IR58025A, the heterotic value for number of grains per panicle ranged from -21.77 to 43.02 over the mid parent and -12.25 to 49.92 % over the better parent (Table 2). It was also reported that 58 crosses showed positive mid-parent heterosis and 54 cross combinations registered positive heterobeltiosis. Cross combination, IR58025A × 3018 and IR58025A × NVSR 2309 showed highest positive heterosis for mid parent (49.92 %) and better parent heterosis (43.02 %), respectively. In case of RTN13A, the heterotic values of F_1s ranged from -16.81 to 57.63 and -30.89 to 48.50 % over the mid parent and better parent, respectively (Table 3). Total 50 crosses recorded positive mid-parent heterosis and 40 cross combinations registered positive heterobeltiosis. Cross combination, RTN13A × NVSR 2098 showed highest positive heterosis over mid parent (57.63 %) and also over better parent (48.50%). Positive heterosis for spikelets per panicle was also exhibited by Devi *et al.* (2017) [12], Kumar *et al.* (2017), Thorat *et al*. (2017) [31], Singh *et al.* (2019) [29], Begum *et al*. (2020) [5] and Azad *et al.* (2022) [4].

Heterosis for grain yield in positive direction is desirable as higher grain yield is the main objective for almost all the breeding programmes. For F_1s of female IR58025A, mid parent heterosis ranged from -5.00 to 34.77 and heterobeltiosis ranged from -26.91 to 28.35 % (Table 2). Also 56 crosses exhibited positive heterosis over mid parent and 44 crosses showed positive heterosis over their better parent. Cross combination, IR58025A × NVSR 2247 and IR58025A × NVSR 2529 registered the highest positive value of mid parent heterosis (34.77 %) and heterobeltiosis (28.35 %), respectively. The heterotic response showed by F_1s of RTN13A ranged from -5.43 to 28.61 and -17.66 to 17.89 % over mid parent and better parent, respectively (Table 3). Also 55 crosses exhibited significant positive heterosis over mid parent and 37 crosses over their better parent. Cross combination, RTN13A × NVSR 2927 registered the highest positive value of 28.61 and 17.89 % for mid parent heterosis and heterobeltiosis, respectively. A wide range of heterosis between negative and positive values for grain yield have also been reported by Borah *et al.* (2017) [7], Devi *et al.* (2017) [12], Kumar *et al.* (2017) [18], Thorat *et al*. (2017) [31], Singh *et al.* (2019) [29], Begum *et al*. (2020) [5] and Azad *et al.* (2022) [4].

Positive heterosis for straw yield is desirable. Heterotic value regarding F_1s of female IR58025A for mid parent ranged from -7.09 to 50.46 % while for, better parent ranged from -16.01 to 41.77 % (Table 2). It was also found that 54 hybrids exhibited significant positive heterosis over mid parent and 47 hybrids exhibited significant positive heterosis over better parent. Cross combination, IR58025A × Sugandhamati and IR58025A × NAUR-1 registered the highest positive value of mid parent heterosis (50.46%) and heterobeltiosis (41.77 %), respectively. On the other hand, for F_1s of female RTN13A heterotic values for mid parent ranged from -21.87 to 49.87 % and better parent varied from -25.65 to 41.22 (Table 3) . There were 54 and 47 hybrids observed with positive mid parent heterosis and heterobeltiosis, respectively. RTN13A × IET 22582 and RTN13A × NAUR-1 cross combinations recorded with highest mid parent (49.87 %) and better parent heterosis (41.22 %), respectively. Borah *et al.* (2017) [7], Kumar *et al.* (2017) [18], Thorat *et al*. (2017) [31], Singh *et al.* (2019) [29], Begum *et al*. (2020) [5] and Azad *et al.* (2022) [4] reported positive as well as negative values of heterosis for straw yield.

Heterosis for harvest index in positive direction is desirable as it reflects the source to sink ratio of the plant. F_1s in correspondence to female IR58025A, varied for mid parent heterosis from -11.70 to 13.80 % and heterobeltiosis from -18.69 to 9.18 %. Total 18 F_1s exhibited positive heterosis over mid parental value and 10 F_1s exhibited positive heterosis over their better parents,. Cross combination, IR58025A × NVSR 2309 and IR58025A × NVSR 3224 registered the highest positive value for both heterobeltiosis (9.18 %) and mid parent heterosis (13.80 %), respectively. Likewise, RTN13A F_1s exhibits mid parent heterosis ranged from -13.08 to 19.67 % and better parent heterosis ranged from -18.49 to 13.33 %. It was found that 16 F_1s exhibited positive heterosis over mid parental value and 32 hybrids exhibited positive heterosis over their better parents. Cross combination RTN13A × NVSR 3306 registered the highest positive value for both mid parent heterosis (19.67 %) and heterobeltiosis (13.33 %), respectively. A wide range of heterosis ranging from negative to positive values for grain yield has been reported by Devi *et al*. (2017) [12], Kumar *et al*. (2017) [18], Thorat *et al*. (2017) [31], Singh *et al*. (2019) [29] and Begum *et al*. (2020) [5].

Table 1: Mean performance for hybrids regarding yield and its component trait

Sr. No	Cross	DTF		PH (cm)		PTP		PL (cm)		GPP		GYPP (g)			SYPP (g)		HI (%)
		25A	13A	25A	13A	25A	13A	25A	13A	25A	13A	25A	13A	25A	13A	25A	13A
1	Jaya	86	88	104.00	108.80	6.97	7.94	25.00	27.00	219.50	268.80	25.43	29.69	33.06	41.57	43.48	41.66
2	NAUR-1	85	88	114.60	119.00	7.25	7.75	28.35	29.00	276.20	293.00	28.73	30.81	43.10	46.22	40.00	40.00
3	IR-28	72	74	105.40	106.00	5.60	7.20	26.32	26.70	204.20	216.00	21.66	22.23	28.16	31.12	43.48	41.67
4	GR-7	79	81	118.50	121.00	7.56	8.00	25.50	27.12	259.00	292.00	28.68	27.68	40.74	39.28	39.06	41.34
5	Mahisagar	77	82	107.20	111.00	6.40	7.50	31.32	33.62	322.60	388.50	25.91	PR	33.94	42.20	43.29	40.00
6	PUSA 1509	76	74	108.56	112.33	6.89	8.33	28.38	32.50	209.20	228.30	22.09	24.81	30.04	36.22	42.37	40.65
7	Sugandhamati	84	88	116.40	120.20	7.00	7.89	29.13	29.16	246.00	282.40	24.85	27.81	37.28	43.38	40.00	39.06
8	IET 22582	75	77	119.00	120.67	7.60	7.81	32.18	32.23	288.60	328.60	25.14	27.00	40.22	43.20	38.46	38.46
9	IET 22594	76	81	117.33	117.95	7.60	7.69	32.34	31.89	250.80	271.00	28.14	26.74	41.65	36.37	40.32	42.37
10	IET 22598	76	77	118.50	121.33	8.00	8.34	26.05	29.12	180.50	205.00	23.18	26.18	35.47	34.30	39.52	43.29
11	IET 22086	80	83	122.00	125.00	6.75	7.45	28.68	28.72	210.70	251.00	26.68	29.20	33.62	32.12	44.25	47.62
12	IET 22574	74	77	113.00	112.00	7.67	7.67	28.57	29.12	212.00	241.60	24.85	26.83	27.34	29.51	47.61	47.62
13	IET 22583	73	77	116.20	119.00	6.80	7.67	28.45	30.31	285.80	295.00	21.38	22.89	28.65	34.34	42.73	40.00
14	GAR-1	77	77	112.00	118.21	6.25	8.00	29.35	31.25	240.20	268.00	28.13	PR	26.44	26.75	51.55	52.26
15	GR-104	106	92	120.50	124.00	7.50	8.33	31.10	32.90	338.50	367.00	26.36	29.89	39.28	40.99	40.16	42.17
16	WGL-14	78	79	98.00	111.23	8.00	8.50	28.78	28.00	294.20	310.00	17.22	24.51	24.97	34.31	40.82	41.67
17	Dhanteshwari	81	82	118.26	128.20	6.80	7.00	29.08	30.84	238.60	293.20	25.06	29.70	34.08	31.51	42.37	48.52
18	NVSR 2628	81	88	122.40	123.10	6.60	7.00	28.52	29.08	294.60	312.40	20.12	23.50	27.77	29.38	42.01	44.44
19	NWGR 13138	84	82	112.67	114.80	6.67	7.20	26.87	29.22	294.00	297.20	24.34	PR	32.62	31.74	42.73	45.25
20	NVSR 2529	82	85	105.50	112.00	7.50	7.51	25.20	28.23	338.50	374.00	29.63	29.29	26.07	28.12	53.20	51.02
21	NVSR 2756	77	78	113.20	115.60	7.10	7.33	30.38	30.73	228.60	288.20	24.80	27.35	27.03	33.46	47.85	44.98
22	NVSR 2701	77	78	118.00	121.06	7.33	8.50	26.47	28.25	202.00	230.00	21.59	23.09	25.91	28.63	45.45	44.64
23	NVSR 2778	74	76	111.80	112.67	6.80	7.67	28.24	29.80	231.00	265.60	23.77	PR	32.56	29.23	42.20	45.25
24	GAR-14	82	85	120.00	122.00	7.80	6.33	30.10	29.13	307.60	326.00	25.78	28.23	30.68	36.98	45.66	43.29
25	IET 22584	88	112	120.50	123.50	8.00	7.50	25.25	29.00	202.20	374.50	25.73	29.90	31.13	33.49	45.25	47.17
26	NVSR 2896	78	77	119.20	121.00	7.40	6.67	30.90	27.60	188.60	186.00	25.05	26.17	31.06	31.51	44.64	45.37
27	NVSR 2934	83	81	110.33	110.40	6.40	6.00	29.56	30.23	223.00	227.00	20.69	26.53	25.86	27.80	44.45	48.83
28	NVSR 3001	78	75	109.67	107.20	6.50	6.71	26.57	27.41	214.00	243.00	30.38	32.51	28.37	30.88	51.71	51.29
29	NVSR 3002	78	75	112.60	113.40	5.80	7.60	26.70	28.28	262.20	295.80	26.37	28.10	26.63	30.91	49.75	47.62
30	NVSR 2965	75	78	112.20	114.00	7.80	8.00	27.67	27.30	279.00	404.00	26.53	28.70	31.84	31.57	45.45	47.62
31	NVSR 2098	74	88	101.60	105.33	7.80	8.60	29.80	28.50	358.00	399.70	24.13	PR	27.03	30.56	47.17	48.54

