Madras Agric. J., **2018**, *105 (7-9)(2)*: 442-450; doi: 10.29321/MAJ.2018.000180

Heterosis for Yield, Yield components and Sodicity Tolerance Characters in Rice (*Oryza sativa* L.)

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The present study was conducted to estimate relative heterosis, heterobeltiosis and standard heterosis of cross components in rice genotypes under sodicity. All three types of heterosis were worked out through diallel analysis of 30 hybrids developed by crossing six parents to know the genetic architecture of 14 physio-morphological traits *viz.,* days to 50 percent flowering, plant height, number of productive tillers per plant, panicle length, number of filled grains per panicle, spikelet fertility percentage, 100 grain weight, single plant yield, dry root weight, dry shoot weight, root: shoot ratio, Na^+: K^+ ratio, chlorophyll content and proline content under sodic environment. On perusal of data for hybrids based on *per se*, *sca* effects and standard heterosis, five hybrids *viz*., FL 478 / IW Ponni, IW Ponni / IR 64, IW Ponni / BPT 5204, BPT 5204 / FL 478, IW Ponni / FL 478 were found to be suitable for heterosis breeding under sodicity. As there was dominance gene action involved, *inter se* mating followed by recombination breeding might be advocated for improvement of yield, its components and physiological traits under sodicity.

Key words: Rice, Sodicity, Diallele, Relative heterosis, Heterobeltiosis, Standard heterosis.

India is capable of producing 134.5 MT of rice over an area of 44.50 m ha with productivity of 3.01 t ha^{-1} against 6.23 t ha^{-1} of China (Maclean *et al*., 2002). This difference in productivity is due to the slow development of new exploitable hybrids for various abiotic stresses. About 6.5 % (831 million ha) of the world's total area (12.78 billion ha) is affected by salt stress (Kinfemichael and Melkamu, 2008). In India, salinity is the second most important abiotic stress. The salt affected area is 8.90 million ha area out of which 3.40 million ha under sodicity and rest under salinity. Area under salt stress is on the increase due to many factors including climate change, rise in sea levels, excessive irrigation without proper drainage in inlands, underlying rocks rich in harmful salts etc. Vast areas of land are not utilized due to salinity and alkalinity problems. Rice is a salt sensitive crop (Shannon *et al*., 1998).

Breeding rice varieties with in-built salt tolerance is realized as the most promising, less resource consuming, economically viable and socially acceptable approach. The importance of developing varieties tolerant to sodicity with increased yield is needed. To frame a yield improvement programme in rice, information about *per se*, standard heterosis of parents and hybrids and the magnitude of gene action involved in the inheritance of quantitative traits are very much essential. This prompted the present investigation to estimate the gene action regulating the complex mechanisms involved in rice genotypes under sodicity.

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Material and Methods

The present investigation was carried out at the Research farm of Department of Plant Breeding and Genetics, Anbil Dharmalingam Agricultural College and Research Institute, Trichy, where the soil is found to be sodic in nature with a pH of 9.5 and ESP of 23. The water used for irrigating the experimental field was taken from the bore well with pH ≥ 9.0 and Relative Sodium Content (RSC) is 10 meq/l. The experimental materials consisted of two high yielding, two sheath blight resistant, one fine grain and one sodicity tolerant parental genotypes *viz.,* BPT 5204, IR 64, RNR 57979, TETEP, IW Ponni and FL 478 respectively to produce 30 hybrids through full diallel mating design (Griffings, 1958). The experiment was laid out in randomized bock design with three replications adopting a recommended spacing of 20x15 cm in field during 2013 to 2014. Recommended package of practices were followed to establish the crop. Five plants were selected at random from each entry in each replication to record data on 14 physio-morphological traits *viz*., days to 50 per cent flowering, plant height, number of productive tillers per plant, panicle length, number of filled grains per panicle, spikelet fertility percentage, 100 grain weight, single plant yield, dry root weight, dry shoot weight, root:shoot ratio, Na^+: K^+ ratio, chlorophyll content and proline content. The biometrical observations were recorded for yield and its component traits under sodicity as per the Standard Evaluation System for rice (SES, 1996). The mean data were subjected to ANOVA and to estimate relative heterosis, heterobeltiosis and standard heterosis.

Estimation of heterosis

Heterosis was estimated as per cent deviation of F_1 performance from its parental or check performance. The mean values were used to estimate heterosis per cent under three categories (Fonseca and Patterson, 1968).

Heterosis over mid parental value (Relative heterosis)

Relative heterosis was estimated as per cent deviation of F_1 mean performance over mean performance of the mid parent.

$$\text{Relative heterosis (di)} = \frac{F_1 - MPV}{MPV} \times 100$$

where,

F_1 - Mean Performance of hybrids

MPV - Mean mid parental value *i.e.*, $P_1 + P_2$ 2

P_1, P_2 -Mean value of the first and the second parent respectively.

