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Exploitation of Heterosis in Rice for Yield Improvement and Salt Tolerance in India.

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ABSTRACT

Heterosis breeding and recombination breeding have been well utilized to enhance crop productivity over years, especially in rice. With the discovery of a wild abortive cytoplasmic male sterile line, three line hybrids came into being in China. Though the hybrids were successful they had drawbacks in maintenance and seed production. The chance discovery of a photoperiod-sensitive genic male sterile genotype led to the development of two line hybrids with much success. With the world facing yield decline from fields subjected to biotic and abiotic stresses it becomes necessary to breed high yielding hybrids suitable to overcome them. Attempts made by plant breeders in India to improve yield and salt tolerance in rice have been reviewed in the article.

Keywords: Rice, heterosis, salt, yield, hybrid

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INTRODUCTION

Heterosis may be defined as the increased vigour or decreased vigour of F_1 population over the mid parent (relative heterosis), better parent (heterobeltiosis) or a standard parent (standard heterosis) with respect to any character in the direction of breeders desire [1]. The phenomenon of heterosis in rice was first reported by Jones (1926) followed by Ramiah (1933) and subsequently by many other workers [2,3]. Shull (1948) explained heterosis as the genetic expression of the beneficial effects of hybridization [4]. Yuan Longping of China is considered the father of hybrid rice and Chinese were the the pioneers in adopting hybrid rice. The identification of WA type cytoplasmic male sterility (CMS) in 1970 along with the maintainer and restorer lines led to the development of three-line hybrid rice system. Successful development and extensive adoption of hybrid rice technology in China prompted the development of hybrid rice breeding in India since 1980 [5]. For the past two decades study on heterosis in two line hybrids has also been undertaken in India.

Crop species show varied responses to salt leading to growth and yield reduction. Salt effects are due to the interactions among different morphological, physiological and biochemical processes [6]. Salinity is one of the major obstacles to increase production in rice growing areas worldwide. Rice is rated as an especially salt-sensitive crop [7]. Exploitation of heterosis for salt tolerance is limited and has a scope for improvement. To know the potential of hybrids, study on magnitude and direction of heterosis are very important. Considering the significance and the need for information on salt tolerance and stable heterotic hybrids in rice, a brief review is furnished below.

Heterosis in rice under saline/alkaline condition:

Hybrids have been developed in various plants including cereals, fibre yielding plants, fodder, vegetables etc. The increase in yield offered by hybrids attracts farmers and hence there is an expansion of area under hybrid rice cultivation from 1995 in India. Though hybrids in rice have been made popular in Asia the rate of acceptance of hybrid rice in India is slower. Research related to hybrids possessing stress tolerance is inadequate.

Hybrid rice cultivation in problem soils was first attempted in 1995 under sodic soils but with little success since tolerance of sodicity is a complex problem. Most of the genes responsible for sodicity tolerance complement each other in the early phase, but fail to complement each other in the last phase, that is, from flowering to maturity, when yield levels fall drastically [8]. In India, the area under problem soils is nearly 11 million ha, with about 0.42 million ha in Tamil Nadu [9]. The area under problem soils is on the rise.

Sajjad (1988) reported that heterosis was variable and inconsistent not only for plant attributes but also for crosses. He observed no heterosis for number of primary branches per panicle and panicle fertility percentage in saline environment. For plant height heterobeltiosis ranged from -13.80 to 12.40 and from -40.80 to 54.68 for productive tillers per plant. He observed a maximum heterosis of 7.8%, 44.2%, 19.7% and 154.4% for the traits ear length, filled grains per ear, 100 grain weight and single plant yield [10].

Paramasivan (1986) reported that among the 15 hybrid combinations tested involving saline resistant donors, IR 26 x Dasal showed significant positive heterosis, heterobeltiosis and standard heterosis for yield [11].

From a salt tolerance study performed by Sajjad and Awan (1989), it was observed that the F_1's showed heterosis over Basmati 370 for all the traits studied. True heterobeltiosis was observed only for the trait plant height [12].

Gregario and Senadhira (1993) confirmed that large heterotic effects gave a hope for the development of potential hybrid rice for salt affected lands [13].

Heterosis for yield components was evaluated in 35 hybrids under normal and saline environments by Rogbell (1995). The hybrids exhibited differential response over environments for various traits. The maximum heterosis for grain yield over better parent was 38.94 and 17.27 recorded by IR 64 x IR 54717-C10-94-3-2-3-2 under two normal environments. The same combination showed negative expression for heterosis under stress environment. The same combination also recorded high magnitude of heterosis for number of productive tillers per plant which was the primary yield contributing character [14].

