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Estimates of Heterosis, Inbreeding Depression and Transgressive Segregation in Rice (*Oryza sativa* L.) Under Sodic Soil

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Abstract

The present investigation was carried out at the Main Experimental Station of Acharya Narendra Deva University of Agriculture and Technology, Narendra Nagar (Kumarganj), Ayodhya (U.P.) India. A field experiment was conducted by using a line x tester set of 63 F_1s and 63 F_2s derived by crossing 21 rice genotypes/varieties as lines (females) with three testers (males) *viz.,* Narendra Usar Dhan 3, CSR 23 and IR 28 with 2 check varieties (Jaya and CSR 43) of rice (*Oryza sativa* L.) in randomized complete block design with three replications to work out the heterosis, transgressive segregation and inbreeding depression effects for various attributes under the sodic soil condition. Among these, F_1s *viz*., NDRK 5037 x Narendra Usar Dhan 3, NDRK 5062 x IR 28, NDRK 5062 x CSR 23, NDRK 5037 x CSR 23 and NDRK 5040 x Narendra Usar Dhan 3 were showed significant positive standard heterosis for grain yield per plant over SV_1 and SV_2. All these crosses also had highly significant inbreeding depression for grain yield per plant in F_2 generation. Inspite of grain yield of these F_1s had significant heterosis and inbreeding depression for some of the other yield contributing characters also. This study indicated the presence of non additive gene action in the inheritance of grain yield per plant and some of the other yield contributing characters. Tolerant breeding populations showed similar banding pattern whereas susceptible exhibited similar banding pattern but possesses wide variations between tolerant and susceptible. At 35 kDa the medium to dark bands were present in parents, F_1s, F_2s, transgressive segregants and checks while in highly inbreeding depressed cross combinations, variable range of the bands were observed *viz.,* absence of bands, light, medium and dark bands. The data offer a valuable resource for advancing the understanding and facilitating the utilization of additive and non-additive information for rice improvement.

Keywords: Rice, heterosis, transgressive segregation, inbreeding depression, SDS PAGE, protein profiling, breeding populations and sodic soil.

Introduction

Rice (*Oryza sativa* L.), is a staple food for more than 50% of the world population (Jiang *et al*., 2020, Shrivastav *et al.,* 2023). It forms the breath of life '*prana*' for the human being. Rice is a high caloric food, which contain 75% starch, 6-7% protein, 2-2.5% fat, 0.8% cellulose and 5-9% ash. India has the largest area of 46.38 million hectare constituting 28.26% of the land under rice in the world and rank second in total production 130.29 million tonnes next to China with an average productivity of 2809 Kg/ha (DAC and FW, 2021-2022). It showed that the average productivity of rice is very low in our country. Therefore, there is immence need to develop high yielding, multiple resistance and wider adoptive hybrid varieties. Taking the above points under consideration the present investigation was carried out to sort out the best heterotic hybrids for yield and its component characters. Heterosis is a common phenomenon in which an F_1 hybrid performs better than either inbred parent (Shrivastav *et al.*, 2022, Modunshim *et al.,* 2022).

Heterosis or hybrid vigor refers to the phenomenon that the heterozygous first filial generation (F_1) performs better than its parental inbred lines in target traits. With the development of the first commercial hybrid maize variety in the 1930s (Ayalneh 2020) and the development of rice hybrid varieties in the early 1970s in China, exploitation of heterosis in crop plants has achieved remarkable yield advantages over inbred lines and remains a crucial approach to increase agricultural production for global food demand in response to rapidly increasing global population and changing climate (Gu *et al.,* 2023).

In crop genetic research, the mechanism of heterosis has always been a key topic and several hypotheses have been proposed the dominance hypothesis, which proposes the masking of deleterious recessive parental alleles in the hybrid; the overdominance hypothesis, which attributes heterosis to the superiority of heterozygotes over parental homozygotes at individual loci; and the epistatic hypothesis, which postulates the contribution of positive epistatic interactions between non-allelic genes. However, there are no reports explaining the genetic mechanisms responsible for heterosis of rice grain quality traits (You *et al.,* 2022).

Inbreeding depression and heterosis are related phenomena of fundamental importance to evolutionary biology and applied genetics. Inbreeding depression refers to reduced fitness of progenies resulting from inbreeding (Stebbins 1958; Wright 1977). In contrast, heterosis, or hybrid vigor, is defined as the superiority of an F_1 hybrid over its parents (Stuber, 1994). Both heterosis and inbreeding depression are widely observed in both animal and plant kingdoms. In evolution, inbreeding depression may contribute to formation of reproductive barriers between species and populations, while heterosis may be an important force in maintenance of genetic variation in populations. In applied genetics, exploitation of heterosis has played a major role in the genetic improvement of many crop plants and animals (Falconer, 1981; Stuber, 1994). Heterosis and inbreeding depression are considered two aspects of the same phenomenon (Falconer, 1981; Mather and Jinks, 1982). Heterosis is clearly related to heterozygosity, but it has long been debated how heterozygosity results in heterosis. Two predominant theories were proposed as the genetic basis of heterosis. The overdominance hypothesis (Shull, 1908; East, 1936) states that heterozygosity at single loci confers properties that are superior to either homozygote. In contrast, the dominance hypothesis (Bruce, 1910; Keeble and Pellew, 1910; Jones, 1917) proposed that dominant factors from either parent mask deleterious recessive mutations from the other parent in the heterozygous F_1. In both cases, the inbreeding depression is due to segregation and expression of deleterious recessive mutations in inbred progenies (Allard, 1960; Simmonds, 1979). A third, less widely embraced hypothesis suggests that heterosis may arise from epistasis between alleles at different loci (Stuber, 1994; Goodnight, 1999).

Transgressive segregation is common in plant breeding populations, where small minority of recombinants are outliers relative to parental phenotypes. While this phenomenon has been attributed to complementation and epistatic effects, the physiological, biochemical and molecular bases have not been fully illuminated. The phenomenon of transgressive segregation, which is observed in both natural and artificial populations created by plant breeding, is characterized by the occurrence of minority phenotypic outliers relative to parental range across segregating or recombinant population derived from genetically divergent parents. In addition to the classic explanations attributing complementation and epistatic interactions as major mechanisms behind transgressive traits, the possible roles of coupling and uncoupling effects and genetic network rewiring have also been recently proposed (Vega and Frey, 1980; Rieseberg *et al.,* 1999; Dittrich-Reed and Fitzpatrick, 2013; de Los Reyes, 2019). Combined with the paradigms of genomic biology, the potential of transgressive individuals for enhanced yield of crops have been established, but its true potential for adaptive traits is yet to be determined (DeVicente and Tanksley, 1993).

The soil sodicity is a major factor that adversely affects the growth and yield of crop plant. Approximately one third of the land area on which rice grown is affected by salinity. Approximately 10% of the world's total land area (950 million ha), 20% of the world's arable land (300 million ha) and 50% of the total irrigated land (230 million ha) are affected by soil salinization. Further, it is expected to influence 50% of total cultivated land in 2050 at a dis-quieting rate. Every year almost 12 billion US$ are globally lost due to salt stress that significantly affects the agricultural production (Shrivastav *et al.,* 2022a).

Materials and Methods

This experiment was carried out at the Main Experimental Station of A.N.D. University of Agriculture and Technology, Narendra Nagar (Kumarganj), Ayodhya (U.P.) India. The experimental material was based on a line x tester set of 63 hybrids (F_1s) and 63 F_2s developed by crossing 21 lines (females) *viz.,* NDRK 5004, NDRK 5093, NDRK 5040, NDRK 5062, NDRK 5037, NDRK5025, NDRK 50059, NDRK 5081, NDRK 50047, NDRK 5039, IR 66946-3R-178-1-1 (FL 478), Sushk Samrat, IR 85897, Pant 10, CSR 10, Sarjoo 52, Narendra 2064, Narendra Usar Dhan 2, Deepak, Sundri and Pusa Basamati 1 with 3 testers (males) *viz.,* Narendra Usar Dhan 3, CSR 23 and IR 28. An attempt was made to make a sixty three cross combinations during *kharif* season 2016 for F_1s production and grown in *kharif* season 2017 for F_2s production and *kharif* season 2017 again fress F_1s generated by crossing The 63 F_1s and 63 F_2s along with their parents including two checks, Jaya and CSR 43 (total set of 152 genotypes) were studied to work out the heterosis, transgressive segregation and inbreeding depression effects of their various attributes on grain yield under the sodic soil in randomized complete block design with three replications during *Kharif* 2018 (Arunachalam, 1974). Data on various attributes *viz*., days to 50% flowering, chlorophyll content, leaf nitrogen, leaf temperature, flag leaf area (cm^2), plant height (cm), panicle bearing tillers per plant, panicle length(cm), spikelets per panicle, grains per panicle, spikelet fertility (%), biological yield per plant (g), harvest-index (%), L:B ratio, 1000-grain weight (g), amylose content, protein content and grain yield per plant (g) were recorded and analysed as per Kempthorne (1957). Heterobeltiosis and standard heterosis estimated as per Fonseca and Patterson (1968) and inbreeding depression as per Hill (1966). For the transgressive segregation the observations were recorded on fifteen randomly selected plants taken from each genotype of each replication. The per centage of superior segregants in particular cross is recorded by calculating the number of plants exceeding mean value of best check to the total number of plants in a cross.

