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Full Research Article

Heterosis Manifestation in Rice (*Oryza sativa* L.) Hybrids under Water Limited Rainfed Condition

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Abstract

The three-line hybrid system involving cytoplasmic male sterile A- line, maintainer B-line and restorer R-line is a common approach for hybrid development in rice. The hybrids developed through this technique has been successful in increasing the rice production under favourable irrigated condition but hybrids under water-limited rainfed condition has not been much evaluated. Hybrids developed for non-irrigated rainfed lowland environment can help in sustaining the rice production under decreasing water and land resources. The emphasis therefore should be given for developing improved hybrids specifically suited for unfovourable water limited rainfed conditions. Keeping this in view, F_1 crosses were generated using line x tester mating design to evaluate rice hybrids under rainfed stress. Assessment of heterosis in 64 F_1 cross combination under water-limited rainfed condition revealed scope of exploiting hybrid vigour and developing heterotic hybrids for non-irrigated rainfed lowland environment. Significant standard heterosis over commercial hybrid checks (KRH 2 and PA 6444) observed in many cross combinations for various traits viz., filled grain per panicle, spikelet fertility percent, grain yield per plant, biomass per plant and harvest index highlight the importance of these traits in selecting parents based on above traits and developing hybrids with drought tolerance and high yield for water limited rainfed lowland ecology

1. Introduction

Rice is an important food crop grown and consumed world over. With ever increasing human population, there is a need for increasing rice yield in areas where rice is primarily grown as a rainfed crop. The rice rainfed ecosystem which occupy nearly 38% of the total rice cropped area, contributes only 21% of the total rice production (Khush, 1997) due to low productivity caused by frequent occurance of drought . In this context, hybrid rice technology holds great promise. Under irrigated environment it has contributed to 10-30% yield advantage over conventional inbreds (Virmani et al. 1982). But, the performance of rice hybrids under unfavourable water limited rainfed condition has not been much evaluated. Instances of better performance of hybrid rice under unfavourable environments has been observed (Virmani, 2003). Atlin et al. (2008) identified drought tolerant high yielding hybrids suitable for lowland environment. Villa et al. (2011) reported better performance of rice hybrids under both well watered and severe drought. Development of drought tolerant rice hybrids for drought prone rainfed lowland regions could thus help in sustaining the rice production during drought years.

2. Materials and Methods

2.1. Study sites

The experiment was conducted at Barwale Foundation Research Farm, Hyderabad, India (78^{0}12'40" E longitude and 17^{0}24'20" N latitude situated 536m above mean sea level). The soil type of the site comprised of vertisol/clay loam with a soil pH of 7.9.

2.2. Method of data collection

The genetic materials used in the study were sourced from International Rice Research Institute. The lines includes 4 cytoplasmic male sterile lines (IR58025A; IR68897A; IR68902A; IR79156A), 16 drought tolerant advance breeding lines (IR 77298-5-6-18; IR 77298-14-1-2-10; IR 78581-12-3-2-2; IR 78908-193-B-3-B; IR 79906-B-5-3-3; IR 79906-B-192-2-1; IR 79956-B-60-2-3; IR 79959-B-217-1-2; IR

80408-B-43-3; IR 80461-B-7-1; IR 83376-B-B-91-3; IR 83376-B-B-110-3; IR 83381-B-B-6-2; IR 83381-B-B-55-4; IR 83387-B-B-40-1; IR 83887-B-B-11-4) and 2 hybrid checks (KRH 2 and PA 6444). The crosses were made following line×tester mating design (Kempthrone, 1957) by crossing 4 inbred lines (CMS lines with WA cytoplasm) with 16 testers (advance drought breeding lines) to generate 64 crosses during the 2011wet season. During the 2012 wet season all 64 hybrids and their parents along with standard hybrid checks (KRH2 and PA 6444) were grown in a randomized block design with two replications. Two rows of 2 m row length per hybrid and two rows of parents and standard checks were planted. Twenty one day old seedlings were transplanted in the field at 20×20 cm spacing. All the recommended agronomics practices were followed to raise a healthy crop. Ten plants were selected randomly for recording of observations on 12 different yield related traits viz. days to 50% flowering, plant height (cm), number of tillers plant^{-1}, number of panicles plant^{-1}, panicle length (cm), filled grains per panicle^{-1}, total spikelets panicle^{-1}, spikelet fertility percent, hundred seed weight, grain yield plant^{-1} (g), biomass plant^{-1} (g) and harvest index.

