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RESEARCH ARTICLE

Studies on component of genetic variance and heterotic response in rice (*Oryza sativa* L.) for high yield with quality and sodicity tolerance

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Abstract

A study was conducted to evaluate the potential and limitations of using component of variance and combining ability for establishing heterotic patterns in rice (*Oryza sativa* L.) under the sodic soil. The results revealed highly significant variations within parents and hybrids (F_1s) indicating a wide genetic variability for 18 quantitative and qualitative characteristics and the possibility of genetic improvement of rice. Estimates of specific combining ability (SCA) variance were higher than the corresponding estimates of general combining ability (GCA) variance for majority of the traits. Parents such as NDRK 5062, NDRK 5037, Sarjoo 52, Narendra 2064, NDRK 5081, NDRK 5004, NDRK 5039, CSR 10, NDRK 5059 and FL 478 showed significant and positive GCA effects for grain yield per plant, and some of the yield-contributing traits to emerge as useful donor for hybridization programmes. Twenty three crosses emerged with positive and significant SCA effects for grain yield per plant from 63 F_1s. A wide range of variation in the estimates of heterobeltiosis and standard heterosis in positive and negative direction 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 (SV_1) as well as CSR 43 (SV_2) 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. 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.

Keywords: Component of genetic variance, combining ability, heterosis, sodicity tolerance, rice

Introduction

Rice (*Oryza sativa* L.) is the most important staple food crop of the world, particularly the developing world where it forms the staple diet of about half of the population. More than 90% of the world's rice is grown and consumed in Asia, known as rice bowl where 60% of the earth's people and two third of world's poor live (Khush and Virk 2000). About 75% of the world's supply is consumed by the people in Asian countries and thus, rice is of immense importance to food security of Asia. The demand for rice is expected to increase with continuous increase in global population. Salt-affected soils can have a major impact on the global food production (Dang et al. 2013; Xin et al. 2014). The current scenario indicates an approximately 10% of the world's total land area (950 Mha), 20% of the world's arable land (300 Mha), and 50% of the total irrigated land (230 Mha) are afected by soil salinization. Further, it is expected to influence 50% of total cultivated land in 2050 at a dis-quieting rate (Munns and Tester 2008; Ruan et al. 2010). Every year almost 12 billion US $ are globally lost due to salt stress that significantly affects the agricultural production (Qadir et al. 2008; Flowers et al. 2010; Kashyap et al. 2020). It has been reported in several crops that percent germination, shoot

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and root length, and dry weight was reduced due to high accumulation of Na^+ making nutrient uptake difficult (Qadir et al.2001; Singh et al. 2016; Joshi et al. 2022). Thus, development of improved high yielding pure line and hybrid rice varieties suitable for adverse conditions (salt affected soil) would be an important strategy to meet this challenge. The successful breeding program for developing sodicity tolerant and high yielding rice genotypes requires great breeding efforts to screen the available materials to identify suitable sources of sodicity tolerance. In this context, Singh et al. (2016) evaluated breeding lines of rice under a range of sodic environment and selected an early maturing line CSR89IR 8 which later released as CSR 43. Amendments to saline-sodic soils have shown long-term effects on improving plant growth and yield of rice (*Oryza sativa* L.) (zhao et al.2020). The understanding the components of genetic variance, inheritance nature and heritability of important agronomic traits under salt affected stress conditions assist rice breeders to apply suitable breeding strategies. Rosielle and Hamblin (1981) and Fernandez (1992)have suggested the selection methodology for yield in stress and non-stress environments. The diallel mating design is a powerful biometric approach to assess general combining ability (GCA) and specific combining ability (SCA) effects and determine the gene action involved in various characteristics (Fasahat et al. 2016; Salem et al. 2020). These models are efficacious tools to identify the best parents and their cross combinations for generating superior progenies in breeding for stress tolerance. Therefore, the present study was carried out to find out the components of genetic variance and combining ability for better exploitation of heterotic potential among rice genotypes and their hybrids for salt affected conditions.

Materials and methods

Experimental site and development of materials

The experiment was conducted at the main experimental station of Acharya Narendra Deva University of Agriculture & Technology, Narendra Nagar (Kumarganj), Ayodhya, Uttar Pradesh, India. The experimental material was based on a line x tester set of 63 hybrids (F_1s) and segregating population (F_2s) developed by crossing 21diverse lines (females), namely, 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. A toal of 63 cross combinations were made to generate F_1s and F_2s during *kharif* 2016 and 2017. Thus a total set of 89 genotypes comprising 63 F_1s along with their parents including two checks, Jaya and CSR 43 as standard varieties (SV_1 and SV_2, respectively) were evaluated to work out the gene action, component of genetic variance, combining ability and heterotic response in rice under the sodic soil in randomized complete block design with three replications during *kharif* 2018. The sodic soils are generally defined as the soil condition with high ESP that results in poor soil physical condition and low concentration of soluble salts present but a high exchangeable Na^+ percentage (Qadir et al. 2001). Generally, the sodic soil is characterized with EC<4dS/m, with pH >8.5 and ESP >15 (Joshi et al. 2021). Geographically experimental site is located between 24°47A° and 26°56A°N latitude; 82°12A° and 83°98A°E longitude and at an altitude of 113 m amsl. The soil on which the experiment was conducted holds pH, EC and ESP as 9.5, 3.2dSm-1 and 45%, respectively. Such soils are poor or very poor in gypsum and exchangeable sodium affecting uptake of P, Fe, Mn and Zn, which inhibits root growth and other morphological and physiological traits.

Observations recorded

Data on morho-physiological and quality traits were recorded on 18 characters, namely, 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), no. of spikelets/panicle, no. of grains/panicle, spikelet fertility (%), biological yield/plant (g), harvest index (%),L/B ratio, thousand grains weight (g), amylose content, protein content (%) and grain yield/plant (g).

Statistical analysis

Analysis of variance for Randomized Block Design was done as per the procedure of Panse and Sukhatme (1967). Line x Tester analysis which was given by Kempthorne (1957) and further elaborated by Arunachalam (1974) to estimate general combining ability (GCA) and specific combining ability (SCA) variances and their effects using the observations taken on F_1 hybrids gerenrated through line x tester sets of crosses. In Line x Tester mating system, a random sample of 'l' lines is taken and each line is mated to each of 't' testers (Singh and Chaudhary 1977). The heterosis was estimated as per cent increase or decrease of the mean values of crosses (F_1's) over better parent (heterobeltiosis) and standard variety (standard/economic heterosis) by Fonseca and Patterson (1968) and Meredith and Bridge (1972), respectively. Critical difference was used to test the significance of difference mean value of F_1 over better parent and check variety which signified with respective heterosis.

