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Research Article

Heterosis and heterobeltosis studies for grain yield and yield attributing traits in rice (O*ryza sativa* L.)

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Abstract
The heterosis study on grain yield and its nine components was carried out by using ten parents, their fourty five hybrids at Main Rice Research Centre, Navsari Agricultural University (NAU), Navsari during *kharif*-2015. Analysis of variance for parents and hybrids revealed that the mean squares due to genotypes were significant for all the characters. Considerable magnitude of heterosis, heterobeltiosis and standard heterosis was observed for all the characters. Crosses GNR-3 x GAR-13, GNR-3 x IET-23825 and IET-24762 x IET-24765 were found to be most heterotic hybrids for grain yield per plant. Simultaneous increase in grains per panicle per plant and productive tillers per plant had positive effects towards higher grain yield.

Key words
Heterosis, heterobeltiosis and standard heterosis, qualitative traits, grain yield

Introduction

Heterosis in rice has been known since 1926. China was the first country to commercially exploit heterosis in rice. The magnitude of heterosis depends on the choice of appropriate parental lines. The commercial exploitation of heterosis in rice has been possible, primarily, by use of cytoplasmic-genetic male sterility and fertility restoration system. Extensive research work is going throughout India and abroad on different aspects of hybrid rice. The average yield of rice hybrid is 6.3 t/ha while that of the inbred varieties is 4.5 t/ha.

Materials and Methods

The experimental material consisted of 56 entries including 10 parents, 1 check and their 45 crosses. The crossing was done by using half Diallel fashion. The flowers were hand emasculated and pollinated at the Main Rice Research Centre, NAU, Navsari during summer 2015. Three complete sets of 56 entries comprising of 45 F_1's, 10 parents and 1 check were evaluated during kharif 2015. The experiment was laid out in a randomized block design replicated three times at Main Rice Research Center, Navsari Agricultural University, Navsari. The parents and F_1's were represented by single row plot of 10 plants placed at 20 cm x 10 cm spacing. Five Sample plants were randomly selected from each plot excluding the border plant and the following data were recorded: Days to 50 per cent flowering, Plant height, Productive tillers per plant, Grains per panicle**,** Grain yield per plant, Straw yield per plant, Test weight, Protein content, Iron content, Zinc content, Amylose content. Iron (Fe) and Zinc (Zn) content of rice grain samples was determined by using Atomic Absorption Spectrophotometer (AAS), The nitrogen content was estimated from each sample by micro kjeldahl method, The amylose content was estimated as per the simplified colorimetric procedure

Result and Discussion

Analysis of variance revealed that the mean squares due to genotypes were significant for all the characters, which indicated the considerable amount of variability among genotypes for various characters. The mean squares due to genotypes were further partitioned into parents, hybrids and parents *vs*. hybrids. The differences between parents were highly significant for all the characters except days to 50% flowering. The mean squares due to hybrids were found highly significant for all the characters. Parents *vs.* hybrids comparison was found significant for all the characters except days to 50% flowering indicating substantial amount of heterosis among hybrids (Table 1).

The heterosis was found to be ranged from -16.40 (GNR-3 x Gurjari) to 15.86 (IET-24762 x IET-24767) per cent and heterobeltiosis ranged from -18.50 (GNR-3 x Gurjari) to 12.45 (IET-24762 x

IET-24767) per cent. 18 crosses showed desirable negative heterosis while, 27 crosses showed desirable heterobeltiosis. As regard to standard heterosis 36 crosses showed negative significant heterosis. The heterosis was found to be ranged from -26.61 (GNR-3 x Gurjari) to 0.59 (IET-24762 x IET-24767) per cent (Table 2). The results are in akin with the findings of Singh (2006), Isssac (2007), Raj *et al*. (2007), Tiwari *et al.* (2011), Kumar *et al.* (2012), Nagesh *et al.* (2012), Patil *et al.* (2012), Latha *et al.* (2013), Padmavathi *et al.* (2013) and Bhati *et al.* (2015).

The heterosis varied from -24.86 (GNR-3 x IET-23825) to 12.63 (GNR-3 x IET-24765) per cent and heterobeltiosis ranged from -32.91 (GNR-3 x IET-23825) to 11.29 (GNR-3 x IET-24765) per cent. Out of 45 hybrids evaluated 27 hybrids showed negative heterosis over mid parent and 34 hybrids showed negative heterobeltiosis. The value of standard heterosis ranged from -16.12 (GNR-3 x IET-23825) to 24.43 (IET-24762 x GAR-13) per cent. 14 crosses showed negative standard heterosis (Table 2). The present findings are in accordance with results reported by Eradasappa *et al*. (2007), Raj *et al*. (2007), Parihar and Pathak (2008), Tiwari *et al.* (2011), Vennila *et al.* (2011), Kumar *et al.* (2012), Nagesh *et al.* (2012), Patil *et al.* (2012), Latha *et al.* (2013) and Padmavathi *et al.* (2013).

The value of heterosis varied from -7.61 (NAUR-1 x GAR-13) to 52.07 (IET-24767 x NVSR-303-6) per cent and for heterobeltiosis, it varied from -2.88 (NAUR-1 x Gurjari) to 44.64 (IET-24762 x Gurjari) per cent. Total 40 hybrids showed significant positive heterosis over mid parent. As regards to 29 hybrids showed significant positive heterobeltiosis. Heterosis over check variety ranged from -20.35 (IET-24772 x NVSR-303-6) to 14.49 (GNR-3 x IET-24772) per cent. 15 crosses showed positive standard heterosis for this character (Table 2). Singh (2006), Eradasappa *et al*. (2007), Raj *et al*. (2007), Parihar and Pathak (2008), Tiwari *et al.* (2011), Vennila *et al.* (2011), Nagesh *et al.* (2012), Bhadru *et al.* (2013), Padmavathi *et al.* (2013), Shinde and Patel (2014), Bhati *et al.* (2015) and Mistry *et al.* (2015) also reported similar results in rice.

