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Variation in quantitative characters and heterosis in F_1 rice (*Oryza sativa* L.) hybrids as affected by male sterile cytoplasm

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Abstract

In hybrid breeding programme based on cytoplasmic-genic male sterility, the effect of sterility inducing cytoplasm on agronomic traits is of considerable importance. In rice (*Oryza sativa* L.) there are reports showing that sterile cytoplasm reduced the productive capacity of hybrids compared with normal cytoplasm of the maintainers. Forty eight hybrid combinations including 24 A/R hybrids and their reciprocals were evaluated and mean values for 15 different characters were compared. It was found that there is significant difference between direct hybrids and their reciprocals for almost all characters except days to flowering, total dry matter production, panicle length and 100 seed weight. This difference in performance of these two sets of hybrids can be attributed to cytoplasmic effect. Even though these are the average performances of the two groups of hybrids, when different cross combinations are compared, it can be seen that these are cross specific and each cross differs in their performance. Evaluation of heterosis expressed by different hybrids revealed that number of reciprocal hybrids expressing positive and significant heterosis for grain yield was high compared to direct hybrids. All these explain the possible negative influence of sterile cytoplasm on quantitative characters.

Key words: Rice, male sterile cytoplasm, direct hybrids, reciprocal hybrids, heterosis

Introduction

The genetic gains in yield and yield stability offered by heterosis have prompted the use of hybrids in several crops. Heterosis in rice (*Oryza sativa* L.) 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. As in other crops where cytoplasmic-genetic male sterility has been used to develop hybrids, in rice too only a few CMS lines could be utilised for development of commercial hybrids. In hybrid breeding programme based on cytoplasmic-genic male sterility, the effect of sterility inducing cytoplasm on agronomic traits is of considerable importance. In maize, reciprocal differences for yield, maturity and other agronomic attributes have been related to the cytoplasmic differences [1]. In rice there are reports showing that sterile cytoplasm reduced the productive capacity of hybrids compared with normal cytoplasm of the maintainers [2, 3]. High level of cytoplasm × environment interactions has been reported in rice by many workers [2-4].

Materials and methods

A total of 48 hybrid combinations developed by hybridisation between seven CMS lines having WA cytoplasmic male sterility source and 12 genetically diverse rice genotypes were evaluated for yield and yield contributing characters along with Ptb 50 (a high yielding popular rice variety of Kerala) as check variety. These hybrids include 24 direct hybrids (A × R) with CMS lines as female parents and genetically diverse restorers as male parents and 24 reciprocal hybrids (R × B) evolved by hybridisation between restorers as female parents and maintainers of CMS lines as pollen parents. Twenty five day old seedlings were transplanted at the rate of one seedling per hill with a spacing of 20 × 15cm. Recommended package of practices and need based plant protection measures were adopted. Harvesting was done when the crop attained physiological maturity. Observations on plant height, total number of tillers, panicles per plant, days to flowering, leaf area index, grain yield per plant, straw yield per plant, harvest index, grains per panicle, spikelet sterility percent, panicle exertion, 100 seed weight, grain density, total dry matter production and panicle length were recorded from all the hybrid combinations and check varieties. Statistical analysis was conducted to compare direct and reciprocal hybrids and also to evaluate heterosis from both the sets of hybrids. Standard heterosis (commercial heterosis) was estimated as percent deviation of the F_1 from the best popular rice variety *viz.*, Ptb 50.

Results and discussion

Observations on 15 agronomic attributes were subjected to 't' test and the results indicated significant values of 't' for most of the characters indicating reciprocal difference for these characters. The reciprocal cross

effects were significant for plant height, tiller production, grain yield, straw yield, harvest index, grains per panicle, spikelet sterility, panicle exertion, grain density and leaf area index. Characters like days to flowering, total dry matter production, panicle length and 100 seed weight did not exhibit reciprocal difference.

