Environment and Ecology 40 (4C) : 2690—2696, October—December 2022
ISSN 0970-0420

Study of Heterosis in Alkaline Tolerant, Saline Tolerant and Long Grained Rice (*Oryza sativa* L.) Genotypes under Sodic Soil

Snehansu Singh, Shiva Mohan, Aarti Sharma, Veerendra Kumar, O. P. Verma

Received 30 March 2022, Accepted 16 September 2022, Published on 25 November 2022

ABSTRACT

An experiment was conducted to study heterobeltiosis (HB) and standard heterosis (SH) against saline check (CSR43) and alkaline check (USAR3) on 36 crosses, obtained from a crossing program in 15 rice genotypes (saline soil tolerant, ST, alkaline soil tolerant, AT and long grained, LG), following Line x Tester mating design; with the main objective to divulge the potential of F_1s under soil conditions of Genetics and Plant Breeding Department Research Farm at ANDUAT, Ayodhaya UP. In way to study the F_1s based on types of parents involved in the cross; the 36 crosses were divided into six different types based on viz., AT x AT, ST x ST, AT x ST, ST x AT, LG x AT and LG x ST. The results indicated considerable amount of HB and SH for all the yield and yield attributing traits in aforementioned six types of crosses, except in ST x ST types which did not show significant positive heterosis for yield per plant trait either for HB or SH (against both saline and alkaline checks). For yield per plant traits, cross IR 71895-3 x AGAMI MI; a LG X ST type of cross showed highest SH against both saline and alkaline checks. Cross NDRK 5012 x FL 478, a AT x ST type of cross showed highest significant value for HB.

Keywords Rice, Line x tester, Heterobeltiosis, Standard heterosis.

INTRODUCTION

Rice is an important cereal crop of world and India too; half of the world population and nearly half of the Indian population depend on it. As a food, rice is of paramount importance and it is on frontline in the fight against world's hunger and poverty. The United Nations General Assembly (UNGA) during its 57th session on 16th December 2002 declared, 2004 as the "International Year of Rice". Rice is grown in all types of soil in India, including problematic soil viz., saline, alkaline. According to data published by ICAR; "Degraded and Wastelands of India-Status and Spatial Distribution" in 2010; alkaline and saline soils in India cover an area of 3.7 and 2.73 million hectares of land respectively. The cultivation practiced on problematic soil adversely affects the production potential of rice. There are many ways to overcome

Snehansu Singh [1]
[1] Senior Research Fellow Indian Institute of Wheat and Barley Research, ICAR, Karnal, Haryana, India

Shiva Mohan [2]*, Veerendra Kumar [4]
[2, 4] Assistant Professor, Department of Agriculture Invertis University, Bareilly 243003, UP, India

Aarti Sharma [3]
[3] Assistant Professor, Department of Genetics and Plant Breeding Lovely Professional University, Phagwara, Punjab, India

O. P. Verma [5]
[5] Associate Professor, Department of Genetics and Plant Breeding, ANDUA and T, Ayodhaya, UP, India

Email: shivagupta136@gmail.com
*Corresponding author

Table1. List of genotypes used in the present experiment. Alkaline soil tolerant genotypes= AT, Saline soil tolerant genotype=ST, Long-grained genotypes=LG.

Lines	Characteristics	Lines	Characteristics	Lines	Characteristics
AT401	ST	IR61920	LG	NDRK50035	AT
CSR10	ST	IR71866	LG	NDRK50012	AT
Jallahri	AT	IR71895	LG	NDRK50014	AT
CSR23	ST	NDRK50033	AT	NDRK50024	AT
Testers	Characteristics	Testers	Characteristics	Testers	Characteristics
Agami MI	ST	FL478	ST	NDU2009	AT
Check	Characteristics	Check	Characteristics	--	--
CSR 43	ST	USAR3	AT	--	--

problems of saline and alkaline soil for cultivation purposes. Developing salt/alkaline tolerant varieties through systematic breeding program can be one of those solutions.