Results

Analysis of variance (ANOVA) was carried out with respect to all of the 18 characters. The mean squares due to treatments were highly significant for all the characters which showed significant differences, indicating presence of sufficient variability in the material. The analysis of variance for 87

Table 1. Components of genetic variance, average degree of dominance, predictability ratio, heritability in narrow sense and genetic advance in per cent of mean for 18 characters in rice under sodic soil

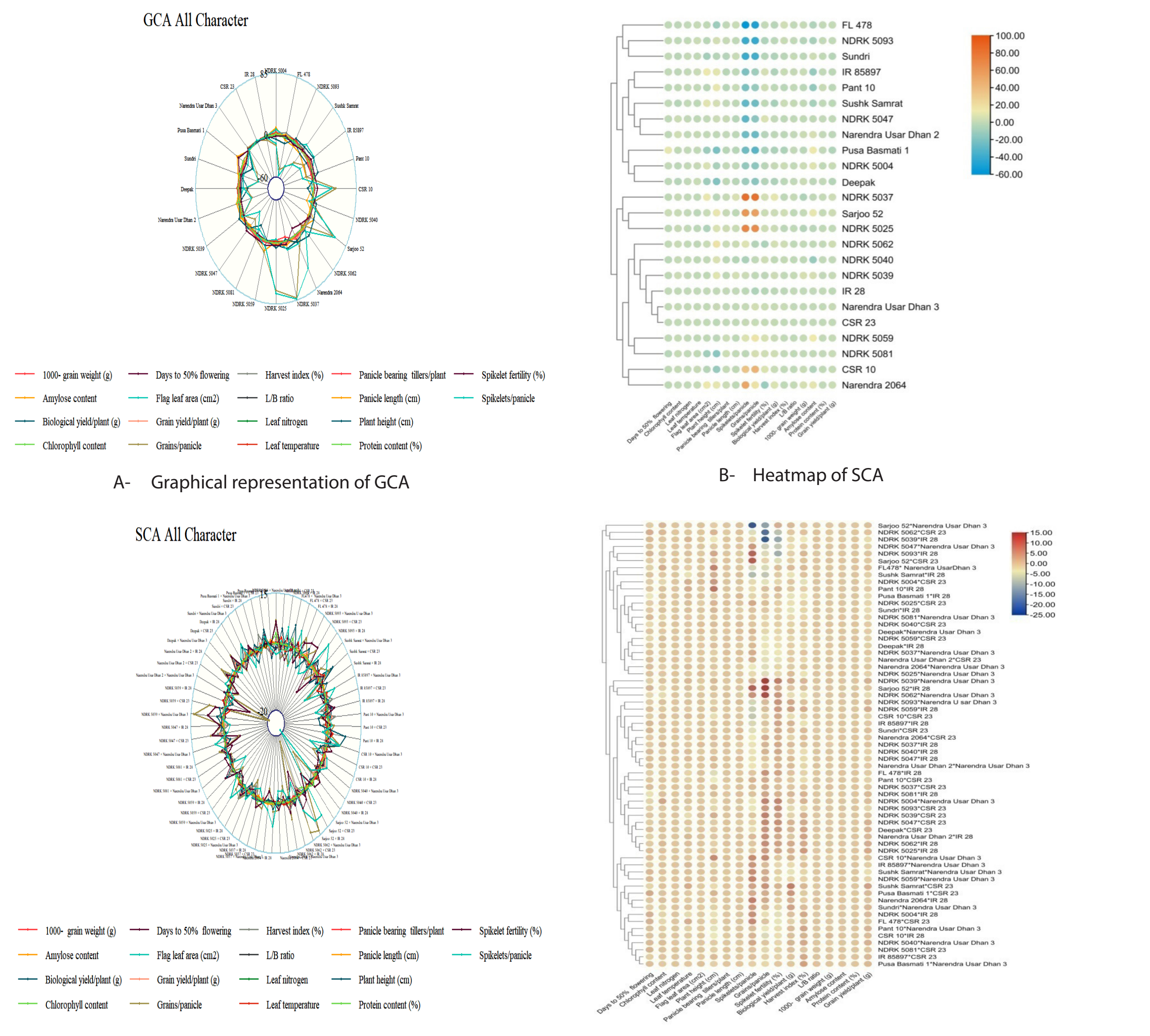
Characters	GCA variance (σ^2g)	SCA variance (σ^2s)	Average degree of dominance $\sqrt{\sigma^2s/2\sigma^2g}$	Predictability ratio $2\sigma^2g/(2\sigma^2g+\sigma^2s)$	σ^2A	σ^2D
Days to 50% flowering	0.1710	0.9657	1.6804	0.2615	0.3420	0.9657
Chlorophyll content	0.0971	1.0219	2.2939	0.1597	0.1942	1.0219
Leaf nitrogen	0.0001	0.0021	2.9593	0.1025	0.0002	0.0021
Leaf temperature	0.0221	1.4091	5.6473	0.0304	0.0442	1.4091
Flag leaf area (cm^2)	1.4171	0.1169	0.2031	0.9604	2.8343	0.1169
Plant height (cm)	3.2575	7.3796	1.0643	0.4689	6.5149	7.3796
Panicle bearing tillers/plant	0.1080	0.0382	0.4202	0.8499	0.2161	0.0382
Panicle length (cm)	0.1648	0.1086	0.5741	0.7521	0.3296	0.1086
Spikelets/panicle	40.0569	37.7572	0.6865	0.6797	80.1138	37.7572
Grains/panicle	34.0755	52.9589	0.8815	0.5627	68.1510	52.9589
Spikelet fertility (%)	0.6432	21.2613	4.0656	0.0570	1.2863	21.2613
Biological yield/plant (g)	0.5838	6.1788	2.3004	0.1589	1.1676	6.1788
Harvest index (%)	0.1566	5.4384	4.1666	0.0545	0.3133	5.4384
L/B ratio	0.0045	0.0396	2.0960	0.1854	0.0090	0.0396
1000-grain weight (g)	0.2203	0.0099	0.1496	0.9781	0.4406	0.0099
Amylose content	1.9206	0.0051	0.0365	0.9987	3.8413	0.0051
Protein content (%)	0.0049	0.0015	0.3903	0.8678	0.0098	0.0015
Grain yield/plant (g)	0.1403	2.9517	3.2431	0.0868	0.2806	2.9517