Mean grain yield recorded by direct hybrids was 20.74g and that by reciprocal hybrids was 22.9g. Average straw yield recorded was low (20.75g) in reciprocal hybrids and high (22.23g) in direct hybrids. Even though there was difference between direct and reciprocal hybrids for grain and straw yield, total dry matter did not differ significantly, which indicated that though the hybrids produced using CMS lines are capable of producing high dry matter, partitioning into economic yield is being suppressed This is more evident from the low harvest index of (A/R) hybrids compared to the hybrids in which restorers with normal cytoplasm are the female parents. Direct hybrids had less number of fertile grains per panicle (111.4) and high spikelet sterility (17.69) as against higher number of grains per panicle (130.21) and low spikelet sterility (10.62) in reciprocal hybrids. These factors indicate that the low grain yield of direct hybrids could be due to less number of filled grains per panicle, high spikelet sterility, poor panicle exertion and low grain density as a result of the negative influence of cytoplasm on these characters.

Among the 24 hybrids evaluated, 18 reciprocal hybrids expressed higher grain yield than their direct hybrids. Highest difference in grain yield between direct and reciprocal cross was expressed by the cross combinations IR 58025A × Jaya, IR 67684A × Kanchana and IR 68890A × Annapoorna. Hybrids IR 62829A × Aathira and IR 68891A × Jaya had lowest difference. Hybrid combination IR 68890A × Aiswarya, which expressed highest grain yield, produced high yielding reciprocals also (Table 1 and 2).

All the reciprocal hybrids except IR 68891A × IR 36, PMS 3A × Jaya and PMS 10A × Ptb 10 produced more number of grains per panicle than corresponding direct hybrids. Most of the CMS lines used in the programme expressed low panicle exertion of 52.79% to 78.97%. This character also seems to be influenced by cytoplasmic genes with a wide difference between direct and reciprocal hybrids and almost all direct hybrids expressing very low panicle exertion (58.1 % to 106.5%).

Since there are differences in performance between crosses it can be interpreted that the cytoplasmic influence differs with nuclear background and it is actually the result of interaction between cytoplasmic and nuclear genes. Hence, the undesirable effect of cytoplasm can be eliminated by selecting suitable parents in hybrid breeding programs.

Table 1. Mean performance of direct and reciprocal hybrids in rice — direct hybrids