Sr. No	Cross	DTF		PH (cm)		PTP		PL (cm)		GPP		GYPP (g)		SYPP (g)		HI (%)	
		25A	13A	25A	13A	25A	13A	25A	13A	25A	13A	25A	13A	25A	13A	25A	13A
32	NVSR 3175	83	81	107.33	112.13	6.60	8.67	30.50	32.03	312.50	318.30	25.53	28.98	28.85	29.27	46.95	49.75
33	NVSR 3192	71	72	111.33	118.80	4.33	6.00	28.40	28.90	225.40	256.40	27.52	29.94	36.05	34.74	43.29	46.29
34	NVSR 3195	75	73	109.50	113.80	7.26	7.20	30.38	31.83	344.70	369.20	29.63	30.46	32.44	36.55	47.74	45.46
35	NVSR 3204	79	79	114.00	117.33	7.23	7.91	26.54	27.56	276.00	291.00	29.47	29.89	33.30	36.17	46.95	45.25
36	NVSR 3216	73	68	119.80	116.00	6.60	8.00	29.33	30.75	241.00	277.00	23.90	25.67	29.64	33.10	44.64	43.68
37	NVSR 3316	86	76	116.60	122.40	7.20	7.00	29.24	29.03	338.20	296.00	25.27	23.33	35.13	31.23	41.84	42.76
38	NVSR 3384	90	82	111.75	109.80	5.50	8.00	30.38	31.21	369.20	395.80	24.90	26.13	32.62	29.91	43.29	46.63
39	NVSR 3167	87	88	108.60	112.50	8.20	7.94	27.66	28.05	278.00	258.50	28.75	29.58	34.79	34.30	45.25	46.31
40	NVSR 3224	74	76	103.80	107.50	6.20	7.67	29.54	30.83	239.20	240.60	29.15	28.67	27.40	30.94	51.55	48.10
41	NVSR 3280	84	86	106.80	105.00	7.53	8.60	24.30	27.26	246.00	269.20	23.17	26.01	30.35	28.26	43.29	47.93
42	NVSR 3306	71	75	98.80	112.50	5.00	6.50	25.10	30.25	168.60	247.50	28.49	29.36	27.35	25.54	51.02	53.48
43	NVSR 2876	76	76	121.80	127.33	8.67	9.20	34.20	30.13	385.80	351.20	30.90	28.85	34.61	32.03	47.17	47.39
44	NVSR 3046	77	76	111.00	115.60	7.50	8.33	28.56	27.04	398.00	411.00	27.33	29.47	35.26	34.89	43.67	45.79
45	NVSR 3019	76	89	123.75	129.12	9.13	9.25	32.33	29.75	331.00	347.20	29.13	31.59	40.20	46.19	42.02	40.61
46	NVSR 2309	74	90	103.80	112.40	6.60	7.72	29.06	23.38	303.20	321.50	32.14	33.33	27.03	32.66	54.32	50.51
47	NVSR 3319	83	84	118.20	119.00	8.00	6.67	31.52	28.40	374.80	389.00	25.39	28.14	30.72	32.84	45.25	46.15
48	NVSR 2927	73	87	114.00	126.00	7.00	7.67	29.78	30.30	293.00	335.00	31.97	33.02	33.57	37.64	48.78	46.73
49	NVSR 3018	79	85	134.50	135.40	8.50	8.67	31.10	31.26	359.50	337.80	28.07	26.02	38.74	35.39	42.01	42.37
50	NVSR 2138	89	86	119.33	120.40	6.50	6.80	28.76	29.40	281.00	285.80	26.75	28.17	34.51	36.34	43.67	43.67
51	NVSR 2460	84	86	110.67	112.50	7.67	7.94	24.50	25.90	225.00	246.50	26.88	29.23	36.56	32.74	42.37	47.17
52	NVSR 2341	78	76	117.00	125.40	4.67	5.00	28.60	30.48	291.00	309.70	28.08	29.14	33.98	34.94	45.25	45.47
53	NVSR 2395	73	72	109.00	110.40	7.90	7.40	27.56	29.34	269.00	281.60	26.50	27.32	32.07	31.72	45.25	46.27
54	NVSR 2447	83	85	122.00	127.00	7.60	8.12	27.80	27.12	289.80	281.00	22.27	23.60	27.61	34.46	44.65	40.65

55	NVSR 2148	72	72	97.40	116.60	8.00	9.00	29.52	29.74	291.00	241.00	PR	25.87	30.52	33.33	43.29	43.70
56	NVSR 2247	73	87	112.20	117.00	6.00	5.80	29.86	30.21	249.40	201.00	30.24	31.03	36.59	31.34	45.25	49.75
57	NVSR 2131	72	75	102.40	111.80	7.60	7.80	28.14	28.40	202.40	192.00	23.46	25.00	29.56	30.25	44.25	45.25
58	NVSR 2129	75	85	117.20	119.24	7.00	7.98	29.38	30.25	242.80	255.50	26.51	28.49	37.64	32.92	41.33	46.39
59	NVSR 2885	89	89	121.40	125.60	6.20	7.12	30.67	33.13	301.50	345.00	22.11	27.97	30.29	38.60	42.19	42.02
60	NVSR 2817	80	80	119.40	116.60	6.40	7.20	35.46	32.58	388.30	367.20	23.48	27.93	30.76	37.71	43.29	42.55
61	NVSR 2996	89	89	117.00	126.20	6.60	7.40	29.16	29.33	319.40	346.00	26.09	28.19	31.57	36.40	45.25	43.64
Range		71-106	68-112	97.40-134.50	105.00-135.40	4.33-9.13	5.00-9.25	24.30-35.46	23.38-33.62	168.60-398.00	186.00-411.00	17.22-32.14	22.23-33.33	24.97-43.10	25.54-46.22	38.46-54.32	38.46-53.48
General Mean		79.25	81.31	113.43	117.27	7.04	7.61	28.82	29.44	274.34	296.51	25.92	27.85	32.17	33.94	44.62	45.17

DTF: Days to 50 % flowering, PH: Plant height (cm); PTP: Productive tillers per plant; PL: Panicle length (cm); GPP: Grains per panicle; GYPP: Grain yield per plant (g); SYPP: Straw yield per plant (g); HI: Harvest index (%)

Table 2: Estimation of heterosis for hybrids yield and its component traits for hybrids of female IR58025A (WA)