genotypes of line × tester set comprising of 63 crosses and 24 parents were revealed that the mean squares due to treatments, parents, crosses and parents (lines) were highly significant for all the characters. It further revealed that mean squares due to parents (tester) were highly significant for all the characters except for days to 50% flowering, leaf nitrogen and leaf temperature. The variance due to parents *vs.* crosses was highly significant for all the characters except for flag leaf area. Mean squares due to lines effect were found highly significant for all the characters. Mean squares due to line × tester interaction effects were highly significant for all the characters except for 1000-grain weight and amylose content. The variances due to testers effect were non-significant for all the ten characters except highly significant variances for no. of grains per panicle, spikelet fertility, biological yield per plant, harvest index, L:B ratio, grain yield per plant and significant variances for chlorophyll content and plant height. The mean squares due to lines x tester interactions, representing importance of specific combining ability and non-additive gene effects, was also found to be highly significant for all the characters under study.

Estimates of component variance

The estimates of GCA and SCA variances, average degree of dominance, predictability ratio, additive and dominance variances are presented in Table 1. Estimates of SCA variance were found higher than the corresponding estimates of GCA variance for all the eleven traits except flag leaf area, no. of panicle bearing tillers per plant, panicle length, no. of spikelets per panicle, 1000-grain weight, amylose content and protein content in F_1s. The more than unity (>1) values of an average degree of dominance were found for ten characters *viz.,* leaf temperature, harvest index, spikelet fertility, grain yield per plant, leaf nitrogen, biological yield per plant, chlorophyll content, L:B ratio, days to 50% flowering and plant heigh. The predictability ratio was lesser than one for all the characters studied.

For illustrating genetic worth of parents for hybridization programme, the general combining ability effects of 24 parents (21 lines and 3 testers) for the 18 characters under sodic soil alongwith the parents exhibiting significant GCA effects for different characters are presented in Table 2 and depicted in Fig. 1. The ten lines, namely, NDRK 5062 (3.607), NDRK 5037(3.531), Sarjoo 52 (2.765), Narendra 2064 (2.589), NDRK 5081 (1.757), NDRK 5004 (1.492), NDRK 5039 (1.142), CSR 10 (0.787), NDRK 5059 (0.588) and FL 478 (0.409) showed significant and positive GCA effects for grain yield per plant. Among the testers, Narendra Usar Dhan 3 (1.227) recorded significant and positive GCA effects, whereas IR 28 (-1.282) exhibited significant and negative GCA effect forgrain yield per plant.The lines, Pant 10 (1.541), Sarjoo 52 (0.439), NDRK 5037 (0.426) and NDRK 5047 (0.148) possessed significant



A- Graphical representation of GCA

B- Heatmap of SCA

C- Graphical representation of SCA

D- Heatmap of SCA

Fig. 1. Graphical representation and Heatmap of GCA&SCA for yield and its attributing traits

and positive GCA effects for protein content.

For illustrating genetic worth of parents for hybridization programme, the general combining ability effects of 24 parents (21 lines and 3 testers) for the 18 characters under sodic soil alongwith the parents exhibiting significant GCA effects for different characters are presented in Table 2 and depicted in Fig. 1. Among the ten lines, highest (3.607) and the lowest (0.409) GCA effect for grain yield per plant was observed with NDRK 5062 and FL 478, respectively. Similarly, the tester had GCA effect ranging from 1.227 (N U Dhan) to -1.282 (IR28). The GCA effects for protein content also found to vary from 1.541 to 0.148.

The SCA effects, which are supposed to be manifestation of non-additive components of genetic variance, are highly valuable for discrimination of crosses for their genetic worth as breeding materials. The estimates of SCA effects for 63 crosses of line×tester set for 18 characters are presented in Supplementary Table S1 and Fig. 1. The ten outstanding crosses, namely, Sushk Samrat x CSR 23 (3.56), NDRK 5025 x IR 28 (2.67), NDRK 5059 x IR 28 (2.40), NDRK 5062 x IR 28 (2.22), NDRK 5039 x Narendra Usar Dhan 3 (2.01), NDRK 5047 x CSR 23 (1.98), NDRK 5040 x Narendra Usar Dhan 3 (1.96), Deepak x CSR 23 (1.80), Pant 10 x Narendra Usar Dhan 3 (1.71), and Sundri x Narendra Usar Dhan 3 (1.46) had positive

Table 2. Estimates of general combining ability (GCA) effects of F_1s parents (lines and testers) for 18 characters in rice under sodic soil