Sl. No.	Hybrids	Plant height (cm)	Panicles per plant	Days to flowering	Leaf area index	Grain yield (g)	Straw yield (g)	Harvest index	Grains per panicle	Spikelet sterility (%)	Panicle exertion (%)	100 seed wt. (g)	Grain density (g/100ml)
1.	IR 62829A/Matte Triveni	98.0	9.2	78.3	9.7	19.7	22.9	0.5	93.5	16.5	58.1	2.4	52.7
2.	IR 62829A/Kanchana	98.0	15.7	79.0	11.5	23.4	15.8	0.6	119.2	16.2	86.4	2.5	54.0
3.	IR 62829A/Aiswarya	94.0	13.7	81.5	12.1	17.2	27.9	0.4	128.2	14.1	64.4	2.6	52.9
4.	IR 68890A/Annapoorna	98.8	10.8	84.0	11.4	20.1	18.8	0.5	96.0	16.4	93.8	2.6	54.7
5.	IR 68890A/Kanchana	105.5	14.8	85.0	9.8	24.8	21.7	0.5	128.5	14.3	85.1	2.4	56.4
6.	IR 68890A/IR 36	96.0	8.5	86.5	9.4	17.9	24.9	0.4	104.2	16.2	70.8	2.6	54.8
7.	IR 68890A/Aiswarya	105.7	10.8	87.0	9.3	29.9	25.8	0.5	107.5	20.7	86.9	3.0	55.9
8.	IR 68891A/Annapoorna	92.5	8.3	82.5	7.1	21.2	20.8	0.5	98.5	21.8	106.4	2.0	53.4
9.	IR 68891A/IR 36	93.5	9.8	84.0	7.8	24.5	19.1	0.6	156.2	14.8	101.0	2.0	51.8
10.	PMS 10A/IR 36	94.0	10.8	81.2	8.2	20.2	21.2	0.5	124.7	15.4	106.5	1.9	54.6
11.	PMS 10A/Aiswarya	110.8	9.0	90.0	8.4	21.5	20.2	0.5	120.5	15.1	85.6	2.3	54.4
12.	IR 58025A/IR 8	86.3	9.5	88.7	7.4	20.8	17.4	0.5	108.9	17.3	76.0	2.4	53.8
13.	IR 58025A Jaya	88.8	6.0	87.9	7.4	12.2	21.8	0.4	86.0	22.9	84.3	2.2	54.3
14.	IR 58025A/Aiswarya	117.3	5.9	88.8	6.6	12.3	23.4	0.3	91.8	20.5	70.8	2.4	54.2
15.	IR 62829A/Kairali	95.5	16.4	82.6	10.0	17.7	22.3	0.4	95.4	17.9	71.7	1.9	52.8
16.	IR 62829A/Aathira	111.7	13.2	80.2	11.6	24.3	23.3	0.5	115.3	13.8	83.5	2.3	54.3
17.	IR 67684A/Kanchana	91.9	13.0	84.3	11.6	15.3	19.7	0.4	100.4	17.5	71.3	2.2	53.0
18.	IR 68890A/Ptb 10	124.1	7.3	81.7	9.3	22.1	24.6	0.5	127.2	14.0	101.9	2.5	56.5
19.	IR 68891A/IR 8	87.6	16.7	86.9	9.3	16.7	24.4	0.4	96.2	24.9	93.3	2.5	52.7
20.	IR 68891A/Jaya	90.6	15.6	85.9	9.0	18.1	21.5	0.5	96.2	24.2	93.2	2.5	53.1
21.	PMS 3A/Jaya	97.5	10.0	96.7	9.2	17.2	21.5	0.4	126.3	21.9	100.3	2.4	54.3
22.	PMD 3A/Aiswarya	104.2	7.6	92.3	9.8	17.9	22.5	0.4	100.0	20.5	102.0	2.2	53.3
23.	PMS 10A/Aruna	93.5	10.1	88.1	9.1	22.2	18.8	0.5	123.1	15.2	103.9	1.9	57.9
24.	PMS 10A/Ptb 10	130.0	9.7	85.4	9.1	22.8	23.5	0.5	169.6	13.2	96.9	2.4	59.0

Table 2. Mean performance of direct and reciprocal hybrids in rice — reciprocal hybrids