Development of new varieties for saline and alkaline types of soil can be done following heterosis breeding. Heterosis is widely exploited in varietal development program, and it can be used to develop saline and alkaline varieties too. In the present study, heterosis, (heterobeltiosis and standard heterosis against an alkaline soil tolerant variety and a saline tolerant variety) was studied on F_1s developed from crosses of alkaline tolerant, saline tolerant and long grained varieties in problematic soil (sodic soil) of Ayodhaya, UP.

MATERIALS AND METHODS

The experiment was conducted at Genetics and Plant Breeding Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhaya in *kharif* season 2013 and 2014. Experimental material constituted of 15 rice genotypes (Table 1). These genotypes were sown in crossing block to obtain 36 F_1 seeds by crossing 12 lines with 3 testers, following Line x Tester mating design in *kharif* 2013. The 36 F_1 seeds were harvested and kept in dry and cool place to be sown in next season. In *kharif* 2014, 36 F_1s and 15 parents seeds were sown along with two check varieties CSR43 (check for saline tolerant F_1s) and USAR3 (check for alkaline tolerant F_1s) in a Randomized Block Design in three replications. The soil of experimental plot had plant height 9.37 and electrical conductivity 2.74 dS/m. Measurements of extents of problematic soils, viz., plant height and electrical conductivity were measured in laboratory of Soil Science Department of ANDUAT. Field data were recorded on randomly selected 5 plants from each line of three replications (36F_1s, 15 parents and 2 checks). Data was recorded for traits viz., days to 50% flowering, flag leaf area, plant height, number of effective tillers plant^{-1}, panicle length, spikelets plant^{-1}, spikelet fertility, harvest index and grain yield plant^{-1}.

ANOVA for Randomized Block Design (Table 2) was calculated by Panse and Sukhatme (1967). Heterobeltiosis was calculated over better parent, while, standard heterosis was calculated against one saline soil tolerant variety CSR4A3 (SH_1) and one alkaline soil tolerant variety USAR 3 (SH_2).

RESULTS AND DISCUSSION

Analysis of variance for all the traits was significant at 1% level of significance which indicated presence of variability in the experimental populations and

Table 2. ANOVA of 36 F_1s for nine traits. *, ** significant at 5% and 1%, respectively.

Traits	Treatment (df=35)	Replication (df=2)
Days to 50% flowering	94.47**	3.24
Flag leaf area	26.13**	1.02
Plant height	147.76**	22.78**
Number of effective tillers plant^{-1}	13.09**	6.08
Panicle length	23.01**	1.43
Spikelets plant^{-1}	686.69**	117.69
Spikelet fertility	47.45**	6.70
Grain yield plant^{-1}	64.95**	0.19
Harvest index	10.95**	0.05

paved way for further biometrical calculations. Thakor *et al*. (2018), Sharma and Jaiswal (2020) have observed similar findings of ANOVA in the traits studied by them.

Heterobeltiosis (HB) for nine traits are discussed based on types of crosses viz., AT x ST (12), AT x AT (6), LG x ST (6), ST x ST (6), LG x AT (3) and ST x AT (3) which were obtained following hybridization program in 15 rice genotypes.

Salt tolerant x salt tolerant types of cross

This group contained six crosses out of which none of the crosses showed significant high HB or SH against either check salt tolerant variety or alkaline tolerant variety. However, for yield attributing traits viz., days to fifty per cent flowering, flag leaf area, plant height, number of effective tillers plant^{-1} and spikelets plant^{-1}, crosses showed high SH against saline and alkaline checks in desired direction (Tables 3 - 4). Rani and Reddy (2014) have recorded significant heterosis of cross Swarna x CSRC(S) 7-1-4 over better-parents for traits viz., number of filled grains panicle per panicle and grain yield per plant under coastal saline soil.