S. no.	Parents	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)
	Lines																		
1	NDRK 5004	0.005	-1.721**	-0.083**	0.986**	6.601**	-7.100**	0.134	0.209	-13.519**	-15.931**	-2.718**	0.989*	2.599**	0.173**	2.684**	8.908**	-0.286**	1.492**
2	FL 478	-0.328	-1.724**	-0.101**	0.600**	-0.829**	-11.211**	-0.799**	1.625**	-56.852**	-48.265**	-0.086	-2.788**	3.830**	0.155**	0.525*	-5.693**	0.019	0.409**
3	NDRK 5093	0.561	-0.555**	0.009	2.481**	-2.542**	4.600**	1.012**	-0.609**	-40.185**	-41.265**	-5.315**	-1.566**	1.380**	0.169**	-4.197**	-7.501**	-0.151**	-0.065
4	Sushk Samrat	0.005	-3.325**	-0.037**	-1.266**	9.787**	5.144**	0.001	-0.909**	-28.519**	-25.153**	-0.812	-7.566**	2.283**	0.333**	-0.461*	-8.195**	-0.708**	-2.206**
5	IR 85897	0.116	-1.383**	-0.013	1.849**	12.267**	10.111**	-2.844**	-0.520*	-20.852**	-10.265**	5.193**	-5.788**	1.376**	0.349**	1.796**	-13.099**	0.013	-1.863**
6	Pant 10	-1.217	-0.814**	-0.008	-0.040	-2.698**	11.278**	-2.877**	1.569**	-21.074**	-13.042**	3.394**	-1.122*	-2.276**	-0.203**	-2.273**	-13.523**	1.541**	-1.395**
7	CSR 10	-0.661	0.598**	-0.008	1.206**	-3.655**	-12.898**	0.945**	-0.853**	35.370**	44.180**	7.358**	1.767**	0.257	-0.530**	1.337**	-4.730**	-0.255**	0.787**
8	NDRK 5040	-1.772**	0.911**	0.129**	-0.968**	0.124	7.278**	-1.855**	-3.586**	-6.407**	-0.487	3.249**	-0.233	0.381	-0.327**	-1.305**	-11.834**	-0.092**	0.093
9	Sarjoo 52	2.339**	1.476**	0.023**	-1.622**	1.598**	11.511**	1.056**	-1.131**	60.259**	54.847**	2.225**	2.434**	4.030**	-0.527**	0.813**	11.149**	0.439**	2.765**
10	NDRK 5062	0.005	1.367**	0.025**	-1.024**	1.698**	17.555**	1.812**	2.036**	8.148**	-4.265**	-6.349**	5.101**	3.368**	-0.406**	0.066	-0.500**	0.010	3.607**
11	Narendra 2064	-0.995	0.184	0.009	0.484**	12.678**	10.433**	2.056**	-1.269**	52.148**	17.847**	-11.707**	7.434**	-0.629	0.617**	5.519**	10.355**	0.018	2.589**
12	NDRK 5037	-0.884	0.441**	0.063**	-0.569**	12.051**	-2.300**	0.801**	6.102**	83.593**	82.180**	4.930**	10.545**	-1.161*	0.602**	-5.905**	-0.786**	0.426**	3.531**
13	NDRK 5025	-0.884	1.184**	-0.006	-1.754**	-5.471**	6.844**	2.887**	2.125**	70.148**	65.958**	3.123**	2.323**	-1.689**	-0.545**	-4.005**	-2.553**	-0.301**	0.109
14	NDRK 5059	-0.439	0.660**	0.011	-0.859**	-0.964**	-1.733**	2.256**	-1.242**	7.704**	16.291**	5.863**	1.767**	-0.171	-0.434**	0.822**	13.171**	-0.096**	0.588**
15	NDRK 5081	-3.106**	0.559**	0.097**	-0.213	-9.825**	-16.578**	3.012**	-0.042	-1.519	5.291**	4.170**	4.212**	0.294	-0.606**	-0.098	-0.737**	-0.034**	1.757**
16	NDRK 5047	-0.661	2.286**	0.100**	-0.821**	0.023	2.478**	1.103**	-3.140**	-30.185**	-16.153**	7.047**	-0.011	-1.179*	-0.242**	-0.218	-0.942**	0.148**	-0.547**
17	NDRK 5039	-0.884	2.557**	0.105**	-0.292*	-0.822**	9.133**	-0.955**	4.869**	1.926*	-0.709	-1.379*	2.767**	-0.001	0.535**	5.279**	5.400**	-0.096**	1.142**
18	Narendra Usar Dhan 2	-0.884	4.103**	-0.048**	0.350**	0.056	-0.545	0.101	-1.220**	-24.519**	-26.376**	-3.842**	-1.677**	-1.819**	0.060	1.987**	5.211**	-0.132**	-1.481**
19	Deepak	-1.328*	-3.767**	-0.146**	1.729**	-10.067**	-19.256**	-0.978**	-2.799**	-11.407**	-16.153**	-4.065**	-6.344**	-2.122**	-0.003	2.022**	-1.595**	-0.044**	-3.313**
20	Sundri	0.228	-2.814**	-0.080**	-0.472**	-8.906**	-3.489**	-3.926**	1.691**	-39.296**	-37.487**	-3.315**	-5.677**	-2.532**	0.553**	-1.861**	3.318**	-0.269**	-3.158**
21	Pusa Basmati 1	10.783**	-0.222	-0.040**	0.215	-11.105**	-21.256**	-2.944**	-2.909**	-24.963**	-31.042**	-6.966**	-6.566**	-6.218**	0.278**	-2.528**	14.175**	-0.149**	-4.839**
SE (gi) Line		0.6316	0.1647	0.0079	0.1169	0.1323	0.4658	0.1006	0.2225	0.7860	0.8699	0.6660	0.4922	0.5097	0.0327	0.2024	0.0090	0.0108	0.0948
SE(gi – gj) lines		0.8933	0.2329	0.0112	0.1653	0.1871	0.6587	0.1423	0.3146	1.1116	1.2302	0.9419	0.6960	0.7208	0.0462	0.2863	0.0128	0.0153	0.1341
	Tester																		
22	Narendra Usar Dhan 3	0.164	0.480**	-0.003	0.034	-0.123*	0.995	0.011	0.183*	0.767*	4.386**	2.293**	1.291**	1.717**	-0.097**	-0.063	-0.004	-0.002	1.227**
23	CSR 23	-0.138	-0.177**	0.010**	0.003	0.055	-1.276	0.010	-0.165	1.132**	1.735**	0.576*	0.307	-0.040	-0.022	-0.012	0.004	0.009	0.054
24	IR 28	-0.026	-0.303**	-0.007*	-0.036	0.068	0.281	-0.021	-0.018	-1.899**	-6.122**	-2.869**	-1.598**	-1.678**	0.119**	0.074	0.000	-0.007	-1.282**
SE (gi) Tester		0.2387	0.0623	0.0030	0.0442	0.0500	0.1760	0.0380	0.0841	0.2971	0.3288	0.2517	0.1860	0.1926	0.0123	0.0765	0.0034	0.0041	0.0358
SE(gi – gj) testers		0.3376	0.0880	0.0042	0.0625	0.0707	0.2490	0.0538	0.1189	0.4202	0.4650	0.3560	0.2631	0.2724	0.0175	0.1082	0.0048	0.0058	0.0507

*,** Significant at 5% and 1% probability levels, respectively

Table 3. Most promising cross combinations for different characters along with their mean performance, SCA effects and GCA effects of parents in F_1s