The experimental material was exposed to limited moisture condition by draining out water from the field after 20 days of transplanting. Thereafter no supplementary irrigation was provided to the field and plant thrives solely on rainfall received during the wet season of the conduction of the experiment i.e. after discarding the water, plants were raised under rainfed condition without any standing water all through the crop growth stage. During the season (1st June to 30th November) , the total rainfall received was 698 mm and total number of rainless days was 140. After discarding water from the field (1st September to 30th November), total rainfall received was 188 mm and number of rainless days was 73.

The data was subjected to analysis by Windostat v.9.1 and the heterosis over mid parent (relative heterosis), better parent (heterobeltiosis) and commercial checks (standard heterosis) was worked out.

3. Results and Discussion

3.1. Analysis of variance

The analysis of variance (Table 1) for yield and related traits in the line×tester experiment revealed significance differences due to genotypes for most of the traits except panicle plant^{-1}.

3.2. Heterosis estimate for agronomic traits

The average heterosis, heterobeltiosis and standard heterosis (over the hybrid checks KRH2 and PA 6444) observed for days to 50% flowering under limited moisture rainfed condition showed desirable significant negative heterosis (Table 2 and 3). Cross combination IR 58025A×IR 80461-B-7-1 and IR 58025A×IR 83381-B-B-55-4 exhibited highest significant negative heterobeltiosis and standard heterosis over both the checks. Out of the 64 crosses, 19 crosses exhibited significant negative average heterosis while 55 crosses depicted significant negative heterobeltiosis. The standard heterosis over both the hybrid checks KRH2 and PA 6444 showed significant negative heterosis for all the studied crosses. The negative heterosis for days to 50% flowering is desirable for breeding early maturing lines that can complete their life cycle early in the limited available moisture. Heterosis for earliness has been reported by Young and Virmani (1990). Early flowering of hybrids was observed in both well watered and stress environment by Villa et al. (2011). Heterotic effect of both negative and positive nature in flowering behaviour was reported by Jarwar et al. (2012), Hussain and Sanghera (2012) and Rajkumar and Ibrahim (2013).

For the trait plant height, out of the 64 crosses, 35 crosses depicted significant positive average heterosis. None of the crosses showed significant positive heterobeltiosis and significant positive standard heterosis over KRH2 while 6 crosses exhibited significant positive standard heterosis over the check PA6444. Similar nature of both positive and negative standard heterosis in rice hybrids was observed in aerobic condition by Rajkumar and Ibrahim (2013) and in temperate conditions by Hussain and Sanghera (2012).

For the trait number of tillers plant^{-1}, the cross IR 68902A×IR 80461-B-7-1 depicted the highest significant positive heterosis (35.64%) and heterobeltiosis (35.51%). With regard to standard heterosis, highest significant positive heterosis of 17.36% and 21.89% was depicted by the cross IR 58025A×IR 79959-B-217-1-2 over the hybrid checks, KRH 2 and PA 6444, respectively. Out of the 64 crosses, 19 crosses depicted significant positive average heterosis, 10 crosses exhibited significant positive heterobeltiosis, 2 crosses exhibited significant positive standard heterosis over the check hybrid KRH2 and 4 crosses over the check hybrid PA 6444 under rainfed condition. Only two crosses i.e IR 58025A×IR 79959-B-217-1-2 and IR 68897A×IR 79906-B-5-3-3 exhibited significant and positive average heterosis, heterobeltiosis and standard heterosis over both the hybrid checks. Similar result of standard heterosis under drought condition was reported by Souframanien et al. (1998) and under aerobic condition by Amudha et al. (2010).