Sr. No	Crosses	Days to 50% flowering				Plant height (cm)				Productive tillers/plant				Panicle length (cm)			
		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)	
		Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB
1	IR58025A × Jaya	88.00	86.00	-1.94	-1.60	109.33	104.00	3.64	13.82	6.89	6.97	0.34	-0.47	25.73	25.00	0.06	-2.84
2	IR58025A × NAUR-1	86.00	85.00	-1.96	-1.16	109.20	114.60	14.27	25.42	7.00	7.25	3.55	3.53	29.37	28.35	5.76	-3.47
3	IR58025A × IR-28	73.00	72.00	-10.22	-1.37	101.33	105.40	9.39	15.36	6.33	5.60	-16.00	-20.03	26.67	26.32	3.40	-1.31
4	IR58025A × GR-7	81.00	79.00	-6.18	-2.47	113.00	118.50	15.97	29.69	7.33	7.56	5.49	3.14	23.40	25.50	7.05	5.19
5	IR58025A × Mahisagar	78.00	77.00	-6.89	-1.28	105.00	107.20	9.18	17.33	4.67	6.40	9.65	-8.61	27.67	31.32	20.67	13.19
6	IR58025A × PUSA 1509	75.00	76.00	-6.40	1.33	99.67	108.56	13.65	18.81	7.00	6.89	-1.59	-1.61	26.87	28.38	11.05	5.62
7	IR58025A × Sugandhamati	90.00	84.00	-5.30	-3.89	117.33	116.40	11.55	27.39	6.33	7.00	5.00	-0.04	28.67	29.13	10.11	1.60
8	IR58025A × IET 22582	80.00	75.00	-10.39	-6.25	122.10	119.00	11.49	30.24	5.67	7.60	19.94	8.52	29.33	32.18	20.14	9.72
9	IR58025A × IET 22594	79.00	76.00	-8.65	-3.80	117.00	117.33	12.62	28.41	7.33	7.60	6.05	3.68	27.83	32.34	24.22	16.21
10	IR58025A × IET 22598	75.00	76.00	-6.40	1.33	114.67	118.50	15.03	29.69	7.33	8.00	11.63	9.14	28.20	26.05	-0.65	-7.62
11	IR58025A × IET 22086	79.00	80.00	-3.85	1.27	123.33	122.00	13.65	33.52	7.33	6.75	-5.81	-7.91	29.50	28.68	6.73	-2.78
12	IR58025A × IET 22574	84.00	74.00	-13.65	-11.90	112.33	113.00	10.95	23.67	7.00	7.67	9.55	9.52	29.53	28.57	6.27	-3.25
13	IR58025A × IET 22583	84.00	73.00	-14.82	-13.10	100.33	116.20	21.23	27.18	8.00	6.80	-9.35	-15.00	23.57	28.45	19.01	17.36
14	IR58025A × GAR-1	75.00	77.00	-5.17	2.67	108.33	112.00	12.17	22.58	6.67	6.25	-8.58	-10.75	27.27	29.35	13.96	7.63
15	IR58025A × GR-104	112.00	106.00	6.32	21.28	118.33	120.50	14.93	31.88	6.33	7.50	12.50	7.10	28.60	31.10	17.71	8.74
16	IR58025A × WGL-14	75.00	78.00	-3.94	4.00	95.33	98.00	4.98	7.26	6.81	8.00	15.83	14.24	26.00	28.78	14.57	10.69
17	IR58025A × Dhanteshwari	75.00	81.00	-0.25	8.00	116.00	118.26	14.06	29.43	3.33	6.80	31.62	-2.90	27.90	29.08	11.54	4.23
18	IR58025A × NVSR 2628	77.00	81.00	-1.46	5.19	121.33	122.40	15.09	33.96	4.67	6.60	13.08	-5.75	29.30	28.52	6.54	-2.66
19	IR58025A × NWGR 13138	78.00	84.00	1.57	7.69	109.67	112.67	12.09	23.31	6.67	6.67	-2.44	-4.76	26.00	26.87	6.96	3.35
20	IR58025A × NVSR 2529	81.00	82.00	-2.61	1.23	99.67	105.50	10.45	15.46	7.00	7.50	7.12	7.10	24.97	25.20	2.42	0.92
21	IR58025A × NVSR 2756	77.00	77.00	-6.33	0.00	109.33	113.20	12.81	23.89	6.00	7.10	9.21	1.39	25.17	30.38	22.97	20.70
22	IR58025A × NVSR 2701	85.00	77.00	-10.67	-9.41	126.00	118.00	8.57	29.15	5.33	7.33	18.87	4.67	22.50	26.47	13.26	9.20
23	IR58025A × NVSR 2778	76.00	74.00	-9.42	-2.63	127.00	111.80	2.40	22.36	7.33	6.80	-5.11	-7.23	28.83	28.24	6.42	-2.05
24	IR58025A × GAR-14	93.00	82.00	-9.09	-6.18	114.00	120.00	16.86	31.33	5.67	7.80	23.10	11.38	25.50	30.10	21.03	18.04
25	IR58025A × IET 22584	87.00	88.00	0.92	1.15	120.27	120.50	13.87	31.88	5.33	8.00	29.73	14.24	26.10	25.25	0.32	-3.26
26	IR58025A × NVSR 2896	79.00	78.00	-6.25	-1.27	117.00	119.20	14.41	30.46	6.67	7.40	8.24	5.67	29.83	30.90	14.29	3.59
27	IR58025A × NVSR 2934	78.00	83.00	0.36	6.41	110.67	110.33	9.22	20.75	4.20	6.40	14.26	-8.61	28.94	29.56	11.17	2.14
28	IR58025A × NVSR 3001	75.00	78.00	-3.94	4.00	89.50	109.67	21.27	22.54	7.67	6.50	-11.40	-15.25	25.55	26.57	6.73	3.99
29	IR58025A × NVSR 3002	76.00	78.00	-4.53	2.63	109.00	112.60	12.39	23.24	6.33	5.80	-13.00	-17.18	25.00	26.70	8.45	6.80
30	IR58025A × NVSR 2965	75.00	75.00	-7.64	0.00	111.67	112.20	10.52	22.80	6.67	7.80	14.09	11.38	25.50	27.67	11.26	8.51

Sr. No	Crosses	Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)	
		Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB
31	IR58025A × NVSR 2098	81.00	74.00	-12.11	-8.64	114.33	101.60	-1.22	11.20	6.00	7.80	19.97	11.38	27.73	29.80	14.68	7.46
32	IR58025A × NVSR 3175	82.00	83.00	-2.01	1.22	115.00	107.33	4.02	17.47	7.33	6.60	-7.90	-9.96	29.23	30.50	14.08	4.34
33	IR58025A × NVSR 3192	75.00	71.00	-12.56	-5.33	109.33	111.33	10.94	21.85	5.00	4.33	-27.85	-38.17	26.40	28.40	12.16	7.58
34	IR58025A × NVSR 3195	80.00	75.00	-10.39	-6.25	107.33	109.50	10.22	19.84	5.00	7.26	20.97	3.67	25.17	30.38	22.97	20.70
35	IR58025A × NVSR 3204	78.00	79.00	-4.47	1.28	112.67	114.00	11.74	24.77	6.30	7.23	8.70	3.24	23.56	26.54	11.04	9.48
36	IR58025A × NVSR 3216	75.00	73.00	-10.10	-2.67	128.33	119.80	9.06	31.12	7.00	6.60	-5.73	-5.75	27.45	29.33	13.48	6.85
37	IR58025A × NVSR 3316	85.00	86.00	-0.23	1.18	115.67	116.60	12.64	27.61	3.33	7.20	39.36	2.81	27.00	29.24	14.13	8.30
38	IR58025A × NVSR 3384	98.00	90.00	-2.91	2.97	105.33	111.75	13.62	22.30	5.33	5.50	-10.81	-21.46	23.83	30.38	26.40	25.32
39	IR58025A × NVSR 3167	76.00	87.00	6.49	14.47	108.00	108.60	8.94	18.86	5.33	8.20	32.98	17.09	25.00	27.66	12.35	10.64
40	IR58025A × NVSR 3224	90.00	74.00	-16.57	-15.33	108.00	103.80	4.13	13.60	5.33	6.20	0.54	-11.47	25.07	29.54	19.81	17.83
41	IR58025A × NVSR 3280	84.00	84.00	-1.98	0.00	104.67	106.80	8.96	16.89	6.33	7.53	12.95	7.53	22.33	24.30	4.36	0.24
42	IR58025A × NVSR 3306	79.00	71.00	-14.66	-10.13	107.00	98.80	-0.39	8.13	6.33	5.00	-25.00	-28.60	26.80	25.10	-1.65	-6.34
43	IR58025A × NVSR 2876	76.00	76.00	-6.98	0.00	131.33	121.80	9.38	33.30	3.33	8.67	67.81	23.80	30.83	34.20	24.20	10.93
44	IR58025A × NVSR 3046	79.00	77.00	-7.45	-2.53	115.33	111.00	7.40	21.48	5.60	7.50	19.02	7.10	26.54	28.56	12.48	7.61
45	IR58025A × NVSR 3019	76.00	76.00	-6.98	0.00	134.00	123.75	9.82	35.44	8.33	9.13	19.09	9.60	31.33	32.33	16.36	3.19
46	IR58025A × NVSR 2309	76.00	74.00	-9.42	-2.63	117.00	103.80	-0.37	13.60	8.33	6.60	-13.91	-20.77	24.47	29.06	19.32	18.76
47	IR58025A × NVSR 3319	78.00	83.00	0.36	6.41	114.00	118.20	15.11	29.36	3.00	8.00	59.95	14.24	30.97	31.52	14.18	1.78
48	IR58025A × NVSR 2927	76.00	73.00	-10.65	-3.95	113.33	114.00	11.38	24.77	4.67	7.00	19.93	-0.04	25.73	29.78	19.19	15.74
49	IR58025A × NVSR 3018	87.00	79.00	-9.40	-9.20	145.67	134.50	13.48	47.20	6.33	8.50	27.50	21.38	26.60	31.10	22.34	16.92
50	IR58025A × NVSR 2138	85.00	89.00	3.25	4.71	112.00	119.33	17.35	30.60	6.12	6.50	-0.94	-7.18	27.00	28.76	12.25	6.52
51	IR58025A × NVSR 2460	74.00	84.00	4.09	13.51	101.67	110.67	14.66	21.12	4.67	7.67	31.41	9.52	24.07	24.50	1.43	1.07
52	IR58025A × NVSR 2341	75.00	78.00	-3.94	4.00	112.00	117.00	15.06	28.05	3.33	4.67	-9.61	-33.31	27.17	28.60	11.26	5.26
53	IR58025A × NVSR 2395	74.00	73.00	-9.54	-1.35	104.00	109.00	11.58	19.30	7.20	7.90	11.24	9.72	25.12	27.56	11.67	9.71
55	IR58025A × NVSR 2148	73.00	72.00	-10.22	-1.37	119.00	97.40	-7.40	6.60	5.00	8.00	33.30	14.24	29.93	29.52	8.99	-1.37