Alkaline x alkaline tolerant types of cross

Six out of 36 crosses were AT x AT types; among which four crosses showed significant positive HB for yield per plant. Three crosses each showed high SH against CSR 43 and USAR3. Cross NDRK 50024 x NDU 2009, showed highest HB and SH against both saline and alkaline check varieties. Performance of crosses against saline check CSR43 was poor for yield attributing traits viz., plant height, panicle length, spikelets plant^{-1}, spikelet fertility and harvest index; as no cross exhibited significant heterosis in desired direction for these traits (Tables 3, 4 - 5). Similar findings have been reported by Shukla *et al*. (2020) in their work.

Long grained x saline tolerant types of cross

LT x ST type of crosses were six in number out of which, four crosses showed high HB. Four crosses each showed significant SH against CSR43 and USAR3. Cross IR 71895-3 x AGAMI MI, showed highest HB and SH for saline and alkaline tolerance. More number of crosses exhibited high heterosis against alkaline check than saline check for yield attributing traits viz., days to fifty per cent flowering, flag leaf area, plant height, number of effective tillers plant^{-1} and grain yield plant^{-1} (Tables 3, 4 - 5). Senguttuvel *et al*. (2015) have studied standard heterosis among crosses in saline soil conditions and recorded high standard heterosis among few crosses for yield per plant and other yield attributing traits.

Long grained x alkaline tolerant types of cross

Out of three crosses under this group, two crosses each showed significant high HB and SH against check varieties (CSR43 and USAR3). Cross IR 61920-3 x NDU 2009 and IR 71895-3 x NDU 2009, showed high HB and SH against both types of checks. However, no cross showed HB or SH for panicle length, spikelets plant^{-1} and spikelet fertility (Tables 4 - 5). These results are in congruent with work of Shanthi *et al*. (2011).

Salt tolerant x alkaline tolerant types of cross

Three crosses were in this group, out of which two crosses viz., CSR10 x NDU 2009 and CSR23 x NDU 2009 exhibited high significant positive HB and SH against CSR43 and USAR3 for yield per plant trait. However, cross CSR10 x NDU 2009 and CSR23 x NDU-2009, showed no HB, and SH for traits viz., spikelets plant^{-1}, spikelet fertility and harvest index (Table 4 and 5). Rajpoot *et al*. (2017) have reported similar findings in their work.

A thorough evaluation of six types of crosses for yield and yield attributing traits of rice studied in the present study divulged that experimental material contained considerable degree of heterobeltiosis and standard heterosis against saline and alkaline check varieties for yield and yield related traits. ST x ST type of crosses showed no heterosis for yield per plant trait. While in other group of crosses, considerable number of crosses showed HB and SH against alkaline variety check (CSR43) and saline variety check (USAR3). Following findings are in congruent with work of Shanthi *et al*. (2011), Gopikannan and Ganesh (2013), Rani and Reddy (2014), Rajpoot *et al*. (2017),

Table 3. Heterobeltiosis (HB) and standard heterosis against saline soil tolerant variety (SH_1) alkaline soil tolerant variety (SH_2). *, ** significant at 5% and 1%, respectively.