The crosses for the trait panicles plant^{-1} exhibited heterosis of both positive and negative nature but were mostly non significant. Out of the 64 crosses, 3 crosses viz., IR 58025A×IR 79959-B-217-1-2 (26.54%), IR 68902A×IR 79959-B-217-1-2 (24.20%) and IR 68902A×IR 80461-B-7-1 (23.53%) exhibited significant positive average heterosis while none of the crosses depicted significant positive heterobeltiosis and standard heterosis for this trait. In another study under

Table 1: Analysis for variance for Line×Tester analysis for yield and component traits under water limited rainfed condition

Source of variations	df	Days to 50% flowering	Plant height (cm)	Tillers plant^{-1}	Pan-icles plant^{-1}	Panicle length (cm)	Filled grains panicle^{-1}	Spikelets panicle^{-1}	Spikelet fertility %	100 Seed weight (g)	Grain yield plant^{-1} (g)	Biomass plant^{-1} (g)	Harvest index
Replication	1	0.0536	0.8657	0.0000	0.0629	0.0191	143.7080	33.5715	31.4125	0.0000	2.7874	5.2930	0.0006
Genotypes	83	18.5326**	92.7627**	0.6958**	0.4566	0.7686**	645.3292**	327.1904**	183.8776**	0.0311**	11.5440**	23.1845**	0.0055**
Parents	19	50.6039**	265.6736**	1.1587**	0.2828	0.5187**	279.9014**	91.4570	106.1074**	0.1298**	5.4300**	15.4170**	0.0017**
Parent (Line)	3	11.5000**	106.4866**	0.8301*	0.3289	1.3548**	18.7170	56.4512	14.7351	0.0668**	0.2756	0.9392	0.0002
Parent (Testers)	15	43.2479**	58.2981**	1.1690**	0.2923	0.3504**	128.1845	104.5413	57.2787**	0.0049**	2.2387	5.1677	0.0012*
Parent (L vs T)	1	278.2563**	3853.9580**	1.9892**	0.0012	0.5348**	3339.2080**	0.2102	1112.6559**	2.1926**	68.7620**	212.5901**	0.0137**
Parent vs Cross	1	35.0146**	285.7924**	1.9505**	0.0801	1.7980**	1960.5769**	5685.9424**	38.5666	0.0494**	1.1867	36.5501**	0.0001
Cross	63	8.5987**	37.5510**	0.5363**	0.5151*	0.8276**	734.6606**	313.2251**	209.6386**	0.0010**	13.5523**	25.3150**	0.0067**
Line Effect	3	31.8646**	209.6169**	1.3355*	0.7787	7.9203**	3984.6328**	2179.5286**	910.5095**	0.0034**	70.8255**	147.2199**	0.0329**
Tester Effect	15	17.8479**	85.7358**	0.7323	0.9223**	1.1462**	1390.5995**	377.4703*	412.5277**	0.0023**	26.2814**	43.7514**	0.0136**
Line *Tester Eff.	45	3.9646**	10.0183**	0.4177**	0.3618	0.2486**	299.3495**	167.3898**	95.2842**	0.0004	5.4910**	11.0425**	0.0026**
Error	83	0.7885	5.3832	0.2257	0.3487	0.0504	116.2613	82.5791	18.6559	0.0005	2.0428	5.2239	0.0006
Total	167	9.6030	48.7843	0.4580	0.4006	0.4071	379.3755	203.8589	100.8485	0.0157	6.7694	14.1508	0.0030

*Significant at $p<0.05$; **Significant at $p<0.01$ level of probability

aerobic condition, out of 136 hybrids, only 6 hybrids expressed significant positive standard heterosis over the standard check CORH 3 (Rajkumar and Ibrahim 2013) while negative heterobeltiosis under water stressed condition was reported by Ashfaq et al. (2013). Significant positive standard heterosis for this triat under both rainfed and dry condition was reported by Muthuramu et al. (2010).

The crosses for the trait panicle length showed significant heterosis of both positive and negative nature. Out of the 64 crosses, 30 crosses exhibited significant positive average heterosis and 8 crosses showed significant positive hetrobeltiosis. With regard to standard heterosis, none of the crosses depicted significant positive standard heterosis over KRH2 while most of the crosses exhibited significant positive heterosis over PA6444. Similar results by Muthuramu et al. (2010) reported significant positive standard heterosis over MDU 5 for panicle length under rainfed condition. Hussain and Sanghera, (2012) reported significant standard heterosis over the checks SR-1 and Jhelum for most of the cross combinations under temperate conditions. Significant positive heterosis over CORH 3 under aerobic condition was reported by Rajkumar and Ibrahim (2013).