56	IR58025A × NVSR 2247	87.00	73.00	-16.28	-16.09	117.67	112.20	7.35	22.80	7.33	6.00	-16.28	-18.14	25.77	29.86	19.41	15.87
57	IR58025A × NVSR 2131	77.00	72.00	-12.41	-6.49	102.33	102.40	5.73	12.07	4.67	7.60	30.22	8.52	23.33	28.14	18.31	16.08
58	IR58025A × NVSR 2129	79.00	75.00	-9.86	-5.06	121.00	117.20	10.37	28.27	5.67	7.00	10.47	-0.04	27.00	29.38	14.67	8.81
59	IR58025A × NVSR 2885	92.00	89.00	-0.78	1.83	135.67	121.40	6.94	32.87	5.00	6.20	3.31	-11.47	24.94	30.67	24.72	22.98
60	IR58025A × NVSR 2817	74.00	80.00	-0.87	8.11	123.00	119.40	11.40	30.68	4.00	6.40	16.33	-8.61	32.50	32.58	14.84	0.25
61	IR58025A × NVSR 2996	90.00	89.00	0.34	1.83	129.00	117.00	6.19	28.05	4.00	6.60	19.97	-5.75	28.17	29.16	11.27	3.51
	IR58025B	87.40	-	-	-	91.37	-	-	-	7.00	-	-	-	24.24	-	-	-

Sr. No	Crosses	Grain/panicles				Grain yield/plant (g)				Straw yield/plant (g)				Harvest index (%)			
		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)	
		Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB
1	IR58025A × Jaya	189.50	219.50	12.60	9.54	23.33	25.43	8.47	7.94	28.00	33.06	21.77	18.07	45.45	43.48	-6.26	-8.10
2	IR58025A × NAUR-1	236.40	276.20	26.47	16.84	24.73	28.73	18.99	16.17	34.62	43.10	41.50	24.49	41.67	40.00	-10.09	-15.45
3	IR58025A × IR-28	192.50	204.20	3.95	1.91	19.71	21.66	0.12	-8.06	23.65	28.16	12.76	7.08	45.46	43.48	-6.26	-8.10
4	IR58025A × GR-7	241.50	259.00	17.23	7.25	21.85	28.68	26.32	21.73	31.90	40.74	40.01	27.71	40.65	41.31	-6.06	-12.67
5	IR58025A × Mahisagar	282.00	322.60	33.75	14.40	24.30	25.91	8.27	6.63	29.36	33.94	21.96	15.60	45.29	43.29	-6.49	-8.49
6	IR58025A × PUSA 1509	175.50	209.20	11.31	4.40	21.02	22.09	-0.90	-6.24	28.80	30.04	9.04	4.31	42.19	42.37	-5.31	-10.43
7	IR58025A × Sugandhamati	234.40	246.00	13.16	4.95	18.87	24.85	17.13	5.48	24.72	37.28	46.15	41.77	43.29	40.00	-11.70	-15.45
8	IR58025A × IET 22582	250.60	288.60	27.99	15.16	18.26	25.14	20.23	6.71	31.04	40.22	40.29	29.57	37.04	38.46	-8.80	-18.69
9	IR58025A × IET 22594	209.00	250.80	22.53	20.00	21.58	28.14	24.68	19.44	31.51	41.65	44.10	32.18	40.65	40.32	-8.32	-14.77
10	IR58025A × IET 22598	211.00	180.50	-12.25	-14.45	20.43	23.18	5.39	-1.61	31.87	35.47	21.96	11.30	39.06	39.52	-8.48	-16.46
11	IR58025A × IET 22086	218.50	210.70	0.60	-3.57	24.49	26.68	11.05	8.94	29.63	33.62	20.23	13.47	45.25	44.25	-4.40	-6.47
12	IR58025A × IET 22574	271.00	212.00	-10.05	-21.77	19.70	24.85	14.89	5.48	25.61	27.34	5.34	3.97	43.48	47.61	4.89	0.65
13	IR58025A × IET 22583	211.00	285.80	38.95	35.45	15.15	21.38	10.46	-9.25	20.60	28.65	22.18	8.95	42.38	42.73	-4.70	-9.67
14	IR58025A × GAR-1	209.00	240.20	17.35	14.93	24.47	28.13	17.14	14.96	26.92	26.44	-0.63	-1.78	47.62	51.55	8.61	8.26
15	IR58025A × GR-104	287.00	338.50	38.91	17.94	25.60	26.36	7.24	2.97	39.41	39.28	19.56	-0.33	39.38	40.16	-7.35	-15.11
16	IR58025A × WGL-14	243.00	294.20	32.71	21.07	11.07	17.22	-0.55	-26.91	15.28	24.97	20.11	-5.05	42.01	40.82	-8.61	-13.72
17	IR58025A × Dhanteshwari	196.60	238.60	20.21	19.07	18.64	25.06	18.77	6.37	24.05	34.08	35.38	29.60	43.66	42.37	-6.84	-10.43
18	IR58025A × NVSR 2628	306.00	294.60	16.36	-3.73	12.42	20.12	11.84	-14.60	20.87	27.77	17.75	5.60	37.31	42.01	-0.70	-11.19
19	IR58025A × NWGR 13138	274.50	294.00	23.82	7.10	18.56	24.34	15.57	3.31	23.20	32.62	31.81	24.04	44.44	42.73	-6.85	-9.67
20	IR58025A × NVSR 2529	312.00	338.50	32.13	8.49	20.41	29.63	34.77	25.76	21.02	26.07	10.19	-0.86	49.26	53.20	10.17	7.98
21	IR58025A × NVSR 2756	186.70	228.60	18.12	14.08	20.07	24.80	13.68	5.26	24.69	27.03	6.03	2.79	44.84	47.85	3.85	1.14
22	IR58025A × NVSR 2701	178.00	202.00	6.77	0.81	19.92	21.59	-0.69	-8.36	29.48	25.91	-7.09	-12.11	40.32	45.45	3.74	-3.92
23	IR58025A × NVSR 2778	217.50	231.00	10.56	6.21	22.37	23.77	3.51	0.89	30.87	32.56	13.91	5.47	42.02	42.20	-5.52	-10.80
24	IR58025A × GAR-14	271.00	307.60	30.51	13.51	21.04	25.78	15.61	9.42	22.30	30.68	26.26	16.67	48.55	45.66	-4.73	-5.94
25	IR58025A × IET 22584	193.00	202.20	2.80	0.91	21.34	25.73	14.61	9.21	27.53	31.13	15.67	13.08	43.67	45.25	-0.52	-4.35
26	IR58025A × NVSR 2896	169.80	188.60	1.90	-5.88	22.11	25.05	9.70	6.32	28.74	31.06	12.87	8.07	43.48	44.64	-1.65	-5.63
27	IR58025A × NVSR 2934	201.00	223.00	11.12	10.95	20.00	20.69	-5.00	-12.18	24.80	25.86	1.22	-1.66	44.64	44.45	-3.32	-6.05
28	IR58025A × NVSR 3001	186.00	214.00	10.77	6.80	30.99	30.38	11.38	-1.97	27.10	28.37	6.26	4.69	53.35	51.71	2.75	-3.07
29	IR58025A × NVSR 3002	223.50	262.20	23.71	17.32	19.90	26.37	21.35	11.93	25.87	26.63	2.10	1.27	43.48	49.75	9.61	5.17
30	IR58025A × NVSR 2965	285.70	279.00	14.80	-2.35	23.78	26.53	12.08	11.56	30.91	31.84	11.32	3.01	43.48	45.45	0.13	-3.92
31	IR58025A × NVSR 2098	278.00	358.00	49.67	28.78	20.39	24.13	9.81	2.42	26.91	27.03	1.60	0.45	43.11	47.17	4.33	-0.30
32	IR58025A × NVSR 3175	245.00	312.50	40.33	27.55	22.87	25.53	9.97	8.36	32.25	28.85	-1.45	-10.54	41.49	46.95	5.74	-0.76