The selected genotypes of different breeding populations were used to work out the SDS PAGE protein profiling of rice seed following method described by Laemmli, (1970).

Results and Discussions

The heterosis breeding has been used extensively in improving yield potential through development of hybrid cultivars in most of the allogamous crops and some autogamous crops like rice as well. The exploitation of heterosis for developing high yielding commercial hybrids in rice has been found highly fruitful inspite of its autogamous nature because significant heterosis is encountered in F_1 hybrids and successful and economical technology for commercial hybrid seed production is available. A wide range of variation in the estimates of heterobeltiosis and standard heterosis was observed for grain yield per plant and other related traits. Top five F_1s that showed good heterotic potential for grain yield and yield contributing traits over Jaya (SV1) as well as CSR 43 (SV2) were NDRK 5037 x Narendra Usar Dhan 3, NDRK 5062 x IR 28, NDRK 5062 x CSR 23, NDRK 5037 x CSR 23 and NDRK 5040 x Narendra Usar Dhan 3 (**Table 1**). The findings will help promote rice improvements in context to establishment of heterotic patterns as a requirement for a sustainable long-term success of hybrid rice breeding (Shrivastav *et al.,* 2022a).

The estimates of inbreeding depression of eighteen characters of sixty-three crosses are presented in **Table 2.** The range of inbreeding depression for grain yield per plant was ranged from 4.39 (NDRK 5004 x Narendra Usar Dhan 3) to 38.74% (NDRK 5037 x CSR 23). The depressed cross was 38.74% (NDRK 5037 x CSR 23) followed by 31.98 (NDRK 5047 x Narendra Usar Dhan 3), 30.95 (Sundri x IR 28), 30.90 (NDRK 5004 x IR 28) and 30.56% (NDRK 5025 x CSR 23). Among 63 crosses all were positively significant while none had negatively significant inbreeding depression.

Table 1: Most promising crosses based on mean performance, heterobeltiosis and standard heterosis (SV_1 and SV_2), SCA effect, GCA effect of parent for grain yield / plant

S. No.	Crosses	*per se* Performance	Heterosis over better-parent	Heterosis over SV_1	Heterosis over SV_2	SCA effect	GCA effect of parent	Traits for which these the cross also exhibited desirable heterosis
1	NDRK 5004* NarendraUsarDhan 3	19.73**	26.47**	45.32**	36.10**	3.08**	HxH	CC, FLA, PL, S/P, G/P, SF, BY/P, HI, 1000-GW, AC
2	Sarjoo 52 * NarendraUsarDhan 3	19.61**	25.41**	44.44**	35.27**	1.92**	HxH	LN, PBT/P, PL, S/P, G/P, SF, BY/P, HI, AC, PC
3	NDRK 5040* NarendraUsarDhan 3	19.48**	24.89**	43.51**	34.40**	3.68**	HxH	CC, S/P, G/P, SF, BY/P, HI,
4	NDRK 5062 * IR 28	18.92**	21.26**	39.33**	30.49**	2.10**	HxL	CC, PH, PL, S/P, G/P, BY/P, L/B
5	CSR 10* NarendraUsarDhan 3	18.65**	19.55**	37.37**	28.65**	0.63**	HxH	CC, PH, PBT/P, PL, S/P, G/P, SF, BY/P, HI
6	NDRK 5062* CSR 23	18.47**	18.38**	36.02**	27.39**	0.50*	HxA	CC, LN, PL, S/P, G/P, BY/P
7	Narendra 2064* Narendra UsarDhan 3	17.80**	7.81**	31.11**	22.79**	1.26**	HxH	CC, FLA, PH, PBT/P, S/P, G/P, BY/P, 1000-GW, AC
8	NDRK 5039* NarendraUsarDhan 3	17.61**	12.88**	29.71**	21.48**	1.73**	HxH	DF, CC, PL, S/P, BY/P, L/B, 1000-GW, AC
9	NDRK 5059* IR 28	17.12**	17.39**	26.10**	18.10**	3.35**	HxL	CC, LN, FLA, PH, PL, G/P, SF, BY/P, L/B, AC
10	NDRK 5037* NarendraUsarDhan 3	16.82**	7.84**	23.91**	16.05**	1.22**	HxH	CC, FLA, PH, PL, S/P, G/P, SF, BY/P, HI, L/B, PC

Traits: DF=Days to 50% flowering, **CC=**Chlorophyll content (spad value), **LN**= Leaf nitrogen (spad value), **LT**= Leaf temperature (spad value), **FLA**=Flag leaf area(cm^2), **PH**=Plant height (cm), **PBT/P**=Panicle bearing tillers / plant, **PL**=Panicle length (cm), **S/P**=Spikelets / panicle, **G/P=** Grains per panicle, **SF**=Spikelet fertility (%), **BY/P**= Biological yield / plant (g), **HI**=Harvest index (%), **L/B**=L/B ratio**, 1000-GW=**1000- grain weight (g), **AC**= Amylose content, **PC**= Protein content and **GY/P**=Grain yield / plant(g)

Table 2: Estimates of inbreeding depression (%) in different yield and yield contributing traits of rice under sodic soil