Ali *et al.* (1998) have reported that TNRH 16 derived from moderately salt tolerant parents (IR 58025 A x C 20 R) recorded a grain yield of 5002 Kg/ha compared to the salt tolerant CO 43 at 4160 Kg/ha. The standard heterosis was 23% [15].

Eight parents and 16 hybrids of rice genotypes were evaluated under coastal salinity for heterosis for nine yield related traits by Thirumeni and Subramanian (2000). The hybrid SSRC 920761 x TRY 1 was found to be superior for productive tillers per plant, spikelet sterility, Na^+ : K^+ ratio and grain yield per plant and hence recommended for commercial exploitation. A maximum negative heterosis of -23.13 for earliness was exhibited by SSRC 92076 x TKM 9 indicating the possibility of developing early hybrids [16].

Lakshmi Narayanan (2000) reported that the hybrid combination IR 64 x CO 43 performed well under normal and saline conditions for the trait grain yield per plant based on per se, *sca* effects and standard heterosis. The hybrid showed a maximum standard heterosis of 44.39 % under normal condition and 55.49 and 52.35 % under saline environment of Karaikal and Trichy respectively [17].

Thirumeni *et al.* (2000) found SSRC 92058/TRY 1 and SSRC 92076/CO 43 to be promising under saline conditions for heterosis breeding [18].

Babu (2002) considered standard heterosis as a criterion for the selection of hybrids in his study on salt tolerant rice hybrids over saline environments. The study revealed that the hybrid TS 29 x BTS 24 was the best as it recorded high standard heterosis value than BTS 24 and CORH 2 in all environments and pooled condition for productive tillers per plant, leaf proline content, Na^+ : K^+ ratio besides single plant yield [19].

In a study undertaken at Central Soil Salinity Research Institute, significant heterosis over the mid-parent and better parent was observed for almost all the characters studied by Mishra *et al.* 2003. Out of the 15 F_1's, crosses Pokkali/IR 28 (79.87), CSR 10/IR 28 (67.18), CSR 13/IR 28 (54.58) and CSR 1/IR 28 (48.56) indicated a positive and significant heterotic response over the mid-parent and cross Pokkali/IR 28 (49.31) over the better parent in alkali soil, whereas CSR 13/ IR 28 (35.17) and CSR 10/CSR 13 (26.72) over the mid-parent and only one cross (CSR 10/CSR 13, 24.53) over the better parent in saline soil exhibited better heterotic effects [20].

A set of rice genotypes comprising of five thermo sensitive genic male sterile (TGMS) lines, eight salt tolerant testers and 40 hybrids obtained by crossing in line x tester design were evaluated for their genetic worth and salinity tolerance by Deepa Sankar *et al.* (2008). The parents and hybrids were raised and evaluated in three different environments including normal and salt affected environments. Twelve characters *viz.,* days to 50 per cent flowering, plant height, productive tillers per plant, panicle exsertion, panicle length, panicle weight, filled grains per panicle, spikelet fertility, 100 grain weight, Na^+ : K^+ ratio, harvest index and grain yield per plant were studied and the hybrids were assessed for heterosis and adaptation using CO 43 as the standard parent. The hybrid GD 98179/CSSRI 60 recorded the highest standard heterosis per cent for the trait grain yield per plant in all the environments followed by GD 98168/Vytilla 3, GD 98029/CSSRI 60, GD 98029/CSR 23 and GD 98028/ Nona Bokra. In salt affected environments the hybrids GD 98028/CSR 23 and GD 98021/CO 43 recorded high heterosis for both Na^+ : K^+ ratio and grain yield per plant. Hybrids GD 98028/CSR 23, GD 98028/CO 43 and GD 98021/CO 43 can be exploited for improving salt tolerance and yield by heterosis breeding [21].

Shanthi *et al.* (2011) have reported that the hybrids *viz.,* BPT 5204 x Pokkali, IR 36 x CSR 10, IR 64 x CSR 10, BPT 5204 x N 13, BPT 5204 x CT 9993, White Ponni x Moroberekan, TRY(R) 2 x CSR 10, CO 43 x Pokkali and CO 47 x Pokkali as the best yielding hybrids suitable for heterosis breeding in sodic soils [22].