Sr. No	Crosses	Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)	
		Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB
32	IR58025A × NVSR 3175	245.00	312.50	40.33	27.55	22.87	25.53	9.97	8.36	32.25	28.85	-1.45	-10.54	41.49	46.95	5.74	-0.76
33	IR58025A × NVSR 3192	167.50	225.40	22.54	12.49	20.10	27.52	26.07	16.81	24.32	36.05	42.44	37.09	45.25	43.29	-6.46	-8.49
34	IR58025A × NVSR 3195	253.00	344.70	52.06	36.25	24.14	29.63	24.23	22.74	33.07	32.44	9.29	-1.91	42.20	47.74	6.67	0.91
35	IR58025A × NVSR 3204	239.00	276.00	25.63	15.48	25.01	29.47	21.35	17.83	27.51	33.30	23.78	21.05	47.62	46.95	-1.08	-1.41
36	IR58025A × NVSR 3216	179.80	241.00	26.78	20.27	25.76	23.90	-3.08	-7.22	35.29	29.64	-3.75	-16.01	42.19	44.64	-0.25	-5.64
37	IR58025A × NVSR 3316	292.00	338.20	37.37	15.82	15.69	25.27	28.76	7.26	20.40	35.13	50.46	33.59	43.47	41.84	-7.83	-11.56
38	IR58025A × NVSR 3384	311.00	369.20	44.39	18.71	17.41	24.90	21.55	5.69	24.72	32.62	27.88	24.04	41.32	43.29	-2.32	-8.49
39	IR58025A × NVSR 3167	222.50	278.00	31.48	24.94	23.22	28.75	22.92	22.03	28.79	34.79	26.31	20.84	44.65	45.25	-1.59	-4.36
40	IR58025A × NVSR 3224	186.00	239.20	23.82	19.37	22.54	29.15	26.46	23.73	29.53	27.40	-1.84	-7.21	43.29	51.55	13.80	8.96
41	IR58025A × NVSR 3280	211.00	246.00	19.60	16.59	20.28	23.17	5.70	-1.66	26.16	30.35	15.71	15.41	43.67	43.29	-4.83	-8.49
42	IR58025A × NVSR 3306	148.70	168.60	-3.40	-15.86	22.53	28.49	23.63	20.93	30.64	27.35	-3.93	-10.74	42.37	51.02	13.78	7.85
43	IR58025A × NVSR 2876	322.00	385.80	47.71	19.81	25.88	30.90	25.00	19.40	26.14	34.61	32.01	31.61	49.75	47.17	-2.80	-5.19
44	IR58025A × NVSR 3046	361.00	398.00	41.79	10.25	24.60	27.33	13.50	11.10	31.24	35.26	22.56	12.87	44.05	43.67	-4.41	-7.70
45	IR58025A × NVSR 3019	296.50	331.00	33.23	11.64	27.44	29.13	14.24	6.16	39.24	40.20	22.68	2.45	41.15	42.02	-5.00	-11.19
46	IR58025A × NVSR 2309	212.00	303.20	47.05	43.02	30.97	32.14	17.88	3.78	31.28	27.03	-6.11	-13.59	49.75	54.32	11.93	9.18
47	IR58025A × NVSR 3319	339.00	374.80	38.97	10.56	17.81	25.39	22.75	7.77	24.40	30.72	21.19	16.82	42.19	45.25	1.12	-4.35
48	IR58025A × NVSR 2927	253.00	293.00	29.25	15.81	25.37	31.97	30.68	26.01	28.67	33.57	22.15	17.09	46.95	48.78	3.51	3.11
49	IR58025A × NVSR 3018	279.20	359.50	49.92	28.76	29.41	28.07	5.98	-4.56	42.64	38.74	12.39	-9.15	40.82	42.01	-4.65	-11.19
50	IR58025A × NVSR 2138	231.00	281.00	30.28	21.65	20.99	26.75	20.09	13.54	28.97	34.51	24.88	19.12	42.01	43.67	-2.23	-7.70
51	IR58025A × NVSR 2460	215.00	225.00	8.33	4.65	21.84	26.88	18.41	14.09	25.33	36.56	41.63	39.03	46.30	42.37	-9.47	-10.44
52	IR58025A × NVSR 2341	264.50	291.00	25.19	10.02	21.82	28.08	23.75	19.19	23.13	33.98	37.50	29.22	48.54	45.25	-5.59	-6.79
53	IR58025A × NVSR 2395	224.00	269.00	26.77	20.09	20.23	26.50	21.03	12.48	27.11	32.07	20.10	18.30	42.73	45.25	0.50	-4.36
54	IR58025A × NVSR 2447	255.00	289.80	27.28	13.65	20.26	22.27	1.64	-5.48	27.54	27.61	2.57	0.25	42.38	44.65	-0.44	-5.62
55	IR58025A × NVSR 2148	288.00	291.00	19.17	1.04	18.90	23.30	9.75	-1.10	25.52	30.52	17.80	16.06	42.55	43.29	-3.64	-8.49
56	IR58025A × NVSR 2247	184.00	249.40	29.77	24.46	23.12	30.24	29.56	28.35	29.74	36.59	30.59	23.03	43.74	45.25	-0.60	-4.35
57	IR58025A × NVSR 2131	165.80	202.40	10.55	1.01	18.03	23.46	12.82	-0.42	23.62	29.56	18.44	12.41	43.29	44.25	-2.32	-6.47

58	IR58025A × NVSR 2129	231.00	242.80	12.57	5.11	21.20	26.51	18.45	12.52	31.59	37.64	30.05	19.15	40.16	41.33	-5.51	-12.65
59	IR58025A × NVSR 2885	254.00	301.50	32.71	18.70	19.41	22.11	2.91	-6.15	30.47	30.29	6.72	-0.59	38.91	42.19	-2.12	-10.81
60	IR58025A × NVSR 2817	333.00	388.30	45.60	16.61	21.97	23.48	3.14	-0.34	28.78	30.76	11.70	6.88	43.29	43.29	-4.44	-8.49
61	IR58025A × NVSR 2996	301.50	319.40	27.28	5.94	19.37	26.09	21.55	10.74	29.06	31.57	14.06	8.64	40.00	45.25	3.66	-4.35
	IR58025B	200.38	-	-	-	23.56	-	-	-	26.30	-	-	-	47.31	-	-	-

HB: Heterobeltiosis; MP: Mid Parent heterosis

Table 3: Estimation of heterosis for hybrids yield and its component traits for hybrids of female RTN13A (Gambiaca)