Heterosis over better parent (Heterobeltiosis)

Heterobeltiosis was estimated as per cent deviation of F_1 mean performance over mean performance of the better parent.

$$\text{Heterobeltiosis (dii)} = \frac{F_1 - BPV}{BPV} \times 100$$

where,

BPV - Mean of better parental value

Heterosis over the standard variety (Standard heterosis)

Standard heterosis was estimated as per cent deviation of F_1 mean performance over mean performance of the standard parent.

$$\text{Standard heterosis (diii)} = \frac{F_1 - SPV}{SPV} \times 100$$

where,

SPV - Mean value of standard parent

The significance for three type of heterosis is tested by the following formulae as suggested by Turner (1953):

$$t' \text{ for relative heterosis} = \frac{\overline{F_1} - \overline{MPV}}{\sqrt{\sigma^2 e / r \times 2}} \times 100$$

$$t' \text{ for heterobeltiosis} = \frac{\overline{F_1} - \overline{BPV}}{\sqrt{\sigma^2 e / r \times 2}} \times 100$$

$$t' \text{ for standard heterosis} = \frac{\overline{F_1} - \overline{SPV}}{\sqrt{\sigma^2 e / r \times 2}} \times 100$$

where, $\sigma^2 e$ = Error Variance (EMS),

r = Number of replications.

Results and Discussion

The manifestation of heterosis over mid parent, better parent and standard parent were estimated for 14 traits and are presented in Tables 1, 2 and 3. The parent FL 478 was considered as the standard parent for all traits taken in the present study. For days to 50 per cent flowering, the standard heterosis for the hybrids ranged from - 6.83 (P_4 / P_3) to 5.39 (P_6 / P_2). Twenty three hybrids *viz.,* P_1 / P_2 (-4.25), P_1 / P_3 (-6.07), P_1 / P_4 (-3.41), P_1 / P_5 (-6.07), P_1 / P_6 (-5.84), P_2 / P_1 (-4.40), P_2 / P_3 (-3.79), P_2 / P_4 (-5.46), P_2 / P_5 (-4.48), P_3 / P_1(-6.45), P_3 / P_2 (-4.78), P_3 / P_4 (-4.86), P_3 / P_5 (-6.37), P_4 / P_1 (-5.46), P_4 / P_2 (-3.64), P_4 / P_3 (-6.83), P_4 / P_5 (-5.08), P_5 / P_1 (-6.15), P_5 / P_2 (-2.28), P_5 / P_3 (-5.46), P_5 / P_4 (-5.46), P_6 / P_3 (-3.79) and P_6 / P_4 (-2.81) had significant negative values over the standard parent for the trait. For plant height, the standard heterosis ranged from - 41.18 (P_5 / P_2) to 30.38 (P_1 / P_2). Out of 30 hybrids, 29 hybrids showed negative standard heterosis for plant height. Only one hybrid P_1 / P_2 (30.38) recorded positive standard heterosis for plant height. For number of productive tillers per plant, the standard heterotic expression had ranged from -6.67 per cent P_2 / P_3 to 11.21 per cent in P_2 / P_4. Only one hybrid P_2 / P_4 (11.21) expressed significant positive standard heterotic values.

For panicle length, significant negative standard heterosis was observed in all 30 hybrids. For number of filled grains per panicle, the standard heterotic expression ranged from -37.11 (P_3 / P_2) to 5.43 (P_1 / P_6). Only one hybrid P_1 / P_6 (5.43) expressed significant positive standard heterosis. Other 29 hybrids registered negative significant values for this trait. For spikelet fertility percentage, the lowest standard heterosis of -34.27 per cent in P5 / P6 was registered. Nineteen hybrids *viz*., P_1 / P_2 (-6.91), P_1 / P_6 (-28.15), P_2 / P_3 (-7.17), P_2 / P_5 (-7.60), P_2 / P_6 (-31.03), P_3 / P_1 (-7.52), P_3 / P_5 (-11.80), P_3 / P_6 (-16.85), P_4 / P_1 (-6.47), P_4 / P_2 (-6.64), P_4 / P_3 (-10.14), P_4 / P_6 (-29.11), P_5 / P_2 (-9.44), P_5 / P_6 (-34.27), P_6 / P_1 (-27.62), P_6 / P_2 (-28.32), P_6 / P_3 (-23.60), P_6 / P_4 (-22.03) and P_6 / P_5 (-23.34) registered significant negative standard heterosis for this trait. For 100 grain weight, standard heterosis ranged between -13.49 (P_5 / P_2) to 7.28 (P_3 / P_1) per cent. Four hybrids *viz.,* P_1 / P_2 (5.57), P_2 / P_4 (5.14), P_3 / P_1 (7.28) and P_4 / P_1 (5.35) expressed positive significant heterosis for 100 grain weight over the standard parent. Eleven hybrids registered negative significant standard heterosis for this trait.

