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Investigation on combining ability and heterosis for sodicity tolerance in rice (*Oryza sativa* L.)

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The present study was conducted to estimate combining ability, gene action and proportional contribution of cross components in rice genotypes under sodicity. Heterosis and combining ability estimates were worked out through Line × Tester analysis of 25 hybrids developed by crossing five lines with five testers to know the genetic architecture of 13 physio-morphological traits under sodic environment. The analysis of variance of combining ability displayed variances of specific combining ability **(SCA) and were higher in magnitude than the corresponding general combining ability (GCA) variances for all the traits under study which indicated preponderance of non-additive gene action governing these traits. Results of *per se* and *gca* effects of parents revealed that multiple crosses involving IR 20, CO (R) 50, FL 478, TRY (R) 2 and CSR 23 would be considered as invaluable sources of genetic materials. An outset on perusal of data for hybrids based on *per se*, *sca* effects and standard heterosis, three hybrids *viz.,* IR 20 / FL 478, IR 20 / CSR 23 and ADT 49 / TRY (R) 2 were found to be suitable for heterosis breeding under sodicity. As there was dominance gene action involved, *inter se* matings followed by recombination breeding might be advocated for improvement of yield under sodicity.**

Key words: Rice, sodicity tolerance, general combining ability (GCA), specific combining ability (SCA), heterosis.

INTRODUCTION

Rice, most loved cereal of Asia, feeds the majority of the world's population. To cope up with the ever increasing demand for rice it should be met with quantum jump in production in fixed cultivable area. This is a daunting task, in view of plateauing trend observed in yield potential of high yielding varieties and decreasing and declining natural resource base. 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). 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 rated as an especially 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. Salt tolerance is a multigenic trait that allows plants to grow and maintain economic yield in the presence of non-physiologically high and relatively constant levels of salt (Hurkman, 1992). The importance of developing varieties tolerant to sodicity with increased yield is felt timely need. To frame a yield improvement programme in rice, information about *per se*, combining ability effects 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

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Table 1. Analysis of variance of combining ability for different biometrical and physiological traits.

Source of variation	df	DFF	PH (cm)	NPT	PL (cm)	NFG	SF (%)	HGW (g)	SPY (g)	$Na^+ : K^+$ ratio	PC (µg g^{-1})	TCT (mg g^{-1})	CAB ratio	CSI (%)
Hybrids	24	366.65*	63.05*	26.88*	8.28*	537.23*	112.57*	0.073*	87.49*	0.12*	88929.10*	0.06*	0.023*	77.20*
Lines	4	761.59*	170.67*	33.98*	8.61*	547.78*	121.69*	0.257*	123.01*	0.10*	61849.29*	0.07*	0.041*	89.48*
Testers	4	963.22*	65.44*	31.32*	16.11*	738.09*	110.43*	0.024*	112.88*	0.08*	198089.95*	0.10*	0.019*	47.27*
Lines × Testers	16	118.78*	35.54*	23.99*	6.25*	484.39*	110.82*	0.040*	72.26*	0.14*	68408.85*	0.05*	0.019*	81.61*
Error	48	2.30	1.55	0.58	0.37	29.30	5.13	0.001	0.48	0.001	2178.19	0.001*	0.001	1.67

*Significant at 5% level. DFF, days to 50% flowering; PH, plant height; NPT, number of productive tillers per plant; PL, panicle length; NFG, number of filled grains per panicle; SFP, spikelet fertility percentage; HGW, 100-grain weight; SPY, single plant yield; PC, proline content; TCT, total chlorophyll content; CABR, chlorophyll a/b ratio; CSI, chlorophyll stability index.

to dissect the gene action regulating the complex mechanisms involved in rice genotypes under sodicity.

MATERIALS 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 (district), Tamil Nadu, India, where the soil is found to be sodic in nature. The soil in the experimental field was sodic soil with a pH of 9.5 and ESP 23. The water used for irrigating the experimental field was taken from the bore well with pH 9.00 and RSC is 10 meq/L. The breeding material comprised of 10 rice genotypes. Five high yielding and sodicity susceptible lines *viz*., ASD 18, IR 20, ADT 49, CO (R) 49 and CO (R) 50 were crossed with five sodicity tolerant testers *viz*., TRY(R) 2, FL 478, CSR 23, CO 43 and Vytilla 6 to produce 25 F_1 hybrids according to line × tester mating design. Lines were used as female whereas testers as male parents. The experiment was laid out in randomized complete block design with three replications adopting a recommended spacing of 20 x 15 cm in field during 2012 to 2013. Recommended package of practices were followed to establish the crop. Ten plants were selected randomly from each entry in each replication to record data on 13 physio-morphological traits *viz.,* days to 50% 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, Na^+:K^+ ratio, proline content, total chlorophyll content, chlorophyll a/b ratio and chlorophyll stability index. The biometrical observations were recorded for yield and its component traits under sodicity as per the Standard Evaluation System (SES) for rice (IRRI). The mean data were subjected to ANOVA and combining ability studies using the Line x Tester analysis (Kempthorne, 1957).