Significant heterosis of both positive and negative nature were observed in the studied crosses for the trait filled grains panicle^{-1} under rainfed stress. The highest magnitude of significant positive relative heterosis of 33.33% was depicted by the cross IR 68897A×IR 78908-193-B-3-B. The same cross also showed the highest significant and positive standard heterosis of 32.54% and 53.42% over the hybrid check KRH 2 and PA 6444, respectively. Among the 64 F_1 crosses, 11 hybrids exhibited significant positive relative heterosis while none of the hybrids depicted significant positive heterobeltiosis. Two hybrids expressed significant positive standard heterosis over KRH2 and 19 hybrids exhibited significant positive standard heterosis over the check PA 6444. One hybrid viz., IR 68897A×IR 80461-B-7-1 exhibited significant positive average heterosis and standard heterosis over both the hybrid checks. Significant positive standard heterosis under both rainfed and dry condition was also reported by Muthuramu et al. (2010) while no significant positive standard heterosis was observed by Hussain and Sanghera (2012) for this trait under temperate environment.

For the trait number of spikelets panicle^{-1}, none of the crosses exhibited significant positive average heterosis, heterobeltiosis and standard heterois over the checks KRH2 and PA 6444. Negative heterobeltiosis for seeds per panicle under water stress condition was also reported by Ashfaq et al. (2013) while standard heterosis of both positive and negative nature under temperate conditions was reported by Hussain and Sanghera (2012).

For spikelet fertility percent, the highest positive and significant relative heterosis and heterobeltiosis of 42.37% and 41.40% was exhibited by the cross IR 58025A×IR 83376-B-B-91-3 and IR 68897A×IR 79906-B-5-3-3, respectively. The highest, significant and positive standard heterosis of 45.50% and 58.62% over the hybrid checks KRH 2 and PA 6444, respectively was exhibited by the cross IR 79156A×IR 77298-5-6-18. Out of the 64 crosses, 23 crosses depicted significant positive relative heterosis, 8 crosses expressed significant positive heterobeltiosis while 21 crosses depicted significant positive standard heterosis over KRH2 and 29 crosses exhibited significant positive standard heterosis over the check PA 6444. Seven hybrids recorded significant positive average heterosis, heterobeltiosis and standard heterosis over both the hybrid checks under moisture limited rainfed condition. Muthuramu et al. 2010[13] reported similar result of positive and significant standard heterosis for the cross NPT 107 / MDU 5 under both rainfed and dry conditions. The importance of this trait under

Table 2: Range of heterosis, heterobeltiosis and standard heterosis over KRH 2 and PA 6444 observed for 12 characters in rice under water limited rainfed condition

Sl. No.	Characters	Range of average heterosis (%)	Range of hetero-beltiosis (%)	Range of standard heterosis (%) over	
				KRH 2	PA 6444
1.	Days to 50% flowering	-7.81** to 3.83**	-12.81** to -2.03*	-12.38** to -2.48**	-14.90** to -5.29**
2.	Plant height (cm)	-3.22 to 14.90**	-18.85** to 3.23	-20.13** to 1.46	-13.69** to 9.63**
3.	Total tillers plant^{-1}	-26.63** to 35.64**	-37.44** to 35.51**	-30.78** to 17.36*	-28.11** to 21.89**
4.	Panicles plant^{-1}	-25.23** to 26.54**	-26.31* to 22.94	-22.45* to 17.58	-24.16* to 18.01
5.	Panicle length	-2.80** to 8.55**	-5.36** to 7.34**	-9.35** to 1.74	-0.26 to 11.93**
6.	Filled grains panicle^{-1}	-53.27** to 33.33**	-59.56** to 22.84	-59.76** to 32.54*	-53.42** to 53.42**
7.	Spikelets panicle^{-1}	-24.28** to 8.25	-25.84** to 6.86	-27.82** to 1.38	-23.17** to 7.92
8.	Spikelet fertility %	-48.12** to 42.37**	-55.27** to 41.40**	-53.36** to 45.50**	-49.16** to 58.62**
9.	Hundred seed weight	6.05** to 21.10**	-6.93** to 2.27*	-4.02** to 0.67	-6.93** to -2.38*
10.	Grain yield plant^{-1}	-58.78** to 54.13**	-65.57** to 38.11*	-64.52** to 52.58**	-62.71** to 60.34**
11.	Biomass plant^{-1}	-36.00** to 26.73**	-44.93** to 14.55	-38.93** to 22.59*	-39.58** to 26.00**
12.	Harvest index	-35.66** to 23.44**	-37.84** to 21.60**	-40.00** to 25.33**	-39.19** to 27.03**