Sl. No.	Hybrids	Plant height (cm)	Panicles per plant	Days to flowering	Leaf area index	Grain yield (g)	Straw yield (g)	Harvest index	Grains per panicle	Spikelet sterility (%)	Panicle exertion (%)	100 seed wt.(g)	Grain density (g/100ml)
1.	Matta Triveni/IR 62829B	87.8	8.8	76.4	5.4	23.1	19.2	0.6	115.8	19.6	105.4	2.3	55.8
2.	Kanchana/IR 62829B	88.0	8.4	77.6	7.5	27.2	19.5	0.6	124.2	9.1	107.7	2.2	56.2
3.	Aiswarya/IR 62829B	98.0	9.8	82.4	7.2	23.4	20.1	0.5	137.0	12.2	107.3	2.4	56.5
4.	Annapoorna/IR 68890B	91.6	6.2	79.6	6.5	28.2	22.0	0.6	131.6	11.4	108.8	2.7	56.0
5.	Kanchana/IR 68890B	106.0	9.6	85.8	6.2	18.0	18.1	0.5	130.0	9.3	107.8	2.3	55.7
6.	IR 36/IR 68890B	99.6	10.6	86.8	6.0	18.9	19.1	0.5	115.2	14.5	103.4	2.4	52.7
7.	Aiswarya/IR 68890B	98.8	8.4	87.0	6.7	28.8	25.0	0.5	140.0	10.7	110.6	2.7	58.1
8.	Annapoorna/IR 68891B	86.6	8.8	79.8	6.2	15.4	15.9	0.5	121.4	11.7	102.0	2.4	53.5
9.	IR 36/IR 68891B	96.8	8.8	81.4	6.4	21.4	17.9	0.5	153.2	9.8	105.7	2.3	52.4
10.	IR 36/IR 68891 B	93.4	8.6	85.0	5.7	23.6	22.2	0.5	136.0	13.7	99.6	2.3	54.4
11.	Aiswarya/PMS 10B	101.2	8.6	90.2	6.5	20.6	21.0	0.5	145.0	11.7	99.7	2.6	58.9
12.	IR 8/IR 62825B	95.8	8.2	86.4	6.4	25.9	18.8	0.6	112.6	11.1	90.9	2.4	55.1
13.	Jaya/IR 62825B	93.0	9.0	87.0	5.0	26.3	19.9	0.6	122.0	11.0	100.2	2.4	55.9
14.	Aiswarya/IR 62825B	96.6	8.2	90.0	5.1	25.3	21.0	0.5	105.4	11.2	104.0	2.0	56.5
15.	Kairali/IR 62829B	85.4	8.4	80.8	6.9	21.5	20.2	0.5	133.4	12.7	104.9	2.2	53.2
16.	Aathira/IR 62829B	95.4	8.0	87.4	7.6	24.4	19.1	0.6	119.0	10.9	107.5	2.4	55.7
17.	Kanchana/IR 67684B	95.0	8.0	83.2	6.3	23.4	19.0	0.5	124.0	18.3	99.3	2.5	54.7
18.	Ptb 10/IR 68890B	104.0	8.8	84.0	5.6	20.7	24.9	0.5	134.4	11.4	109.1	2.5	56.2
19.	IR 8/IR 68891 B	95.4	11.0	86.6	6.4	20.6	21.6	0.5	143.2	12.0	104.6	2.4	57.7
20.	Jaya/IR 68891 B	92.6	9.2	91.2	6.5	18.2	19.3	0.5	124.8	12.1	104.3	2.2	54.9
21.	Jaya/PMS 3B	92.0	8.8	93.2	5.3	22.5	19.0	0.5	124.8	14.6	101.4	2.3	57.0
22.	Aiswarya/PMS 3B	97.8	8.6	98.0	6.1	22.6	26.9	0.5	159.2	8.3	104.9	2.5	58.7
23.	Aruna/PMS 10B	92.6	8.6	90.4	5.3	25.3	20.6	0.6	146.0	13.9	108.9	2.5	57.3
24.	Ptb 10/PMS 10B	101.2	8.0	84.0	6.5	24.2	27.0	0.5	126.8	12.4	102.1	2.5	57.7

Differences in performance between reciprocal and direct hybrids have been reported by Virmani and Wan [5] and Hassan and Siddique [6]. Virmani and Edwards [7] indicated that sterile cytoplasm had negative effects on number of spikelets per panicle, number of filled grains per panicle, 1000 grain weight and yield per plant, although it had positive effect on number of tillers per hill. These results hold good in the present study also. Similar results were reported by Rosamma *et al.* [8] and Skikh [9].