For single plant yield, the standard heterosis was minimum in P_3 / P_6 with a deviation of -53.53 and maximum of 43.96 per cent in P2 / P3. Three hybrids *viz.,* P_2 / P_3 (43.96), P_3 / P_1 (20.62) and P_5 / P_3 (26.42) expressed positive and significant heterosis over the standard parent. Four hybrid combinations viz., P1 / P_2 (4.25), P_2 / P_4 (15.12), P_4 / P_1 (1.59) and P_5 / P_2 (18.58) registered positive and non-significant standard heterotic values, while, 14 hybrids registered negative and significant standard heterosis for single plant yield (Table 1).

Table 1. Evaluation of hybrids based on per se performance, sca effects and standard heterosis

Trait	*per se* performance	*sca* effect	*per se* and *sca* effects	Standard heterosis	*per se, sca* and standard heterosis
Days to 50 per cent flowering	FL 478 / BPT 5204, FL 478 / RNR 57979, BPT 5204 / FL 478, BPT 5204 / RNR 57979, IR 64 / BPT 5204 and RNR 57979 / FL 478	FL 478 / TETEP, IW Ponni / IR 64, IR 64 / IW Ponni, RNR57979 / IW Ponni, TETEP / FL 478 and TETEP / IW Ponni	_	FL 478 / IW Ponni, FL 478 / BPT 5204, FL 478 / IR 64, FL 478 / RNR 57979, FL 478 / TETEP, IW Ponni / FL 478, IW Ponni / BPT 5204, IW Ponni / IR 64, IW Ponni / RNR 57979, BPT 5204 / FL 478, BPT 5204 / IW Ponni, BPT 5204 / IR 64, BPT 5204 / RNR 57979, IR 64 / FL 478, IR 64 / IW Ponni, IR 64 / BPT 5204, IR 64 / RNR 57979, RNR 57979 / FL 478, RNR 57979 / IW Ponni, RNR 57979 / BPT 5204, RNR 57979 / IR 64, TETEP / IW Ponni, TETEP / BPT 5204 and TETEP / IR 64	_
Plant height	FL 478 / IW Ponni, FL 478 / BPT 5204, FL 478 / IR 64, FL 478 / RNR 57979, IW Ponni / FL 478, IW Ponni / IR 64, IW Ponni / RNR 57979, BPT 5204/ FL 478, BPT 5204 / IW Ponni, BPT 5204/ IR 64, BPT 5204 / RNR 57979, IR 64 / FL 478, IR 64 / BPT 5204, IR 64 / RNR 57979, RNR 57979 / FL 478, RNR 57979 / IW Ponni, RNR 57979 / BPT 5204 and RNR 57979 / IR 64	FL 478 / IW Ponni, IW Ponni / BPT 5204, IW Ponni / RNR 57979, BPT 5204 / FL 478, IR 64 / IW Ponni, IR 64 / BPT 5204 and TETEP / IR 64	FL 478 / IW Ponni, IW Ponni / RNR 57979, BPT 5204 / FL 478 and IR 64 / BPT 5204	FL 478 / BPT 5204, FL 478 / IR 64, FL 478 / RNR 57979, FL 478 / TETEP, IW Ponni / FL 478, IW Ponni / BPT 5204, IW Ponni / IR 64, IW Ponni / RNR 57979, IW Ponni / TETEP, BPT 5204 / FL 478, BPT 5204 / IW Ponni, BPT 5204 / IR 64, BPT 5204 / RNR 57979, BPT 5204 / TETEP, IR 64 / FL 478, IR 64 / IW Ponni, IR 64 / BPT 5204, IR 64 / RNR 57979, IR 64 / TETEP, RNR 57979 / FL 478, RNR 57979 / IW Ponni, RNR 57979 / BPT 5204, RNR 57979 / IR 64, RNR 57979 / TETEP, TETEP / FL 478, TETEP / IW Ponni, TETEP / BPT 5204, TETEP / IR 64 and TETEP / RNR 57979	IW Ponni / RNR 57979, BPT 5204 / FL 478 and IR 64 / BPT 5204
Number of productive tillers per plant	IW Ponni / IR 64	FL 478 / RNR 57979, IW Ponni / IR 64 and IR 64 / IW Ponni	IW Ponni / IR 64	IW Ponni / IR 64	IW Ponni / IR 64
Panicle length	TETEP / RNR 57979	_	_	_	_
Number of filled grains per panicle	FL 478 / IW Ponni, FL 478 / TETEP, IW Ponni / FL 478, BPT 5204 / FL 478 and TETEP / RNR57979	FL 478 / IW Ponni, BPT 5204 / IW Ponni, BPT 5204 / IR 64, BPT 5204 / RNR 57979, RNR 57979 / TETEP, TETEP / FL 478 and TETEP / IW Ponni	FL 478 / IW Ponni	FL 478 / TETEP	_