Crosses	Days to fifty per cent flowering			Flag leaf area			Plant height		
AT x ST type of cross	BP	SH_1	SH_2	BP	SH_1	SH_2	BP	SH_1	SH_2
JAL LAHRI*AGAMI MI	-16.31**	-1.07	-7.67**	-15.49**	-8.93**	14.27**	9.90**	15.73**	2.42
JAL LAHRI*FL 478	-9.45**	-0.71	-7.33**	-10.94**	-1.79	23.23**	7.82**	9.47**	-3.12
NDRK 50033*AGAMI MI	-3.78**	0	-6.67**	-1.15	8.25**	35.83**	14.98**	16.86**	3.42
NDRK 50033*FL 478	-5.15**	-1.43	-8.00**	-15.53**	-6.85*	16.88**	-11.20**	-9.85**	-20.21**
NDRK 50035*AGAMI MI	-7.01**	2.29	-4.53**	-5.78	-13.33**	8.75*	-9.67**	-0.91	-12.30**
NDRK 50035*FL 478	-10.42**	-1.79	-8.33**	-23.23**	-15.34**	6.23	2.11	3.67	-8.25**
NDRK 5012*AGAMI MI	-15.56**	-5.00**	-11.33**	-4.84	-9.51**	13.55**	-3.63	4.04*	-7.92**
NDRK 5012*FL 478	-2.61*	6.79**	-0.33**	-17.61**	-9.15**	14.00**	-2.1	-0.61	-12.03**
NDRK 5014*AGAMI MI	12.50**	12.50**	5.00**	-19.95**	-16.26**	5.07	6.93**	10.98**	-1.78
NDRK 5014*FL 478	8.57**	8.57**	1.33**	-22.02**	-14.00**	7.90*	19.39**	21.21**	7.27**
NDRK 5024*AGAMI MI	-2.93*	6.43**	-0.67	-2.33	-13.28**	8.82*	0.8	10.35**	-2.34
NDRK 5024*FL 478	-0.98	8.57**	1.33	-19.58**	-11.32**	11.27**	2.45	4.02*	-7.95**
AT x AT type of cross									
JAL LAHRI*NDU 2009	-12.08**	-6.43**	-12.67**	-19.07**	-12.79**	9.43*	0.81	6.16**	-6.05**
NDRK 50033*NDU 2009	-4.12**	-0.36	-7.00**	-3.31	5.88	32.85**	9.73**	11.52**	-1.31
NDRK 50035*NDU 2009	5.70**	12.50**	5.00**	-7.96**	-7.91**	15.55**	-4.83**	4.39*	-7.61**
NDRK 5012*NDU 2009	-12.42**	-6.79**	-13.00**	16.86**	16.92**	46.71**	-3.79*	3.86	-8.08**
NDRK 5014*NDU 2009	1.79	1.79	-5.00**	-17.01**	-13.19**	8.92*	12.04**	16.29**	2.92
NDRK 5024*NDU 2009	-2.68*	3.57**	-3.33**	17.37**	17.43**	47.35**	12.11**	22.73**	8.62**
LG x ST type of cross									
IR 61920-3*AGAMI MI	13.92**	11.07**	3.67**	-12.28**	-9.88**	13.07**	6.99**	10.23**	-2.45
IR 61920-3*FL 478	14.65**	11.79**	4.33**	-1.16	9.00**	36.76**	-6.40**	-4.97*	-15.90**
IR 71866-3*AGAMI MI	-13.31**	-4.64**	-11.00**	-23.50**	-16.62**	4.62	20.98**	16.40**	3.02
IR 71866-3*FL 478	-5.86**	3.21*	-3.67**	-12.28**	-3.27	21.37**	10.82**	6.63**	-5.64**
IR 71895-3*AGAMI MI	-6.49**	2.86*	-4.00**	-8.39**	-6.21*	17.68**	-4.62*	-1.52	-12.84**
IR 71895-3*FL 478	4.89**	15.00**	7.33**	-19.07**	-10.76**	11.98**	3.85	5.43**	-6.69**
ST x ST type of cross									
AT 401*AGAMI MI	-8.12**	1.07	-5.67**	-3.22	-14.77**	6.95	6.33**	5.68**	-6.47**
AT 401*FL 478	-6.19**	2.86*	-4.00**	-18.88**	-10.54**	12.25**	0.7	0.09	-11.42**
CSR10*AGAMI MI	10.74**	6.79**	-0.33	-33.31**	-20.87**	-0.71	10.74**	-5.20*	-16.10**
CSR10*FL 478	-5.19**	-8.57**	-14.67**	-29.99**	-16.94**	4.22	11.65**	-4.42*	-15.41**
CSR23*AGAMI MI	-4.75**	0.36	-6.33**	-14.96**	-12.42**	9.89*	9.85**	14.43**	1.27
CSR23*FL 478	-5.42**	-0.36	-7.00**	-11.83**	-2.77	22.00**	-3.15	-1.67	-12.97**
LG x AT type of cross									
IR 61920-3*NDU 2009	2.56	0	-6.67**	-1.88	0.81	26.49**	2.19	5.29**	-6.82**
IR 71866-3*NDU 2009	-0.34**	6.07**	-1	10.35**	20.28**	50.92**	16.42**	12.01**	-0.87
IR 71895-3*NDU 2009	-4.36**	1.79	-5.00**	16.33**	19.09**	49.43**	6.38**	9.85**	-2.78
ST x AT type of cross									
AT 401*NDU 2009	2.35	8.93**	1.67	-6.41*	-6.36*	17.50**	10.52**	9.85**	-2.78
CSR10*NDU 2009	15.56**	11.43**	4.00**	-21.30**	-6.63*	17.16**	9.05**	-6.65**	-17.38**
CSR23*NDU 2009	-5.42**	-0.36	-7.00**	8.39**	11.63**	40.07**	-2.55	1.52	-10.16**