Data presented in Table 3 and 4 reveal that there is difference in magnitude and direction of heterosis in the direct and reciprocal hybrids for different characters. Only very few direct hybrids *viz.*, IR 62829A × Kanchana, IR 68890A × Kanchana, IR 68890A × Aiswarya, IR 68891A × IR 36 and IR 62829A × Aathira exhibited positive and significant standard heterosis over Ptb 50 (the most poular high yielding variety, used as check variety), whereas out of 24 reciprocal hybrids 12 expressed significant and positive standard heterosis for grain yield. The magnitude of heterosis ranged from –22.1% to 45.9% and only three hybrids expressed negative heterosis. Direct hybrids exhibited high heterosis for characters such as number of productive tillers per plant, straw yield, leaf area index and spikelet sterility. Sixteen direct hybrids recorded significant positive heterosis for number of productive tillers per plant whereas only nine reciprocal hybrids expressed significant positive heterosis for this character. In the case of straw yield, all the reciprocal hybrids expressed lower heterosis (–4.2% to 62.2%) than the A × R hybrids (–3.1% to 71.8%). Significant positive heterosis was recorded by 19 direct hybrids whereas only 11 reciprocal hybrids recorded significant positive heterosis for straw yield. Twenty two direct hybrids expressed significant positive heterosis for leaf area index whereas only eight reciprocal hybrids expressed significant positive heterosis for this character. High heterosis for vegetative characters with low heterosis for grain yield in most of the direct hybrids indicate mat there are some factors which hinter grain production in these hybrids. Since these two sets of hybrids differ only in their cytoplasm, it can be considered as negative influence of sterile cytoplasm. This is more evident from the positive and higher heterosis for filled grains per panicle in reciprocal hybrids compared to negative heterosis in A × R hybrids. Twenty direct hybrids expressed significant positive heterosis for spikelet sterility whereas all reciprocal hybrids exhibited nonsignificant or negatively significant heterosis for this

Table 3. Heterosis expressed by direct and reciprocal hybrids in rice — direct hybrids

Sl. No.	Hybrids	Plant height (cm)	Panicles per plant	Days to flowering	Leaf area index	Grain yield (g)	Straw yield (g)	Harvest index	Grains per panicle	Spikelet sterility (%)	Panicle exertion (%)	100 seed wt.(g)	Grain density (g/100ml)