Spikelet fertility	FL 478 / BPT 5204, FL 478 / IR 64, IW Ponni / FL 478, BPT 5204 / IW Ponni, BPT 5204 / IR 64, IR 64 / RNR 57979, RNR 57979 / FL 478, RNR 57979 / BPT 5204 and RNR 57979 / IR 64	BPT 5204 / TETEP and TETEP / BPT 5204	_	_	_
100 grain weight	FL 478 / IW Ponni, IW Ponni / I R 64, BPT 5204 / FL 478, BPT 5204 / IR 64, IR 64 / FL 478, IR 64 / IW Ponni, IR 64 / BPT 5204, IR 64 / RNR57979, IR 64 / TETEP, TETEP / FL 478, TETEP / IW Ponni, TETEP / BPT 5204, TETEP / IR 64 and TETEP / RNR 57979	FL 478 / IW Ponni, FL 478 / BPT 5204, IW Ponni / FL 478, IW Ponni / IR 64, BPT 5204 / IR 64, IR 64 / RNR 57979, RNR 57979 / FL 478, RNR 57979 / IR 64 and RNR 57979 / TETEP	FL 478 / IW Ponni, IW Ponni / IR 64, BPT5204 / IR 64 and IR 64 / RNR 57979	FL 478 / IW Ponni, IW Ponni / IR 64, BPT 5204 / FL 478 and IR 64 / FL 478	IW Ponni / IR 64
Single plant Yield	FL 478 / IW Ponni, IW Ponni / BPT 5204, IW Ponni / IR 64, BPT 5204 / FL 478, RNR 57979 / IW Ponni and RNR57979 / BPT5204	IW Ponni / FL 478, IW Ponni / BPT 5204, BPT 5204 / IW Ponni, IR 64 / IW Ponni, IR 64 / BPT 5204 and TETEP / IW Ponni	IW Ponni / BPT 5204	IW Ponni / BPT 5204, BPT 5204 / FL 478 and RNR 57979 / BPT 5204	IW Ponni / BPT 5204
Dry root weight	_	FL 478 / IR 64, FL 478 / RNR 57979, IR 64 / TETEP, TETEP / FL 478, TETEP / IW Ponni, TETEP / IR 64 and TETEP / RNR57979	_	_	_
Dry shoot weight	FL 478 / IW Ponni, FL 478 / BPT 5204, FL 478 / IR 64, FL 478 / RNR 57979, FL 478 / TETEP, IW Ponni / FL 478, IW Ponni / BPT 5204, IW Ponni / IR 64, IW Ponni / RNR 57979 and IW Ponni / TETEP	FL478 / IW Ponni, IW Ponni / FL 478, BPT 5204 / FL 478, BPT 5204 / IW Ponni, IR 64 / FL 478, IR 64 / IW Ponni, RNR 57979 / FL 478, RNR 57979 / IW Ponni, RNR 57979 / BPT 5204, RNR 57979 / IR 64, TETEP / FL 478, TETEP / IW Ponni and TETEP / IR 64	FL 478 / IW Ponni and IW Ponni / FL 478	_	_
Root :Shoot Ratio	BPT 5204 / FL 478, BPT 5204 / IW Ponni, BPT 5204 / IR 64, BPT 5204 / RNR57979, BPT 5204 / TETEP, RNR 57979 / FL 478, RNR 57979 / IW Ponni, RNR 57979 / BPT 5204, RNR 57979 / IR 64 and RNR 57979 / TETEP	IW Ponni / TETEP, BPT 5204 / IR 64, BPT 5204 / RNR 57979, IR 64 / BPT 5204, IR 64 / RNR 57979, RNR 57979 / TETEP and TETEP / RNR57979	BPT 5204 / IR 64, BPT 5204/ RNR 57979 and RNR 57979 / TETEP	BPT 5204 / FL 478, BPT 5204 / IW Ponni, BPT 5204 / IR 64, BPT 5204 / RNR 57979, RNR 57979 / FL 478, RNR 57979 / IW Ponni, RNR 57979 / BPT 5204, RNR 57979 / IR 64 and RNR 57979 / TETEP	BPT 5204 / IR 64, BPT 5204 / RNR 57979 and RNR 57979 / TETEP
Na^+:K Ratio	TETEP / FL 478, TETEP / IW Ponni, TETEP / BPT 5204, TETEP / IR 64 and TETEP / RNR57979	IW Ponni / TETEP, BPT 5204 / IW Ponni, IR 64 / FL 478 and IR 64 / IW Ponni	_	IW Ponni / BPT 5204, IW Ponni / IR 64, BPT 5204 / FL 478, TETEP / FL 478, TETEP / IW Ponni, TETEP / BPT 5204, TETEP / IR 64 and TETEP / RNR57979	_