Sr. No	Crosses	Days to 50% flowering				Plant height (cm)				Productive tillers/plant				Panicle length (cm)			
		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)	
		Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB
1	RTN13A × Jaya	89.00	88.00	-2.49	-1.12	106.67	108.80	6.48	11.38	7.12	7.94	5.57	0.23	24.40	27.00	2.21	-5.04
2	RTN13A × NAUR-1	85.00	88.00	-0.28	3.53	110.60	119.00	14.27	21.82	6.67	7.75	6.22	-2.17	28.53	29.00	1.82	1.65
3	RTN13A × IR-28	74.00	74.00	-10.57	0.00	98.67	106.00	7.97	8.51	6.67	7.20	-1.32	-9.11	26.43	26.70	-2.67	-6.10
4	RTN13A × GR-7	85.00	81.00	-8.22	-4.71	110.50	121.00	16.24	23.87	7.60	8.00	3.08	0.98	22.13	27.12	7.27	-4.62
5	RTN13A × Mahisagar	76.00	82.00	-2.09	7.89	108.00	111.00	7.93	13.63	5.33	7.50	13.19	-5.33	28.77	33.62	17.55	16.86
6	RTN13A × PUSA 1509	73.00	74.00	-10.03	1.37	96.43	112.33	15.74	16.49	8.00	8.33	4.64	4.13	28.53	32.50	14.11	13.92
7	RTN13A × Sugandhamati	90.00	88.00	-3.03	-2.22	120.67	120.20	10.10	23.05	6.33	7.89	10.72	-0.40	29.03	29.16	1.49	0.45
8	RTN13A × IET 22582	81.00	77.00	-10.72	-4.94	120.00	120.67	10.87	23.53	6.87	7.81	5.60	-1.41	31.20	32.23	8.09	3.30
9	RTN13A × IET 22594	83.00	81.00	-7.16	-2.41	116.67	117.95	10.05	20.75	7.31	7.69	0.97	-2.93	26.00	31.89	17.17	12.16
10	RTN13A × IET 22598	79.00	77.00	-9.68	-2.53	116.24	121.33	13.43	24.21	7.64	8.34	7.18	5.28	27.60	29.12	3.94	2.42
11	RTN13A × IET 22086	82.00	83.00	-4.32	1.22	120.33	125.00	14.67	27.96	6.90	7.45	0.53	-5.96	27.56	28.72	2.58	1.01
12	RTN13A × IET 22574	76.00	77.00	-8.06	1.32	111.67	112.00	7.00	14.66	7.29	7.67	0.84	-3.18	30.93	29.12	-1.89	-5.85
13	RTN13A × IET 22583	86.00	77.00	-13.24	-10.47	102.33	119.00	18.99	21.82	7.78	7.67	-2.31	-3.18	22.80	30.31	18.32	6.60
14	RTN13A × GAR-1	74.00	77.00	-6.95	4.05	110.67	118.21	13.47	21.01	7.00	8.00	7.22	0.98	26.37	31.25	14.04	9.91
15	RTN13A × GR-104	98.00	92.00	-2.90	0.55	117.33	124.00	15.34	26.94	7.41	8.33	8.66	5.15	28.73	32.90	15.11	14.51
16	RTN13A × WGL-14	78.00	79.00	-6.78	1.28	96.67	111.23	14.46	15.06	7.67	8.50	9.03	7.30	25.57	28.00	3.70	-1.52
17	RTN13A × Dhanteshwari	75.00	82.00	-1.50	9.33	113.67	128.20	21.31	31.24	3.67	7.00	20.77	-11.64	28.87	30.84	7.64	6.82
18	RTN13A × NVSR 2628	77.00	88.00	4.45	14.29	120.67	123.10	12.75	26.02	4.00	7.00	17.43	-11.64	29.17	29.08	0.97	-0.31
19	RTN13A × NWGR 13138	79.00	82.00	-3.81	3.80	110.00	114.80	10.55	17.52	7.33	7.20	-5.59	-9.11	26.93	29.22	5.56	2.77
20	RTN13A × NVSR 2529	74.00	85.00	2.72	14.86	98.00	112.00	14.47	14.66	6.71	7.51	2.65	-5.20	26.33	28.23	3.10	-0.71
21	RTN13A × NVSR 2756	75.00	78.00	-6.31	4.00	112.33	115.60	10.09	18.34	6.23	7.33	3.59	-7.47	25.60	30.73	13.75	8.08
22	RTN13A × NVSR 2701	81.00	78.00	-9.57	-3.70	121.33	121.06	10.55	23.93	6.00	8.50	22.11	7.30	23.07	28.25	9.70	-0.64
23	RTN13A × NVSR 2778	75.00	76.00	-8.71	1.33	123.33	112.67	1.96	15.34	8.00	7.67	-3.66	-4.13	27.57	29.80	6.42	4.81
24	RTN13A × GAR-14	97.00	85.00	-9.81	-7.10	115.67	122.00	14.36	24.89	5.33	6.33	-4.47	-20.10	24.73	29.13	9.59	2.45
25	RTN13A × IET 22584	82.00	112.00	29.11	36.59	122.67	123.50	12.09	26.43	4.12	7.50	24.56	-5.33	25.13	29.00	8.28	1.99
26	RTN13A × NVSR 2896	83.00	77.00	-11.75	-7.23	118.00	121.00	12.20	23.87	6.98	6.67	-10.48	-15.80	28.37	27.60	-2.82	-2.93
27	RTN13A × NVSR 2934	76.00	81.00	-3.28	6.58	111.33	110.40	5.64	13.02	4.00	6.00	0.65	-24.26	29.17	30.23	4.96	3.63
28	RTN13A × NVSR 3001	77.00	75.00	-10.98	-2.60	93.00	107.20	12.44	15.27	7.99	6.71	-15.66	-16.02	24.73	27.41	3.12	-3.60
29	RTN13A × NVSR 3002	75.00	75.00	-9.91	0.00	105.00	113.40	11.90	16.09	5.67	7.60	11.83	-4.06	26.13	28.28	3.66	-0.54
30	RTN13A × NVSR 2965	76.00	78.00	-6.87	2.63	111.33	114.00	9.08	16.70	5.33	8.00	20.74	0.98	27.17	27.30	-1.80	-3.98
Sr. No	Crosses	Days to 50% flowering				Plant height (cm)				Productive tillers/plant				Panicle length (cm)			
		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)	
		Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB
31	RTN13A × NVSR 2098	81.00	88.00	2.03	8.64	108.33	105.33	2.26	7.83	6.00	8.60	23.55	8.56	26.98	28.50	2.86	0.24
32	RTN13A × NVSR 3175	82.00	81.00	-6.63	-1.22	118.00	112.13	3.98	14.79	7.67	8.67	11.21	9.44	28.67	32.03	12.18	11.72
33	RTN13A × NVSR 3192	73.00	72.00	-12.46	-1.37	110.00	118.80	14.41	21.62	5.00	6.00	-7.14	-24.26	28.10	28.90	2.24	1.64
34	RTN13A × NVSR 3195	76.00	73.00	-12.84	-3.95	101.00	113.80	14.55	16.50	5.67	7.20	5.94	-9.11	25.67	31.83	17.66	11.95
35	RTN13A × NVSR 3204	82.00	79.00	-8.93	-3.66	111.00	117.33	12.45	20.11	6.12	7.91	12.66	-0.15	24.76	27.56	3.62	-3.07
36	RTN13A × NVSR 3216	76.00	68.00	-18.81	-10.53	120.67	116.00	6.25	18.75	6.00	8.00	14.93	0.98	27.83	30.75	9.31	8.15
37	RTN13A × NVSR 3316	86.00	76.00	-14.37	-11.63	118.33	122.40	13.33	25.30	4.33	7.00	14.27	-11.64	28.18	29.03	2.56	2.10
38	RTN13A × NVSR 3384	66.00	62.00	-21.27	-6.06	105.00	109.80	8.35	12.40	4.67	8.00	27.06	0.98	25.13	31.21	16.54	9.77
39	RTN13A × NVSR 3167	75.00	88.00	5.71	17.33	106.33	112.50	10.29	15.17	5.69	7.94	16.66	0.23	26.23	28.05	2.63	-1.35
40	RTN13A × NVSR 3224	90.00	76.00	-16.25	-15.56	106.00	107.50	5.56	10.05	6.00	7.67	10.19	-3.18	25.50	30.83	14.33	8.43
41	RTN13A × NVSR 3280	86.00	86.00	-3.10	0.00	99.00	105.00	6.77	7.49	5.67	8.60	26.55	8.56	22.07	27.26	7.95	-4.13
42	RTN13A × NVSR 3306	85.00	75.00	-15.01	-11.76	114.33	112.50	6.13	15.17	7.33	6.50	-14.77	-17.95	23.67	30.25	16.12	6.39
43	RTN13A × NVSR 2876	79.00	76.00	-10.85	-3.80	123.67	127.33	15.05	30.35	5.00	9.20	42.39	16.13	29.60	30.13	3.84	1.79
44	RTN13A × NVSR 3046	76.00	76.00	-9.25	0.00	118.67	115.60	6.86	18.34	4.28	8.33	36.53	5.15	29.17	27.04	-6.12	-7.30
45	RTN13A × NVSR 3019	76.00	89.00	6.27	17.11	128.67	129.12	14.09	32.18	7.00	9.25	23.98	16.76	29.50	29.75	2.70	0.85
46	RTN13A × NVSR 2309	89.00	90.00	-0.28	1.12	111.00	112.40	7.72	15.07	7.67	7.72	-0.97	-2.55	23.17	23.38	-9.39	-17.77
47	RTN13A × NVSR 3319	81.00	84.00	-2.61	3.70	112.00	119.00	13.50	21.82	4.00	6.67	11.89	-15.80	30.07	28.40	-2.91	-5.55
48	RTN13A × NVSR 2927	75.00	87.00	4.50	16.00	112.33	126.00	19.99	28.99	4.33	7.67	25.20	-3.18	26.27	30.30	10.78	6.57
49	RTN13A × NVSR 3018	88.00	85.00	-5.29	-3.41	136.67	135.40	15.55	38.61	6.67	8.67	18.83	9.44	25.27	31.26	16.42	9.94
50	RTN13A × NVSR 2138	80.00	86.00	0.29	7.50	109.33	120.40	16.32	23.26	5.33	6.80	2.63	-14.16	26.97	29.40	6.13	3.40
51	RTN13A × NVSR 2460	72.00	86.00	5.20	19.44	98.67	112.50	14.59	15.17	4.33	7.94	29.61	0.23	24.00	25.90	-1.21	-8.91
52	RTN13A × NVSR 2341	73.00	76.00	-7.60	4.11	107.33	125.40	22.33	28.37	3.33	5.00	-11.13	-36.88	27.27	30.48	9.44	7.20
53	RTN13A × NVSR 2395	72.00	72.00	-11.93	0.00	99.67	110.40	11.88	13.02	7.00	7.40	-0.82	-6.59	24.60	29.34	10.65	3.19
54	RTN13A × NVSR 2447	81.00	85.00	-1.45	4.94	115.00	127.00	19.43	30.01	8.12	8.12	1.23	0.00	26.23	27.12	-0.77	-4.62
55	RTN13A × NVSR 2148	75.00	72.00	-13.51	-4.00	123.67	116.60	5.35	19.37	6.33	9.00	26.30	13.61	29.33	29.74	2.97	1.40
56	RTN13A × NVSR 2247	89.00	87.00	-3.60	-2.25	124.67	117.00	5.24	19.78	8.33	5.80	-28.62	-30.37	23.50	30.21	16.34	6.25
57	RTN13A × NVSR 2131	76.00	75.00	-10.45	-1.32	108.00	111.80	8.71	14.45	5.67	7.80	14.77	-1.54	27.18	28.40	2.13	-0.12
58	RTN13A × NVSR 2129	80.00	85.00	-0.87	6.25	122.00	119.24	8.56	22.07	5.67	7.98	17.42	0.73	26.40	30.25	10.34	6.39
59	RTN13A × NVSR 2885	90.00	89.00	-1.93	-1.11	142.00	125.60	4.81	28.58	6.33	7.12	-0.08	-10.12	31.18	33.13	11.15	6.25

60	RTN13A × NVSR 2817	73.00	80.00	-2.74	9.59	129.33	116.60	2.73	19.37	3.67	7.20	24.22	-9.11	31.50	35.46	18.33	12.57
61	RTN13A × NVSR 2996	89.00	89.00	-1.39	0.00	135.67	126.20	8.16	29.19	5.00	7.40	14.53	-6.59	27.58	29.33	4.73	3.15
	RTN 13B					97.68	-	-	-	7.92	-	-	-	28.43	-	-	-