1.	IR 62829A/Matta Triveni	2.3	27.5**	−8.2**	76.0**	12.2	41.1**	−11.7	−14.4	56.3**	−13.6**	−11.3**	−9.1**
2.	IR 62829A/Kanchana	1.5	117.2**	−7.3**	107.2**	33.3**	−3.1	15.6*	9.1	53.8**	−15.3**	−3.8	−6.8**
3.	IR 62829A/Aiswarya	−1.5	89.6**	−4.3**	118.4**	−2.2	71.8**	−25.4**	17.3	33.8*	−36.9**	−1.1	−8.7**
4.	IR 68890A/Annapoorna	3.4	48.2**	−1.4	106.0**	14.4	15.2	0.0	−12.1	55.2**	−8.0*	−0.7	−5.6**
5.	IR 68890A/Kanchana	10.4**	103.4**	−2.9**	77.0**	21.7**	33.4**	3.9	17.6	37.1**	−16.6**	−10.2**	−2.7*
6.	IR 68890A/IR 36	0.5	17.2	1.4	68.5**	1.9	52.9**	−19.6**	−4.5	53.2**	−30.6**	−24.5**	−5.3**
7.	IR 68890A/Aiswarya	10.5**	48.2**	2.1*	66.7**	70.6**	58.6**	5.8	−1.6	96.2**	−14.8**	12.8**	−3.6**
8.	IR 68891A/Annapoorna	−3.1	13.7	−3.2**	28.0	20.7	27.7*	−1.9	−9.8	107.1**	4.34	−24.9**	−6.3**
9.	IR 68891A/IR 36	−2.1	34.4*	−1.4	41.4**	39.6**	17.4	9.8	43.0**	40.2**	−0.9	−24.5**	−10.6**
10.	PMS 10A/IR 36	−1.5	48.2**	−4.6**	46.9**	14.9	30.5*	−7.8	14.1	46.1**	4.4	−25.7**	−5.7**
11.	PMS 10A/Aiswarya	15.9**	24.1	5.5**	52.3**	22.6	22.5*	−3.9	10.2	42.8**	−16.0**	−12.0**	−6.1**
12.	IR 58025A/IR 8	−10.7**	31.9*	4.2**	37.0**	4.8	4.9	−2.0	−5.5	40.6**	−17.2**	−13.2**	−5.7**
13.	IR 58025A/Jaya	−11.2**	−16.6	3.3**	38.8**	−38.3**	31.3**	−35.6**	−25.5**	87.0**	−8.1*	−15.0**	−4.7**
14.	IR 58025A/Aiswarya	21.3**	−18.1	4.3**	22.3	−37.7**	40.5**	−36.7**	−20.4**	66.7**	−22.9**	−8.7**	−4.9**
15.	IR 62829A/Kairali	−1.2	127.8**	−2.9**	85.8**	10.0	34.2**	−19.3**	−17.1**	45.5**	−21.9**	−29.4**	−7.5**
16.	IR 62829A/Aathira	15.5**	83.3**	−5.7**	88.7**	23.3**	40.2**	−6.3	0.0	12.2	−9.0**	−11.7**	−4.9**
17.	IR 67684A/Kanchana	−5.0*	80.5**	−0.9	113.7**	−22.1*	18.6*	−19.4**	−13.0	42.3**	−22.3**	−15.5**	−7.1**
18.	IR 68890A/Ptb 10	28.3**	1.39	−4.1**	72.8**	12.2	48.1**	−12.9*	10.3	13.8	11.0**	−4.9**	−0.8
19.	IR 68891A/IR 8	−9.4**	131.9**	2.1*	74.0**	−15.5	46.4**	−25.1**	−16.3*	103.3**	1.6	−7.1**	−7.7**
20.	IR 68891A/Jaya	−6.3**	8.5	0.9	67.2**	−8.0	29.4**	−16.2**	−16.5*	96.7**	1.5	−6.0**	−6.8**
21.	PMS 3A/Jaya	0.8	38.8**	13.6**	71.0**	−12.7	31.0**	−19.2**	9.5	78.9**	9.4**	−8.6**	−4.9**
22.	PMS 3A/Aiswarya	7.8**	5.5	8.5**	82.9**	−8.9	35.2**	−18.5**	−13.3	66.6**	11.1**	−16.6**	−6.6**
23.	PMS 10A/Aruna	−3.3	40.3**	3.5**	68.5**	12.6	13.1	−0.3	6.7	23.0	13.2**	−28.3**	−9.1**
24.	PMS 10A/Ptb 10	34.4**	34.7**	0.3	68.5**	15.5	41.0**	−9.2	47.0**	8.1	5.5	−9.0**	3.3**