Chlorophyll content	FL 478 / BPT 5204 and IR 64 / FL 478	FL 478 / BPT 5204, FL 478 / IR 64, BPT 5204 / FL 478, BPT 5204 / IW Ponni, IR 64 / BPT 5204, RNR 57979 / FL 478, RNR 57979 / TETEP and TETEP / BPT 5204	FL 478 / BPT 5204	_	_
Proline content	FL 478 / RNR 57979, IW Ponni / IR 64, RNR 57979 / BPT 5204, RNR 57979 / IR 64, TETEP / BPT 5204 and TETEP / RNR57979	FL 478 / RNR 57979, IW Ponni / FL 478, IW Ponni / IR 64, IR 64 / FL 478, IR 64 / IW Ponni and RNR 57979 / FL 478	FL 478 / RNR 57979 and IW Ponni / IR 64	TETEP / BPT 5204	_

For dry root weight, the standard heterosis expressed negative and significant in 13 hybrids *viz.,* P_1 / P_2 (-19.98), P_1 / P_6 (-11.02), P_2 / P_4 (-12.74), P_2 / P_5 (-12.55), P_2 / P_6 (-7.99), P_3 / P_6 (-10.67), P_5 / P_1 (-8.11), P_5 / P_2 (-8.32), P_6 / P_1 (-18.10), P_6 / P_2 (-18.66), P_6 / P_3 (-13.75), P_6 / P_4 (-13.14) and P_6 / P_5 (-14.48). None of the hybrids expressed positive and significant standard heterosis for this trait. For dry shoot weight, none of the hybrids showed positive and significant standard heterosis for this trait, while, 20 hybrids expressed negative and significant standard heterosis. For root:shoot ratio, nine hybrids viz., P_3 / P_1 (17.24), P_3 / P_2 (19.66), P_3 / P_4 (25.52), P3 / P5 (17.59), P_5 / P_1 (24.83), P_5 / P_2 (25.52), P_5/ P3 (33.79), P_5 / P_4 (31.38) and P_5 / P_6 (31.72) expressed positive and significant standard heterosis for root:shoot ratio. Nine hybrids registered negative and significant standard heterosis.

Table 2. Range of standard heterosis for various yield and sodicity tolerance characters and number of hybrids showing significant heterosis

Characters	Range	SE(±)	No. of hybrids showing desirable significant heterosis
Days to 50 per cent flowering	-6.83 to 5.39	0.88	23
Plant height	-41.18 to 30.38	1.19	29
Number of productive tillers per plant	-6.67 to 11.21	0.88	01
Panicle length	-31.30 to -14.02	1.07	_
Number of filled grains per panicle	-37.11 to 5.43	3.51	01
Spikelet fertility percentage	-34.27 to -1.84	2.43	_
100 grain weight	-13.49 to 7.28	0.03	04
Single plant yield	-53.53 to 43.96	1.91	03
Dry root weight	-19.98 to -1.65	0.56	_
Dry shoot weight	-35.00 to 3.22	0.29	_
Root:shoot ratio	-30.41 to 33.79	0.05	09
Na+: K+ ratio	-72.34 to 43.83	0.15	01
Chlorophyll content	-30.57 to -1.77	1.74	_
Proline content	-49.25 to 22.13	70.13	01

For Na+: K+ ratio, eight hybrids showed negative and significant standard heterosis for this trait. Only one hybrid *viz.,* P_4 / P_1 (43.83) registered positive and significant standard heterosis for this trait. Eight hybrids viz., P_2 / P_3 (-41.28), P_2 / P_4 (-44.26), P_3 / P_1 (-39.57), P_6 / P_1 (-60.43), P_6 / P_2 (-58.30), P_6 / P_3 (-60.43), P_6 / P_4 (-72.34) and P_6 / P_5 (-67.66) recorded negative and significant standard heterosis for this trait. For chlorophyll content, twenty nine hybrids expressed negative and significant standard heterosis for chlorophyll content. For proline content, the standard heterosis per cent varied from - 49.25 (P_4 / P_1) to 22.13 (P_6 / P_3). Twelve hybrids expressed negative and significant standard heterosis for this trait. Only one hybrid P_6 / P_3 (22.13) registered positive and significant value for this trait (Table 1).