The value of heterosis over mid parent ranged from -13.28 (NAUR-1 x GNR-3) to 58.18 (Gurjari x IET-23825) per cent. 19 cross exhibited significant positive heterosis. With respect to heterobeltiosis, it varied from -23.49 (NAUR-1 x IET-24765) to 34.51 (Gurjari x IET-23825) per cent. As regards to heterobeltiosis six cross exhibited significant positive heterobeltiosis. The standard heterosis range from -24.61 (IET-24767 x IET-24772) to 10.32 (IET-24765 x IET-23825). Total eight crosses showed significant positive heterosis for the panicle length (Table 3). The present findings are uniformity with the results reported by Pandya and Tripathi (2006), Eradasappa *et al*. (2007), Raj *et al.* (2007), Singh *et al*. (2007), Parihar and Pathak (2008), Nagesh *et al.* (2012), Patil *et al.* (2012), Bhadru *et al.*, (2013), Jarwar *et. al.* (2013), Latha *et al.* (2013), Pratap *et al.* (2013), Shinde and Patel (2014), Bhati *et al.* (2015), Nayak *et al.* (2015), Mistry *et al.* (2015) and Padmavathi *et al.* (2013).

The heterosis varied from -39.61 (IET-24762 x Gurjari) to 110.60 (NVSR-303-6 x IET-23825) per cent. Total 42 crosses showed significant positive heterosis for this trait. The heterosis over better parent varied from -48.35 (IET-24762 x Gurjari) to 109.81 (NVSR-303-6 x IET-23825) per cent. Total 36 crosses showed positive significant heterobeltiosis for this trait. The estimates of standard heterosis varied from -63.23 (IET-24762 x Gurjari) to 34.57 (NVSR-303-6 x IET-23825) per cent. 21 crosses exhibited positive and significant standard heterosis (Table 3). The results are in agreement with the findings of Pandya and Tripathi (2006), Singh (2006), Raj *et al*. (2007), Tiwari *et al.* (2011), Vennila *et al.* (2011), Nagesh *et al.* (2012), Patil *et al.* (2012), Bhadru *et al.* (2013), Padmavathi *et al.* (2013), Shinde and Patel (2014), Bhati *et al.* (2015), Mistry *et al.* (2015) and Nayak *et al.* (2015).

The results revealed that heterosis ranged from -50.12 (IET-24762 x NVSR-303-6) to 90.41 (IET-24762 x IET-24765) per cent while the magnitude of heterobeltiosis ranged from -55.72 (IET-24762 x NVSR-303-6) to 66.85 (GNR-3 x GAR-13) per cent. As many as 26 hybrids showed significant positive heterosis whereas, 18 hybrids registered significant positive heterobeltiosis. The standard heterosis ranged from -61.04 (IET-24762 x Gurjari) to 43.08 (GNR-3 x GAR-13) per cent. Nine crosses showed significant positive values of standard heterosis (Table 3). Significant positive heterosis for grain yield was also reported by Kshirsagar *et al.* (2005), Aananthi and Jabaraj (2006), Pandya and Tripathi (2006), Eradasappa *et al.* (2007), Parihar and Pathak (2008), Venkatesan *et al.* (2008), Roy *et al.* (2009), Tiwari *et al.* (2011), Kumar *et al.* (2012), Nagesh *et al.* (2012), Jarwar *et. al.* (2013), Latha *et al.* (2013), Padmavathi *et al.* (2013), Pratap *et al.* (2013), Shinde and Patel (2014), Bhati *et al.* (2015), Mistry *et al.* (2015) and Nayak *et al.* (2015).

The results revealed that heterosis ranged from -53.77 (GNR-3 x IET-23825) to 70.38 (GNR-3 x IET-24765) per cent while the magnitude of heterobeltiosis ranged from -60.89 (GNR-3 x IET-23825) to 51.49 (NAUR-1 x IET-24765) per cent. The standard heterosis ranged from -77.36 (GNR-3 x IET-23825) to 28.12 (NAUR-1 x IET-24765) per cent (Table 4). The results are in agreement with the findings of Singh (2006)**,** Issac (2007), Raj *et al.* (2007), Pratap *et al.* (2013) and Mistry *et al.* (2015).

The heterosis for this trait ranged from -8.36 (GNR-3 x Gurjari) to 80.80 (IET-24765 x IET-24772) per cent while the magnitude of heterobeltiosis ranged from -25.13 (IET-24772 x Gurjari) to 76.58 ((IET-24765 x IET-24772) per cent. And the standard heterosis ranged from -8.50 (IET-24772 x Gurjari) to 42.21 (GNR-3 x IET-24772) per cent. As many as 38 hybrids showed significant positive heterosis whereas, 21 hybrids registered significant positive heterobeltiosis and 27 showed significant positive standard heterosis for test weight (Table 4). Results are in agreement with the findings of Pandya and Tripathi (2006), Singh *et al.* (2007), Raj *et al.* (2007), Parihar and Pathak (2008), Tiwari *et al.* (2011), Kumar *et al.* (2012), Nagesh *et al.* (2012), Patil *et al.* (2012), Jarwar *et al.*(2013), Latha *et al.*(2013), Padmavathi *et al.* (2013), Pratap *et al.* (2013), Shinde and Patel (2014), Bhati *et al.* (2015), Mistry *et al.* (2015) and Nayak *et al.* (2015).

The results revealed that heterosis ranged from -35.84 (Gurjari x NVSR-303-6) to 39.15 (IET-24765 x IET-23825) per cent while the magnitude of heterobeltiosis ranged from -42.84 (Gurjari x NVSR-303-6) to 38.94 (IET-24765 x IET-23825) per cent. The value of standard heterosis ranged from -37.65 (Gurjari x NVSR-303-6) to 15.33 (GAR-13 x NVSR-303-6) per cent (Table 4). As many as 25 hybrids showed significant positive heterosis, 20 showed significant positive heterobeltiosis and 15 showed positive significant standard heterosis for protein content. Positive heterosis for this trait was reported by Venkatesan *et al.* (2008), Roy *et al.* (2009), Patil *et al.* (2012), Shinde and Patel (2014), Nayak *et al.* (2015) and Patel (2015).

The results revealed that heterosis ranged from -56.20 (NAUR-1 x NVSR-303-6) to 37.78 (IET-24762 x GAR-13) per cent while the magnitude of heterobeltiosis ranged from -65.81 (NAUR-1 x NVSR-303-6) to 27.75 (GNR-3 x IET-24762) per cent. The value of standard heterosis ranged from -67.95 (NAUR-1 x GAR-13) to 7.46 (GNR-3 x IET-24765) per cent (Table 5). As many as 14 hybrids showed significant positive heterosis, six hybrids showed significant positive heterobeltiosis and only two hybrids showed significant positive standard heterosis. The results are in agreement with the findings of Nagesh *et al.* (2012) and Patel (2015).