Gopikannan and Ganesh (2013) have reported three hybrids *viz.*, IR 20/FL 478, IR 20/CSR 23 and ADT 49/TRY(R) 2 as suitable for heterosis breeding under sodicity [23].

Heterosis in two line rice hybrids:

Real attempts in heterosis exploration in rice by developing rice hybrids were initiated only in 1966 by Yuan Longping in China. Even though tremendous gains in heterosis breeding have been achieved in China and other countries during the last two decades, it was felt that the maximum yield potential of hybrid rice was not been fully studied and exploited. The problems associated with the classical three line system on maintenance of sterile lines, low heterotic potential and high seed production costs may be overcome by two-line system of hybrid rice breeding. Two-line hybrid rice was successfully commercialized in 1995 with a yield advantage of 5-10 per cent than that of existing three line hybrid rice [24].

Two line breeding emerged following the chance discovery of a photoperiod-sensitive genic male sterile genotype Nongken 58 by Prof. Shi Ming Song of China [25] which was found to be sterile under longer photoperiods (>14 hr) and fertile under shorter photoperiods (<13 hr) subsequently. TGMS lines were identified by Chinese and Japanese scientists. They are sterile under high temperature (>32^0c) but under low temperature (< 24^0c) they are fertile [26, 27].

TGMS can combine with other cultivars without the need for specific restorers [28] and hence can be utilized for developing high yielding saline tolerant hybrids. With the availability of many types of TGMS lines and no restriction of restorer it is relatively easier to develop desirable new two-line hybrids than three line rice hybrids [29].

Shukla and Pandey (2008) studied 30 elite indica TGMS lines and four cultivars, *viz.*, Pant Dhan 4 (indica), Ajaya (indica), Taichung 65 (japonica), and IR 65598-112-2 (tropical japonica) and the 120 hybrids obtained in line x tester mating design. The heterosis for grain yield has been reported as 49.3%, 71.9% and 92.7% for indica/indica, indica/japonica and indica/tropical japonica hybrid groups respectively. The study explored the possibility of development of TGMS based hybrids for exploitation of intersubspecific heterosis [30].

Chandirakala and Thiyagarajan (2010) estimated heterosis with checks (CORH 2 and ADTRH 1) in 88 crosses made from four TGMS lines and 22 testers. They concluded that the hybrids, GD 98029 x IR 61608-213, GD 9804 x IR 61608-213 and GD 98014 x RR 166-645 could be exploited for earliness as they exhibited negative and significant standard heterosis for days to 50 per cent flowering. GD 98049 x IR 63875-196-2-2-1-3, GD 98014 x TKM11, GD 98049 x TKM 11, GD 99017 x TKM 12 were reported to be the high yielders. It was found by them that most of the high yielding hybrids showed significant positive heterosis for yield contributing characters *viz*., more number of productive tillers per plant, long panicles, more number of filled grains per panicle, spikelet fertility and 1000 grain weight [31].

Four TGMS lines *viz.,* TS09 12, TS09 22, TS09 28 and TS09 410, thirteen testers and the hybrids obtained by crossing them in line x tester fashion were studied by Dhivyapriya and Kalaiyarasi (2014) using Improved white ponni and CORH 3 as checks. Based on the specific combining ability effects and heterosis, TS09 22 X T1408.10, TS09 28 X CO 43, TS09 12 X CO 43, TS09 22 X WGL 14 and TS09 22 X CO(R) 50 were identified as potential hybrids [32].

A study was performed involving three newly developed TGMS lines (TNAU60S, TNAU18S and TS-29-150GY) for their floral traits, seed production potential and outcrossing ability in ten cross combinations by Arasakesary *et al.* (2015). TNAU18S/IET21508 (36 g/plant), TNAU18S/IET21044 (13 g/plant), TNAU18S/IET21009 (26.5 g/plant), TNAU60S/CB-09-106 (26.2 g/plant), TNAU60S/IET21009 (14 g/plant) and TS29-150-GY/DRR 3306 (39.2 g/plant) showed perfect synchronization with acceptable hybrid seed yield, indicating suitability of TGMS system under Indian condition [33].

The magnitude of relative heterosis, standard heterosis and heterobeltiosis studied by researchers has been presented in Table 1.