RESULTS AND DISCUSSION

Analysis of variance

The analysis of variance of combining ability displayed high significant differences among parents and hybrids for all traits that depicted wide range of variability for the parents and hybrids (Table 1). The significance of the means of sum of squares due to lines and testers indicated the prevalence of additive variance. However, significant differences due to interactions between line × tester for all the traits indicating the importance of both additive and non-additive variance. Variances due to specific combining ability (SCA) were higher in magnitude than the corresponding general combining ability (GCA) variances for all the traits which indicated preponderance of non-additive gene action in the inheritance of the traits which might be resulted from dominance, epistasis and interaction effects (Table 2). Predominance of non-additive genetic variance indicated the presence of heterozygosity in the population. As such, this type of genetic variance is non-fixable and thus development of hybrids is also an appropriate crop improvement tool. But rice, being a self-pollinated crop, heterosis is not widely adopted unlike recombination breeding because of the strain involved in the synthesis of hybrids. Preponderance of non-additive gene action in terms of yield components was also reported by (Karthikeyan et al., 2009; Shanthi et al., 2011). The proportional contribution of lines, testers and their interactions to total variances showed that contribution of interactions of line × tester was higher than lines or testers for number of productive tillers per plant, panicle length, number of filled grains per panicle, spikelet fertility, single plant yield, Na^+: K^+ ratio, proline content, total chlorophyll content, chlorophyll a/b ratio and chlorophyll stability index.

Combining ability analysis

There were significant differences among genotypes under study, which lead to the

Table 2. Estimates of variance through L × T analysis.

Parameter	σ^2 GCA	σ^2 SCA	σ^2 A (F=1)	σ^2 D (F=1)	σ^2 A / σ^2 D
Days to 50% flowering	6.19	38.84	12.40	38.84	0.32
Plant height (cm)	0.68	11.32	1.37	11.32	0.12
Number of productive tillers per plant	0.08	7.90	0.14	7.90	0.02
Panicle length (cm)	0.06	2.00	1.00	2.00	0.50
Number of filled grains per panicle	1.32	152.00	3.00	152.00	0.02
Spikelet fertility (%)	0.04	35.23	1.00	35.23	0.03
100-grain weight (g)	0.005	0.013	0.002	0.013	0.15
Single plant yield (g)	0.38	23.93	0.76	23.93	0.03
Na^+ : K^+ ratio	0.0004	0.045	0.001	0.045	0.02
Proline content (µg g^{-1})	513.01	22076.89	1026.01	22076.89	0.05
Total chlorophyll content (mg g^{-1})	0.0002	0.018	0.0005	0.018	0.03
Chlorophyll a : b ratio	0.0001	0.0064	0.0002	0.0064	0.03
Chlorophyll satability index (%)	0.11	26.65	0.22	26.65	0.01

Table 3. GCA effects of parents for different biometrical traits.

Parents	DFF	PH (cm)	NPT	PL (cm)	NFG	SF (%)	HGW (g)	SPY (g)
Lines								
ASD 18	-8.17**	-4.41**	-1.36**	-0.47**	-0.99	0.99	0.03**	-1.91**
IR 20	4.09**	5.00 **	1.54**	-0.49**	4.08**	1.90**	0.13**	3.52**
ADT 49	4.43**	-0.22	-0.45*	-0.57**	0.48	-0.47	-0.19**	-1.86**
CO (R) 49	6.90**	-0.85**	-1.38**	0.35*	-9.59**	-4.73**	0.10**	-2.45**
CO (R) 50	-7.24**	0.49	1.66**	1.18**	6.02**	2.30**	-0.07**	2.70**
Testers								
TRY (R) 2	-7.31**	-0.71*	1.52**	1.09**	7.55**	2.90**	0.04**	3.14**
FL 478	-7.04**	-2.20**	-1.64**	-0.38*	-2.02	0.82	0.01*	-2.19**
CSR 23	7.76**	3.40**	1.54**	1.02**	6.72**	1.83**	0.03**	2.72**
CO 43	9.30**	0.25	-0.68**	-0.41*	-3.34*	-1.90**	-0.05**	-1.01**
Vytilla 6	-2.71**	-0.74*	-0.73**	-1.32**	-8.92**	- 3.66**	-0.04**	-2.65**