Table 4. Heterobeltiosis (HB) and standard heterosis against saline soil tolerant variety (SH_1) alkaline soil tolerant variety (SH_2). *, ** significant at 5% and 1%, respectively.

Crosses	Number of effective tillers plant^{-1}			Panicle length			Spikelets plant^{-1}		
AT x ST type of cross	BP	SH_1	SH_2	BP	SH_1	SH_2	BP	SH_1	SH_2
JAL LAHRI*AGAMI MI	2.63	14.71	34.48*	-16.88**	-22.38**	-23.80**	-8.74	-6.7	-3.09
JAL LAHRI*FL 478	13.16	26.47*	48.28**	34.75**	25.83**	23.54**	14.58**	11.17*	15.46**
NDRK 50033*AGAMI MI	5.13	20.59	41.38**	8.35*	-10.60**	-12.22**	-26.21**	-24.57**	-21.65**
NDRK 50033*FL 478	28.21**	47.06**	72.41**	36.54**	14.83**	12.74**	20.46**	16.87**	21.39**
NDRK 50035*AGAMI MI	8.33	14.71	34.48*	-10.26**	-14.30**	-15.86**	-5.83	-3.72	0
NDRK 50035*FL 478	-8.33	-2.94	13.79	-12.07**	-16.03**	-17.56**	2.28	0.25	4.12
NDRK 5012*AGAMI MI	36.36**	32.35**	55.17**	29.61**	1.46	-0.39	-6.55	-4.47	-0.77
NDRK 5012*FL 478	30.30*	26.47*	48.28**	42.20**	19.60**	17.43**	18.93**	15.38**	19.85**

Table 4. Continued.