The results revealed that heterosis ranged from -35.53 (IET-24765 x NVSR-303-6) to 59.68 (NAUR-1 x GNR-3) per cent while the magnitude of heterobeltiosis ranged from -49.10 (NAUR-1 x NVSR-303-6) to 48.22 (NAUR-1 x GNR-3) per cent. The value of standard heterosis ranged from -50.61 (NAUR-1 x NVSR-303-6) to 22.28 (NVSR-303-6 x IET-23825) per cent (Table 5). As many as 15 hybrids showed significant positive heterosis, eight hybrids showed significant positive heterobeltiosis and five hybrids showed significant positive standard heterosis. The results are in agreement with the findings of Nagesh *et al.* (2012) and Patel (2015).

In all, 15 and six hybrids registered significant heterosis over mid parent and better parent in desirable direction respectively. The value of heterosis over mid parent ranged from -10.78 (IET-24762 x IET-24767) to 19.04 (GNR-3 x NVSR-303-6) per cent while the value of heterosis over better parent varied from -15.06 (IET-24762 x IET-24767) to 13.63 (GNR-3 x NVSR-303-6) per cent. The value of standard heterosis ranged from -6.23 (NAUR-1 x GNR-3) to 17.20 (GNR-3 x NVSR-303-6) per cent (Table 5). 20 of the crosses manifested significant and positive standard heterosis in desirable direction.The results are in agreement with the findings of Venkatesan *et al.* (2008), Roy *et al.* (2009), Patil *et al.* (2012), Shinde and Patel (2014), Mistry *et al.* (2015), Nayak *et al.* (2015) and Patel (2015).

It can thus be concluded that sufficiently high magnitude of heterosis, heterobeltiosis and standard heterosis was observed in desired direction for all the characters. The higher estimate of heterosis for grain yield per plant was registers by the crosses IET-24762 x IET-24765, GNR-3 x IET-23825 and GNR-3 x GAR-13. 18 crosses showed significant positive heterosis over their respective better parental value for grain yield per plant. The highest heterobeltiosis for grain yield per plant was registered by the cross GNR-3 x GAR-13, IET-24762 x IET- 24765 and GAR-13 x IET-24772. The highest standard heterosis for grain yield per plant was registered by the cross GNR-3 x GAR-13, GNR-3 x IET-23825 and GNR-3 x Gurjari. Nine crosses showed significant positive heterosis over their respective better parental value for grain yield per plant. crosses GNR-3 x GAR-13, GNR-3 x IET-23825, GNR-3 x Gurjari, Gurjari x NVSR-303-6 and NAUR-1 x IET-24765 could be exploited fully in future rice breeding programme by adopting heterosis breeding.

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Table1. Analysis of variance (mean sum of squares) for experimental design for different characters in rice.

Sr. no.	Character	Df	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)	Test weight (g)	Protein content (%)	Iron content (ppm)	Zinc content (ppm)	Amylose content (%)
1	**Replicates**	2	1.26	276.01	0.76	3.83	73.83	1.43	6.04	0.76	0.13	0.40	0.07	0.59
2	**Treatments**	54	4391.05 **	12765.64 **	311.64 **	932.38 **	520071.48 **	12285.40 **	19786.84 **	2772.90 **	175.98 **	17069.27 **	2767.30 **	223.82 **
3	**Parents**	9	190.96	2401.96 **	36.56 **	480.77 **	41025.95 **	961.45 **	3011.69 **	731.06 **	15.97 **	6325.39 **	490.60 **	41.42 **
4	**Hybrids**	44	4176.95 **	9966.87 **	131.34 **	411.19 **	296163.89 **	10564.87 **	16613.45 **	1134.80**	156.15 **	9694.72 **	2269.86 **	173.44 **
5	**Parent Vs. Hybrids**	1	23.13	396.81 *	143.73 **	40.42 **	182881.64 **	759.07 **	161.70 **	907.03 **	3.85 **	1049.15 **	6.84 **	8.96 **
6	**Error**	108	3478.57	7492.38	85.84	220.39	24470.77	675.07	1191.13	293.32	6.23	106.68	52.78	85.39

* Significant at 5 % and **Significant at 1 %

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Table 2. Estimation of heterosis, heterobeltiosis and standard heterosis for days to 50% flowering, plant height and productive tillers per plant in rice.