Heterosis is a genetic phenomenon and conventionally refers to develop the expression of increased or decreased vigour of hybrid over mid parent (Relative heterosis), better parent (Heterobeltiosis) and standard parent (Standard heterosis). Though three estimates of heterosis are important, Kadambavanasundaram (1980) suggested that the heterotic expression over standard variety should alone be given due importance for commercial exploitation of hybrid vigour. Hence, the crosses that showed significant high value of standard heterosis over FL 478 for yield and sodicity tolerant traits were taken into account and discussed hereunder:

Table 3. Standard heterosis of top ten heterotic combinations based on sodicity tolerant characters

Crosses	DFF	PHT	NPT	PL	NFGP	SFP	HGW	SPY	DRW	DSW	RSR	$Na^+:K^+$	CC	PC
FL478 / BPT 5204	-6.1**	-32.0**	0.3	-31.3**	-21.4**	-4.9	-6.6**	-51.1 **	-5.2	3.1	-19.7**	-31.1	-1.8	-20.9*
IW Ponni /BPT 5204	-3.8**	-24.2**	-6.6	-29.7**	-17.5**	-7.2*	-3.0	43.9 **	-5.3	-2.5	-14.5 *	-41.3*	-15.9**	-2.8
IW Ponni / IR 64	-5.5**	-28.8**	11.2**	-26.6**	-28.9**	-6.3	5.1*	15.1	-12.7**	-3.6	-19.3**	-44.3*	-23.7**	16.3
BPT 5204 / FL 478	-6.5**	-30.1**	2.4	-25.6**	-12.0**	-7.5*	7.3**	20.6 *	-5.6	-32.3**	17.2 **	-39.6	-12.7**	-11.1
RNR 57979 / BPT 5204	-5.5**	-31.7**	1.2	-26.4**	-15.0**	-3.2	-13.5**	26.4*	-2.4	-35.0**	33.8 **	-30.6	-24.4**	11.1
TETEP / FL 478	-1.1	-6.1**	2.7	-16.5**	-33.9**	-27.6**	4.7	-29.7 **	-18.1**	-26.2**	1.0	-60.4**	-21.1**	-24.8**
TETEP / IW Ponni	5.4**	-5.4**	0.9	-25.4**	-31.3**	-28.3**	2.8	-39.3 **	-18.7**	-26.2**	-2.1	-58.3**	-21.8**	-14.4
TETEP / BPT 5204	-3.8**	-7.5**	2.1	-19.5**	-14.4**	-23.6**	3.2	-21.4 **	-13.8**	-25.9**	3.1	-60.4**	-23.3**	22.1*
TETEP / IR 64	-2.8**	-6.6**	2.7	-22.8**	-17.6**	-22.0**	1.1	-37.1 **	-13.1**	-25.9**	3.5	-72.3**	-20.5**	-17.1*
TETEP / RNR 57979	-0.7	-9.2**	-3.3	-14.0**	-4.7	-23.3**	2.1	-17.5	-14.5**	-30.2**	2.8	-67.7**	-15.8**	12.4

*and ** significant at P=0.05 and 0.01, respectively; Yield, yield components and sodicity tolerance compared with FL 478, DFF- Days to 50 per cent flowering, PHT- Plant height, NPT- Number of productive tillers per cent, PL- Panicle length, NFGP- Number of filled grains per panicle, SFP- Spikelet fertility percentage, HGW- Hundred grain weight, SPY- Single plant yield, DRW- Dry root weight, DSW- Dry shoot weight, RSR- Root:Shoot ratio, $Na^+:K^+$- Sodium potassium ratio, CC- Chlorophyll content, PC- Proline content

Heterosis towards negative direction will be useful for the breeder to develop early maturing rice varieties. Among 30 hybrids evaluated, 23 hybrids viz., FL 478 / IW Ponni, FL 478 / BPT 5204, FL 478 / IR 64, FL 478 / RNR 57979, FL 478 / TETEP, IW Ponni / FL 478, IW Ponni / BPT 5204, IW Ponni / IR 64, IW Ponni / RNR 57979, BPT 5204 / FL 478, PT 5204 / IW Ponni, BPT 5204 / IR 64, BPT 5204 / RNR 57979, IR 64 / FL 478, IR 64 / IW Ponni, IR 64 / BPT 5204, IR 64 / RNR 57979, RNR 57979 / FL 478, RNR 57979 / IW Ponni, RNR 57979 / BPT 5204, RNR 57979 / IR 64, TETEP / BPT 5204 and TETEP / IR 64 showed negative and significant standard heterosis. These early maturing hybrids might possess the advantage of avoidance from sodicity besides genetic potential.