* Significant at 5% level; ** Significant at 1% level; DFF, Days to 50% flowering; PH, Plant height; NPT, Number of productive tillers per plant; PL, Panicle length; NFG, Number of filled grains per panicle; SFP, Spikelet fertility percentage; HGW, 100-grain weight; SPY, Single plant yield.

combining ability analysis. The negative *gca* and *sca* effects were considered for days to 50% flowering, plant height, Na^+: K^+ ratio and chlorophyll a/b ratio, where negative *gca* and *sca* were desirable. In case of other traits positive *gca* and *sca* effects were desirable. The effects of *gca* and *sca* were presented in Tables 3, 4, 5 and 6.

General combining ability (GCA)

In the present study, the lines CO (R) 50 and IR 20 were adjudged as the best general combiners, since they expressed significant *gca* effects for all traits, except for plant height, 100-grain weight and chlorophyll stability index by the former and days to 50% flowering, plant height, 100 grain weight and chlorophyll stability index by the later. Among testers, TRY (R) 2 and CSR 23 were adjudged as good general combiners, as they showed significantly favorable *gca* effects for all the traits except for proline content for the former and days to 50% flowering and plant height for the later. The *gca* effect is considered as intrinsic genetic value of the parent for a trait, which is due to additive gene effects and it is fixable (Simmonds, 1989). Singh and Singh (1985) suggested that parents with high *gca* would produce transgressive segregants in F_2 or later generations. Hence, the lines and testers with high *gca* effects may be utilized in hybridization programme to improve the salt tolerant traits through transgressive breeding. Chandra et al. (1969)

Table 4. GCA effects of parents for different physiological traits.

Parents	$Na^+:K^+$ ratio	PC (μg g^{-1})	TCT (mg g^{-1})	CABR	CSI (%)
Lines					
ASD 18	-0.01	12.89	-0.03**	0.01	1.35**
IR 20	-0.09**	29.03*	-0.01	-0.04**	1.24**
ADT 49	0.01	-41.84**	-0.02**	0.03**	-1.49**
CO (R) 49	0.13**	-82.91**	-0.05**	0.07**	-3.52**
CO (R) 50	-0.05**	82.83**	0.12**	-0.07**	2.43**
Testers					
TRY (R) 2	-0.04**	-54.57**	0.09**	-0.05**	1.99**
FL 478	0.05**	-57.91**	-0.01	0.04**	-0.87**
CSR 23	-0.11**	178.43**	0.07**	0.01	1.71**
CO 43	0.05**	46.03**	-0.10**	-0.02**	-0.71*
Vytilla 6	0.05**	-111.97**	-0.05**	0.03**	-2.12**

*Significant at 5% level; **Significant at 1% level; PC, proline content; TCT, total chlorophyll content; CABR, chlorophyll a/b ratio; CSI, chlorophyll stability index.

Table 5. SCA effects of hybrids for different biometrical traits.