Table 1: Magnitude of heterosis observed in two line rice hybrids

Reported by	Relative heterosis	Heterobeltiosis	Standard heterosis
Days to 50 per cent flowering			
Aananthi (2000)	-16.91 to 10.27	-3.05 to 24.07	-8.43 to7.28 [34]
Bini Philip (2001)	-11.50 to 16.77	-13.71 to 19.62	-7.98 to 15.95 [35]
Babu (2002)	-25.70 to 9.20	-21.50 to 22.70	-31.00 to 27.00 [19]
Gnanasekaran (2003)	-	-	-10.04 to 4.46 [36]
Patil *et al*. (2003)	-4.68 to 36.41	max. -20.65	max. -30.34 [37]
Deepa Sankar (2005)	-	-	max. -34.19 [38]
Chandirakala and Thiyagarajan (2010)	-	-	max. -11.90 [31]
Plant height			
Hussain (1996)	-15.52 to1.65	-26.82 to -4.62	-45.79 to -26.12 [39]
Elsy (1997)	-29.70 to 26.24	-40.50 to 23.95	-21.74 to 31.81 [40]
Aananthi (2000)	-23.13 to 5.25	-4.54 to 8.47	-21.66 to -4.47 [34]
Bini Philip (2001)	-6.00 to15.09	-2.74 to 22.07	1.07 to 27.60 [35]
Babu (2002)	-26.30 to 15.2	-23.00 to 52.60	-23.60 to 25.30 [19]
Gnanasekaran (2003)	-	-	-9.60 to 51.75 [36]
Deepa Sankar (2005)	-	-	max. -28.28 [38]
Chandirakala and Thiyagarajan (2010)	-	-	max. -16.32 [31]
Productive tillers per plant			
Hussain (1996)	-26.71 to 35.81	-33.52 to 28.45	-31.02 to 31.02 [39]
Elsy (1997)	-29.60 to 144.51	-40.74 to 195.88	-53.71 to 31.14 [40]
Aananthi (2000)	-45.28 to 25.54	-57.05 to 13.78	-48.97 to 4.40 [34]
Bini Philip (2001)	-15.69 to 50.37	-23.03 to 23.03	-41.20 to -1.39 [35]
Babu (2002)	-17.00 to 68.70	-32.00 to 68.70	-29.20 to 20.80 [19]
Gnanasekaran (2003)	-	-	29.68 to 96.77 [36]
Patil *et al*. (2003)	-46.57 to 74.69	max. 48.11	max. 29.95 [37]
Deepa Sankar (2005)	-	-	max. 55.17 [38]
Chandirakala and Thiyagarajan (2010)	-	-	max. 33.22 [31]
Panicle length			
Hussain (1996)	-3.52 to 35.54	-11.88 to 21.51	-8.26 to 21.85 [39]
Elsy (1997)	-21.93 to 40.72	-33.21 to 37.53	-20.80 to 27.56 [40]
Aananthi (2000)	-10.57 to 22.86	-15.60 to 10.67	-17.76 to 22.42 [34]
Bini Philip (2001)	-10.69 to 19.14	-17.69 to 18.86	-1.67 to 35.13 [35]
Babu (2002)	-21.80 to 31.60	-28.60 to 20.10	-28.60 to 11.80 [19]
Gnanasekaran (2003)	-	-	9.84 to 28.14 [36]
Patil *et al.* (2003)	max. 29.31	max. 17.06	max. 45.72 [37]
Deepa Sankar (2005)	-	-	max. 37.28 [38]
Chandirakala and Thiyagarajan (2010)	-	-	max. 30.09 [31]
Spikelet fertility			
Hussain (1996)	-12.06 to 14.07	13.68 to 10.35	-14.85 to 13.31 [39]
Elsy (1997)	-100.00 to 107.54	-100.00 to 3.64	-100.00 to 19.43 [40]
Reddy *et al.* (1998)	-	-	3.6 to 96.00 [41]
Aananthi (2000)	0.58 to 21.67	-14.51 to 0.33	-18.70 to 3.31 [34]
Bini Philip (2001)	-3.35 to 29.26	-12.52 to 11.23	-18.42 to 5.25 [35]
Babu (2002)	-82.60 to 13.60	-82.90 to 13.10	-82.70 to 15.70 [19]
Gnanasekaran (2003)	-	-	-27.65 to 9.28 [36]
Deepa Sankar (2005)	-	-	max. 6.54 [38]
Chandirakala and Thiyagarajan (2010)	-	-	max. 52.77 [31]
Filled grains per panicle			
Hussain (1996)	-22.57 to 39.46	-30.56 to 4.66	-40.49 to -6.71 [39]
Elsy (1997)	-60.04 to 109.72	-62.41 to 104.53	-43.57 to 127.21 [40]
Aananthi (2000)	5.06 to 41.14	-3.01 to 15.68	-34.35 to 17.74 [34]
Bini Philip (2001)	-20.00 to 81.75	-32.08 to 64.90	18.69 to 142.93 [35]