Sr.no.	Crosses	Days to 50% flowering			Plant height (cm)			Productive tillers per plant		
		MP	BP	SC	MP	BP	SC	MP	BP	SC
1.	NAUR-1 X GNR-3	-5.26	-6.59	-15.89 **	3.19	0.51	4.16	18.60 **	12.54 *	8.96
2.	NAUR-1 X IET 24762	-0.31	-1.39	-11.79 **	-15.80 **	-21.72 **	-5.61	20.40 **	2.83	-0.44
3.	NAUR-1 X GAR-13	0.10	-0.54	-11.81 **	-14.08 *	-17.81 **	-6.74	-7.61	-2.86	-5.95
4.	NAUR-1 X IET-24765	1.77	-0.96	-13.32 **	9.08	7.50	11.40	18.45 **	6.26	2.88
5.	NAUR-1 X IET-24767	1.47	-0.46	-12.88 **	-13.39 *	-14.11 *	-11.00	29.16 **	12.54 *	8.96
6.	NAUR-1 X IET-24772	8.72	8.68	-4.81	9.62	6.67	10.54	20.40 **	6.28	2.90
7.	NAUR-1 X Gurjari	2.09	0.93	-11.66 *	-4.28	-6.65	1.76	10.71	-2.88	-5.97
8.	NAUR-1 X NVSR-303-6	-1.82	-2.10	-14.31 **	5.18	4.91	9.28	30.99 **	7.40	3.98
9.	NAUR-1 X IET-23825	1.40	-1.13	-13.46 **	-1.22	-9.68	12.93	15.77 *	2.86	-0.41
10.	GNR-3 X IET-24762	-5.17	-5.48	-14.89 **	3.65	-5.95	13.40	38.06 **	23.48 **	7.33
11.	GNR-3 X GAR-13	-0.41	-1.18	-11.01 *	1.85	-4.98	7.81	17.39 **	11.36	-3.21
12.	GNR-3 X IET-24765	2.45	-1.66	-11.45 *	12.63 *	11.29	12.00	31.05 **	23.48 **	7.33
13.	GNR-3 X IET-24767	6.10	2.65	-7.57	-0.03	-1.83	0.04	28.16 **	17.09 *	1.77
14.	GNR-3 X IET-24772	3.08	1.67	-8.45	9.11	9.00	7.08	42.19 **	31.72 **	14.49 *
15.	GNR-3 X Gurjari	-16.40 **	-18.50 **	-26.61 **	5.58	0.37	9.41	25.86 **	15.81 *	0.66
16.	GNR-3 X NVSR-303-6	-15.00 **	-16.43 **	-24.74 **	8.18	5.11	9.48	38.92 **	18.96 **	3.40
17.	GNR-3 X IET-23825	1.41	-2.47	-12.18 **	-24.86 **	-32.91 **	-16.12 *	20.76 **	12.63	-2.10
18.	IET-24762 X GAR-13	-3.50	-3.92	-14.06 **	6.33	3.20	24.43 **	13.98	7.09	-16.48 **
19.	IET-24762 X IET-24765	1.05	-2.70	-12.96 **	-2.22	-10.31	8.15	33.11 **	25.90 **	-3.21
20.	IET-24762 X IET-24767	15.86 **	12.45 *	0.59	-3.62	-11.08	7.22	29.12 **	26.12 **	-9.32
21.	IET-24762 X IET-24772	13.30 **	12.12 *	0.29	-11.83 *	-20.07 **	-3.62	28.71 **	23.88 **	-8.19
22.	IET-24762 X Gurjari	1.99	-0.24	-10.77 *	-8.11	-12.51 *	5.49	49.22 **	44.64 **	5.64
23.	IET-24762 X NVSR-303-6	13.39 **	11.85 *	0.05	-6.18	-12.57 *	5.42	22.10 **	16.22	-20.33 **
24.	IET-24762 X IET-23825	-1.71	-5.17	-15.17 **	-9.66 *	-11.27 *	10.94	26.18 **	20.59 *	-9.29
25.	GAR-13 X IET-24765	-2.97	-6.17	-16.80 **	0.22	-5.45	7.28	-7.11	6.35	-17.06 **
26.	GAR-13 X IET-24767	3.80	1.18	-10.29 *	5.86	0.47	14.00 *	29.89 **	24.82 **	-2.65
27.	GAR-13 X IET-24772	-8.37	-8.93	-19.25 **	-15.59 **	-21.32 **	-10.73	30.18 **	26.95 **	-1.00
28.	GAR-13 XGurjari	-1.22	-2.96	-13.96 **	-4.63	-6.50	6.09	15.73 *	12.06	-12.61 *
29.	GAR-13 X NVSR-303-6	6.54	5.55	-6.41	-5.25	-9.14	3.09	28.89 **	15.64 *	-9.82
30.	GAR-13 X IET-23825	-1.35	-4.41	-15.24 **	-19.40 **	-23.13 **	-3.89	30.69 **	28.37 **	0.11
31.	IET-24765 XIET-24767	8.98	8.09	-9.00 *	3.38	2.74	4.69	37.55 **	33.09 **	2.32
32.	IET-24765 X IET-24772	7.57	4.65	-8.34	-10.20	-11.36	-10.80	17.95 *	15.83 *	-10.95
33.	IET-24765 X Gurjari	2.60	0.97	-13.64 **	0.82	-3.05	5.69	26.91 **	23.74 **	-4.87
34.	IET-24765 X NVSR-303-6	-0.72	-3.12	-15.70 **	-3.28	-4.91	-0.96	29.88 **	17.27 *	-9.85
35.	IET-24765 X IET-23825	1.12	0.91	-16.08 **	-20.41 **	-28.18 **	-10.20	32.40 **	30.97 **	0.69
36.	IET-24767 X IET-24772	-5.29	-7.12	-18.65 **	-7.38	-9.13	-7.41	35.61 **	33.58 **	-1.00
37.	IET-24767 X Gurjari	4.19	3.37	-11.58 *	-4.38	-7.50	0.83	26.73 **	25.75 **	-8.16
38.	IET-24767 X NVSR-303-6	-5.42	-6.96	-19.03 **	-9.87	-10.85	-7.14	52.07 **	41.54 **	1.77
39.	IET-24767 X IET-23825	0.68	0.06	-15.76 **	-2.58	-11.59 *	10.54	12.78	10.29	-17.04 **
40.	IET-24772 X Gurjari	3.54	2.32	-10.38 *	0.67	-4.39	4.22	29.34 **	28.40 **	-4.84
41.	IET-24772 X NVSR-303-6	-3.87	-4.18	-16.07 **	-6.25	-9.00	-5.21	17.07 *	7.46	-20.35 **
42.	IET-24772 X IET-23825	0.91	-1.65	-13.85 **	-10.67 *	-20.31 **	-0.36	31.11 **	30.15 **	-2.10
43.	Gurjari X NVSR-303-6	-0.98	-1.82	-14.57 **	1.96	-0.30	8.68	27.02 **	17.38 *	-14.27 *
44.	Gurjari X IET-23825	6.80	5.31	-9.92 *	-12.87 *	-18.45 **	1.96	36.54 **	34.56 **	1.22
45.	NVSR-303-6 X IET-23825	8.82	6.41	-7.41	2.49	-6.06	17.45 *	25.00 **	13.97	-14.27 *
	SEd±	4.0130	4.6338	4.6338	5.8895	6.8006	6.8006	0.6304	0.7279	0.7279
	CD 1%	7.9545	9.1851	9.1851	11.6741	13.4801	13.4801	1.249	1.4429	1.4429
	CD 5%	10.5226	12.1504	12.1504	15.4430	17.8320	17.8320	1.6530	1.9087	1.9087

*Significant at 5 % and **Significant at 1 %

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Table 3. Estimation of heterosis, heterobeltiosis and standard heterosis for panicle length, grains per panicle and grain yield per plant in rice.