*,**Significant at P = 0.05 and 0.01 levels respectively

Table 4. Heterosis expressed by direct and reciprocal hybrids in rice — reciprocal hybrids

Sl. No.	Hybrids	Plant height (cm)	Panicles per plant	Days to flowering	Leaf area index	Grain yield (g)	Straw yield (g)	Harvest index	Grains per panicle	Spikelet sterility (%)	Panicle exertion (%)	100 seed wt. (g)	Grain density (g/100ml)
1.	Matta Triveni/IR 62829B	−9.2**	22.2*	−10.2**	1.1	16.9	15.5	1.1	0.4	−21.8	14.8**	−14.9**	−2.2*
2.	Kanchana/IR 62829B	−8.9**	16.6	−8.8**	39.4**	37.9**	17.2	8.1	7.7	−25.9*	17.3**	−17.1**	−1.6
3.	Aiswarya/IR 62829B	−1.3	36.1**	−3.1**	33.6**	18.8*	20.9*	−0.5	18.8	−0.5	17.0**	−6.0*	−1.0
4.	Annapoorna/IR 68890B	−5.2	−13.8	−6.4**	20.3**	43.0**	32.4**	4.2	14.1	−7.2	18.5**	0.0	−1.9
5.	Kanchana/IR 68890B	9.6**	33.3**	0.8	15.4	8.5	9.3	−8.3	12.7	−24.3*	17.4**	−12.5**	−2.5*
6.	IR 367/IR 68890B	2.9	47.2**	2.0	11.5	−3.9	14.8	−8.3	0.0	18.6	12.6**	−8.8**	−7.7**
7.	Aiswarya/IR 68890B	−2.1	16.6	2.2*	24.4**	45.9**	50.5**	−1.2	21.4*	−12.2	20.4**	0.7	1.6
8.	Annapoorna/IR 68891B	7.6**	22.2*	−6.2**	14.7	−22.1*	−4.2	−9.2	5.2	−4.3	11.1	−8.7**	−6.3**
9.	IR 36/IR 68891B	10.4**	36.1**	−4.3**	20.0*	8.8	8.1	0.5	32.8**	−20.4	15.1**	−12.5**	−8.2**
10.	IR 36/IR 68891B	−6.7	19.4	0.0	5.2	19.8*	33.9**	−4.9	17.9	9.0	8.4	−13.6**	−4.7**
11.	Aiswarya/PMS 10B	−3.4	19.4	5.6**	20.9*	4.4	26.5**	−8.3	25.7*	−4.8	8.6	−3.4	3.1**
12.	IR 8/IR 62825B	−0.9	13.9	1.5	19.1	31.4**	13.2	7.5	−2.3	−9.8	−0.9	−6.2*	−3.5**
13.	Jaya/IR 62825B	−3.8	25.0	2.2*	−7.0	33.2**	19.5	4.9	5.8	−11.3	9.1	−8.0**	−2.2*
14.	Aiswarya/IR 62825B	0.7	13.8	6.0**	−5.4	28.2**	26.2**	0.7	−8.5	−9.0	13.3**	7.6**	−1.1
15.	Kairali/IR 62829B	−11.7**	16.6	−5.0**	29.0**	9.1	21.4	−4.9	15.7	3.8	14.3**	−18.5**	−3.4**
16.	Aathira/IR 62829B	−1.3	11.1	2.7**	41.3**	24.0**	14.8	4.1	3.2	−10.4	17.1**	−8.3**	−2.4**
17.	Kanchana/IR 67684B	−1.7	11.1	−2.2*	17.1*	18.4*	14.3	1.4	7.5	7.8	8.1	−6.4*	−4.2**
18.	Ptb 10/IR 68890B	2.1	19.4	−1.3	3.5	4.9	50.2**	−16.2	16.5	−7.1	20.4**	−6.8*	−1.6
19.	IR 8/IR 68891B	0.1	22.2	1.7	18.2*	4.5	29.8**	−10.1	24.1*	−2.0	13.9**	−7.6**	1.1
20.	Jaya/IR 68891B	−4.2	12.9	7.1**	21.4**	−7.5	15.8	−10.1	8.2	−1.9	19.0**	−15.5**	−3.7**
21.	Jaya/PMS 3B	−4.8	52.7**	7.1**	−1.1	13.9	14.7	0.1	8.2	−18.7	10.4*	−10.9**	−0.1
22.	Aiswarya/PMS 3B	1.1	27.7*	3.4**	13.4	14.4	62.2**	−15.7	38.1**	−32.3**	14.2**	−4.5	2.7*
23.	*Aruna/PMS 10B*	−4.2	50.0**	6.2**	−1.5	28.2**	24.1*	1.8	26.6**	−13.2	18.6**	−6.8*	0.2
24.	Ptb 10/PMS 10B	4.6	11.1	-1.3	20.4*	22.7*	62.3**	−12.5	9.9	0.8	11.2*	−5.7*	1.0

*,**Significant at P = 0.05 and 0.01 levels respectively

character. These factors explain the lower level of heterosis expressed by A × R hybrids for grain yield than their corresponding reciprocal hybrids. This is of considerable importance in heterosis breeding programs in rice, since hybrid seed production can be made economic only by the use of CMS lines and if these lines are having negative influence on economic traits it can hinter the pace of development of hybrid rice programs. Young and Virmani [10] also reported negative influence of cytoplasm on agronomic attributes and they have opined that different genotypes interact differently with the same cytoplasm exhibiting different cytoplasmic effects and proper selection of CMS lines as well as restorers can lead to better heterotic combinations. In the present study hybrid combinations such as IR 62829A × Kanchana, IR 68890A × Kanchana, IR 68890A × Aiswarya and JR 68891A × IR 36 had high grain yield, grains per panicle and grain density in spite of the sterile cytoplasm in them.

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