Babu (2002)	-70.80 to 42.00	-75.40 to 21.60	-77.70 to 60.40 [19]
Gnanasekaran (2003)	-	-	0.99 to 119.48 [36]
Patil *et al.* (2003)	-38.98 to 29.87	Max. 50.63	- [37]
Deepa Sankar (2005)	-	-	max. 15.95 [38]
Chandirakala and Thiyagarajan (2010)	-	-	max. 125.55 [31]
100 grain weight			
Hussain (1996)	-7.68 to 66.36	-23.60 to 54.33	-30.28 to 49.83 [39]
Aananthi (2000)	-3.38 to 24.79	-10.76 to 21.54	-38.95 to -11.42 [34]
Bini Philip (2001)	-17.15 to 8.31	-18.99 to 3.28	-17.88 to 9.58 [35]
Babu (2002)	-23.70 to 27.50	-35.20 to 21.70	-8.70 to 54.30 [19]
Gnanasekaran (2003)	-	-	-29.87 to 9.96 [36]
Deepa Sankar (2005)	-	-	max. 24.86 [38]
Chandirakala and Thiyagarajan (2010)	-	-	max. 53.50 [31]
Single plant yield			
Hussain (1996)	-35.46 to 20.51	-49.93 to 8.66	-35.90 to 31.44 [39]
Elsy (1997)	-100.00 to 76.59	-100.00 to 8.13	-100.00 to 17.88 [40]
Reddy *et al.* (1998)	-	-	max. 58.00 [41]
Thiyagarajan *et al.* (1998)	-	-	max. 41.36 [42]
Aananthi (2000)	-23.58 to 50.86	-37.20 to 39.41	-42.31 to 51.65 [34]
Bini Philip (2001)	0.20 to 84.14	-7.67 to 57.44	-16.77 to 53.52 [35]
Babu (2002)	-44.00 to 94.20	-49.70 to 89.90	-60.00 to 36.80 [19]
Gnanasekaran (2003)	-	-	5.86 to 89.79 [36]
Patil *et al.* (2003)	-72.08 to 52.30	max.59.59	max. 49.66 [37]
Deepa Sankar (2005)	-	-	max. 30.52 [38]
Chandirakala and Thiyagarajan (2010)	-	-	max. 75.65 [31]
Panicle exsertion			
Bini Philip (2001)	0.00 to 36.17	-5.21 to 0.00	-5.21 to 0.00 [35]
Gnanasekaran (2003)	-	-	-85.07 to 70.13 [36]
Deepa Sankar (2005)	-	-	max. 11.40 % [38]
Harvest Index			
Aananthi (2000)	-17.65 to 43.82	-19.23 to 42.22	-16.32 to 30.61 [34]
Bini Philip (2001)	-8.84 to 24.84	-12.20 to 20.51	-15.38 to 25.64 [35]
Gnanasekaran (2003)	-	-	-13.47 to 60.00 [36]
Deepa Sankar (2005)	-	-	max. 41.45 [38]
Chandirakala and Thiyagarajan (2010)	-	-	max. 20.00 [31]

CONCLUSION

Hybrid vigor in plants has been exploited by breeders to feed the growing world population. Both positive and negative heterosis for various traits in rice has been utilized in designing new genotypes. Seventy eight rice hybrids have been released in India according to the Directorate of Rice Development India. The hybrids available for cultivation include KRH 2, Pusa RH 10, DRRH 2, Rajlaxmi, Sahyadri 4, DRRH 3, CRHR 32, PSD 3, Ajay, CoRH 3, Indira Sona, JRH 8, PHB 71, PA 6129, PA 6201, PA 6444, JKRH 401, Suruchi, GK 5003, DRH 775, HRI-157, PAC 835, PAC 837, US 312, Indam 200-017, NK 5251, 27P11 according to the Directorate of Rice Research, India. Salinity is one among the major stress problems faced due to climatic changes and over utilisation of cultivable land. But humans cannot afford yield decline in crop plants and hence need to innovate to overcome biotic and abiotic stresses. Heterosis breeding has been proven to be the reason for increasing productivity in many crops but there is still more scope for exploiting heterosis.

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