Genotype	DFF	PH (cm)	NPT	PL (cm)	NFG	SF (%)	HGW (g)	SPY (g)
ASD 18 / TRY (R) 2	4.90**	3.37**	2.21**	0.51	11.29**	5.29**	-0.10**	2.46**
ASD 18 / FL 478	-3.70**	0.50	-1.03*	-1.01**	-3.54	-2.30	0.01	-2.63**
ASD 18 / CSR 23	0.84	0.07	-2.51**	-1.29 **	-23.48**	-11.85**	-0.02	-5.72**
ASD 18 / CO 43	-2.36**	-8.11**	2.50**	1.94**	11.98**	8.09**	-0.05**	4.84**
ASD 18 / Vytilla 6	0.31	4.17**	-1.18*	-0.14	3.76	0.78	0.17**	1.05*
IR 20 / TRY (R) 2	5.64**	0.78	-3.38 **	-2.40**	-14.24**	-6.29**	-0.14**	-7.15**
IR 20 / FL 478	4.04**	-2.00**	4.24**	2.31**	16.12**	4.13**	0.10**	10.05**
IR 20 / CSR 23	-2.76**	-1.37	0.60	1.65**	11.66**	7.18**	0.06**	2.85**
IR 20 / CO 43	-5.63**	1.98 **	-3.59**	-1.16**	-6.09	-1.29	0.05**	-5.14**
IR 20 / Vytilla 6	1.30	0.62	2.13**	-0.39	-7.44*	-3.73**	-0.07**	-0.60
ADT 49 / TRY (R) 2	6.31**	0.16	2.80**	1.53**	-2.44	2.82*	0.21**	5.56**
ADT 49 / FL 478	-3.63*	0.40	-1.04*	-0.97**	0.52	-0.37	-0.05**	-2.32**
ADT 49 / CSR 23	-6.76**	-3.59**	-0.08	0.82*	19.49**	6.89**	0.01	1.51**
ADT 49 / CO 43	3.04**	4.06**	0.60	-1.30**	-10.49**	-4.85**	-0.01	-1.18**
ADT 49 / Vytilla 6	1.04	-1.05	-2.28**	-0.08	-7.08*	-4.49**	-0.16 **	-3.57**
CO (R) 49 / TRY (R) 2	-14.83**	-3.43**	-2.93**	0.15	-2.44	-4.46**	-0.01	-3.58**
CO (R) 49 / FL 478	4.91**	2.55**	-1.14**	-0.68	3.32	-4.95**	0.10**	-0.17
CO (R) 49 / CSR 23	0.11	2.91**	0.32	-1.51**	-8.14*	-1.33	-0.02	0.18
CO (R) 49 / CO 43	6.57**	1.98**	-0.40	0.89*	0.24	-2.26	-0.01	-0.97*
CO (R) 49 / Vytilla 6	3.24**	-4.00**	4.45**	1.16**	7.02*	3.10*	-0.07**	4.54**
CO (R) 50/ TRY (R) 2	-2.03*	-0.89	1.30**	0.22	7.84*	2.65*	0.05**	2.71**
CO (R) 50 / FL 478	-1.63	-1.43	-0.74	0.35	-16.42**	-6.41**	-0.16**	-4.92**
CO (R) 50 / CSR 23	8.58**	1.97**	1.68**	0.34	0.48	-0.89	-0.02	1.19**
CO (R) 50 / CO 43	-1.63	0.10	0.89*	-0.36	4.36	0.31	0.01	2.45**
CO (R) 50 / Vytilla 6	-3.30**	0.25	-3.12**	-0.54	3.74	4.34**	0.13**	-1.42**
SE	0.86	0.72	0.44	0.35	3.12	1.31	0.02	0.40

* Significant at 5% level, ** Significant at 1% level; DFF, days to 50% flowering; PH, plant height; NPT, number of productive tillers per plant; PL, panicle length, NFG, number of filled grains per panicle; SFP, spikelet fertility percentage; HGW, 100-grain weight; SPY, single plant yield.

Table 6. SCA effects of hybrids for different physiological traits.