S.No.	Characters	Crosses with significant effects	SCA effects	Mean performance of crosses	GCA effects of parents
1	Days to 50% flowering	1- Pusa basamati 1 x IR 28	-3.31	91.67	LxA
		2-NDRK 5081 x IR 28	-2.75	78.33	HxA
2	Chlorophyll content	1-NDRK 5004 x Narendra Usar Dhan 3	3.13	15.24	LxH
		2-FL 478 x Narendra Usar Dhan 3	2.48	14.59	LxH
		3 -Sarjoo 52 x Narendra Usar Dhan 3	1.33	16.63	HxH
		4- NDRK 5062 x IR 28	1.16	15.57	HxL
		5- NDRK 5062x CSR 23	1.05	15.59	HxL
3	Leaf nitrogen	1- Narendra Usar Dhan 2 x CSR 23	0.15	0.70	LxH
		2- Sundri x IR 28	0.05	0.55	LxL
		3- NDRK 5047 x CSR 23	0.05	0.75	HxH
		4 -NDRK 5062 x Narendra Usar Dhan 3	0.05	0.66	HxA
		5- Sarjoo 52 x Narendra Usar Dhan 3	0.05	0.66	HxA
4	Leaf temperature	1- Sushk Samrat x CSR 23	2.35	36.85	LxA
		2- FL 478 x CSR 23	2.27	38.64	HxA
		3- Pant 10 x IR 28	2.25	37.94	AxA
		4 -NDRK 5004 x CSR 23	1.96	38.71	HxA
		5 -NDRK 5039 x IR 28	1.30	36.74	LxA
5	Flag leaf area (cm^2)	1 -NDRK 5004 x CSR 23	0.77	40.22	HxA
		2 -NDRK 5037 x IR 28	0.70	45.62	HxA
		3 -NDRK 5025 x Narendra Usar Dhan 3	0.67	27.88	LxL
		4 -NDRK 5039 x CSR 23	0.57	32.61	LxA
6	Plant height (cm)	1 -Pant 10 x Narendra Usar Dhan 3	-4.42	123.40	LxA
		2 -Pant 10 x CSR 23	-3.75	121.80	LxA
		3 -CSR 10 x IR 28	-3.46	99.47	HxA
		4 -NDRK 5039 x IR 28	-3.33	121.63	LxA
		5 -NDRK 5004 x IR 28	-2.73	160.00	HxA
7	Panicle bearing tillers/plant	1- NDRK 5037 x IR 28	0.40	12.60	HxA
		2- NDRK 5062 x Narendra Usar Dhan 3	0.39	13.63	HxA
		3 -NDRK 5037 x Narendra Usar Dhan 3	0.37	12.60	HxA
		4- CSR 10 x Narendra Usar Dhan 3	0.36	12.73	HxA
8	Panicle length (cm)	1- Pusa Basamati 1 x IR 28	1.02	22.93	LxA
9	Spikelets/panicle	1- Sarjoo 52 x CSR 23	10.65	238.00	HxH
		2 -Sarjoo 52 x IR 28	10.34	234.67	HxL
		3- NDRK 5093 x IR 28	9.79	133.67	LxL
		4 -Narendra 2064 x IR 28	7.12	223.33	HxL
		5 -Narendra 5059 x Narendra Usar Dhan 3	6.57	181.00	HxH
10	Grains/panicle	1 -NDRK 5039 x Narendra Usar Dhan 3	13.72	157.00	AxH
		2 -Sarjoo 52 x IR 28	13.68	202.00	HxL
		3 -NDRK 5062 x Narendra Usar Dhan 3	12.28	152.00	LxH
		4- NDRK 5039 x CSR 23	7.04	147.67	AxH
		5 -NDRK 5004 x Narendra Usar Dhan 3	6.95	135.00	LxH

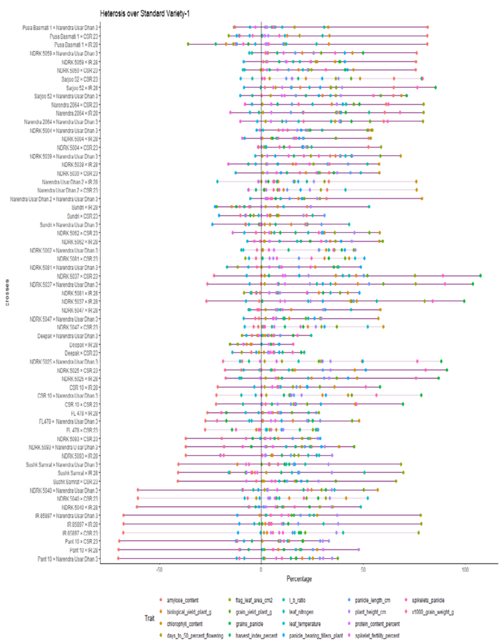
11	Spikelet fertility (%)	1- NDRK 5039 x Narendra Usar Dhan 3	7.31	92.17	LxH
		2 -NDRK 5004 x Narendra Usar Dhan 3	6.49	90.01	LxH
		3 -NDRK 5093 x CSR 23	5.66	84.87	LxH
		4- NDRK 5047 x CSR 23	5.47	97.04	HxH
		5 -NDRK 5093 x Narendra Usar Dhan 3	5.00	85.92	LxH
12	Biological yield/plant (g)	1 -Sushk Samrat x CSR 23	7.03	42.67	LxA
		2 -Pusa Basamati 1 x CSR 23	4.69	41.33	LxA
		3 -NDRK 5059 x IR 28	3.60	46.67	HxL
		4- Sundri x Narendra Usar Dhan 3	3.49	42.00	LxH
13	Harvest index (%)	1 -NDRK 5025 x IR 28	4.34	40.76	LxL
		2 -Pusa Basamati 1 x Narendra Usar Dhan 3	3.67	38.95	LxH
		3 -Narendra Usar Dhan 2 x IR 28	3.57	39.85	LxL
		4 -Deepak x CSR 23	3.31	40.92	LxA
		5 -Pant 10 x Narendra Usar Dhan 3	3.18	42.40	LxH
14	L/B ratio	1 -Sushk Samrat x IR 28	0.35	3.75	HxH
		2 -Deepak x Narendra Usar Dhan 3	0.26	3.10	AxL
		3 -NDRK 5059 x IR 28	0.25	2.88	LxH
		4- NDRK 5037 x IR 28	0.24	3.90	HxH
		5- NDRK 5025 x CSR 23	0.23	2.61	LxA
15	1000-grain weight (g)	1 -CSR 10 x IR 28	1.06	27.11	HxA
16	Amylose content	1 -FL 478 x IR 28	0.14	13.47	LxA
		2 -Narendra Usar Dhan 2 x IR 28	0.11	24.35	HxA
		3 -Narendra 2064 x CSR 23	0.11	29.50	HxA
		4- NDRK 5025 x Narendra Usar Dhan 3	0.11	16.58	LxA
17	Protein content (%)	1- Sarjoo 52 x CSR 23	0.19	6.89	HxA
		2 -NDRK 5062 x Narendra Usar Dhan 3	0.09	6.35	AxA
18	Grain yield/plant (g)	1 -Sushk Samrat x CSR 23	3.56	18.52	LxA
		2- NDRK 5025 x IR 28	2.67	18.60	AxL
		3 -NDRK 5059 x IR 28	2.40	18.82	HxL
		4- NDRK 5062 x IR 28	2.22	21.65	HxL
		5 -NDRK 5039 x Narendra Usar Dhan 3	2.01	21.48	HxH

and significant SCA effects for grain yield per plant. While, two crosses *viz.,*Sarjoo 52 x CSR 23 (0.19) and NDRK 5062 x Narendra Usar Dhan 3 (0.09) had positive and significant SCA effects for protein content.The most promising specific cross combinations for different characters along with their mean performance and GCA effects of parents are listed in Table 3.