*,**Significant at 5% and 1% level of probability, repestively

Table 3: Number of crosses showing significant heterosis, heterobeltiosis and standard heterosis over KRH 2 and PA 6444 for 12 characters in rice under water limited rainfed condition

Sl. No.	Characters	Number of cross combination with significant average heterosis (%)		Number of cross combination with significant heterobeltiosis (%)		Number of cross combination showing significant standard heterosis (%) over check hybrids			
						KRH 2		PA 6444	
		positive nature	negative nature	positive nature	negative nature	positive nature	negative nature	positive nature	negative nature
1.	Days to 50% flowering	9	19	0	55	0	64	0	64
2.	Plant height (cm)	35	0	0	48	0	54	6	20
3.	Total tillers plant^{-1}	19	4	10	9	2	2	4	1
4.	Panicles plant^{-1}	3	2	0	3	0	3	0	2
5.	Panicle length	30	2	8	17	0	58	46	0
6.	Filled grains panicle^{-1}	11	12	0	22	2	10	19	7
7.	Spikelets panicle^{-1}	0	27	0	31	0	37	0	22
8.	Spikelet fertility %	23	11	8	19	21	10	29	7
9.	Hundred seed weight	64	0	1	47	0	18	0	64
10.	Grain yield plant^{-1}	17	9	4	14	16	10	17	9
11.	Biomass plant^{-1}	10	8	0	16	1	10	3	8
12.	Harvest index	23	12	10	16	19	10	21	10

water deficit condition has been suggested in earlier studies (Garrity and O' Toole, 1994).

The crosses exhibiting highest significant and positive average heterosis and heterobeltiosis of 21.10% and 2.27% for hundred seed weight were IR 68902A×IR 80461-B-7-1 and IR 58025A×IR 77298-5-6-18, respectively. All the studied crosses showed significant positive average heterosis, and only one cross viz., IR 58025A×IR 77298-5-6-18 depicted significant positive heterobeltiosis while none of the crosses exhibited significant positive standard heterois over the checks KRH2 and PA 6444. Contrary to this finding, significant positive standard heterosis over MDU 5 was reported by Muthuramu et al. (2010) for the cross NPT 107 / MDU 5 under both rainfed and completely moisture stress conditions.

For the trait grain yield plant^{-1}, significant heterosis of both positive and negative nature were observed among the studied crosses. The cross IR 68897A×IR 80461-B-7-1 (54.13%) depicted the highest significant positive average heterosis. The cross IR 68897A×IR 79906-B-5-3-3 (38.11%) exhibited the highest significant positive heterobeltiosis. The cross IR 79156A×IR 77298-5-6-18 showed the highest significant positive standard heterosis of 52.58% and 60.34% over the hybrid checks KRH 2 and PA 6444, respectively. Out of the 64 crosses, 17 crosses exhibited significant positive average heterosis, 4 crosses depicted significant positive heterobeltiosis while 16 crosses over the check hybrid KRH2 and 17 crosses over the check hybrid PA 6444 exhibited significant positive standard heterosis. Four cross combinations viz., IR 68897A×IR 79906-B-5-3-3, IR 68897A×IR 80461-B-7-1, IR 68897A×IR 83376-B-B-91-3 and IR 79156A×IR 77298-5-6-18 showed significant positive average heterosis, heterobeltiosis and standard heterois over both the hybrid checks. The heterosis in both positive and negative direction were also reported by Amudha and Thiyagarajan (2008), Malarvizhi et al. (2009), Selvaraj et al. (2010) and Muthuramu et al. (2010).