S. No.	Crosses	Days to 50% flowering	Chlorophyll content	Leaf nitrogen	Leaf temperature	Flag leaf area (cm^2)	Plant height (cm)	Panicle bearing tillers/ plant	Panicle length (cm)	Spikelets/ panicle	Grains/ panicle	Spikelet fertility (%)	Biological yield/ plant (g)	Harvest index (%)	L/B ratio	1000-grain weight (g)	Amylose content	Protein content (%)	Grain yield/ plant (g)
1	NDRK 5004*NarendraUsarDhan 3	-2.01	4.90**	-12.08**	9.23**	0.92**	-0.93	8.65**	1.06*	1.33	5.43**	4.17**	2.96**	1.42	0.72**	0.51	1.18**	0.63**	4.39**
2	NDRK 5004*CSR 23	-0.40	-6.85**	-8.80**	8.53**	2.40**	-0.30	10.03**	1.81**	1.76	3.86*	2.08	10.61**	7.87**	0.11	0.13	0.99**	0.58**	17.59**
3	NDRK 5004*IR 28	-1.54	1.68**	-0.62**	-0.29	0.86**	0.63	16.57**	1.60**	1.71	2.03	0.31	2.34*	29.14**	0.11	0.18	1.40**	0.45**	30.90**
4	FL478*NarendraUsarDhan 3	-2.81	26.96**	-17.72**	1.55**	-1.05**	5.36**	8.78**	2.75**	-12.18**	-12.18**	0.04	9.45**	13.39**	0.54**	0.09	1.08**	0.51**	21.54**
5	FL 478*CSR 23	-0.78	-20.78**	-19.06**	6.70**	-1.05**	0.66	9.40**	2.02**	4.01*	-5.00**	-9.49**	14.41**	2.97**	0.42**	0.52	0.55**	0.57**	16.97**
6	FL 478*IR 28	-0.80	4.06**	-23.28**	-6.61**	-1.03**	1.34	10.06**	1.90**	3.74*	0.00	-3.87**	8.62**	7.47**	0.22**	0.41	1.26**	0.53**	15.50**
7	NDRK 5093*Narendra U sarDhan 3	-0.79	13.68**	-8.44**	5.56**	-2.19**	-0.17	15.96**	4.11**	3.04	19.61**	17.03**	7.30**	20.29**	0.32**	0.15	1.19**	0.26**	26.17**
8	NDRK 5093*CSR 23	0.40	-7.09**	13.75**	3.71**	-5.48**	-1.14	15.78**	2.93**	4.34*	11.82**	7.87**	2.52*	24.56**	0.73**	0.56	2.20**	0.26**	26.49**
9	NDRK 5093*IR 28	0.39	2.66**	8.94**	7.96**	-2.22**	-0.29	16.26**	3.09**	3.74*	3.83*	0.06	3.45**	7.00**	0.54**	0.49	2.00**	0.28**	10.10**
10	SushkSamrat*NarendraUsarDhan 3	-0.39	-1.25**	-11.46**	0.32	3.90**	-1.31	17.16**	2.23**	4.63**	6.87**	2.33	4.12**	19.73**	0.33**	0.20	1.90**	0.54**	23.17**
11	SushkSamrat*CSR 23	-3.23*	-20.35**	-17.38**	4.73**	2.38**	-0.71	17.29**	3.00**	3.29	7.97**	4.85**	4.69**	16.01**	-0.11	0.22	2.34**	0.64**	20.14**
12	SushkSamrat*IR 28	-2.37	-7.00**	-1.76**	-8.18**	3.88**	-1.22	17.49**	2.17**	3.69*	8.28**	4.78**	4.30**	14.35**	3.73**	0.18	3.66**	0.66**	18.27**
13	IR 85897*NarendraUsarDhan 3	-1.59	7.96**	9.30**	10.07**	0.74**	-0.32	11.72**	2.70**	11.28**	18.81**	8.47**	11.93**	2.39	1.06**	0.18	3.48**	0.27**	13.99**
14	IR 85897*CSR 23	0.00	11.41**	-6.98**	6.41**	2.97**	-0.59	10.12**	2.23**	12.02**	18.72**	7.62**	7.08**	4.63**	1.53**	0.31	3.49**	0.30**	11.30**
15	IR 85897*IR 28	0.00	8.58**	-7.32**	1.81**	1.47**	-0.19	12.74**	1.23*	8.96**	17.03**	8.87**	16.07**	-0.82	1.13**	0.28	3.93**	0.53**	15.51**
16	Pant 10*NarendraUsarDhan 3	-2.79	14.12**	1.10**	-3.92**	-2.92**	0.32	10.59**	1.63**	10.93**	13.58**	2.97*	9.85**	3.28**	-2.91**	0.37	2.86**	0.56**	12.88**
17	Pant 10*CSR 23	-3.23*	17.06**	-18.56**	0.27**	-0.55	0.11	11.42**	1.50**	14.90**	15.78**	1.07	4.00**	11.75**	-1.34**	0.23	3.43**	0.56**	15.25**
18	Pant 10*IR 28	-1.61	9.21**	-10.40**	6.55**	-0.91**	0.20	12.31**	3.21**	6.87**	10.19**	3.58*	2.52**	21.85**	-0.34**	0.22	3.46**	0.55**	23.80**
19	CSR 10*NarendraUsarDhan 3	0.79	16.60**	-1.19**	0.12	-2.54**	3.26**	7.33**	3.19**	4.49**	10.12**	5.92**	8.39**	-3.96**	-6.53**	0.45	1.17**	1.17**	4.80**
20	CSR 10*CSR 23	-3.23*	6.48**	0.00	5.55**	-2.61**	3.48**	7.73**	2.39**	3.93*	10.11**	6.43**	3.13**	5.28**	-0.59**	0.22	0.84**	0.66**	8.28**
21	CSR 10*IR 28	-1.59	-1.00**	0.55**	1.49**	0.00	1.11	1.40**	1.37**	3.32*	6.58**	3.39	2.29*	3.58**	1.96**	0.37	1.67**	0.72**	5.82**
22	NDRK 5040*NarendraUsarDhan 3	-1.99	7.79**	9.96**	-4.16**	3.25**	0.92	10.14**	2.04**	8.98**	7.67**	-1.43	2.19*	2.33	-5.29**	0.16	1.43**	0.48**	4.42**
23	NDRK 5040*CSR 23	-4.15**	16.70**	20.44**	-5.21**	3.00**	1.36	9.03**	2.78**	9.75**	6.46**	-3.65*	6.40**	17.99**	-1.85**	0.24	29.26**	0.38**	23.26**
24	NDRK 5040*IR 28	-3.60**	10.76**	15.90**	-1.42**	4.09**	-0.60	11.50**	2.87**	9.48**	8.17**	-1.42	2.46*	19.50**	-1.70**	0.21	0.84**	0.15**	21.51**
25	Sarjoo 52*NarendraUsarDhan 3	-0.39	34.47**	-4.05**	-6.71**	5.78**	0.39	15.05**	1.93**	5.34**	7.86**	2.63	3.50**	5.55**	0.28**	0.38	0.54**	1.02**	8.89**
26	Sarjoo 52*CSR 23	-2.33	17.29**	-10.59**	-0.55**	3.47**	-0.18	15.92**	2.15**	8.96**	6.34**	-3.03*	4.48**	21.62**	1.26**	0.35	0.43**	2.33**	25.26**
27	Sarjoo 52*IR 28	-0.38	17.61**	-8.20**	-6.20**	2.06**	0.26	14.71**	2.11**	7.95**	8.25**	0.18	7.63**	11.52**	2.82**	0.23	0.50**	1.13**	18.33**
28	NDRK 5062*NarendraUsarDhan 3	-2.02	13.32**	-3.55**	-7.92**	2.88**	0.05	14.91**	2.13**	4.63**	7.46**	2.96*	7.09**	9.13**	-0.89**	0.41	1.30**	0.38**	15.65**
29	NDRK 5062*CSR 23	-1.93	12.62**	-14.27**	-4.00**	4.83**	0.15	8.73**	2.49**	5.09**	5.04**	-0.08	4.86**	6.45**	-1.08**	0.12	1.58**	0.32**	11.03**
30	NDRK 5062*IR 28	-1.59	12.61**	-9.78**	-5.04**	3.86**	0.10	13.61**	2.32**	3.68*	8.89**	5.39**	0.68	12.03**	-0.86**	0.29	1.35**	0.36**	12.64**
31	Narendra 2064*NarendraUsarDhan 3	-1.59	9.92**	-4.01**	1.84**	2.64**	-0.18	7.44**	2.67**	5.88**	5.10**	-0.89	-2.61**	16.67**	0.80**	0.21	0.60**	0.35**	14.49**
32	Narendra 2064*CSR 23	-2.42	16.53**	-3.78**	-6.05**	2.77**	-0.66	7.39**	1.96**	4.33*	6.40**	2.18	2.70**	24.99**	0.76**	1.35**	12.44**	0.39**	27.00**
33	Narendra 2064*IR 28	-6.02**	18.31**	-10.11**	0.02	0.51	0.00	5.45**	1.55**	8.96**	9.31**	0.40	5.26**	21.89**	2.01**	1.04*	0.90**	0.36**	26.07**