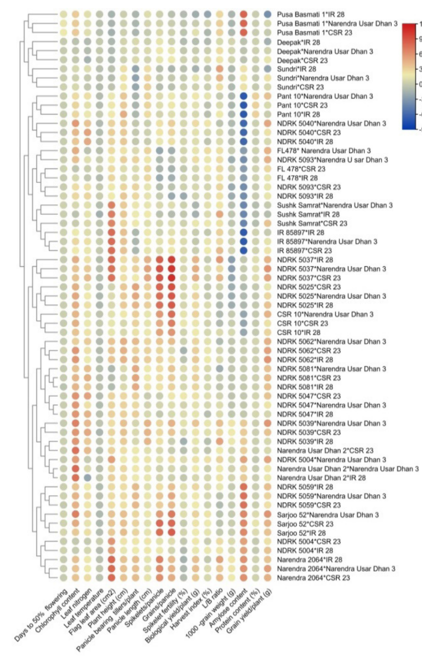
Estimates of Heterosis over better-parentand standard variety

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. Heterosis was estimated as per cent increase or decrease of F_1 value over better-parent (BP) and standard variety (SV), namely, Jaya (SV_1) and CSR 43 (SV_2). The estimates of heterobeltiosis and standard heterosis for eighteen characters of sixty three crosses are presented in Supplementary Figs. 1 and 2.

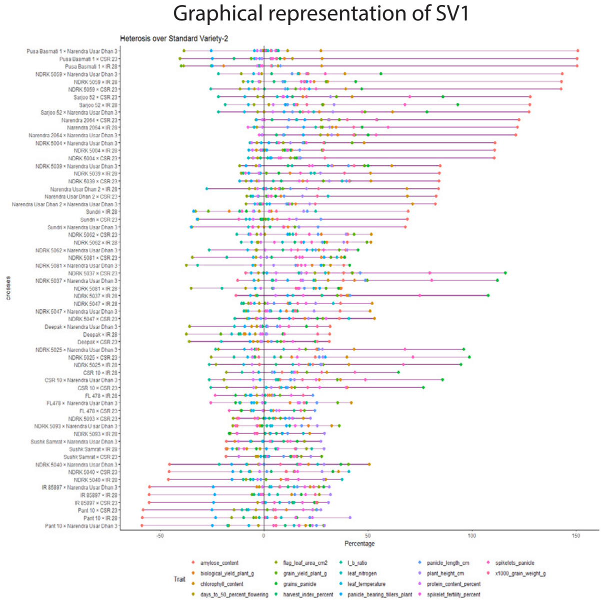
For grain yield per plant, the heterosis over better-parent varied from -12.86 (Shusk Samrat x Narendra Usar Dhan 3) to 40.40 per cent (NDRK 5081 x CSR 23). The 56 crosses showed positive and significant heterosis over BP and the best five among them were NDRK 5081 x CSR 23 (40.40%), NDRK 5081 x IR 28 (39.66%), NDRK 5037 x Narendra Usar Dhan 3(39.02%), NDRK 5062 x IR 28 (38.80%) and NDRK 5039 x Narendra Usar Dhan 3 (37.71%). The standard heterosis for



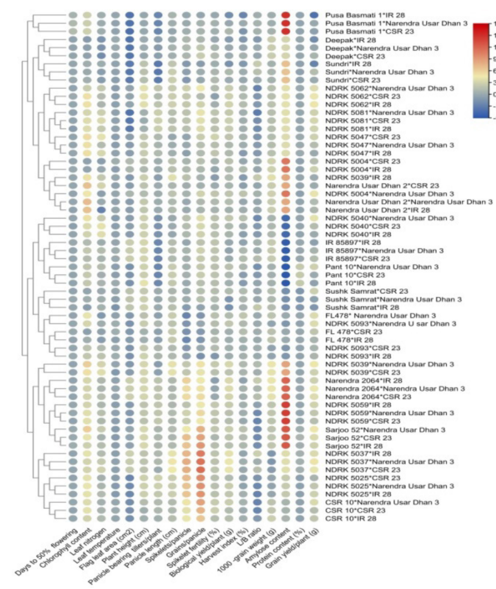
A- Graphical representation of SV1



B- Heatmap of SV1



C- Graphical representation of SV2



D- Heatmap of SV2

Fig. 2. Graphical representation and Heatmap of Standard heterosis(SV1&SV2) for yield and its attributing traits

grain yield per plant ranged from -35.92 (Pusa Basamati 1 x IR 28) to 59.73% (NDRK 5037 x Narendra Usar Dhan 3) over SV_1; and from -39.99 (Pusa Basamati 1 x IR 28) to 49.60% (NDRK 5037 x Narendra Usar Dhan 3) over SV_2. The 55 F1s showed positive and significant heterosis over SV_1 and the top five among them were NDRK 5037 x Narendra Usar Dhan 3 (59.73%), NDRK 5062 x IR 28 (59.49%), NDRK 5062 x CSR 23(52.88%), NDRK 5037 x CSR 23 (51.93%) and NDRK 5040 x Narendra Usar Dhan 3 (50.14%). However, 47 crosses showed positive and significant heterosis over SV_2 and the most promising five crosses were NDRK 5037 x Narendra Usar Dhan 3 (49.60%), NDRK 5062 x IR 28 (49.37%), NDRK 5062 x CSR 23(43.18%), NDRK 5037 x CSR 23 (42.29%) and NDRK 5040 x Narendra Usar Dhan 3 (40.61%).