Crosses	Number of effective tillers plant^{-1}			Panicle length			Spikelets plant^{-1}		
AT x ST type of cross	BP	SH_1	SH_2	BP	SH_1	SH_2	BP	SH_1	SH_2
NDRK 5014*AGAMI MI	20	23.53*	44.83**	1.52	-2.52	-4.29	2.43	4.71	8.76
NDRK 5014*FL 478	-5.71	-2.94	13.79	-2.76	-6.62*	-8.32*	1.49	1.49	5.41
NDRK 5024*AGAMI MI	-7.32	11.76	31.03*	-3.4	-5.96	-7.67*	-16.50**	-14.64**	-11.34*
NDRK 5024*FL 478	-36.59**	-23.53*	-10.34	2.99	0.26	-1.56	6.33	8.44	12.63*
AT x AT type of cross									
JAL LAHRI*NDU 2009	-34.21**	-26.47*	-13.79	-12.34**	-18.15**	-19.64**	1.38	9.18	13.40**
NDRK 50033*NDU 2009	-15.38	-2.94	13.79	22.19**	5.03	3.12	-20.74**	-14.64**	-11.34*
NDRK 50035*NDU 2009	27.78*	35.29**	58.62**	9.85**	4.9	2.99	-14.52**	-7.94	-4.38
NDRK 5012*NDU 2009	3.03	0	17.24	17.89**	1.34	-0.51	-14.06**	-7.44	-3.87
NDRK 5014*NDU 2009	17.14	20.59	41.38**	-11.31**	-14.83**	-16.38**	-27.19**	-21.59**	-18.56**
NDRK 5024*NDU 2009	-7.32	11.76	31.03*	-4.22	-6.75*	-8.45**	-36.64**	-31.76**	-29.12**
LG x ST type of cross									
IR 61920-3*AGAMI MI	-13.33	14.71	34.48*	-7.10*	-4.64	-6.37*	-5.58	-3.47	0.26
IR 61920-3*FL 478	-31.11**	-8.82	6.9	-20.39**	-18.28**	-19.77**	-0.51	-3.47	0.26
IR 71866-3*AGAMI MI	8.11	17.65	37.93**	-22.45**	-18.54**	-20.03**	-1.94	0.25	4.12
IR 71866-3*FL 478	24.32*	35.29**	58.62**	-11.22**	-6.75*	-8.45**	8.18	4.96	9.02
IR 71895-3*AGAMI MI	-21.05*	-11.76	3.45	-8.66*	-21.72**	-23.15**	3.88	6.2	10.31*
IR 71895-3*FL 478	15.79	29.41*	51.72**	22.26**	4.77	2.86	0.77	-2.23	1.55
ST x ST type of cross									
AT 401*AGAMI MI	-25.00*	-11.76	3.45	19.29**	-6.62*	-8.32*	-10.92*	-8.93	-5.41
AT 401*FL 478	-15	0	17.24	8.82*	-8.48*	-10.14**	-3.84	-6.7	-3.09
CSR10*AGAMI MI	37.04*	8.82	27.59*	-0.6	-11.92**	-13.52**	10.44*	12.90**	17.27**
CSR10*FL 478	59.26**	26.47*	48.28**	9.42*	-3.05	-4.81	-11.11*	-12.66*	-9.28
CSR23*AGAMI MI	41.94**	29.41*	51.72**	23.18**	-3.58	-5.33	-3.94	2.73	6.7
CSR23*FL 478	38.71**	26.47*	48.28**	12.60**	-5.3	-7.02*	10.44*	18.11**	22.68**
LG x AT type of cross									
IR 61920-3*NDU 2009	-6.67**	-2.94	13.79	3.61	6.36	4.42	-18.20**	-11.91*	-8.51
IR 71866-3*NDU 2009	16.22	26.47*	48.28**	-14.88**	-10.60**	-12.22**	-7.14	0	3.87
IR 71895-3*NDU 2009	-2.63	8.82	27.59*	5.55	-9.27**	-10.92**	-9.91*	-2.98	0.77
ST x AT type of cross									
AT 401*NDU 2009	-22.50*	-8.82	6.9	-1.08	-14.97**	-16.51**	-13.59**	-6.95	-3.35
CSR10*NDU 2009	-3.7	-23.53*	-10.34	13.60**	0.66	-1.17	-10.60*	-3.72	0
CSR23*NDU 2009	25.81*	14.71	34.48*	18.03**	1.46	-0.39	-3.69	3.72	7.73

Table 5. Heterobeltiosis (HB) and standard heterosis against saline soil tolerant variety (SH_1) alkaline soil tolerant variety (SH_2). *, ** significant at 5% and 1%, respectively.