Sr.no.	Crosses	Panicle length (cm)			Grains per panicle			Grain yield per plant (g)		
		MP	BP	SC	MP	BP	SC	MP	BP	SC
1.	NAUR-1 X GNR-3	-13.28 **	-23.00 **	-21.66 **	26.94 **	16.93 **	5.84	-9.3	-12.98 *	-18.78 **
2.	NAUR-1 X IET 24762	-6.65	-6.76	4.90 *	-1.53	-7.25	-25.31 **	18.94 **	5.61	-1.42
3.	NAUR-1 X GAR-13	6.96	-5.08	-3.42	-8.39	-13.36 *	-30.23 **	40.90 **	24.77 **	16.46 **
4.	NAUR-1 X IET-24765	-10.23 *	-23.49 **	-22.15 **	26.74 **	-3.74	-22.48 **	66.69 **	26.58 **	18.15 **
5.	NAUR-1 X IET-24767	0.93	-7.75	6.13**	37.83 **	18.03 **	-4.96	8.61	2.78	-4.06
6.	NAUR-1 X IET-24772	12.74 **	-1.45	0.27	46.60 **	25.96 **	11.43 **	36.95 **	13.43 *	5.88
7.	NAUR-1 X Gurjari	-0.14	-15.74 **	-14.26 **	39.23 **	13.33 *	8.74 *	16.02 *	-1.10	-7.69
8.	NAUR-1 X NVSR-303-6	5.06	-1.94	-0.22	59.64 **	24.91 **	0.58	0.11	0.09	-6.54
9.	NAUR-1 X IET-23825	10.13 *	-18.40 **	-16.97 **	48.62 **	15.96 **	6.62	22.67 **	-5.91	-12.17 *
10.	GNR-3 X IET-24762	-7.95	-18.36 **	-16.73 **	48.22 **	44.71 **	3.01	33.63 **	23.24 **	5.69
11.	GNR-3 X GAR-13	17.43 **	17.35 **	7.37**	25.93 **	22.45 **	-12.09 **	81.43 **	66.85 **	43.08 **
12.	GNR-3 X IET-24765	7.62	2.68	-18.95 **	82.77 **	47.71 **	17.17 **	73.49 **	35.73 **	16.39 **
13.	GNR-3 X IET-24767	-1.27	-4.39	-19.44 **	49.71 **	38.20 **	16.28 **	-7.54	-8.85	-21.83 **
14.	GNR-3 X IET-24772	2.32	0.50	-20.67 **	54.93 **	43.54 **	12.65 **	25.18 **	7.32	-7.97
15.	GNR-3 X Gurjari	12.18 *	5.81	-16.48 **	69.26 **	47.74 **	20.00 **	64.02 **	44.92 **	24.28 **
16.	GNR-3 X NVSR-303-6	-4.78	-9.78 *	-20.42 **	65.28 **	38.06 **	16.37 **	27.23 **	22.03 **	13.95 *
17.	GNR-3 X IET-23825	29.00 **	4.56	-17.47 **	78.17 **	48.39 **	0.63	86.80 **	47.69 **	26.66 **
18.	IET-24762 X GAR-13	-11.17 **	-21.26 **	-19.68 **	39.43 **	38.84 **	-0.33	37.96 **	37.54 **	-0.39
19.	IET-24762 X IET-24765	-6.10	-20.05 **	-18.45 **	77.77 **	41.08 **	0.42	90.41 **	58.86 **	15.04 **
20.	IET-24762 X IET-24767	-14.02 **	-21.50 **	-19.93 **	57.14 **	41.91 **	11.02 **	-1.30	-7.76	-23.14 **
21.	IET-24762 X IET-24772	-10.65 *	-21.98 **	-20.42 **	43.83 **	30.35 **	7.21 *	2.52	-5.36	-31.46 **
22.	IET-24762 X Gurjari	-1.43	-16.91 **	-15.25 **	-39.61 **	-48.35 **	-63.23 **	-43.63 **	-46.21 **	-61.04 **
23.	IET-24762 X NVSR-303-6	-9.07 *	-15.22 **	-13.53 **	77.08 **	45.12 **	13.3 **	-50.12 **	-55.72 **	-58.65 **
24.	IET-24762 X IET-23825	26.92 **	-6.04	4.16*	76.19 **	43.96 **	12.48 **	-4.08	-19.02 *	-41.36 **
25.	GAR-13 X IET-24765	5.07	0.31	-20.92 **	80.79 **	43.03 **	12.68 **	18.70 *	-0.73	-28.55 **
26.	GAR-13 X IET-24767	-4.53	-7.60	-22.15 **	50.86 **	35.72 **	-2.56	7.65	0.32	-16.41 **
27.	GAR-13 X IET-24772	19.87 **	17.81 **	7.12**	61.72 **	46.01 **	14.82 **	65.57 **	53.27 **	10.32
28.	GAR-13 XGurjari	14.57 **	8.13	-14.76 **	52.63 **	30.07 **	-6.62	2.10	-2.29	-29.67 **
29.	GAR-13 X NVSR-303-6	-0.59	-5.87	-16.97 **	83.63 **	49.98 **	27.67 **	26.42 **	11.94 *	4.52
30.	GAR-13 X IET-23825	26.01 **	2.19	-19.44 **	75.70 **	43.09 **	12.73 **	22.68 **	3.82	-25.27 **
31.	IET-24765 XIET-24767	4.90	-2.92	-18.21 **	32.13 **	14.18	-34.47 **	-23.55 **	-39.56 **	-49.64 **
32.	IET-24765 X IET-24772	13.00 *	9.71	-16.48 **	25.62 **	8.20	-37.41 **	37.39 **	22.98 *	-24.64 **
33.	IET-24765 X Gurjari	16.52 **	15.12 *	-17.47 **	24.69 **	13.87	-42.41 **	42.08 **	23.33 **	-18.87 **
34.	IET-24765 X NVSR-303-6	10.94 *	0.56	-11.31 **	52.34 **	46.17 **	-33.51 **	19.67 **	-9.14	-15.15 **
35.	IET-24765 X IET-23825	48.57 **	25.09 **	10.32 **	109.10 **	101.35 **	29.10 **	18.29	16.6	-41.87 **
36.	IET-24767 X IET-24772	-5.99	-10.53 *	-24.61 **	22.63 **	22.15 **	-29.34 **	6.03	-7.99	-23.34 **
37.	IET-24767 X Gurjari	10.54 *	1.17	-14.76 **	16.89 *	9.95	-36.90 **	12.91	1.02	-15.82 **
38.	IET-24767 X NVSR-303-6	-3.71	-5.87	-16.97 **	16.67 *	4.57	-39.99 **	24.61 **	17.90 **	10.09
39.	IET-24767 X IET-23825	37.15 **	8.48	8.60 **	45.25 **	29.75 **	-25.54 **	-7.75	-26.28 **	-38.57 **
40.	IET-24772 X Gurjari	11.97 *	7.44	-18.21 **	46.44 **	37.24 **	-20.61 **	-0.92	-4.31	-37.05 **
41.	IET-24772 X NVSR-303-6	-5.85	-12.29 *	-22.64 **	87.74 **	67.69 **	13.00 **	-30.85 **	-42.73 **	-46.52 **
42.	IET-24772 X IET-23825	39.37 **	14.56 *	-12.79 **	95.16 **	73.73 **	20.49 **	-9.18	-17.65	-49.53 **
43.	Gurjari X NVSR-303-6	-2.80	-12.85 **	-23.13 **	96.20 **	86.33 **	15.77 **	52.69 **	30.13 **	21.51 **
44.	Gurjari X IET-23825	58.18 **	34.51 **	5.89*	74.66 **	65.29 **	16.41 **	48.50 **	30.52 **	-14.14 *
45.	NVSR-303-6 X IET-23825	13.82 *	-11.45 *	-21.90 **	110.60 **	109.81 **	34.57 **	29.95 **	-0.33	-6.93
	SEd±	1.0101	1.1663	1.1663	10.6438	12.2904	12.2904	1.7678	2.0413	2.0413
	CD 1%	2.0022	2.3119	2.3119	21.0979	24.3617	24.3617	3.5042	4.0463	4.0463
	CD 5%	2.6486	3.0583	3.0583	27.9091	32.2266	32.2266	4.6355	5.3526	5.3526