For protein content, the heterosis over better-parent varied from -4.73 (NDRK 5004 x Narendra Usar Dhan 3) to 6.24 per cent (Sarjoo 52 x CSR 23). The 23 crosses showed positive and significant heterosis over BP and the best five among them were Sarjoo 52 x CSR 23 (6.24%), IR 85897 x CSR 23(2.10%), NDRK 5037 x CSR 23 (2.03%), IR 85897 x IR 28 (2.00%) and NDRK 5037 x Narendra Usar Dhan 3 (1.94%). The standard heterosis for protein content ranged from -7.49 (Shusk Samrat x Narendra Usar Dhan 3) to 30.20% (Pant 10 x IR 28) over SV_1; and from -12.39 (Shusk Samrat x Narendra

Usar Dhan 3) to 23.30% (Pant 10 x IR 28) over SV_2. The fourty eight crosses showed positive and significant heterosis over SV_1 and the best five among them were Pant 10 x IR 28 (30.20%), Pant 10 x Narendra Usar Dhan 3 (30.19%), Pant 10 x CSR 23 (30.17%), Sarjoo 52 x CSR 23(15.05%) and NDRK 5037 x CSR 23 (11.64%). On the other hand, 11 crosses showed positive and significant heterosis over SV_2 and the most promising five crosses were Pant 10 x IR 28 (23.30%), Pant 10 x Narendra Usar Dhan 3 (23.29%), Pant 10 x CSR 23 (23.27%), Sarjoo 52 x CSR 23(8.96%) and NDRK 5037 x CSR 23 (5.73%).

Discussion

The significant interaction between genotype and environment (locations and sowing dates) indicates that genotype ranking was not stable across environments. Highly significant variation has been detected for measured agronomic traits and adequate genetic variability among parents and their hybrids. The exposed genetic variations are useful for developing salt tolerant and climate-resilient cultivars. In this context, high genetic variability for different agronomic traits has been earlier elucidated for different crops under different environments (Rashid et al. 2007; Saleem et al. 2010; Patial et al. 2016; Gramaje et al. 2020; Azad et al. 2022; Gharib et al. 2021; ElShamey et al. 2022). Highly significant variance for parents *vs.* crosses for all the characters except flage leaf area indicated that the crosses that were made, had highly significant heterosis for all the character except flage leaf area. The similar findings have also been reported by Bassuony and Zsembeli (2021) but Abd El-Aty et al. (2022) reported contrasting results on flag leaf area. Highly significant variance amoung parental lines for majority of the traits showed parental diversity forthe characters studied. Significant parental diversity for different characters has also been reported earlier by several researchers working on rice (Geleta et al. 2004; Bagheri and Jelodar 2010; Shanthi et al. 2011).

The use of combining ability in assessment of gene action was suggested by Sprague and Tatum (1942). Higher SCA variance than GCA variance for majority of the characters, showed the predominance of non additive gene action in the inheritance of such characters in rice. It was suggested that the exploitation of heterosis for improvement of theses characters would be fruitful. The more than one average degree of dominance and for most of the character and the lesser than one value of predictability ratio also indicated the predominance of non-additive gene action and importance of heterosis breeding in rice. The importance of additive as well as non-additive gene effects with predominance of non-additive gene effects in inheritance of grain yield and yield components of rice has also been elucidated earlier in different types of rice (Pradhan et al. 2006; Rashid et al. 2007; Saleem et al. 2010; Sanghera and Hussain 2013; Kargbo et al. 2019; Sari et al. 2020; Gramaje et al. 2020; Azad et al. 2022).

In the present investigation, the significant GCA effects for grain yield and its contributing characters were found. NDRK 5062 (3.607), NDRK 5037 (3.531), Sarjoo 52 (2.765), Narendra 2064 (2.589), NDRK 5081 (1.757) were top 5 parents that showed significant and desirable GCA effects for grain yield and some other characters.These parents may be recommended for exploitation for yield and heterosis in hybridization programme as donor parent. The significant SCA effects for grain yield and its contributing characters were found. Sushk Samrat x CSR 23 (3.56), NDRK 5025 x IR 28 (2.67), NDRK 5059 x IR 28 (2.40), NDRK 5062 x IR 28 (2.22), NDRK 5039 x Narendra Usar Dhan 3 (2.01) were top 5 crosses that showed significant and desirable SCA effects for grain yield and some other characters. Rashid et al.(2007); Saravanan and Sabesan (2010) and Bagheri et al. (2010) have also repoted significant GCA and SCA effects for grain yield and its contributing characters in rice. The crosses exhibiting high order significant and desirable SCA effects for different characters involved parents having all types of combinations of GCA effects such as high × high (H × H), high × average (H × A), high × low (H × L), average × average (A × A), average × low (A × L) and low × low (L × L) general combiner parents in rice. The findings of Bano and Singh (2019) and Zewdu (2020) also indicated that there was no particular relationship between positive and significant SCA effects of crosses with GCA effects of their parents for the characters under study.

The ten 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 and some other yield contributing characterswere 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. The existence of wide spectrum heterosis in either direction with expression of high degree of desirable heterosis by some crosses for all the characters was observed in present study. Several researchers working on different crops have also reported high magnitude of heterosis along with high SCA and GCA effects (Singh et al. 2007; Roy et al., 2009; Murthy and Pradeep 2022). High better parent heterosis combined with high sca effects for certain traits and yield in the desired direction demonstrated the presence of reasonable genetic diversity among the parents. Also the expression of heterobeltiosis and sca effects in the desired direction for some traits, stable performance under sodic soil environment, the present study reiterated that the hybrids displayed heterosis over the standard parents in low-yielding environments. Hence, the use of selected hybrids in breeding under stress environments is suggested.

Supplementary material

Supplementary Table S1 and Supplementary Figs. 1 and 2 are provided online at www.isgpb.org.

Authors' Contributions

Conceptualization of research (SPS, OPV); Designing of the experiments (OPV); Contribution of experimental materials (OPV); Execution of field/lab experiments and data collection (SPS, OPV); Analysis of data and interpretation (SPS, OPV, KL); Preparation of the manuscript (SPS, OPV, DSJ, VS, KL).