34	NDRK 5037*NarendraUsarDhan 3	-1.59	5.95**	13.64**	-2.32**	2.46**	-0.62	8.73**	2.85**	10.16**	8.56**	-1.78	2.47**	20.44**	0.53**	0.27	0.73**	2.55**	22.43**
35	NDRK 5037*CSR 23	-4.38**	14.86**	9.17**	2.35**	4.20**	0.21	0.00	1.93**	8.22**	11.06**	3.09*	6.21**	34.58**	1.31**	0.66	0.71**	0.51**	38.74**
36	NDRK 5037*IR 28	-4.44**	10.14**	8.80**	-2.47**	3.07**	-0.76	9.26**	1.77**	11.17**	11.66**	0.55	3.80**	27.67**	1.37**	0.31	0.28**	0.52**	30.40**
37	NDRK 5025*NarendraUsarDhan 3	-5.18**	21.27**	-2.86**	-6.12**	0.12	0.54	13.52**	2.11**	10.09**	8.13**	-2.16	9.86**	14.39**	1.42**	1.11*	1.25**	0.59**	22.77**
38	NDRK 5025*CSR 23	-1.21	21.94**	-2.38**	-5.81**	2.00**	0.08	14.35**	1.73**	12.36**	10.90**	-1.67	6.25**	26.00**	1.53**	0.53	1.43**	0.46**	30.56**
39	NDRK 5025*IR 28	-2.38	15.42**	7.15**	-6.34**	1.34**	0.16	9.42**	1.85**	11.98**	11.62**	-0.40	10.22**	11.29**	-4.60**	0.31	0.88**	0.40**	20.45**
40	NDRK 5059*NarendraUsarDhan 3	-1.57	14.95**	-5.37**	1.66**	1.15**	-0.06	13.45**	2.07**	16.39**	19.80**	4.08**	12.12**	19.79**	0.84**	0.62	0.66**	0.24**	29.53**
41	NDRK 5059*CSR 23	-1.22	16.29**	0.56**	-3.78**	2.32**	-0.74	16.22**	2.27**	11.24**	14.97**	4.20**	6.92**	0.84	0.44**	-0.63	0.55**	0.23**	7.74**
42	NDRK 5059*IR 28	-1.58	16.13**	-3.97**	-6.20**	2.18**	0.00	14.91**	2.01**	15.35**	20.35**	5.96**	8.57**	0.46	0.92**	0.16	0.48**	0.31**	9.02**
43	NDRK 5081*NarendraUsarDhan 3	-4.45**	18.79**	8.82**	-1.53**	-5.96**	-0.83	12.04**	2.99**	19.19**	23.93**	5.86**	12.95**	15.91**	-2.73**	0.19	0.82**	0.33**	26.81**
44	NDRK 5081*CSR 23	-4.03**	18.42**	15.74**	-3.92**	1.57**	-0.55	13.50**	2.04**	19.92**	29.20**	11.58**	11.11**	6.79**	1.33**	0.35	1.20**	0.31**	17.19**
45	NDRK 5081*IR 28	-9.36**	19.84**	15.65**	-0.32	3.02**	-0.30	13.26**	2.10**	20.49**	29.81**	11.72**	5.67**	17.09**	0.14*	0.44	0.59**	0.35**	21.75**
46	NDRK 5047*NarendraUsarDhan 3	-3.17*	25.76**	3.86**	-4.26**	3.06**	0.22	4.70**	2.74**	5.67**	8.52**	3.05*	1.60	30.82**	0.72**	0.07	0.81**	0.61**	31.98**
47	NDRK 5047*CSR 23	-4.44**	19.89**	33.77**	-0.69**	1.02**	0.03	9.21**	1.91**	4.68**	18.02**	14.00**	6.67**	10.46**	1.40**	0.14	0.52**	0.72**	16.45**
48	NDRK 5047*IR 28	-3.57**	12.80**	23.94**	-1.22**	2.62**	0.45	9.19**	3.02**	3.82*	9.07**	5.45**	7.94**	15.79**	1.10**	0.23	0.81**	0.70**	22.33**
49	NDRK 5039*NarendraUsarDhan 3	0.00	9.23**	23.45**	5.60**	0.21	-0.39	14.19**	2.90**	4.89**	22.93**	18.92**	-2.67*	20.14**	0.19**	0.36	0.71**	0.45**	18.03**
50	NDRK 5039*CSR 23	-1.20	23.99**	26.81**	-7.48**	2.76**	0.40	18.24**	1.91**	4.34**	7.00**	2.78	5.22**	12.02**	-1.15**	0.20	0.59**	0.47**	16.66**
51	NDRK 5039*IR 28	-1.19	24.43**	19.90**	0.96**	1.68**	0.05	17.20**	1.13*	3.85*	3.57	-0.36	10.24**	17.80**	1.50**	0.58	0.76**	0.49**	26.11**
52	NarendraUsarDhan 2*NarendraUsarDhan 3	-2.38	13.23**	-11.11**	0.26	2.56**	-0.43	7.47**	1.84**	6.71**	7.14**	0.44	2.31*	10.14**	-0.22**	0.30	0.43**	0.77**	12.39**
53	NarendraUsarDhan 2*CSR 23	-2.79*	17.13**	9.10**	1.88**	1.73**	-0.79	8.09**	2.86**	7.37**	-5.14**	-13.51**	4.10**	9.81**	0.78**	0.81	0.76**	0.31**	13.72**
54	NarendraUsarDhan 2*IR 28	-1.21	10.37**	-64.65**	4.16**	2.61**	-0.14	8.16**	2.64**	13.03**	10.65**	-2.75	5.88**	6.44**	0.76**	0.30	1.01**	0.23**	12.01**
55	Deepak*NarendraUsarDhan 3	-2.01	-2.76**	-34.29**	0.47	4.22**	0.24	6.82**	4.12**	10.64**	5.82**	-5.40**	4.46**	15.36**	1.51**	0.61	0.92**	0.27**	19.16**
56	Deepak*CSR 23	-2.40*	0.92**	-36.24**	1.23**	2.16**	-1.80	10.76**	1.65**	10.43**	14.07**	4.04**	9.57**	5.36**	-0.22**	0.60	0.65**	0.35**	14.53**
57	Deepak*IR 28	-2.83*	-1.78**	-19.27**	1.47**	-0.45	-1.31	8.83**	2.48**	11.28**	9.65**	-1.83	15.69**	11.86**	2.22**	0.22	0.86**	0.22**	25.96**
58	Sundri*NarendraUsarDhan 3	-4.78**	8.11**	-18.24**	-1.31**	0.43	0.00	11.07**	1.87**	13.13**	13.62**	0.57	19.05**	-0.16	0.37**	0.44	0.61**	1.09**	19.01**
59	Sundri*CSR 23	-2.72*	9.04**	-1.36**	-0.80**	2.60**	-0.45	10.87**	1.72**	11.65**	15.21**	4.06**	18.26**	5.94**	0.75**	0.47	0.95**	0.99**	23.09**
60	Sundri*IR 28	-3.57**	6.58**	7.94**	1.19**	4.17**	0.15	14.81**	1.56**	17.60**	15.68**	-2.35	6.38**	26.08**	0.26**	0.92*	1.16**	0.92**	30.95**
61	Pusa Basmati 1*NarendraUsarDhan 3	-1.74	10.18**	4.90**	1.14**	2.05**	0.42	10.28**	2.12**	4.03*	15.02**	11.43**	4.46**	18.70**	1.23**	0.26	0.78**	0.13**	22.34**
62	Pusa Basmati 1*CSR 23	-1.02	17.73**	1.82**	2.38**	3.23**	-0.63	10.59**	1.92**	14.06**	23.67**	11.20**	11.29**	9.29**	0.41**	0.18	0.70**	0.17**	19.61**
63	Pusa Basmati 1*IR 28	-4.00**	17.24**	1.81**	3.55**	3.81**	0.28	10.59**	2.76**	13.08**	19.93**	7.90**	4.40**	22.31**	0.53**	0.47	0.69**	0.46**	25.63**
Range of Inbreeding depression	**Min.**	-9.36	-20.78	-64.65	-8.18	-5.96	-1.80	0.00	1.06	-12.18	-12.18	-13.51	-2.67	-3.96	-6.53	-0.63	0.28	0.13	4.39
	Max.	0.79	34.47	33.77	10.07	5.78	5.36	18.24	4.12	20.49	29.81	18.92	19.05	34.58	3.73	1.35	29.26	2.55	38.74
No. of crosses with significant positive inbreeding depression		**0**	**54**	**27**	**29**	**45**	**3**	**62**	**63**	**57**	**58**	**30**	**59**	**56**	**44**	**4**	**63**	**63**	**63**
No. of crosses with significant negative inbreeding depression		**22**	**9**	**35**	**28**	**11**	**0**	**0**	**0**	**1**	**3**	**6**	**2**	**1**	**16**	**0**	**0**	**0**	**0**

Majority of the crosss combinations possessing high heterosis also had high estimates of inbreeding depression. Further, it indicated that both the heterosis as well as inbreeding depression is closely related phenomenon with preponderance of non additive gene action. The similar findings have also been reported by Alam *et al.,* (2004), Verma and Srivastava (2005), Sharma *et al.,* (2013) and Venkanna *et al.,* (2014). The presence of high heterosis for economically important characters is not only useful for developing hybrids, synthetic or composites through exploitation of heterosis, but also helps in obtaining transgressive segregants for development of superior homozygous lines.

In genetics, transgressive segregation is the formation of extreme phenotypes, or transgressive phenotypes, observed in segregated hybrid populations compared to phenotypes observed in the parental lines. The transgressive segregation was estimated as appearance of these trangressive (extreme) phenotypes either positive or negative in terms of fitness. The estimates of transgressive segregation for eighteen characters of sixty-three crosses are presented in **Table 3**.

For grain yield per plant twenty-one crosses over better parent, twenty-eight crosses over SV_1 and nineteen crosses over SV_2 exhibited positive and significant Transgressive segregation, due to increased *per se* performance in F_2 generation. As such selection of promising lines in segregating generation, especially to pick up the transgressive segregants by maintaining more number of progenies would be best perspective method to make progress for this trait. The top five transgressive segregants over better parent were NDRK 5004 x Narendra Usar Dhan 3 (26.47), Sarjoo 52 x Narendra Usar Dhan 3 (25.41), NDRK 5040 x Narendra Usar Dhan 3 (24.89), NDRK 5062 x IR 28 (21.26) and CSR 10 x Narendra Usar Dhan 3 (19.55) in grain yield per plant and these same crosses have best heterotic potential as well as high amount of inbreeding depression; it clearly indicated that preponderance of non additive gene action (additive x additive) in such type of cross combinations and showing transgressive segregation as well due to heritable and fixable nature of gene action. These results are similar to those of Verma and Srivastava (2005), Saleem *et al.,* (2008) and Seetharam *et al.,* (2013). For amylose content none of the crosse over better parent, twenty-four crosses over SV_1 and forty-two over SV_2 exhibited positive and significant residual heterosis, due to increased *per se* performance in F_2 generation. As such selection of promising lines in segregating generation, especially to pick up the transgressive segregants by maintaining number of progenies would be more persepective method to make progress for this trait. For protein content three crosses over better parent, forty-five over SV_1 and nine over SV_2 exhibited positive and significant residual heterosis. As such selection of promising lines in segregating generation, especially to pick up the transgressive segregants by maintaining number of progenies would be more persepective method to make progress for this trait. In F_2s segregating population, some of the crosses were found as transgressive segregants.