Sr. No	Crosses	Grain/panicles				Grain yield/plant (g)				Straw yield/plant (g)				Harvest index (%)			
		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)	
		Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB
1	RTN13A × Jaya	205.50	268.80	13.26	-0.13	24.60	29.69	13.72	7.52	31.98	41.57	31.95	29.99	43.48	41.66	-8.09	-11.70
2	RTN13A × NAUR-1	218.00	293.00	20.29	8.86	23.38	30.81	20.84	11.57	32.73	46.22	44.98	41.22	41.67	40.00	-9.97	-15.24
3	RTN13A × IR-28	187.00	216.00	-5.29	-19.75	20.30	22.23	-7.21	-19.50	27.41	31.12	6.50	0.29	42.55	41.67	-7.13	-11.70
4	RTN13A × GR-7	249.00	292.00	12.71	8.49	19.85	27.68	16.64	0.24	28.19	39.28	32.66	26.59	41.32	41.34	-6.59	-12.40
5	RTN13A × Mahisagar	312.20	388.50	33.65	24.44	27.04	28.13	2.94	1.87	33.26	42.20	31.28	26.88	44.84	40.00	-13.08	-15.24
6	RTN13A × PUSA 1509	191.00	228.30	-0.77	-15.18	20.58	24.81	2.96	-10.15	25.93	36.22	27.18	16.73	44.25	40.65	-11.08	-13.85
7	RTN13A × Sugandhamati	227.50	282.40	13.72	4.92	17.65	27.81	22.88	0.71	27.00	43.38	49.51	39.80	39.53	39.06	-9.90	-17.21
8	RTN13A × IET 22582	284.00	328.60	18.81	15.70	17.51	27.00	19.67	-2.22	26.62	43.20	49.87	39.22	39.68	38.46	-11.45	-18.49
9	RTN13A × IET 22594	198.00	271.00	16.02	0.69	19.92	26.74	12.51	-3.17	29.08	36.37	21.01	17.21	40.65	42.37	-3.53	-10.21
10	RTN13A × IET 22598	197.50	205.00	-12.14	-23.83	19.77	26.18	10.50	-5.19	30.69	34.30	11.15	10.54	39.18	43.29	0.24	-8.27
11	RTN13A × IET 22086	198.00	251.00	7.46	-6.74	22.49	29.20	16.56	5.74	26.99	32.12	10.72	3.52	45.45	47.62	2.80	0.91
12	RTN13A × IET 22574	287.00	241.60	-13.12	-15.82	20.33	26.83	11.92	-2.84	25.01	29.51	5.32	-4.90	44.84	47.62	3.50	0.92
13	RTN13A × IET 22583	201.30	295.00	25.41	9.60	14.69	22.89	8.22	-17.11	20.42	34.34	33.49	10.67	41.84	40.00	-10.15	-15.24
14	RTN13A × GAR-1	198.00	268.00	14.74	-0.43	22.88	29.28	15.97	6.03	27.74	26.75	-8.97	-13.79	45.20	52.26	13.13	10.75
15	RTN13A × GR-104	291.50	367.00	30.92	25.90	27.13	29.89	9.20	8.24	42.32	40.99	11.77	-3.14	39.06	42.17	-2.22	-10.63
16	RTN13A × WGL-14	229.00	310.00	24.46	15.18	13.32	24.51	19.75	-11.24	17.32	34.31	41.93	10.57	43.47	41.67	-8.08	-11.69
17	RTN13A × Dhanteshwari	226.00	293.20	18.43	8.94	19.79	29.70	25.31	7.55	27.90	31.51	6.94	1.55	41.50	48.52	9.43	2.83
18	RTN13A × NVSR 2628	265.60	312.40	16.84	16.07	11.37	23.50	20.56	-14.90	18.92	29.38	17.64	-5.31	37.54	44.44	4.91	-5.82
19	RTN13A × NWGR 13138	281.00	297.20	8.04	5.77	17.14	26.23	17.22	-5.01	21.08	31.74	21.82	2.29	44.85	45.25	-1.67	-4.11
20	RTN13A × NVSR 2529	354.00	374.00	20.04	5.65	19.71	29.29	23.78	6.07	21.68	28.12	6.70	-9.38	47.62	51.02	7.63	7.14
21	RTN13A × NVSR 2756	176.80	288.20	29.25	7.08	21.63	27.35	11.08	-0.96	25.09	33.46	19.25	7.83	46.30	44.98	-3.78	-4.69
22	RTN13A × NVSR 2701	198.00	230.00	-1.53	-14.55	21.27	23.09	-5.53	-16.38	31.69	28.63	-8.70	-9.66	40.16	44.64	2.22	-5.39
23	RTN13A × NVSR 2778	215.50	265.60	9.60	-1.32	23.90	24.16	-6.20	-12.51	28.92	29.23	-2.48	-5.80	45.25	45.25	-2.09	-4.10
24	RTN13A × GAR-14	258.00	326.00	23.68	21.12	20.96	28.23	16.24	2.23	23.06	36.98	36.74	19.18	47.61	43.29	-8.67	-9.08
25	RTN13A × IET 22584	206.00	374.50	57.63	39.14	22.30	29.90	19.81	8.28	31.00	33.49	7.98	7.93	41.84	47.17	5.97	-0.04
26	RTN13A × NVSR 2896	178.00	186.00	-16.81	-30.89	20.78	26.17	8.15	-5.23	27.01	31.51	8.58	1.55	43.48	45.37	0.08	-3.85
27	RTN13A × NVSR 2934	215.50	227.00	-6.32	-15.66	21.74	26.53	7.51	-3.93	23.91	27.80	1.20	-10.41	47.62	48.83	3.01	2.54
28	RTN13A × NVSR 3001	194.00	243.00	4.93	-9.72	31.15	32.51	10.65	4.37	30.18	30.88	0.90	-0.48	50.79	51.29	4.69	0.97
29	RTN13A × NVSR 3002	234.50	295.80	17.46	9.90	20.09	28.10	17.81	1.76	21.09	30.91	18.61	-0.38	48.79	47.62	-0.77	-2.39
30	RTN13A × NVSR 2965	297.00	404.00	42.72	36.03	20.73	28.70	18.73	3.93	27.50	31.57	7.88	1.74	42.98	47.62	5.62	0.91

Sr. No	Crosses	Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)		Mean		Heterosis (%)	
		Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB	Male	Hybrid	MP	HB
31	RTN13A × NVSR 2098	264.00	399.70	49.94	48.50	23.47	28.83	12.87	4.40	29.10	30.56	1.65	-1.51	44.65	48.54	5.72	2.87
32	RTN13A × NVSR 3175	211.50	318.30	32.45	18.26	24.25	28.98	11.75	4.95	31.28	29.27	-6.05	-6.43	43.67	49.75	9.51	5.43
33	RTN13A × NVSR 3192	188.00	256.40	12.17	-4.74	18.40	29.94	30.13	8.42	23.92	34.74	26.44	11.96	43.48	46.29	2.11	-1.90
34	RTN13A × NVSR 3195	279.00	369.20	34.71	32.33	22.25	30.46	22.17	10.31	30.37	36.55	19.06	17.79	42.28	45.46	1.61	-3.67
35	RTN13A × NVSR 3204	256.00	291.00	10.83	8.12	24.23	29.89	15.31	8.24	27.38	36.17	23.85	16.57	46.95	45.25	-3.87	-4.11
36	RTN13A × NVSR 3216	193.00	277.00	19.87	2.92	23.73	25.67	-0.01	-7.04	31.30	33.10	6.21	5.75	43.12	43.68	-3.27	-7.44
37	RTN13A × NVSR 3316	279.50	296.00	7.90	5.90	16.04	23.33	6.89	-15.51	22.62	31.23	16.42	0.65	41.49	42.76	-3.56	-9.38
38	RTN13A × NVSR 3384	339.00	395.80	30.17	16.76	15.39	26.13	21.52	-5.37	22.47	29.91	11.82	-3.61	40.65	46.63	6.17	-1.19
39	RTN13A × NVSR 3167	239.00	258.50	1.74	-3.96	21.29	29.58	20.97	7.12	26.19	34.30	19.89	10.54	44.84	46.31	0.63	-1.87
40	RTN13A × NVSR 3224	213.00	240.60	-0.20	-10.61	21.21	28.67	17.44	3.82	24.82	30.94	10.80	-0.29	46.08	48.10	3.14	1.93
41	RTN13A × NVSR 3280	203.40	269.20	13.94	0.02	19.81	26.01	9.69	-5.81	22.19	28.26	6.20	-8.92	47.17	47.93	1.59	1.57
42	RTN13A × NVSR 3306	175.00	247.50	11.45	-8.04	25.07	29.36	11.46	6.32	34.35	25.54	-21.87	-25.65	42.19	53.48	19.67	13.33
43	RTN13A × NVSR 2876	301.00	351.20	23.20	16.68	24.24	28.85	11.27	4.48	33.21	32.03	-0.28	-3.55	42.19	47.39	6.04	0.43
44	RTN13A × NVSR 3046	384.60	411.00	25.74	6.86	26.23	29.47	9.46	6.72	36.98	34.89	2.60	-5.65	41.50	45.79	3.26	-2.96
45	RTN13A × NVSR 3019	283.20	347.20	25.72	22.60	25.45	31.59	19.06	14.40	35.12	46.19	39.65	31.52	42.02	40.61	-8.94	-13.93
46	RTN13A × NVSR 2309	232.00	321.50	28.30	19.45	28.00	33.33	19.86	19.04	32.20	32.66	3.31	1.43	46.51	50.51	7.81	7.04
47	RTN13A × NVSR 3319	315.00	389.00	33.18	23.49	20.49	28.14	17.00	1.90	25.20	32.84	16.81	5.84	44.85	46.15	0.28	-2.21
48	RTN13A × NVSR 2927	272.00	335.00	23.81	23.16	28.01	33.02	18.73	17.89	28.29	37.64	26.91	21.31	49.75	46.73	-3.59	-6.07
49	RTN13A × NVSR 3018	256.00	337.80	28.65	25.51	26.31	26.02	-3.49	-5.77	34.50	35.39	8.01	2.58	43.27	42.37	-6.31	-10.21
50	RTN13A × NVSR 2138	227.50	285.80	15.09	6.19	21.13	28.17	15.58	2.01	26.20	36.34	27.00	17.12	44.64	43.67	-4.90	-7.46
51	RTN13A × NVSR 2460	201.00	246.50	4.86	-8.42	20.78	29.23	20.80	5.85	23.07	32.74	21.04	5.51	47.39	47.17	-0.25	-0.47
52	RTN13A × NVSR 2341	251.00	309.70	19.08	15.07	20.21	29.14	21.86	5.53	26.07	34.94	22.38	12.60	43.67	45.47	0.10	-3.63
53	RTN13A × NVSR 2395	209.00	281.60	17.79	4.63	19.85	27.32	15.12	-1.06	24.42	31.72	14.41	2.23	44.84	46.27	0.57	-1.94
54	RTN13A × NVSR 2447	239.50	281.00	10.49	4.40	21.08	23.60	-3.07	-14.54	31.20	34.46	10.75	10.45	40.32	40.65	-7.10	-13.86
55	RTN13A × NVSR 2148	231.00	241.00	-3.63	-10.46	16.38	25.87	17.61	-6.32	25.06	33.33	18.85	7.42	39.53	43.70	0.79	-7.39
56	RTN13A × NVSR 2247	165.60	201.00	-7.53	-25.32	24.51	31.03	19.06	12.37	36.27	31.34	-6.86	-13.59	40.33	49.75	13.70	5.43
57	RTN13A × NVSR 2131	176.20	192.00	-13.78	-28.66	16.62	25.00	13.04	-9.47	24.60	30.25	8.76	-2.51	40.32	45.25	3.42	-4.11
58	RTN13A × NVSR 2129	216.00	255.50	5.33	-5.07	18.09	28.49	24.67	3.17	26.41	32.92	14.63	6.09	40.65	46.39	5.63	-1.68
59	RTN13A × NVSR 2885	297.80	345.00	21.70	15.85	23.24	27.97	10.00	1.29	35.79	38.60	15.54	7.85	39.37	42.02	-2.92	-10.96
60	RTN13A × NVSR 2817	319.00	367.20	24.87	15.11	22.18	27.93	12.18	1.14	29.72	37.71	24.15	21.53	42.74	42.55	-5.36	-9.83
61	RTN13A × NVSR 2996	306.00	346.00	20.32	13.07	21.92	28.19	13.82	2.09	30.03	36.40	19.23	17.31	42.19	43.64	-2.34	-7.51
	RTN 13B	269.15	-	-	-	27.61	-	-	-	31.03	-	-	-	47.19	-	-	-