Crosses	Spikelet fertility			Grain yield plant^{-1}			Harvest index		
AT x ST type of cross	BP	SH_1	SH_2	BP	SH_1	SH_2	BP	SH_1	SH_2
JAL LAHRI*AGAMI MI	-0.85	2.07	-1.16	-9.43	-13.62*	-20.38**	-0.12	-12.49**	-13.08**
JAL LAHRI*FL 478	4.97	8.07*	4.65	50.92**	26.48**	16.59**	22.32**	0.23	-0.44
NDRK 50033*AGAMI MI	-3.56	-4.07	-7.10*	69.00**	61.18**	48.58**	-0.26	-8.38**	-8.99**
NDRK 50033*FL 478	2.45	4.75	1.43	1.37	-4.88	-12.32*	8.30**	-0.52	-1.19
NDRK 50035*AGAMI MI	4.44	5.34	2.01	38.01**	31.62**	21.33**	-8.42**	-11.73**	-12.32**
NDRK 50035*FL 478	-1.43	0.78	-2.41	105.64**	68.64**	55.45**	0.53	-3.1	-3.75
NDRK 5012*AGAMI MI	-0.52	-0.21	-3.36	60.38**	52.96**	41.00**	12.24**	-1.66	-2.32
NDRK 5012*FL 478	8.30**	10.72**	7.22*	126.60**	81.75**	67.54**	15.74**	0.28	-0.39
NDRK 5014*AGAMI MI	0.91	4.24	0.94	-10.13	-11.05	-18.01**	13.67**	-0.41	-1.07
NDRK 5014*FL 478	-0.54	2.75	-0.5	51.95**	50.39**	38.63**	22.85**	0.66	-0.01
NDRK 5024*AGAMI MI	-11.30**	-11.76**	-14.55**	83.29**	74.81**	61.14**	8.67**	-4.7	-5.33*
NDRK 5024*FL 478	5.55	7.91	4.5	104.40**	79.18**	65.17**	14.75**	0.64	-0.03
AT x AT type of cross									
JAL LAHRI*NDU 2009	-2.64	0.24	-2.94	4.72	-3.08	-10.66*	13.13**	-1.84	-2.49
NDRK 50033*NDU 2009	3.9	2.61	-0.64	43.84**	34.96**	24.41**	5.27	-3.3	-3.94
NDRK 50035*NDU 2009	4.85	5.76	2.41	16.11*	7.46	-0.95	3.54	-0.19	-0.86
NDRK 5012*NDU 2009	-3.44	-3.14	-6.20*	50.00**	38.82**	27.96**	7.21*	-6.98**	-7.60*

Table 5. Continued.

Crosses	Spikelet fertility			Grain yield plant^{-1}			Harvest index		
AT x ST type of cross	BP	SH_1	SH_2	BP	SH_1	SH_2	BP	SH_1	SH_2
NDRK 5014*NDU 2009	-2.06	1.17	-2.03	-20.52**	-21.34**	-27.49**	14.69**	-0.49	-1.15
NDRK 5024*NDU 2009	-0.64	-1.88	-4.98	68.33**	55.78**	43.60**	15.47**	1.27	0.6
LG x ST type of cross									
IR 61920-3*AGAMI MI	1.17	2.25	-0.99	71.43**	63.50**	50.71**	-8.73**	-9.13**	-9.74**
IR 61920-3*FL 478	-1.52	0.68	-2.5	81.89**	45.89**	34.48**	0.27	-0.17	-0.84
IR 71866-3*AGAMI MI	1.53	1	-2.2	49.87**	43.70**	32.46**	8.23**	-5.18*	-5.81*
IR 71866-3*FL 478	4.77	7.12*	3.73	-25.74**	-28.79**	-34.36**	8.72**	-10.92**	-11.51**
IR 71895-3*AGAMI MI	3.17	2.63	-0.62	91.91**	83.03**	68.72**	12.34**	-1.18	-1.84
IR 71895-3*FL 478	-1.68	0.52	-2.66	-2.52	-10.54	-17.54**	13.84**	0.14	-0.53
ST x ST type of cross									
AT 401*AGAMI MI	5.29	4.75	1.43	0.27	-4.37	-11.85*	-1.66	-13.84**	-14.42**
AT 401*FL 478	-0.22	2.01	-1.21	-6.79	-22.37**	-28.44**	19.84**	-1.81	-2.46
CSR10*AGAMI MI	-11.35**	-10.79**	-13.61**	2.96	-1.8	-9.48	7.17*	-5.85*	-6.48**
CSR10*FL 478	-0.9	1.32	-1.88	5.93	1.03	-6.87	10.69**	-2.76	-3.41
CSR23*AGAMI MI	4.52	3.98	0.69	11.59	6.43	-1.9	2.66	-1.13	-1.79
CSR23*FL 478	1.83	4.11	0.82	-5.77	-24.42**	-30.33**	5.22*	1.34	0.67
LG x AT type of cross									
IR 61920-3*NDU 2009	-0.18	0.88	-2.31	62.22**	50.13**	38.39**	-3.9	-4.33	-4.97*
IR 71866-3*NDU 2009	-1.89	-2.73	-5.8	-10.46	-14.14*	-20.85**	15.33**	0.06	-0.6
IR 71895-3*NDU 2009	6.25	4.93	1.61	41.39**	30.85**	20.62**	3.23	-9.20**	-9.80**
ST x AT type of cross									
AT 401*NDU 2009	-10.14**	-11.25**	-14.06**	-15.00*	-21.34**	-27.49**	3.16	-10.50**	-11.09**
CSR10*NDU 2009	0.91	1.56	-1.66	56.33**	49.10**	37.44**	3.68	-8.92**	-9.53**
CSR23*NDU 2009	-1.62	-2.84	-5.92	79.44**	66.07**	53.08**	0.03	-3.66	-4.3