Table 3: Extent of transgressive segregation in F_2s for 18 characters in rice under sodic soil

S. No.	Crosses	Days to 50% flowering	Chlorophyll content	Leaf nitrogen	Leaf temperature	Flag leaf area (cm²)	Plant height (cm)	Panicle bearing tillers/plant	Panicle length (cm)	Spikelets/ panicle	Grains/ panicle	Spikelet fertility (%)	Biological yield/ plant (g)	Harvest Index(%)	L/B ratio	1000-grain weight (g)	Amylose content	Protein content (%)	Grain yield/ plant (g)
1	NDRK 5004*NarendraUsarDhan 3	-1.93	8.08	3.73	-10.49**	-0.38	-7.39**	1.60	-0.53	-2.63	-6.36**	-2.99	-2.96	26.33**	-21.56**	2.34	-0.31	-5.34**	26.47**
2	NDRK 5004*CSR 23	-3.09	-9.64	0.00	-5.68*	1.12	-1.47	0.64	-2.26	7.21**	-0.57	-11.22 **	3.51	-17.45**	-0.43	3.22	-0.24	-1.66*	0.59
3	NDRK 5004*IR 28	1.54	-15.34*	-0.62	-7.53**	-0.54	-7.33**	-8.01 **	-2.26	10.58**	-0.59	-12.70 **	9.65**	-14.01**	-3.64	2.53	-0.59	-2.92**	-5.84*
4	FL478* NarendraUsarDhan 3	1.59	-20.53**	4.40	-6.37*	-8.23**	-9.66**	2.46	-3.35	-23.25**	-25.67**	-2.30	-14.81**	-1.91	-25.47**	1.04	-30.56 **	-0.02	-1.32
5	FL 478*CSR 23	3.60	-8.65	13.84	-3.98	1.53	5.23**	1.76	-3.35	-18.49**	-16.24**	-0.40	-3.81	1.26	4.08	-0.68	-40.94 **	0.56	0.40
6	FL 478*IR 28	0.40	-19.57**	13.21	-1.05	-9.11**	0.44	0.70	-3.98	-24.82**	-22.79**	1.94	0.95	-8.70*	1.43	0.51	-33.12 **	0.59	-7.85**
7	NDRK 5093*Narendra U sarDhan 3	0.39	-12.33*	-1.10	-2.61	-11.02**	2.21*	-7.60 **	-1.77	-23.03**	-38.88**	-19.83 **	-5.93*	-17.17**	-24.82**	-13.35**	-39.83 **	-2.40**	-6.60**
8	NDRK 5093*CSR 23	-1.57	31.09**	-13.74	-3.55	5.09**	0.51	-7.89 **	-5.57*	-11.53**	-21.37**	-11.34 **	19.59**	-29.49**	0.96	-5.96*	-49.40 **	0.61	-15.65**
9	NDRK 5093*IR 28	1.57	24.08**	-4.95	-5.56*	-15.14**	5.04**	-9.65 **	-6.39**	8.73**	-0.79	-22.70 **	24.44**	-8.85*	-2.56	-13.71**	-43.24 **	-0.72	13.55**
10	SushkSamrat*NarendraUsarDhan 3	-0.77	-19.49**	0.54	-6.93*	-4.69**	4.08**	-10.83 **	-0.99	-9.65**	-17.11**	-7.45 **	-31.11**	-14.76**	-26.36**	-0.42	-43.78 **	-11.68**	-33.06**
11	SushkSamrat*CSR 23	-1.54	1.55	2.72	-6.49*	-4.52**	-0.42	-8.60 **	-4.51	3.26	-4.56**	-7.80 **	25.77**	-13.59**	-6.90*	4.32*	-52.63 **	-9.03	8.49**
12	SushkSamrat*IR 28	-0.38	-14.84**	-5.98	-8.68**	-3.98**	5.20**	-9.87 **	1.41	0.00	-13.71**	-12.87 **	9.88*	-12.28**	9.95**	2.92	-47.53 **	-9.91	-3.92
13	IR 85897*NarendraUsarDhan 3	-1.92	-13.80*	-11.70	-6.92*	-0.78	2.16*	-18.35 **	-2.96	-12.06**	-19.80**	-8.00 **	-28.89**	9.14*	-24.33**	2.65	-69.71 **	0.17	-14.06**
14	IR 85897*CSR 23	-4.21 *	-2.91	-2.13	-6.07*	-3.52**	2.16*	-7.56 **	-5.66*	-2.76	-9.69**	-7.36 **	8.25*	-0.93	12.79**	3.56	-74.40 **	1.79*	7.36**
15	IR 85897*IR 28	-1.53	-0.12	-6.38	-4.77	-1.32	2.43*	0.00	-2.43	-0.79	-1.29	-2.99	5.62	-3.84	5.46	3.04	-71.34 **	1.47	1.14
16	Pant 10*NarendraUsarDhan 3	0.39	-20.90**	-0.55	-3.70	-12.53**	-0.32	-17.63 **	3.15	-14.25**	-19.07**	-4.80 **	-11.85**	18.25**	-36.78**	-5.48*	-71.91 **	0.25	4.17
17	Pant 10*CSR 23	-0.39	-8.72	8.79	-8.12**	4.28*	-1.40	-9.96 **	3.41	-5.51*	-5.70**	-0.46	6.19	-26.09**	1.97	-1.83	-75.97 **	0.24	-8.54**
18	Pant 10*IR 28	-1.95	-1.24	4.95	-5.70*	-15.79**	9.40**	4.73	-1.18	2.08	3.49*	-1.44	2.65	-21.17**	10.33**	-5.28*	-73.34 **	0.26	0.58
19	CSR 10*NarendraUsarDhan 3	-0.40	-12.58*	-7.57	-1.97	-15.27**	-9.66**	2.02	2.50	29.85**	28.12**	-1.13	-2.96	23.26**	-41.58**	0.43	-25.52 **	-5.04**	19.55**
20	CSR 10*CSR 23	2.40	19.47**	-6.49	-5.04	4.37*	5.72**	-0.29	2.06	22.44**	35.33**	0.48	-6.06*	-12.54**	-9.27*	2.82	-36.69 **	-1.47	5.20*
21	CSR 10*IR 28	2.00	20.09**	-2.70	-4.44	-18.94**	0.48	1.15	5.59*	27.02**	31.25**	-1.57	-3.03	11.97**	6.08	8.39**	-28.84 **	-2.79**	13.48**
22	NDRK 5040*NarendraUsarDhan 3	1.59	2.63	-13.81	-4.60	-9.05**	-1.64	-7.15 **	-2.95	-2.19	-2.93*	-1.82	-0.74	21.82**	-38.49**	-3.53	-62.33 **	-1.41	24.89**
23	NDRK 5040*CSR 23	-0.40	-16.40**	-14.76	-2.75	-2.01	-2.82**	3.56	-2.33	9.02**	11.40**	-0.86	20.62**	-22.63**	9.67**	0.21	-77.12 **	0.83	-6.63**
24	NDRK 5040*IR 28	2.78	-14.58**	-11.90	-4.40	-13.34**	-0.30	0.40	-5.28	14.44**	11.41**	-2.58	22.68**	-19.15**	10.85**	-0.23	-64.42 **	-0.20	-0.86