Genotype	$Na^+ : K^+$ ratio	PC (μg g^{-1})	TCT (mg g^{-1})	CABR	CSI (%)
ASD 18 / TRY (R) 2	-0.28**	99.04**	0.11**	-0.09**	4.05**
ASD 18 / FL 478	-0.04	-57.96*	-0.03*	0.08**	-2.56**
ASD 18 / CSR 23	0.20**	4.04	-0.14**	-0.02	-1.80*
ASD 18 / CO 43	-0.12**	131.44**	0.14 **	-0.05**	-0.05
ASD 18 / Vytilla 6	0.24**	-176.56**	-0.07**	0.08**	0.36
IR 20 / TRY (R) 2	0.28**	-129.56**	-0.04*	0.14**	-10.51**
IR 20 / FL 478	-0.29**	161.57**	0.01	-0.09**	5.48**
IR 20 / CSR 23	-0.12**	108.91**	0.08**	0.04*	5.57**
IR 20 / CO 43	0.29**	-214.69**	-0.15**	0.01	1.39
IR 20 / Vytilla 6	-0.16**	73.97**	0.10**	-0.09 **	-1.93*
ADT 49 / TRY (R) 2	-0.23**	177.11**	0.12**	-0.01	0.76
ADT 49 / FL 478	0.16**	35.77	0.02	0.01	-1.32
ADT 49 / CSR 23	0.02	-96.89**	0.09**	-0.12**	6.91**
ADT 49 / CO 43	-0.01	-32.16	-0.14**	0.06**	-2.95**
ADT 49 / Vytilla 6	0.05	-83.83	-0.08**	0.06**	-3.40**
CO (R) 49 / TRY (R) 2	0.27**	-120.83**	-0.25**	-0.01	1.85*
CO (R) 49 / FL 478	0.11**	-96.83**	0.02	-0.03*	2.31**
CO (R) 49 / CSR 23	-0.06*	-66.49*	-0.10**	0.10**	-6.20**
CO (R) 49 / CO 43	-0.09**	-9.43	0.17**	-0.07**	3.68**
CO (R) 49 / Vytilla 6	-0.23**	293.57**	0.16**	0.02	-1.64*
CO (R) 50/ TRY (R) 2	-0.04**	-25.56	0.05**	-0.02	3.84**
CO (R) 50 / FL 478	0.06*	-42.56	-0.01	0.03	-3.91**
CO (R) 50 / CSR 23	-0.05	50.44	0.08**	0.01	-4.48**
CO (R) 50 / CO 43	-0.07**	124.84**	-0.02	0.05**	-2.07**
CO (R) 50 / Vytilla 6	0.10**	-107.56**	-0.11**	-0.06**	6.61**
SE	0.025	26.95	0.015	0.006	0.74

* Significant at 5% level; ** Significant at 1% level; PC, proline content; TCT, total chlorophyll content; CABR, chlorophyll a/b ratio; CSI, chlorophyll stability index.

reported that parents with high mean performance might not be able to transmit their superior traits into hybrids and hence they insisted the need for combining ability of parents also. Thus, an overview of *per se* performance and *gca* effects of parents revealed that multiple crosses involving IR 20, CO (R) 50, FL 478, TRY (R) 2 and CSR 23 would be considered as invaluable sources of genetic materials as they might throw desirable segregants possessing sodicity tolerance coupled with yield performance.

Specific combining ability (SCA)

Sprague and Tatum (1942) reported that SCA was due to non-additive and epistatic gene action. The *sca* effects of hybrids have been attribute to the combination of positive favorable genes from different parents or might be due to presence of linkage in repulsion phase (Sarasar et al., 1986). Hence, selection of hybrids based on *sca* effects would excel in their heterotic effect. Hybrids with significantly favorable *sca* effects in the present investigation are discussed hereunder. For days to 50% flowering significant *sca* effects were pronounced in nine hybrids *viz.,* ASD 18 / FL 478, ASD 18 / CO 43, IR 20 / CSR 23, IR 20 / CO 43, ADT 49 / FL 478, ADT 49 / CSR 23, CO (R) 50 / Vytilla 6, CO (R) 50 / TRY (R) 2 and CO (R) 49 / TRY (R) 2. Among nine hybrids, three hybrids *viz.,* ASD 18 / FL 478, CO (R) 50 / Vytilla 6 and CO (R) 50 / TRY (R) 2 involved the parents of good combiners. These valuable hybrids would throw desirable segregants for earliness since additive and non-additive type of gene effects would be predominant. For exploiting these type of gene actions, intermating among the segregating populations to accumulate additive gene effects and at the same time maintain heterozygousity for exploiting dominance gene effects would be the ideal method of breeding for the improvement of this trait. Rest of the hybrids possessed parents of either one good combiner or one poor combiner or both poor combiners indicating the importance of non-additive gene action. These hybrids would produce high yielding, transgressive, early maturing segregants in later generations. Kumar et al. (2010) observed similar findings for days to 50% flowering.