*Significant at 5 % and **Significant at 1 %

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Table 4. Estimation of heterosis, heterobeltiosis and standard heterosis for straw yield per plant, test weight and protein content in rice.

Sr.no.	Crosses	Straw yield per plant (g)			Test weight (g)			Protein content (%)		
		MP	BP	SC	MP	BP	SC	MP	BP	SC
1.	NAUR-1 X GNR-3	52.40 **	34.74 **	1.54	20.21 **	4.06	34.24 **	-18.70 **	-21.73 **	-26.52 **
2.	NAUR-1 X IET 24762	13.70 *	11.81	-15.73 **	59.39 **	40.24 **	32.29 **	7.16 *	1.93	-11.43 **
3.	NAUR-1 X GAR-13	17.63 **	10.81	-16.49 **	33.27 **	18.86 **	12.12 *	15.88 **	8.16 **	8.43 **
4.	NAUR-1 X IET-24765	60.22 **	51.49 **	28.12 **	26.44 **	12.01	5.67	25.51 **	20.99 **	5.13
5.	NAUR-1 X IET-24767	31.86 **	7.25	-19.18 **	29.23 **	15.26 *	8.73	-31.51 **	-35.77 **	-36.27 **
6.	NAUR-1 X IET-24772	25.93 **	20.03 **	-0.19	52.53 **	32.37 **	24.87 **	-6.33 *	-13.56 **	-24.89 **
7.	NAUR-1 X Gurjari	-11.20 *	-23.14 **	-20.77 **	20.62 **	6.86	30.59 **	-10.36 **	-19.48 **	-12.17 **
8.	NAUR-1 X NVSR-303-6	9.43	-2.36	-6.22	11.46 *	7.52	9.14	-8.50 **	-9.36 **	-21.24 **
9.	NAUR-1 X IET-23825	48.56 **	13.76 *	-14.27 **	7.92	4.16	5.61	-25.68 **	-28.25 **	-37.64 **
10.	GNR-3 X IET-24762	13.90 *	2.20	-25.53 **	36.66 **	6.29	37.11 **	0.29	-7.98 *	-13.60 **
11.	GNR-3 X GAR-13	49.72 **	39.92 **	-6.78	16.12 **	-8.66	17.82 **	15.31 **	11.65 **	11.93 **
12.	GNR-3 X IET-24765	70.38 **	43.51 **	21.38 **	9.22	-14.57 **	10.20	26.74 **	17.80 **	10.60 **
13.	GNR-3 X IET-24767	8.83	-1.19	-42.79 **	17.62 **	-7.48	19.35 **	-3.47	-6.06 *	-6.80 *
14.	GNR-3 X IET-24772	-6.38	-20.60 **	-33.98 **	43.36 **	10.24 *	42.21 **	15.90 **	3.31	-3.01
15.	GNR-3 X Gurjari	-22.91 **	-39.81 **	-37.95 **	-8.36 *	-10.77 *	15.10 **	-31.81 **	-36.56 **	-30.80 **
16.	GNR-3 X NVSR-303-6	64.20 **	31.59 **	26.39 **	-1.43	-11.94 **	13.60 *	16.75 **	11.39 **	4.58
17.	GNR-3 X IET-23825	-53.77 **	-60.89 **	-77.36 **	-2.86	-13.25 **	11.90 *	11.84 **	4.09	-2.27
18.	IET-24762 X GAR-13	-4.55	-8.64	-33.43 **	51.36 **	49.04 **	10.20	-3.61	-14.11 **	-13.90 **
19.	IET-24762 X IET-24765	34.15 **	24.86 **	5.60	48.16 **	47.00 **	7.03	38.15 **	36.25 **	9.86 **
20.	IET-24762 X IET-24767	31.79 **	8.60	-20.86 **	37.67 **	35.56 **	0.23	-11.04 **	-20.37 **	-21.00 **
21.	IET-24762 X IET-24772	-17.02 **	-22.15 **	-35.27 **	40.08 **	37.87 **	-1.19	21.35 **	17.54 **	-7.84 **
22.	IET-24762 X Gurjari	-47.45 **	-55.15 **	-53.77 **	1.69	-19.33 **	-1.42	-19.24 **	-30.59 **	-24.30 **
23.	IET-24762 X NVSR-303-6	-10.60 *	-21.39 **	-24.50 **	37.74 **	17.50 **	19.26 **	4.85	0.64	-14.19 **
24.	IET-24762 X IET-23825	16.32 *	-9.87	-34.32 **	23.23 **	5.17	6.63	31.99 **	29.98 **	5.13
25.	GAR-13 X IET-24765	-6.09	-16.06 *	-29.00 **	35.14 **	34.10 **	-0.85	-26.81 **	-33.97 **	-33.81 **
26.	GAR-13 X IET-24767	57.57 **	34.64 **	-10.30	38.30 **	38.30 **	2.25	-10.80 **	-11.26 **	-11.04 **
27.	GAR-13 X IET-24772	-20.09 **	-28.03 **	-40.16 **	68.38 **	63.22 **	20.68 **	-9.84 **	-21.88 **	-21.69 **
28.	GAR-13 XGurjari	-40.44 **	-50.97 **	-49.46 **	33.45 **	7.09	30.88 **	4.69	0.45	9.56 **
29.	GAR-13 X NVSR-303-6	-25.89 **	-37.24 **	-39.72 **	24.01 **	7.17	8.78	24.34 **	15.04 **	15.33 **
30.	GAR-13 X IET-23825	60.09 **	28.17 **	-14.61 **	48.10 **	28.05 **	29.83 **	21.47 **	9.73 **	10.00 **
31.	IET-24765 XIET-24767	-7.33	-27.79 **	-38.93 **	73.36 **	72.03 **	27.20 **	9.67 **	-0.60	-1.38
32.	IET-24765 X IET-24772	-17.75 **	-18.45 **	-31.02 **	80.80 **	76.58 **	28.56 **	16.02 **	10.88 **	-10.60 **
33.	IET-24765 X Gurjari	4.92	-4.50	-1.55	35.97 **	8.48	32.58 **	8.70 **	-5.47 *	3.10
34.	IET-24765 X NVSR-303-6	-40.31 **	-43.87 **	-46.09 **	21.57 **	4.38	5.95	27.45 **	23.99 **	5.72
35.	IET-24765 X IET-23825	-15.71 *	-37.90 **	-47.47 **	44.41 **	24.06 **	25.78 **	39.15 **	38.94 **	12.37 **
36.	IET-24767 X IET-24772	28.12 **	0.45	-16.48 **	77.59 **	72.15 **	27.28 **	26.88 **	10.43 **	9.56 **
37.	IET-24767 X Gurjari	-15.66 *	-38.51 **	-36.61 **	24.78 **	0.14	22.38 **	-1.61	-6.06 *	2.46
38.	IET-24767 X NVSR-303-6	28.32 **	-4.29	-8.07	21.43 **	4.94	6.52	17.71 **	9.44 **	8.58 **
39.	IET-24767 X IET-23825	38.53 **	28.01 *	-39.54 **	45.10 **	25.45 **	27.20 **	23.75 **	12.32 **	11.43 **
40.	IET-24772 X Gurjari	12.11 *	1.27	4.40	-4.49	-25.13 **	-8.50	17.39 **	-1.76	7.15 *
41.	IET-24772 X NVSR-303-6	-29.57 **	-34.30 **	-36.89 **	16.03 **	-2.32	-0.85	35.86 **	26.47 **	7.84 **
42.	IET-24772 X IET-23825	40.34 **	3.97	-13.55 *	41.42 **	19.11 **	20.76 **	25.73 **	19.99 **	-2.96
43.	Gurjari X NVSR-303-6	-41.93 **	-43.91 **	-42.18 **	11.26 *	1.83	24.45 **	-35.84 **	-42.84 **	-37.65 **
44.	Gurjari X IET-23825	20.47 **	-16.36 **	-13.78 **	16.81 **	6.86	30.59 **	21.28 **	5.60 *	15.18 **
45.	NVSR-303-6 X IET-23825	17.62 **	-16.66 **	-19.96 **	23.71 **	23.64 **	25.50 **	35.51 **	32.02 **	12.57 **
	SEd±	2.3483	2.7115	2.7115	1.1653	1.3456	1.3456	0.1698	0.1961	0.1961
	CD 1%	4.6547	5.3748	5.3748	2.3098	2.6672	2.6672	0.3367	0.3888	0.3888
	CD 5%	6.1574	7.1100	7.1100	3.0556	3.5283	3.5283	0.4454	0.5143	0.5143