HB: Heterobeltiosis; MP: Mid Parent heterosis

Conclusion

There was higher frequency of restorers than the maintainers in the parental material studied. Majorly, the performance of pollen parents as restorer or maintainer was same for both the CMS sources namely, Wild abortive and Gambiaca. Cross combinations of RTN13A showed high *per se* performance for yield and component traits. From the overall results this can be observed the means were higher for the hybrids of RTN13A comparative to the female IR58025A. Therefore, mostly the hybrids of RTN13A were found to be superior to the hybrids of IR58025A excepting for the days to 50 % flowering and plant height. The magnitude of heterosis was found to be higher for the hybrids of female IR58025A as the female RTN13A used to outperform the female IR58025A in most of the character studied. Therefore, even though the mean values of the various characters were found to be higher for the hybrids with female RTN13A there heterotic reposes were low comparatively. Comparatively F_1s with IR58025A registered higher mid parent heterosis and heterobeltiosis than F_1s with RTN13A.

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Conflict of interest

No conflict of interest was declared.

References

1. Anonymous. Directorate of Economics and Statistics, Department of Agriculture and Co-operation, Government of India; c2021.
2. Anonymous. Directorate of Agriculture, Agriculture, Farmers Welfare and Co-operation Department, Government of Gujarat; c2021.
3. Anonynous. IIRR, Indian Institute of Rice Research, Technical Bulletin, IIRR: Hyderabad; c2019.
4. Azad AK, Sarker U, Ercisli S, Assouguem A, Ullah R, Almeer R, *et al*. Evaluation of combining ability and heterosis of popular restorer and male sterile lines for the development of superior rice hybrids. Agronomy. 2022 Apr 16;12(4):965.
5. Begum S, Reddy V, Srinivas B, Arunakumari CH. Heterosis studies for yield and physical quality traits in hybrid rice (*Oryza sativa* L.). J. Crop Weed. 2020;16(1):38-50.
6. Briggle LW. Heterosis in Wheat - A Review. Crop Sci. 1963;3(5):407-412.
7. Borah P, Sarma D, 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.
8. Chase CD, Gabay-Laughnan S. Cytoplasmic male sterility and fertility restoration by nuclear genes. Molecular biology and biotechnology of plant organelles. Springer; c2004. p. 593-621.
9. Chatterjee D. A modified key and enumeration of species of *Oryza* Linn. Indian J. Agric. Sci. 1948;18:185-192.
10. Cheng SH, Cao LY, Zhuang JY, Chen SG, Zhan XD, Fan YY, *et al*. A super hybrid rice breeding in China: achievements and prospect. Journal of Integrative Plant Biology. 2007 Jun;49(6):805-810.
11. Cheng SH, Cao LY, Zhuang JY, Chen SG, Zhan XD, Fan YY, *et al*. A super hybrid rice breeding in China: achievements and prospect. Journal of Integrative Plant Biology. 2007 Jun;49(6):805-810.
12. Devi A, Kumari P, Dwivedi R, Dwivedi S, Verma OP, Singh PK, *et al*. Estimation of heterosis for seed yield and yield attributing traits in rice (*Oryza sativa* L.) under salinity condition, Journal of Pharmacognosy and Phytochemistry. 2017;6(4):1345-1354.
13. Fonseca S, Patterson FL. Hybrid vigour in a seven parent diallel cross in common winter wheat (*Triticum aestivum* L.). Crop Science. 1968 Jan;8(1):85-95.
14. Fujii S, Toriyama K. Suppressed expression of retrograde-regulated male sterility restores pollen fertility in cytoplasmic male sterile rice plants. Proceedings of the National Academy of Sciences. 2009 Jun 9;106(23):9513-9518.
15. Hoan NT, Nghia NH. Hybrid rice development and use in Vietnam. In: Virmani SS, CX Mao, B Hardy. (eds). Hybrid rice for food security, poverty alleviation, and environmental protection. Proceedings of the 4th International Symposium on Hybrid Rice, Hanoi, Vietnam, 14-17 May 2002. International Rice Research Institute, Philippines; c2003. p. 357-371.
16. Hwa CM, Yang XC. Fixation of hybrid vigor in rice: opportunities and challenges. Euphytica. 2008 Apr;160(3):287-293.
17. Jones JW. Hybrid vigor in rice. J. American Soci. Agron. 1926;18:423-428.
18. Kumar S, Singh NK, Kumar R, Singh SK, Nilanjaya Kumar C, Kumar A. Heterosis studies for various morphological traits of rice under drought conditions. International Journal of Current Microbiology and Applied Sciences. 2017;6(10):507-521.
19. Li JM, Yuan LP. Hybrid rice: genetics, breeding, and seed production. Plant Breeding. 2000;17:15-158.
20. Lin SC, Yuan LP. Hybrid rice breeding in China. Int. innovative approaches to rice breeding, IRRI, Manila, Philippines; c1980. p. 35-51.
21. Matthayatthaworn W, Sripichitt P, Phumichai C, Rungmekarat S, Uckarach S, Sreewongchai T. Development of specific simple sequence repeat (SSR) markers for non-pollen type thermo-sensitive genic male sterile gene in rice (*Oryza sativa* L.). African Journal of Biotechnology. 2011;10(73):16437-16442.
22. Mishra B, Viraktamath BC, Ilyas Ahmad M, Ramesha MS, Vijayakumar C. Hybrid rice development and use in India. In: Virmani SS, CX Mao, B Hardy (eds). Hybrid rice for food security, poverty alleviation, and environmental protection. Proceedings of the 4th International Symposium on Hybrid Rice, Hanoi, Vietnam, 14-17 May 2002. International Rice Research Institute, Philippines; c2003. p. 265-283.
23. Rao YS. Cytohistology of cytoplasmic male sterile lines in hybrid rice. Hybrid Rice; c1988.Pp. 115-128.
24. Redona ED, Malabanan FM, Gaspar MG, Sebastian LS. Hybrid rice development and use in the Philippines. Hybrid rice for food security, poverty alleviation, and environmental protection. Proceedings of the 4th International Symposium on Hybrid Rice, Hanoi, Vietnam, 14-17 May 2002. International Rice Research

Institute, Philippines; c2003.
25. Sampath S, Mohanty HK. Cytology of semi-sterile rice hybrid. Cur. Sci. 1954;23:182-183.
26. Sattari M, Kathiresan A, Gregorio GB, Virmani SS. Comparative genetic analysis and molecular mapping of fertility restoration genes for WA, Dissi, and Gambiaca cytoplasmic male sterility systems in rice. Euphytica. 2008 Apr;160(3):305-315.
27. Sharma SK, Singh SK, Nandan R, Sharma A, Kumar R, Kumar V, *et al*. Estimation of heterosis and inbreeding depression for yield and yield related traits in rice (*Oryza sativa* L.). Molecular Plant Breeding. 2013 Sep 25;4(29):238-246.
28. Singh NK, Singh AK, Singh AK, Mishra V, Mall AK. Heterosis breeding in rice (*Oryza sativa* L.) for quantative traits. Plant Archives. 2019;19(1):544-548.
29. Smith CW, Dilday RH. Rice: Origin, history, technology, and production, 1st ed. John Wiley and Sons, Inc.; Hoboken, New Jersey; c2003.
30. 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.
31. Virmani SS, Wan BH. Development of CMS lines in hybrid rice breeding. Hybrid rice; c1988. p. 103-114.
32. Yuan LP. The execution and theory of developing hybrid rice. Chinese Agri. Sci. 1977;1:27-31.
33. Yuan LP, Virmani SS. Status of hybrid rice research and development, In: Hybrid rice, *International Rice Research Institute*, PO Box 933, Manila, Philippines; c1988. p. 7-2.