For plant height, five hybrids *viz.,* ASD 18 / CO 43, IR 20 / FL 478, ADT 49 / CSR 23, CO (R) 49 / Vytilla 6 and CO (R) 49 / TRY (R) 2 recorded negative and significant *sca* effects. Among five hybrids, three hybrids showed good association for both *per se* performance and *sca* effects. It was observed that parents of all the hybrids except CO (R) 49 / TRY (R) 2 were of either one poor or one good combiner or both poor combiners indicated the presence dominance gene action. As predominance of dominance gene action governed the inheritance of the trait, heterosis breeding was advocated for the improvement. Those crosses would throw desirable segregants in later generations. These results were in accordance with findings of Thirumeni et al. (2000). The measure of *sca* effect for number of productive tillers per plant indicated the positive and significant *sca* effects for nine hybrids *viz.,* ASD 18 / TRY (R) 2, ASD 18 / CO 43, IR 20 / FL 478, IR 20 / Vytilla 6, ADT 49 / TRY (R) 2, CO (R) 49 / Vytilla 6, CO (R) 50 / TRY (R) 2, CO (R) 50 / CSR 23 and CO (R) 50 / CO 43. Two hybrids *viz.,* CO (R) 50/ TRY (R) 2 and CO (R) 50 / CSR 23 possessed parents of good combiners and so these parents appeared to be worthy in varietal programme. Hence additive and dominance gene actions were predominant in these hybrids population involving these parents, in multiple crossing programme, might be developed for isolating desirable lines. Postponement of selection to later generations might be helpful in harnessing the dominant gene action. Remaining hybrids with significant *sca* effects possessed parents with either one good and one poor combiner or both poor combiners.

High and significant *sca* effects were recorded in seven hybrids for panicle length. Moreover, all hybrids possessed parents of either one good combiner or one poor combiner or both poor combiners indicated the importance of harnessing non-additive gene action. Hence, selection in early segregating generations might not yield desirable results so delaying selection to later generations when dominance gene effects disappear as well as resorting to intermating of segregants in F_2 generation might be advocated not only to harness dominant type of gene action but also to break any undesirable linkages. Similar findings were reported by Mishra (1990) and Karthikeyan et al. (2009). For number of filled grains per panicle seven hybrids *viz.,* ASD 18 / TRY (R) 2, ASD 18 / CO 43, IR 20 / FL 478, IR 20 / CSR 23, ADT 49 / CSR 23, CO (R) 49 / Vytilla 6, CO (R) 50/ TRY (R) 2 recorded positive and significant *sca* effects. Three hybrids *viz.,* IR 20 / FL 478, IR 20 / CSR 23 and CO (R) 50/ TRY (R) 2 possessed good combiners as their parents and excelled with superior SCA for this trait. Hence, these hybrids were the best source of varietal improvement through pedigree method of breeding. Four hybrids *viz.,* ASD 18 / TRY (R) 2, ASD 18 / CO 43, ADT 49 / CSR 23 and CO (R) 49 / Vytilla 6 had parents either of one good combiner and one poor combiner or both poor combiners. Hence, biparental mating followed by recurrent selection in the segregating generations would help to break linkages and allow accumulation of desirable genes in those crosses for this trait. Similar results were reported by Sankar et al. (2008).

While considering the *sca* effects of hybrids for spikelet fertility there seemed to be positive and significant *sca* effects for nine crosses *viz.,* ASD 18 / TRY (R) 2, ASD 18 / CO 43, IR 20 / FL 478, IR 20 / CSR 23, ADT 49 / TRY (R) 2, ADT 49 / CSR 23, CO (R) 49 / CO 43, CO (R) 50/ TRY (R) 2 and CO (R) 50 / Vytilla 6. All the hybrids except IR 20 / CSR 23 and CO (R) 50 / TRY (R) 2 possessed parents with both poor combiners or one good and one poor combiner. This indicated the predominance of dominance gene for spikelet fertility. Hence, selection in early segregating generation would not be sufficient to yield desirable segregants. This may possibly overcome by delaying selection to later generations. The result was in accordance with Sankar et al. (2008) and Verma et al. (2010). For 100 grain weight, eight hybrids *viz.,* ASD 18 / Vytilla 6, IR 20 / FL 478, IR 20 / CSR 23, IR 20 / CO 43, ADT 49 / TRY (R) 2, CO (R) 49 / FL 478, CO (R) 50/ TRY (R) 2 and CO (R) 50 / Vytilla 6 recorded negative and significant *sca* effects. It was observed that parents of all the hybrids except IR 20 / FL 478 and IR 20 / CSR 23 were of either one poor or one good combiner or both poor combiners indicated the presence dominance gene action. These results were in accordance with findings of Thirumeni et al. (2000).