*Significant at 5 % and **Significant at 1 %

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Table 5. Estimation of heterosis, heterobeltiosis and standard heterosis for iron content, zinc content and amylose content in rice.

Sr.no.	Crosses	Iron content (ppm)			Zinc content (ppm)			Amylose content (%)		
		MP	BP	SC	MP	BP	SC	MP	BP	SC
1.	NAUR-1 X GNR-3	27.78 **	19.45 **	7.40 **	59.68 **	48.22 **	-10.81 **	-0.82	-1.62	-6.23
2.	NAUR-1 X IET 24762	-5.01 *	-13.75 **	-22.45 **	58.95 **	26.96 **	9.51 **	10.45 **	1.37	15.64 **
3.	NAUR-1 X GAR-13	-46.12 **	-64.36 **	-67.95 **	38.97 **	36.05 **	-29.88 **	12.50 **	7.44 *	12.51 **
4.	NAUR-1 X IET-24765	-43.73 **	-45.23 **	-50.75 **	12.60 **	-10.55 **	-21.70 **	10.26 **	6.07	9.40 **
5.	NAUR-1 X IET-24767	-19.22 **	-19.56 **	-27.68 **	19.39 **	-6.65 *	-14.67 **	8.68 **	4.56	7.83 *
6.	NAUR-1 X IET-24772	-15.10 **	-20.32 **	-28.36 **	15.97 **	-8.69 **	-18.12 **	6.26 *	1.49	6.26
7.	NAUR-1 X Gurjari	-26.01 **	-42.88 **	-48.64 **	-28.05 **	-45.07 **	-46.28 **	10.77 **	4.35	12.51 **
8.	NAUR-1 X NVSR-303-6	-56.20 **	-65.81 **	-45.22 **	-33.51 **	-49.10 **	-50.61 **	13.39 **	9.09 **	12.51 **
9.	NAUR-1 X IET-23825	-35.83 **	-40.22 **	-37.72 **	-0.06	-16.05 **	-36.36 **	14.74 **	8.82 **	15.65 **
10.	GNR-3 X IET-24762	31.81 **	27.75 **	-0.11	59.07 **	35.01 **	16.46 **	2.27	-6.83 *	6.28
11.	GNR-3 X GAR-13	-19.72 **	-44.95 **	-56.96 **	-7.59	-15.88 **	-49.39 **	8.65 **	2.97	7.83 *
12.	GNR-3 X IET-24765	31.61 **	26.26 **	7.46 **	-28.52 **	-39.69 **	-47.21 **	14.28 **	9.09 **	12.51 **
13.	GNR-3 X IET-24767	-36.04 **	-39.97 **	-46.49 **	6.59 *	-11.62 **	-19.21 **	14.29 **	9.10 **	12.51 **
14.	GNR-3 X IET-24772	-0.88	-1.30	-22.18 **	16.82 **	-2.40	-12.47 **	2.38	-2.97	1.59
15.	GNR-3 X Gurjari	2.04	-17.07 **	-35.16 **	-10.42 **	-27.65 **	-29.25 **	10.09 **	2.91	10.97 **
16.	GNR-3 X NVSR-303-6	-38.93 **	-54.56 **	-27.20 **	-21.52 **	-36.42 **	-38.31 **	19.04 **	13.63 **	17.20 **
17.	GNR-3 X IET-23825	-45.96 **	-52.70 **	-50.72 **	-11.05 **	-20.22 **	-39.53 **	12.49 **	5.87	12.51 **
18.	IET-24762 X GAR-13	37.78 **	-3.85	-29.45 **	-19.13 **	-36.42 **	-45.16 **	-0.02	-4.12	9.37 **
19.	IET-24762 X IET-24765	7.04 **	-0.34	-15.18 **	-0.54	-1.27	-13.57 **	-2.14	-6.83 *	6.28
20.	IET-24762 X IET-24767	27.29 **	16.03 **	3.44	-1.47	-4.25	-12.47 **	-10.78 **	-15.06 **	-3.11
21.	IET-24762 X IET-24772	-6.97 **	-10.19 **	-29.19 **	-12.60 **	-14.26 **	-23.11 **	-0.01	-4.12	9.37 **
22.	IET-24762 X Gurjari	27.34 **	6.10 *	-22.15 **	-11.60 **	-16.81 **	-18.65 **	-7.04 **	-9.59 **	3.14