The potentiality of hybrid might be judged by comparing *per se* performance and heterotic vigour. It was highlighted that *per se* performed hybrids possessed desirable standard heterosis for the trait. The close association between *per se* and standard heterosis in six *per se* performed hybrids *viz*., FL 478 / BPT 5204, FL 478 / RNR 57979, BPT 5204 / FL 478, BPT 5204 / RNR 57979, IR 64 / BPT 5204 and RNR 57979 / FL 478 suggested that *per se* itself could be taken as indicator for the development of early or mid-early duration genotypes in rice suitable for *thaladi* season under problem soils. Moreover, those six crosses involved parents of good combiners indicating the important source of valuable materials in utilization in appropriate breeding method. Since, additive as well as dominance type of gene actions governing the inheritance of the trait, *inter se* matings among the selected segregants in F_2 generation followed by simple pedigree method of breeding could be advocated to exploit both types of gene actions besides epistatic gene interactions, if present.

The remaining heterotic hybrids resulted from one good and one poor or both poor combiners suggesting dominance gene action. To harness non – additive gene action, cyclic method of breeding would be advocated to obtain transgressive segregants and also an array of segregants which would vary in maturity groups. The segregants of those hybrids might fit well in different agronomical systems and a range of environments. Heterosis for earliness had been reported by Young and Virmani (1990), Parihar and Pathak (2008), Kannan (2011), Senthilkumar (2012) and Gopikannan and Ganesh (2013)

Dwarfism is also one of the most important breeding objectives because of its linear relationship with plant type, such as light interception, harvest index, fertilizer responsiveness and lodging resistance. In the present study, all hybrids except FL 478 / IW Ponni exhibited negative standard heterosis over FL 478 for the trait. Twelve hybrids *viz*., FL 478 / BPT 5204, FL 478 / IR 64, FL 478 / RNR 57979, BPT 5204 / FL 478, BPT 5204 / IR 64, BPT 5204 / RNR 57979, IR 64 / FL 478, IR 64 / BPT 5204, IR 64 / RNR 57979, RNR 57979 / FL 478, RNR 57979 / BPT 5204 and RNR 57979 / IR 64 had the parents of good combiners. The remaining hybrids possessed one of the parents as poor combiner indicating the prevalence of non-additive gene action. Hence, inter-mating of segregants would yield ideal plant type in later generations. This finding was in line with Gopikannan and Ganesh (2013).

The number of productive tillers per plant was an important yield parameter under sodicity because it determines the grain bearing panicles. The decrease in tillering capacity might be due to the toxic effect of salt on plant growth. The development of more tillers may be the mechanism of salt tolerance by dilution of salts in plant (Aslam *et al*., 1989). Only one hybrid, IW Ponni/IR 64 exhibited significant standard heterosis. The hybrid possessed parents of poor combiners indicating the predominance of non-additive gene action. To harness non additive gene action, bi-parental mating could be advocated to allow accumulation of favorable alleles in the progenies for the trait improvement, which in turn boost yield. These results were in accordance with the findings of Thirumeni and Subramanian, (2000), Sankar *et al*. (2008) and Gopikannan and Ganesh (2013). With reference to panicle length, none of the hybrids recorded positive significant standard heterosis. The major reason of poor yield of the varieties under salt stress might be less number of filled grains per panicle. Only one hybrid, FL 478 / TETEP showed greater magnitude of standard heterosis per cent and was found to be more heterotic for this trait. The hybrid FL 478 / TETEP derived from one good and one poor combiner. In order to harness dominant gene action in this hybrid, bi-parental mating followed by recurrent selection or alternatively, selection could be postponed to later generations for the improvement of this important yield component trait. This finding was in accordance with Babu *et al*. (2005) and Manoj Kumar *et al.* (2010).

Spikelet fertility was highly affected by increased salt concentration (Akbar *et al.,* 1972). Spikelet fertility percentage is an important yield parameter under sodicity because it determines the number of filled grains per panicle. However, in the present study, none of the hybrids recorded positive significant standard heterosis. With reference to 100 grain weight, four hybrids *viz*., FL 478 / IW Ponni, IW Ponni / IR 64, BPT 5204 / FL 478 and IR 64 / FL 478 showed greater magnitude of standard heterosis for this trait. All hybrids derived either from one good and one poor combiner or both poor combiners suggesting the importance of harnessing dominant gene action. Hence, bi-parental mating followed by recurrent selection might be suggested for the improvement of this important yield component trait.