Yield is the complex phenomenon and also is the end product of multiplicative interaction between various yield components. High and significant *sca* effects were recorded in eleven hybrids *viz.,* ASD 18 / TRY (R) 2, ASD 18 / CO 43, ASD 18 / Vytilla 6, IR 20 / FL 478, IR 20 / CSR 23, ADT 49 / TRY (R) 2, ADT 49 / CSR 23, CO (R) 49 / Vytilla 6, CO (R) 50 / CO 43, CO (R) 50 / CSR 23 and CO (R) 50/ TRY (R) 2 for single plant yield. Three hybrids *viz.,* IR 20 / CSR 23, CO (R) 50/ TRY (R) 2 and CO (R) 50 / CSR 23 had both parents of good combiners. If additive genetic system was present in good combiners and the complement effects in F_1 acted in the same direction, these hybrids might produce desirable transgressive segregants in advanced generations. Remaining hybrids possessed parents with either poor combiners or one good and one poor combiner showed the preponderance of dominance gene action. Hence, instead of continuous selfing for a number of generations prior to selection, alternative intermating and selfing might be adopted to increase the spam of selections. These results were in conformity with earlier findings of Karthikeyan and Anbuselvam (2006). For Na^+: K^+ ratio eleven hybrids *viz.,* ASD 18 / TRY (R) 2, ASD 18 / CO 43, IR 20 / FL 478, IR 20 / CSR 23, IR 20 / Vytilla 6, ADT 49 / TRY (R) 2, CO (R) 49 / CSR 23, CO (R) 49 / CO 43, CO (R) 49 / Vytilla 6, CO (R) 50/ TRY (R) 2 and CO (R)

50 / CO 43 registered significant *sca* effects The *per se* performed hybrids *viz.,* IR 20 / FL 478 and CO (R) 50 / TRY (R) 2 had parents of good combiners and *sca* effect was pronounced. Rest of the hybrids possessed parents of both poor combiners or one good and one poor combiner suggesting the role of non-additive gene action. To harness the dominant gene action inter se mating could be practiced among selected segregants that might also breakdown any undesirable linkage for the accumulation of favorable alleles for the improvement of Na^{+}: K^{+} ratio.

The measure of *sca* effects for proline content indicated the significant *sca* effects in eight hybrids *viz.,* ASD 18 / TRY (R) 2, ASD 18 / CO 43, IR 20 / FL 478, IR 20 / CSR 23, IR 20 / Vytilla 6, ADT 49 / TRY (R) 2, CO (R) 49 / Vytilla 6 and CO (R) 50 / CO 43. Two hybrids *viz.,* IR 20 / CSR 23 and CO (R) 50 / CO 43 had both parents of good combiners. In these hybrids additive and dominance gene action might play a key role. Hence, a modified method of recombination breeding that is, one or two cycles of inter-mating the selected segregants followed by pedigree method of breeding might be resorted to harness both type of gene action. Remaining hybrids possessed parents with both poor combiners or one good and one poor combiner indicating the preponderance of dominance gene action. Hence in these crosses, postponement of selections to later generations to tag promising segregants possessing tolerance to sodicity would be of ideal method. The finding was in good accordance with earlier reports of Babu et al. (2005). While considering the *sca* effects of hybrids for total chlorophyll content, there seemed to be positive and significant *sca* effects for 10 crosses *viz.,* ASD 18 / TRY (R) 2, ASD 18 / CO 43, IR 20 / CSR 23, IR 20 / Vytilla 6, ADT 49 / TRY (R) 2, ADT 49 / CSR 23, CO (R) 49 / CO 43, CO (R) 49 / Vytilla 6, CO (R) 50 / TRY (R) 2 and CO (R) 50 / CSR 23. Except to hybrids *viz.,* CO (R) 50 / TRY (R) 2 and CO (R) 50 / CSR 23 all other hybrids possessed parents with both poor combiners and one good and one poor combiner indicating the predominance of non-additive gene action in governing this trait. Hence, selection in advanced generation was only possible method to improve the total chlorophyll content. This finding was in good accordance with earlier reports of Shanthi et al. (2011).

The measure of *sca* effect for chlorophyll a : b ratio indicating the negative and significant *sca* effects for eight hybrids *viz.,* ASD 18 / TRY (R) 2, ASD 18 / CO 43, IR 20 / FL 478, IR 20 / Vytilla 6, ADT 49 / CSR 23, CO (R) 49 / FL 478, CO (R) 49 / CO 43 and CO (R) 50 / Vytilla 6. All hybrids with significant *sca* effects possessed parents with either one good and one poor combiner or both poor combiners. These cross combinations had the greatest chance of producing transgressive segregants in later generations. In these combinations, biparental approach would enhance the variability by breaking the genetical ceiling of the parents.