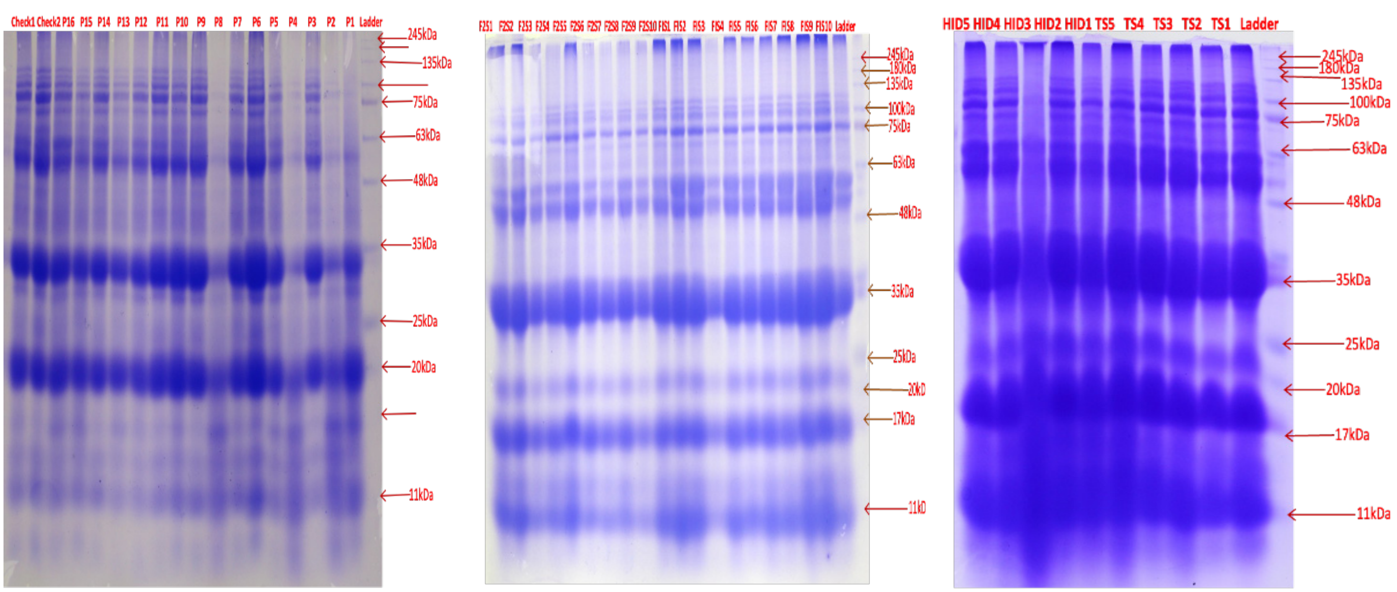
S. No.	Crosses	Days to 50% flowering	Chlorophyll content	Leaf nitrogen	Leaf temperature	Flag leaf area (cm²)	Plant height (cm)	Panicle bearing tillers/plant	Panicle length (cm)	Spikelets/ panicle	Grains/ panicle	Spikelet fertility (%)	Biological yield/ plant (g)	Harvest Index(%)	L/B ratio	1000-grain weight (g)	Amylose content	Protein content (%)	Grain yield/ plant (g)
25	Sarjoo 52*NarendraUsarDhan 3	-1.15	-18.72**	7.29	-3.33	-6.61**	0.45	-7.06 **	0.99	18.18**	21.70**	-0.77	-2.82	22.97**	-41.99**	-2.30	0.92	0.60	25.41**
26	Sarjoo 52*CSR 23	0.38	-8.05	-2.08	-9.03**	-2.91	0.24	-6.76 **	-3.26	31.31**	29.01**	-4.44 **	-9.86**	-18.73**	-6.49	-0.88	1.27	3.77**	-6.61**
27	Sarjoo 52*IR 28	1.15	-17.34**	3.13	-2.30	-7.72**	1.11	-6.18 **	-1.28	30.91**	31.13**	-0.27	-14.79**	9.13*	-4.23	-0.60	1.11	0.64	-3.11
28	NDRK 5062*NarendraUsarDhan 3	-0.78	-16.45**	7.94	-0.68	-4.12*	0.83	1.46	0.91	-5.50**	-12.08**	-7.85 **	-2.96	0.25	-44.67**	-0.18	-3.82	1.45	6.67**
29	NDRK 5062*CSR 23	3.53	1.09	10.05	-4.08	-3.90*	0.33	0.58	1.42	-11.01**	-29.38**	-20.96 **	11.38**	-4.11	6.49	-0.54	-17.94 **	0.51	18.38**
30	NDRK 5062*IR 28	0.00	0.99	1.06	-1.70	-7.93**	-0.48	1.75	3.36	-8.81**	-23.13**	-16.07 **	18.70**	2.17	8.73*	1.46	-8.01 **	0.59	21.26**
31	Narendra 2064*NarendraUsarDhan 3	0.00	-19.01**	-1.62	-2.78	-1.93	3.48**	0.54	-1.45	21.36**	-0.22	-17.42 **	16.30**	-23.08**	-18.96**	5.50**	2.51	0.15	7.81**
32	Narendra 2064*CSR 23	-0.78	-24.54**	3.78	1.86	-1.87	2.93**	1.35	1.74	23.55**	1.12	-17.82**	28.57**	-32.19**	11.35**	2.12	-9.01 **	0.49	-12.82**
33	Narendra 2064*IR 28	3.13	-25.34**	5.95	-5.19	0.33	2.55*	2.96	1.74	21.76**	-6.47**	-22.87**	28.57**	-35.32**	18.77**	4.68**	2.58	0.48	-16.94**
34	NDRK 5037*NarendraUsarDhan 3	-2.30	-12.10*	-13.64	-2.64	-0.73	-2.78*	0.88	-2.74	30.71**	30.13**	-0.71	16.18**	-7.85	-23.03**	-22.05**	-4.15	-0.66	7.84**
35	NDRK 5037*CSR 23	0.38	-20.30**	-5.05	-8.81**	-2.70*	-1.35	0.58	-3.48	32.82**	28.85**	-3.25*	11.03**	-40.43**	8.76**	-10.41**	-18.44 **	1.51*	-18.46**
36	NDRK 5037*IR 28	-0.77	-9.59*	-16.16	-4.74	1.11	0.47	0.29	-6.43**	25.14**	23.08**	-1.92	11.76**	-21.83**	19.07**	-22.59**	-9.10 **	1.37	-11.98**
37	NDRK 5025*NarendraUsarDhan 3	4.76*	-19.86**	-6.25	-3.93	-20.18**	-0.38	0.00	-0.13	38.51**	34.20**	-2.40	-5.19	-31.63**	-43.69**	-14.57**	-13.54 **	-5.27**	-14.17**
38	NDRK 5025*CSR 23	0.00	-22.39**	-10.42	-2.82	-8.91**	0.14	0.00	0.38	38.07**	32.07**	-3.65*	17.65**	-40.97**	2.12	-3.94	-27.05 **	-1.96*	-30.53**
39	NDRK 5025*IR 28	3.20	-15.32**	-11.98	-4.67	-24.99**	-0.41	-0.27	0.76	35.01**	28.27**	-4.30**	20.59**	-21.49**	-6.75	-12.54**	-18.54 **	-3.21**	-5.43*
40	NDRK 5059*NarendraUsarDhan 3	0.39	-10.41*	7.69	-6.54*	-9.86**	-1.85	-4.07*	4.11	-0.44	-3.91**	-2.65	-14.07**	-26.88**	-42.39**	3.87	1.92	-1.51	-20.66**
41	NDRK 5059*CSR 23	-3.49	-11.51*	-2.75	-4.18	-1.54	-2.44*	-6.23**	1.03	9.91**	8.29**	-4.62**	21.00**	-12.68**	-10.33**	3.83	1.78	0.04	5.65*
42	NDRK 5059*IR 28	-0.39	-16.83**	0.55	-2.49	-12.99**	-1.72	-5.69**	0.15	-1.18	-0.55	1.42	28.00**	-8.37*	13.36**	3.19	1.95	0.11	17.39**
43	NDRK 5081*NarendraUsarDhan 3	-1.15	-17.86**	-10.14	-3.93	-32.01**	-14.01**	0.80	-2.73	-12.28 **	-17.60**	-5.22**	-10.37**	-22.05**	-48.01**	-1.23	-4.07	-0.68	-12.52**
44	NDRK 5081*CSR 23	-1.15	-14.19**	-12.08	-1.82	-19.81**	-3.25*	0.27	-1.77	-0.25	-12.25**	-12.25**	31.96**	-14.47**	-1.72	-1.98	-18.51 **	0.84	16.26**
45	NDRK 5081*IR 28	-1.53	-16.07**	-19.32*	-4.47	-37.76**	-0.40	-1.06	1.77	-0.26	0.00	-8.44**	43.01**	-23.57**	-3.57	-2.00	-9.18 **	0.77	9.28**
46	NDRK 5047*NarendraUsarDhan 3	3.17	-15.51**	-16.67*	-3.81	-9.33**	0.28	1.75	1.61	-12.50 **	-18.58**	-11.19**	-8.89**	-26.85**	-33.12**	-5.50**	-5.19	0.80	-27.86**
47	NDRK 5047*CSR 23	3.60	-7.48	-29.05**	-6.97*	0.98	-1.67	0.58	-0.81	-3.01	-9.78**	-11.18**	29.90**	-12.34**	-5.48	-6.42**	-19.48 **	-0.06	13.99**
48	NDRK 5047*IR 28	4.40*	-0.12	-22.86**	-4.03	-10.92**	0.73	0.87	4.51	0.00	-10.34**	-9.59**	28.89**	-22.16**	-1.58	-4.67	-9.65 **	0.93	0.24