Yield is the complex phenomenon and also is the end product of combination of the yield components. The complexity gets worse when rice crop interacts with abiotic stress like sodicity. In the present study, three crosses *viz*., IW Ponni / BPT 5204, BPT 5204 / FL 478 and RNR 57979 / BPT 5204 exhibited significant standard heterosis for single plant yield. The hybrid IW Ponni / BPT 5204 excelled for *per se*, *sca*, standard heterosis. The other two hybrids had better *per se* performance. Parents of those hybrids were either of poor combiners or one good combiner. Such immense valuable hybrids would be the best source for exploiting heterosis. Since, non-additive gene actions might play in the inheritance of yield under sodicity, a slight of conventional selection could be advocated *i.e.,* inter-mating of selected segregants to break any undesirable linkages and to allow accumulation of desirable alleles in later generations through selection would be an ideal approach for yield enhancement under salinity / sodicity. These results were in conformity with earlier findings of Shanthi *et al*. (2011) and Gopikannan and Ganesh (2013). With reference to dry root weight, none of the hybrids were recorded positive significant standard heterosis. Roy *et al.* (1992) observed that salt stress tended to reduce the root and shoot growth of germinating seeds. With reference to dry shoot weight, none of the hybrids were recorded positive significant standard heterosis. With reference to root:shoot ratio, nine hybrids *viz*., BPT 5204 / FL 478, BPT 5204 / IW Ponni, BPT5204 / IR 64, BPT 5204 / RNR 57979, RNR 57979 / FL 478, RNR 57979 / IW Ponni, RNR 57979 / BPT 5204, RNR 57979 / IR 64 and RNR 57979 / TETEP were exhibited significant standard heterosis for root:shoot ratio. Two *per se* performed hybrids *viz*., BPT 5204 / RNR 57979 and RNR 57979 / BPT 5204 derived from parents of good combiners suggesting the importance of both additive and dominant gene actions. The other seven hybrids had the parents of one good combiner and one poor combiner. To exploit heterotic vigor, inter-mating among the selected segregants and selection at later generations would result in segregants with more root:shoot ratio in rice under sodicity.

One of the key features of plant salt tolerance is the ability of plant cells to maintain optimal Na^+:K^+ ratio in the cytosol, when exposed to salt stress (Maathuis and Amtmann, 1999; Carden *et al*., 2003; Tester and Davenport, 2003; Ashraf, 2004; Peng and Ismail, 2004). The Na^+:K^+ ratio also increased significantly because of increase in leaf Na^+. This decrease in Na^+:K^+ ratios may relate directly to an increase in yield in some conditions. There was a positive relationship between low Na^+:K^+ ratio and salt tolerance (Gregorio and Senadhira, 1993) making it best indicator of growth and yield under salt stress (Gill and Singh, 1995). High external concentrations of Na^+ also affect intracellular K^+ accumulation to the extent that K^+ deficiency is considered to be one of the detrimental effects of exposure to NaCl (Rains, 1972). Salinity tolerance is therefore often correlated firstly to the efficiency of Na^+ exclusion processes such as extrusion through salt glands or roots sequestration in vacuoles or in older organs such as leaves or limiting the transport of Na^+ from root to shoot and secondly, to process which increase K^+ content, such as, selective uptake of K^+ by roots and transport of K^+ from older to younger metabolically more active leaves (Yeo and Flowers, 1984). In the present set of hybrids, eight crosses *viz*., IW Ponni / BPT 5204, IW Ponni / IR 64, BPT 5204 / FL 478, TETEP / FL 478, TETEP / IW Ponni, TETEP / BPT 5204, TETEP / IR 64 and TETEP / RNR 57979 had higher magnitude of negative standard heterosis. Five hybrids *viz.,* TETEP / FL 478, TETEP / IW Ponni, TETEP / BPT 5204, TETEP / IR 64 and TETEP / RNR 57979 possessed *per se* performance also. All hybrids had parents of either one good combiner or one poor combiner or of both poor combiners (Table 2). These hybrids exhibited significant standard heterosis over the standard parent and also showed increased *per se* performance for single plant yield suggesting the prevalence of dominant gene action. Hence, postponement of selections to later generations might help in improvement of this trait. This finding was in good agreement with earlier reports of Kannan (2011) and Gopikannan and Ganesh (2013). None of the hybrids showed significant standard heterosis for chlorophyll content.

The accumulation of osmolytes such as proline is a well-known adaptive mechanism in plants against salt stress conditions. It has also been suggested that proline accumulation can serve as a selection criterion for the tolerance of most species to stressed conditions (Parida and Das, 2005; Ashraf and Foolad, 2007; Ahmed *et al*., 2009). Only one hybrid TETEP / BPT 5204 exhibited positive and significant heterosis over the standard check for proline content. This hybrid TETEP / BPT 5204 had both parents as poor combiner. Hence, non-additive gene action was predominant. Reciprocal recurrent selection would be the appropriate breeding method to obtain segregants with the possibility of accumulation of more proline content through breaking undesirable linkages (Table 3). These findings were in consonance with Babu *et al.* (2005) and Gopikannan and Ganesh (2013).

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