The results are in agreement with earlier report of Shanthi et al. (2011). For chlorophyll stability index three hybrids *viz.,* IR 20 / FL 478, IR 20 / CSR 23 and CO (R) 50 / TRY (R) 2 possessed good general combiners as their parents and excelled with superior SCA for this trait. Hence, these hybrids were the best source of varietal improvement through intermating of F_2 segregants followed by pedigree method of breeding. Similar results were reported by Mohan et al. (2000) and Babu et al. (2005).

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 and hence the crosses, which showed significantly high value of standard heterosis over FL 478 for yield and sodicity tolerant traits were taken into account in the present discussion. Two hybrids *viz.,* IR 20 / CSR 23 and CO (R) 50 / TRY (R) 2 excelled with significant heterosis over standard parent for most of the traits under study. The former recorded high standard heterotic effect for seven traits *viz.,* number of productive tillers per plant, panicle length, number of filled grains per panicle, single plant yield, Na^{+}: K^{+} ratio, proline content and chlorophyll stability index and the later registered significant heterosis for number of productive tillers per plant, panicle length, number of filled grains per panicle, single plant yield, chlorophyll a/b ratio and chlorophyll stability index. The third most important hybrid was ASD 18 / TRY (R) 2 which showed, significant standard heterosis for five important sodicity tolerant traits. Three hybrids *viz.,* IR 20 / FL 478, ADT 49 / TRY (R) 2 and CO (R) 50 / CSR 23 recorded significant standard heterotic values for five traits each were found to be suitable for heterosis breeding under sodic environment.

Conclusion

Since, predominance of dominant gene action involved in the inheritance of complex traits like sodicity tolerance and yield, one or two cycles of inter mating among selected segregants in the segregating generations followed by recombination breeding in advanced generations would be an ideal approach to get superior segregants/cultures through breaking up of undesirable linkages and allowing favorable genes to recombine. As a whole, on perusal of data for hybrids based on *per se*, *sca* effects and standard heterosis were presented in Table 7 and the hybrids *viz.,* IR 20 / CSR 23, ADT 49 / TRY (R) 2, CO (R) 50 / TRY (R) 2, IR 20 / FL 478, ASD 18 / TRY (R) 2 and CO (R) 50 / CSR 23 were found to be suitable for heterosis breeding under sodic environment.

Table 7. Evaluation of hybrids based on *per se* performance, *sca* effects and standard heterosis.

S/N	Traits	*Per se*, sca effects and standard heterosis
1.	Days to 50% flowering	CO (R) 49 / TRY (R) 2, CO (R) 50 / Vytilla 6
2.	Plant height (cm)	ASD 18 / CO 43, CO (R) 49 / TRY (R) 2
3.	Number of productive tillers per plant	ASD 18 / TRY (R) 2, IR 20 / FL 478, IR 20 / Vytilla 6, ADT 49 / TRY (R) 2, CO (R) 49 / Vytilla 6, CO (R) 50 / CSR 23, CO (R) 50 / TRY (R) 2
4.	Panicle length (cm)	IR 20 / CSR 23, ADT 49 / TRY (R) 2
5.	Number of filled grains per panicle	ASD 18 / TRY (R) 2, IR 20 / CSR 23, ADT 49 / CSR 23, CO (R) 50 / TRY (R) 2
6.	Spikelet fertility (%)	
7.	100-grain weight (g)	
8.	Single plant yield (g)	IR 20 / FL 478, IR 20 / CSR 23, ADT 49 / TRY (R) 2, CO (R) 50 / TRY (R) 2, CO (R) 50 / CSR 23, CO (R) 50 / CO 43
9.	$Na^+ : K^+$ ratio	ASD 18 / TRY (R) 2, IR 20 / CSR 23, ADT 49 / TRY (R) 2, IR 20 / FL 478,
10.	Proline content (µg g^1)	ASD 18 / CO 43, IR 20 / FL 478, IR 20 / CSR 23
11.	Total chlorophyll content (mg g^{-1})	ADT 49 / TRY (R) 2, CO (R) 50 / TRY (R) 2, CO (R) 50 / CSR 23
12.	Chlorophyll a/b ratio	ASD 18 / TRY (R) 2, ADT 49 / CSR 23, CO (R) 50 / Vytilla 6
13.	Chlorophyll stability index (%)	ASD 18 / TRY (R) 2, IR 20 / CSR 23, ADT 49 / CSR 23, CO (R) 50 / TRY (R) 2, CO (R) 50 / Vytilla 6

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