S. No.	Crosses	Days to 50% flowering	Chlorophyll content	Leaf nitrogen	Leaf temperature	Flag leaf area (cm²)	Plant height (cm)	Panicle bearing tillers/plant	Panicle length (cm)	Spikelets/panicle	Grains/panicle	Spikelet fertility (%)	Biological yield/plant (g)	Harvest Index(%)	L/B ratio	1000-grain weight (g)	Amylose content	Protein content (%)	Grain yield/plant (g)
49	NDRK 5039*NarendraUsarDhan 3	-1.59	-0.42	-27.60**	-7.44**	-9.87**	2.36*	-7.64**	2.47	6.58**	-11.25**	-16.39**	14.07**	-1.05	-15.70**	6.02**	3.65	-1.75*	12.88**
50	NDRK 5039*CSR 23	0.40	-21.85**	-27.15**	-5.47	1.62	0.64	-9.72**	2.94	21.55**	17.38**	-4.96**	13.39**	-13.13**	0.31	4.51*	3.45	-0.05	13.77**
51	NDRK 5039*IR 28	1.99	-22.35**	-28.96**	-3.23	-13.34**	-2.23*	-9.72**	2.94	23.12**	-6.63**	-23.50**	1.79	-17.27**	16.18**	2.39	3.31	0.02	-14.44**
52	NarendraUsarDhan 2*NarendraUsarDhan 3	1.98	6.84	-16.67*	-4.72	-8.90**	-2.12*	2.22	-6.22**	-14.69**	-20.54**	-6.03**	-5.93*	-8.93*	-26.77**	-0.25	3.72	-2.73**	-7.71**
53	NarendraUsarDhan 2*CSR 23	1.98	0.51	-12.04	-7.57**	0.41	-4.57**	0.95	-8.11**	0.75	-0.85	-1.81	6.36	-22.98**	-2.54	-0.03	3.64	0.84	-7.92**
54	NarendraUsarDhan 2*IR 28	-1.19	8.56	-11.57	-5.03	-10.44**	-3.70**	0.00	-5.41*	-7.32 **	-7.36**	-2.22	1.82	-0.51	0.11	0.86	3.97	-0.21	1.21
55	Deepak*NarendraUsarDhan 3	-1.17	-25.95**	21.85	0.71	-37.05**	-17.27**	1.06	2.52	-7.89 **	-12.96**	-4.96**	-20.74**	-7.41	-25.47**	2.12	-8.63 **	-0.70	-26.18**
56	Deepak*CSR 23	-0.39	-4.67	10.19	-3.06	-21.94**	6.64**	-0.70	2.36	3.26	-4.27**	-8.54**	7.22	-8.25*	-16.25**	2.07	-22.43 **	-0.01	-1.86
57	Deepak*IR 28	-1.17	-6.09	8.05	-0.94	-37.71**	0.34	1.41	-1.10	10.54**	-7.21**	-15.29**	-5.49	-14.78**	-26.69**	2.60	-13.12 **	0.06	-19.76**
58	Sundri*NarendraUsarDhan 3	4.37*	-29.60**	7.36	-3.93	-33.34**	-4.69**	-29.19**	2.60	-24.56 **	-31.78**	-8.78**	-24.44**	12.33**	-13.34**	-2.11	4.66	-5.10**	-13.61**
59	Sundri*CSR 23	6.02**	-8.33	-9.20	-6.60*	-17.26**	-2.57*	-17.97**	3.90	-18.30**	-25.36**	-8.87**	-3.09	-15.01**	-14.47**	-4.90*	-0.60	-2.15**	-17.58**
60	Sundri*IR 28	4.40*	-6.28	-7.36	-6.36*	-36.41**	-0.35	-12.26**	-1.30	-8.58 **	-4.35*	-6.92**	22.22**	-28.95**	5.07*	-5.82**	4.96	-3.16**	-13.68**
61	Pusa Basmati 1*NarendraUsarDhan 3	2.82	-12.30*	-17.11	-5.76*	-38.41**	-20.11**	-17.99**	-5.13*	-11.18**	-30.81**	-21.78**	-20.74**	-8.68*	-21.40**	-7.74**	1.79	-2.11**	-27.82**
62	Pusa Basmati 1*CSR 23	4.23*	4.77	-13.37	-7.32*	-28.18**	-5.80**	-8.76**	-10.12**	-6.52 **	-26.50**	-22.60**	13.40**	-29.14**	-2.52	4.81*	1.74	0.34	-19.78**
63	Pusa Basmati 1*IR 28	0.70	5.13	-12.83	-5.98*	-41.76**	-7.25**	4.73	-1.91	1.70	-22.71**	-23.64**	10.13*	-35.17**	-4.83	-7.72**	1.74	-0.63	-24.33**
Range of transgressive segregation	**Min.**	-4.21	-29.60	-29.05	-10.49	-41.76	-20.11	-29.19	-10.12	-24.82	-38.88	-23.64	-24.44	-40.97	-48.01	-22.59	-77.12	-11.68	-30.53
	Max.	6.02	31.09	21.85	1.86	5.09	9.40	4.73	5.59	38.51	35.33	1.94	43.01	26.33	19.07	8.39	4.96	3.77	26.47
No. of crosses with significant positive segregation		**6**	**4**	**0**	**0**	**3**	**15**	**0**	**1**	**25**	**17**	**0**	**29**	**9**	**12**	**6**	**0**	**3**	**21**
No. of crosses with significant negative segregation		**1**	**35**	**8**	**23**	**43**	**19**	**26**	**9**	**22**	**37**	**41**	**15**	**43**	**27**	**16**	**36**	**16**	**30**

*, ** significant at 5 and 1 per cent probability levels, respectively

The most promising crosses based on mean performance, heterobeltiosis and standard heterosis (SV1 and SV2), SCA effect, GCA effect of parent for grain yield per plant and the traits for which these crosses also exhibited desirable heterosis in F_1s and F_2s have been depicted in **Table 1**. The ten most promising crosses *viz*., NDRK 5037 x Narendra Usar Dhan 3, NDRK 5062 x IR 28, Sarjoo 52 x Narendra Usar Dhan 3, Narendra 2064 x Narendra Usar Dhan 3, NDRK 5062 x CSR 23, NDRK 5004 x Narendra Usar Dhan 3, NDRK 5037 x CSR 23, NDRK 5040 x Narendra Usar Dhan 3, NDRK 5093 x Narendra Usar Dhan 3 and Narendra 2064 x CSR 23 in F_1s while in F_2s are NDRK 5004 x Narendra Usar Dhan 3, Sarjoo 52 x Narendra Usar Dhan 3, NDRK 5040 x Narendra Usar Dhan 3, NDRK 5062 x IR 28, CSR 10 x Narendra Usar Dhan 3, NDRK 5062 x CSR 23, Narendra 2064 x Narendra Usar Dhan 3, NDRK 5039 x Narendra Usar Dhan 3, NDRK 5059 x IR 28 and DRK 5037 x Narendra Usar Dhan 3. It indicated that additive and non-additive genetic effects were responsible for increased grain yield in these F_1s over the SV_1 and SV_2. Such type of hybrid could be meaningful for heterosis breeding and desirable segregants could also be screened out in succeeding generations as a substantial part of variance which was considered as fixable one. Heterosis for grain yield in these crosses could be due to desirable heterotic response for component traits such as days to 50% flowering, chlorophyll content, leaf nitrogen, leaf temperature, flag leaf area, plant height, panicle bearing tillers / plant, panicle length, spikelets / panicle, grains per panicle, spikelet fertility, biological yield / plant, harvest index, L/B ratio**,** 1000- grain weight, amylose content, protein content, indicating genetic association of these character with grain yield. The hybrid combinations showing non additive gene action, may be exploited through the use of CMS system, since the stable CMS with perfect restoration in rice are available.

Therefore, the yielding ability in the present set of material might be enhanced due to higher level of manifestation from yield, physiological and few quality contributing traits. Further, rice workers have also observed that grain yield might be due to



A. Protein profiling of selected parents including checks by SDS-PAGE

B. Protein profiling of selected F1s and F2s crosses by SDS-PAGE

C. Protein profiling of selected transgressivesegregants and highly inbreeding depressed crosses by SDS-PAGE

Where, P-Parents, F1S- F_1S crosses, F2s- F_2s segregants, TS-Transgressive segregants, HID- Highly inbreeding depressed

Figure 1: Protein profiling of selected rice genotypes of different breeding populations by SDS-PAGE

heterotic response through all other yield contributing traits. Similar findings have also been reported by Janardanam *et al*., 2001; Punitha *et al*., 2004; Verma and Srivastava, 2005; Singh *et al*., 2007; Roy *et al*., 2009 Chougule *et al.,* 2012 and Sudeepthi *et al.,* 2018.

Seed protein profiling is the most promising tool in determining the molecular polymorphism and genetic homology. Seed storage proteins help in cultivar identification by avoiding the external environmental influences. Electrophoretically detectable proteins in rice grains possess the potential of characterizing the germplasm by their taxonomic and evolutionary aspects. This study was aimed at exploiting the genetic variations among 48 (parents+F_1s+ F_2s+transgressive segregants+checks) elite rice genotypes through electrophoretical separation of grain proteins by sodium dodecyl sulphate polyacryamide gel electrophoresis (SDS PAGE) at 12% (**Figure 1**).

At 35 kDa the medium to dark bands were present in parents, F_1s, F_2s, transgressive segregants and checks while in highly inbreeding depressed cross combinations, variable range of the bands were observed *viz.,* absence of band, light, medium and dark bands.

Majority of these populations have two distinct protein bands in parents; three in F_1s and F_2s; and only one in transgressivesegregants and highly inbreeding depressed cross combination, which indicated that these proteins are developed in the salt tolerant breeding populations and play an important role in salt tolerance. The SDS-PAGE in combination with 2-D electrophoresis is further suggested for documenting contrasting variations of isoforms of protein peptides.