Shukla *et al*. (2020), who had estimated heterosis in rice in sodic or saline soil conditions.

Alkaline x saline tolerant types of cross

This type of crosses was 12 in number, among which for yield per plant trait, 9 crosses showed significant positive HB. Cross NDRK50013 x FL478, showed highest HB followed by NDRK50035 x FL478. Nine crosses each showed significant positive SH against saline tolerant and alkaline tolerant varieties CSR43 and USAR3, respectively (Table 5). Cross NDRK50013 x FL478 also showed highest SH against both saline and alkaline check varieties. For harvest index, no crosses showed significant positive SH. Shukla *et al*. (2020) have obtained significant negative heterosis in four crosses for seed yield per plant trait, in their study.

CONCLUSION

All the six types of crosses, except ST x ST type, showed considerable manifestation of HB, SH against both saline and alkaline checks for yield per plant trait. The crosses which showed high magnitude of heterosis against saline or alkaline checks could be utilized in future breeding program to develop saline or alkaline soil tolerant varieties.

ACKNOWLEDGEMENT

We would like to express our sincere thanks to my beloved endeavors.

REFERENCES

Gopikannan M, Ganesh SK (2013) Investigation on combining ability and heterosis for sodicity tolerance in rice (*Oryza sativa* L.) *Afr J Agricult Res* 8(32): 4326-4333.

Rajpoot P, Singh PK, Verma OP, Tripathi N (2017) Studies on genetic variability and heritability for quantitative characters in rice (*Oryza sativa* L.) under sodic soil. *J Pharma Phtytochem* 6(4): 1162-1165.

Rani MS, Reddy PR (2014) Exploitation of heterosis for various yield attributes in rice (*Oryza sativa* L.) under coastal saline soils. 2nd International Conference on Agricultural and Horticultural Sciences. *Agrotechnol* 4(3): 6-12.

Senguttuvel P, Thiyagarajan K, Vijayalakshmi C, Geetha S, Kannanbapu JR, Brajendra, Viraktamath BC, Bhadana VP, Raju S, Subbarao LV, Padmavathi G, Ravindrababu V (2015)

Prediction of combining ability and heterosis in three line rice hybrids for salinity tolerance. *Annals Plt Soil Res* 17: 438-441.

Shanthi P, Jebaraj S, Geetha S (2011) Study on gene action for sodic tolerance traits in rice (*Oryza sativa* L.). *Elect J Plt Breed* 2(1): 24-30.

Sharma A, Jaiswal HK (2020) Heterosis for yield and grain quality parameters in basmati rice (*Oryza sativa* L.). *Elect J Plt Breed* 11(4): 1106-1115.

Shukla SN, Singh SC, Kumar A (2020) Effects of heterosis for yield and yield contributing characters in rice (*Oryza sativa* L.) under sodic soil. *Curr J Appl Sci Tech* 39(12): 53.

Thakor RP, Balat JR, Delvadiya, IR Rathva SR (2018) Heterosis and heterobeltosis studies for grain yield and yield attributing traits in rice (*Oryza sativa* L.). *Elect J Plt Breed* 9(4): 1286-1294.