For the trait biomass plant^{-1}, out of the 64 crosses, 10 cross combinations exhibited significant positive average heterosis while none of the crosses exhibited significant positive heterobeltiosis. With regard to standard heterosis, only one cross (IR 79156A×IR 77298-5-6-18) over the check hybrid KRH2 and 3 crosses over the check hybrid PA6444 exhibited significant positive standard heterosis. The cross IR 79156A×IR 77298-5-6-18 showed significant mid parent heterosis and standard heterosis over both the hybrids checks. Significant standard heterois for biological yield under temperate conditions was also reported by Hussain and Sanghera (2012).

The F_1 crosses for the trait harvest index under water limited rainfed condition showed significant heterosis in both positive and negative direction. The cross combination IR 68897A×IR 80461-B-7-1 (23.44%) and IR 68897A×IR 79906-B-5-3-3 (21.60%) exhibited highest significant and positive average heterosis and heterobeltiosis, respectively. The highest significant and positive standard heterosis of 25.33% and 27.03% over the hybrid checks KRH 2 and PA 6444, respectively was showed by the cross IR 68897A×IR 83376-B-B-91-3. Out of the 64 crosses, 23 crosses exhibited significant positive average heterosis, 10 crosses depicted significant positive heterobeltiosis while19 crosses over the hybrid check KRH2 and 21 crosses over the hybrid check PA 6444 depicted significant positive standard heterosis. Among the 64 crosses, 9 cross combinations manifested significant and positive average heterosis, heterobeltiosis and standard heterosis over both the hybrid checks. Significant and positive standard heterois under temperate conditions was also reported by Hussain and Sanghera et al. (2012).

It is evident that varying magnitude of heterosis was observed for different traits under water limited rainfed condition. The F_1 crosses studied, showed earliness for days to 50% flowering. The highest significant relative heterosis was observed for grain yield plant^{-1} (54.13%) followed by spikelet fertility percent (42.37%), tillers plant^{-1} (35.64%), filled grains panicle^{-1} (33.33%), biomass plant^{-1} (26.73%) and panicles plant^{-1} (26.54%). For heterobeltiosis, spikelet fertility % showed highest significant heterosis (41.40%) followed by grain yield plant^{-1} (38.11%), tillers plant^{-1} (35.51%) and harvest index (21.60%). For standard heterosis, highest heterosis of 60.34% over hybrid check PA 6444 was observed for grain yield plant^{-1} followed by spikelet fertility percent (58.62%), filled grains panicle^{-1} (53.42%), harvest index (27.03%), biomass plant^{-1} (26.00%) and tillers plant^{-1} (21.89%). However no significant heterobeltiosis and standard heterosis was observed for number of panicles plant^{-1} and number of spikelets panicle^{-1} under rainfed stress. The hybrids IR 68897A×IR 79906-B-5-3-3, IR 68897A×IR 80461-B-7-1, IR 68897A×IR 83376-B-B-91-3 and IR 79156A×IR 77298-5-6-18 exhibited significant positive heterosis over mid parent, better parent and two hybrid checks for grain yield plant^{-1}. The cross IR 68897A×IR 79906-B-5-3-3 also showed significant and desirable heterosis over mid parent, better parent and two hybrid checks for earliness, tillers per plant, spikelet fertility % and harvest index. Over both the hybrid checks KRH2 and PA 6444, cross IR 58025A×IR 83376-B-B-91-3 showed positive and significant heterosis for spikelet fertility %, grain yield plant^{-1} and harvest index. These crosses can be further tested at multi-locations under rainfed lowland environment for their stability across sites.

4. Conclusion

The high magnitude of heterosis observed for grain yield plant^{-1} under moisture limited rainfed condition is worth exploitable for development of superior lines or

hybrids for water limited regions. Superior cross combinations can also be utilized in hybrid breeding program to generate variability by utilizing transgressive segregants. The results suggest that hybrid vigour in rice can be exploited for development of heterotic hybrids for water limited rainfed regions.

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