The RM values and banding pattern of different breeding populations *viz.,* parents, F_1s, F_2s, transgressive segregants including checks have been depicted in **Tables 4, 5** and **6.** Seed protein showed variability in banding pattern of polypeptide at 12% acrylamide gel during SDS-PAGE.

Table 4: Relative mobility at 12% SDS-PAGE of selected parents in rice

kDa value	Length of gel (cm)	R.M. Value	Parents																	
			Check 1	Check 2	P16	P15	P14	P13	P12	P11	P10	P9	P8	P7	P6	P5	P4	P3	P2	P1
	0																			
100	1	0.10	+++	+++	+++	+	++	+	+	+++	+++	+++	-	++	+++	+	-	++	-	-
75	2	0.13	+++	+++	+++	++	+++	+	++	+++	+++	+++	-	++	++	+++	-	+++	-	-
71	3	0.15	+	++	+	-	++	+	+	++	++	++	-	++	+++	+	-	++	-	-
63	4	0.20	+	+	+	-	+	-	+	+	+	+	-	+	++	+	-	+	-	-
55	5	0.24	++	++	++	+	++	+	++	++	++	++	-	++	++	++	-	++	-	+
35	6	0.40	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	++	+++	+++	+++	++	+++	++	+++
25	7	0.45	+	+	+	+	+	+	+	+	++	++	-	+	++	+	-	+	+	++
20	8	0.60	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	++	+++	+++	+++	++	+++	+	+++
17	9	0.70	-	-	+	+	-	-	-	-	+	-	++	-	+	+	+	-	++	++
11	10	0.80	+	+	+	+	+	-	-	+	+	+	+	+	+++	-	+	-	+	+

+ Low intensity of the band, ++Medium intensity of the band, +++ High intensity of the band, -No band was found.

Where, P= Parents

P1-NDRK 5037, P2-NDRK 5062, P3-Sarjoo 52, P4-Narendra 2064, P5-NDRK 5004, P6-NDRK 5040, P7-NDRK 5093, P8-CSR 10, P9- NDRK 5039, P10-NDRK 5059, P11-NDRK 5047, P12-Sundri, P13-NDRK 5025, P14-Narendra UsarDhan 3, P15-CSR 23, P16- IR 28, Check1- Jaya, Check2- CSR 43

Result revealed that majority the parents including checks visualized high to medium intensity of bands on 0.40 and 0.60 RM values (**Table 5**). Similarly, elite hybrids and their segregants showed high to medium intensity of band on 0.50 and 0.75 RM value (**Table 6**). Further, elite transgressive segregants showed high to medium intensity of band on 0.11, 0.22, 0.40 and 0.65 RM value. However, highly inbreeding depressed crosses showed high to medium intensity of band only on 0.65 RM value.

Table 5: Relative mobility at 12% SDS-PAGE of promising F_1s and F_2s in rice

kDa value	Length of gel (cm)	R.M. Value	Crosses																			
			F2S1	F2S2	F2S3	F2S4	F2S5	F2S6	F2S7	F2S8	F2S9	F2S10	F1S1	F1S2	F1S3	F3S4	F1S5	F1S6	F1S7	F1S8	F1S9	F1S10
	0																					
135	1	0.14	-	+	-	++	++	+	-	+	+	+++	+++	+++	+	+	+	+	+	+	+++	+
100	2	0.17	+	++	-	++	++	+	+	+	+	+++	+++	+++	+	++	+	++	++	++	+++	+
75	3	0.20	+	++	+	+++	+++	++	++	++	++	+++	+++	+++	++	+++	+++	+++	+++	+++	+++	+++
63	4	0.28	++	++	+	+	++	+	+	+	+	++	+++	+++	+	++	++	++	++	++	++	++
48	5	0.34	+++	+++	+	+	++	+	+	+	+	++	+++	+++	+	++	++	++	++	++	+++	+
35	6	0.50	+++	+++	++	++	+++	+++	++	++	++	+++	+++	+++	++	+++	+++	+++	+++	+++	+++	+++
20	7	0.64	++	++	+	+	++	+	+	++	+	++	++	++	-	+	+	+	+	++	++	+
17	8	0.75	+++	+++	++	++	+++	++	++	++	++	+++	+++	+++	++	++	++	++	++	++	++	++
11	9	0.80	+	+	-	-	+	-	-	-	-	+	+	+	-	-	-	-	-	+	+	-
9	10	0.89	+++	+++	-	-	++	-	-	-	-	++	++	++	-	++	+	+	+	++	++	+

+ Low intensity of the band, ++Medium intensity of the band

+++ High intensity of the band, -No band was found.

Where,

F1S= F_1S crosses, F2s= F_2s segregants

F1S1- NDRK 5037 x NarendraUsarDhan 3, F1S2- NDRK 5062 x IR 28, F1S3- Sarjoo 52 x NarendraUsarDhan 3, F1S4- Narendra 2064 x NarendraUsarDhan 3, F1S5- NDRK 5062 x CSR 23, F1S6- NDRK 5004 x NarendraUsarDhan 3, F1S7- NDRK 5037 x CSR 23, F1S8- NDRK 5040 x NarendraUsarDhan 3, F1S9- NDRK 5093 x NarendraUsarDhan 3, F1S10-Narendra 2064 x CSR 23, F2S1- NDRK 5004 x NarendraUsarDhan 3 ,F2S2- Sarjoo 52 x NarendraUsarDhan 3, F2S3- NDRK 5040 x NarendraUsarDhan 3, F2S4- NDRK 5062 x IR 28, F2S5- CSR 10 x NarendraUsarDhan 3, F2S6- NDRK 5062 x CSR 23, F2S7-Narendra 2064 xNarendraUsarDhan 3, F2S8- NDRK 5039 x NarendraUsarDhan 3, F2S9- NDRK 5059 x IR 28, F2S10- NDRK 5037 x NarendraUsarDhan 3

Table 6: Relative mobility at 12% SDS-PAGE of highest depressed crosses and top transgressive segregants in rice

kDa value	Length of gel (cm)	R.M. Value	Crosses									
			HID5	HID4	HID3	HID2	HID1	TS5	TS4	TS3	TS2	TS1
	0											
135	1	0.08	++	+	-	++	+	+	++	++	+	++
100	2	0.09	+++	++	-	+++	+	++	++	++	++	++
75	3	0.11	+++	+++	-	+++	++	+++	+++	+++	+++	+++
74	4	0.12	++	++	-	++	+	++	++	++	+	++
63	5	0.19	++	++	-	++	++	++	++	++	++	++
57	6	0.22	++	++	-	++	++	++	++	++	++	++
35	7	0.40	+++	++	-	++	+	+++	+++	+++	++	+++
25	8	0.55	+	+	++	++	+	++	++	++	+	++
20	9	0.65	+++	+++	+	+++	++	+++	+++	+++	+++	+++
11	10	0.85	+++	+	+	+	+	+	+	++	+	+++

+ Low intensity of the band, ++Medium intensity of the band; +++ High intensity of the band, -No band was found.

Where,

TS= Transgressive segregants; HID= Highly inbreeding depressed

TS1- NDRK 5004 x NarendraUsarDhan 3, TS2- Sarjoo 52 x NarendraUsarDhan, TS3- NDRK 5040 x NarendraUsarDhan 3, TS4-), NDRK 5062 x IR 28, TS5- CSR 10 x NarendraUsarDhan 3, HID1-NDRK 5037 x CSR 23, HID2- NDRK 5047 x NarendraUsarDhan 3, HID3- Sundri x IR 28, HID4- NDRK 5004 x IR 28, HID5- NDRK 5025 x CSR 23

Tolerant and susceptible breeding populations showed similar banding pattern but possesses wide variations between tolerant and susceptible. At 35 kDa the medium to dark bands were present in parents, F_1s, F_2s, transgressive segregants and checks while in highly inbreeding depressed cross combinations, variable range of the bands were observed *viz.,* absence of bands, light, medium and dark bands. Such a banding patern reflects that similar banding pattern on 35 kDa may certainly have salt tolerant QTLs in elite parents, which have inherited successfully in F_1s and transgressive segregants. Hence, emphasis should be given to elute these desired QTLs inorder to incorporate these salt tolerant traits of interest in local cultivar and / or widely adopted genotype for sustainability under salt affected soils. The similar reports have been reported by Tripathy *et al.,* (2015).

Authors' Contributions

The idea of this study was developed by Shiv Prakash Shrivastav and O.P. Verma who also assisted in its design and interpretation of the data. Dan Singh Jakhar helped to draft the manuscript. All authors read and approved the final manuscript.

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Availability of data and material

The experimental data used for analysis and further writing of this article are available with the corresponding author on reasonable request.

Declaration

Conflict of interest

We declare that there is no conflict of interest in connection with the work submitted by us.

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