23.	IET-24762 X NVSR-303-6	-38.90 **	-55.46 **	-28.64 **	-5.75 *	-10.98 **	-13.63 **	0.70	-4.12	9.37 **
24.	IET-24762 X IET-23825	-45.59 **	-53.63 **	-51.69 **	-4.45	-10.24 **	-22.58 **	-2.13	-5.48	7.83 *
25.	GAR-13 X IET-24765	26.87 **	-14.92 **	-27.59 **	-5.97	-26.47 **	-35.63 **	2.26	1.49	6.28
26.	GAR-13 X IET-24767	27.52 **	-15.48 **	-24.65 **	7.24 *	-17.42 **	-24.51 **	3.76	2.97	7.83 *
27.	GAR-13 X IET-24772	31.24 **	-10.21 **	-29.21 **	-2.80	-24.65 **	-32.42 **	5.98 *	5.97	10.97 **
28.	GAR-13 XGurjari	26.47 **	0.78	-50.72 **	50.68 **	13.37 **	10.87 **	0.01	-1.43	6.28
29.	GAR-13 X NVSR-303-6	-20.35 **	-52.96 **	-24.63 **	-15.24 **	-36.05 **	-37.95 **	2.26	1.49	6.28
30.	GAR-13 X IET-23825	-32.81 **	-57.04 **	-55.25 **	58.90 **	31.19 **	-0.55	-2.24	-2.95	3.14
31.	IET-24765 XIET-24767	-53.80 **	-54.84 **	-59.74 **	-23.64 **	-25.25 **	-31.67 **	0.01	0.05	3.14
32.	IET-24765 X IET-24772	26.17 **	21.52 **	3.42	-12.90 **	-13.94 **	-22.82 **	0.75	0.23	4.70
33.	IET-24765 X Gurjari	-17.41 **	-34.98 **	-44.66 **	6.79 **	1.20	-1.04	-0.76	-2.91	4.69
34.	IET-24765 X NVSR-303-6	-38.58 **	-52.98 **	-24.66 **	-35.53 **	-38.68 **	-40.51 **	-3.01	-3.01	0.03
35.	IET-24765 X IET-23825	-23.53 **	-30.53 **	-27.62 **	-24.67 **	-29.72 **	-38.47 **	-1.50	-2.95	3.14
36.	IET-24767 X IET-24772	-40.61 **	-44.04 **	-50.12 **	-21.05 **	-21.79 **	-28.51 **	-0.74	-1.49	3.14
37.	IET-24767 X Gurjari	4.83 *	-18.84 **	-27.65 **	-28.92 **	-31.24 **	-32.76 **	-3.68	-5.78	1.59
38.	IET-24767 X NVSR-303-6	-48.03 **	-59.55 **	-35.20 **	-19.48 **	-21.81 **	-24.14 **	3.05	3.04	6.28
39.	IET-24767 X IET-23825	-51.31 **	-54.82 **	-52.93 **	28.27 **	17.32 **	7.25 **	-5.97 *	-7.36 *	-1.55
40.	IET-24772 X Gurjari	10.51 **	-10.48 **	-29.42 **	-19.48 **	-22.82 **	-24.53 **	-2.94	-4.35	3.14
41.	IET-24772 X NVSR-303-6	-13.93 **	-35.79 **	2.88	-26.41 **	-29.19 **	-31.30 **	2.25	1.49	6.26
42.	IET-24772 X IET-23825	-46.96 **	-53.41 **	-51.46 **	-24.77 **	-30.59 **	-37.75 **	-8.14 **	-8.82 **	-3.09
43.	Gurjari X NVSR-303-6	-25.62 **	-51.46 **	-22.23 **	-26.42 **	-26.71 **	-28.32 **	-6.66 *	-8.69 **	-1.55
44.	Gurjari X IET-23825	-18.59 **	-40.19 **	-37.69 **	-35.23 **	-42.52 **	-43.79 **	2.17	1.43	9.37 **
45.	NVSR-303-6 X IET-23825	-25.91 **	-38.87 **	-2.06	41.50 **	26.02 **	22.28 **	-4.50	-5.91	0.11
	SEd±	0.7027	0.8115	0.8115	0.4943	0.5708	0.5708	0.6287	0.7260	0.7260
	CD 1%	1.3930	1.6085	1.6085	0.9798	1.1314	1.1314	1.2463	1.4391	1.4391
	CD 5%	1.8427	2.1278	2.1278	1.2962	1.4967	1.4967	1.6486	1.9037	1.9037

*Significant at 5 % and **Significant at 1 %