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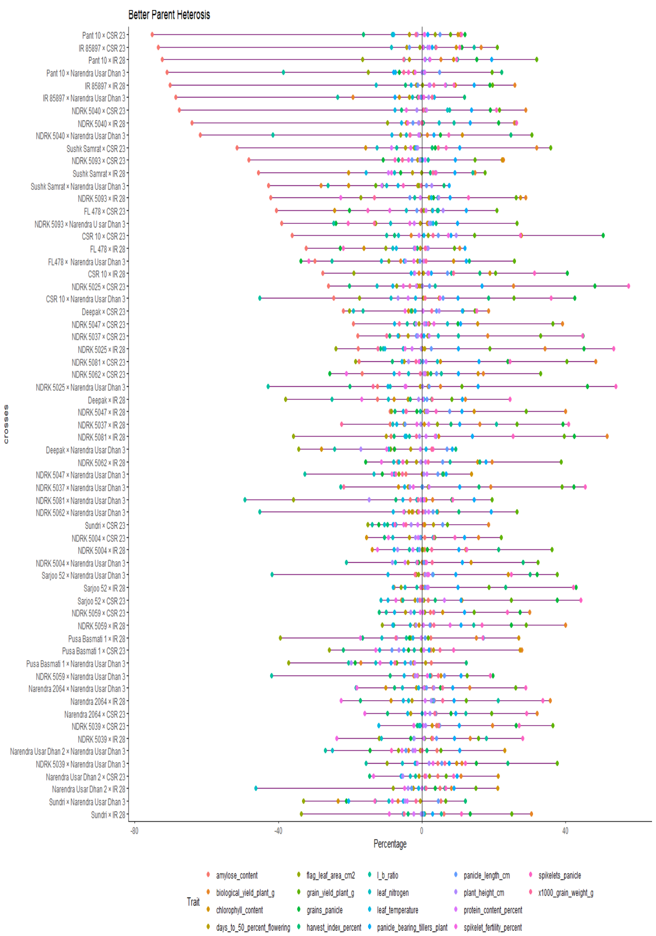

A- Graphical representation

B- Heatmap

Supplementary Fig. S1. Graphical representation and Heatmap of heterobeltiosis for yield and its attributing traits

Supplementary Table S1. Estimates of specific combining ability (SCA) effects of crosses (F_1s) for 18 characters in rice under sodic soil

S.N.	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*Narendra Usar Dhan 3	-1.39	3.13**	-0.01	0.09	-0.24	-1.77*	0.00	0.00	-3.21*	6.95**	6.49**	-0.18	1.77*	0.22**	0.03	0.02	-0.02	0.81**
2	NDRK 5004*CSR 23	-0.75	-1.72**	-0.02	1.96**	0.77**	4.50**	0.07	0.10	-2.24	-4.40**	-1.84	-0.20	-4.51**	0.01	0.11	-0.02	0.01	-2.02**
3	NDRK 5004*IR 28	2.14	-1.41**	0.03*	-2.05**	-0.52*	-2.73**	-0.07	-0.10	5.46**	-2.54	-4.65**	0.38	2.74**	-0.23**	-0.14	0.00	0.01	1.20**
4	FL478* Narendra UsarDhan 3	-1.05	2.48**	-0.01	-0.84**	-0.16	6.67**	0.00	0.02	-5.88**	-5.39**	0.76	0.93	1.04	0.07	0.19	-0.04*	0.00	0.88**
5	FL 478*CSR 23	1.92	-1.83**	0.01	2.27**	-0.27	-1.72*	0.00	0.16	6.09**	0.26	-4.20**	-1.08	0.48	0.08	-0.19	-0.10**	-0.01	-0.26
6	FL 478*IR 28	-0.86	-0.66*	0.01	-1.43**	0.44	-4.95**	0.00	-0.18	-0.21	5.12**	3.45**	0.15	-1.53	-0.15*	0.00	0.14**	0.01	-0.62**
7	NDRK 5093*Narendra U sar Dhan 3	-0.61	0.34	-0.04**	0.28	0.24	-1.01	0.09	0.72	-5.88**	0.95	5.00**	3.04**	0.37	0.07	0.17	0.01	0.00	1.46**
8	NDRK 5093*CSR 23	-0.97	-0.40	0.00	-0.65**	0.11	-1.87*	0.02	-0.20	-3.91**	4.26**	5.66**	-1.97*	-1.66	0.09	-0.16	0.00	0.00	-1.46**
9	NDRK 5093*IR 28	1.58	0.05	0.04**	0.37	-0.36	2.87**	-0.11	-0.52	9.79**	-5.21**	-10.66**	-1.07	1.30	-0.17**	0.00	-0.01	0.00	-0.01
10	Sushk Samrat*Narendra Usar Dhan 3	1.28	0.16	0.00	0.38	0.22	0.05	-0.17	-0.15	5.79**	2.50	-1.17	-4.29**	-1.65	-0.15**	-0.49	0.02	0.00	-2.53**
11	Sushk Samrat*CSR 23	-1.42	0.14	-0.03	2.35**	-0.55*	-2.25**	0.13	-0.47	3.42*	5.15**	1.74	7.03**	1.41	-0.20**	0.35	-0.02	-0.01	3.56**
12	Sushk Samrat*IR 28	0.14	-0.30	0.02	-2.73**	0.33	2.20**	0.03	0.62	-9.21**	-7.66**	-0.58	-2.74**	0.25	0.35**	0.14	0.00	0.01	-1.03**
13	IR 85897*Narendra Usar Dhan 3	-0.50	0.11	0.04**	1.06**	0.17	-1.05	-0.06	0.16	4.79**	0.95	-2.05	-2.07*	0.09	-0.06	-0.07	0.02	0.00	-0.88**
14	IR 85897*CSR 23	-0.86	-0.10	-0.01	0.06	-0.24	0.89	-0.02	-0.29	0.76	-1.07	-1.27	0.25	2.73**	0.22**	0.15	-0.02	-0.01	1.20**
15	IR 85897*IR 28	1.36	-0.01	-0.02	-1.11**	0.07	0.16	0.08	0.13	-5.54**	0.12	3.32**	1.82*	-2.83**	-0.16**	-0.08	0.00	0.00	-0.32
16	Pant 10*Narendra Usar Dhan 3	0.50	-0.67*	0.03*	-1.11**	-0.33	-4.42**	-0.06	0.04	0.68	-3.28*	-2.39*	0.93	3.18**	-0.13*	0.16	-0.02	0.00	1.71**
17	Pant 10*CSR 23	-0.20	0.34	-0.03*	-1.14**	0.37	-3.75**	-0.09	0.42	1.65	2.71	0.82	-0.42	-2.11*	0.01	-0.17	0.04*	-0.01	-1.06**
18	Pant 10*IR 28	-0.31	0.32	0.00	2.25**	-0.04	8.16**	0.14	-0.46	-2.32	0.57	1.57	-0.51	-1.07	0.12*	0.02	-0.01	0.01	-0.66**
19	CSR 10*Narendra Usar Dhan 3	0.61	-0.37	-0.01	-0.30	-0.19	5.92**	0.36*	-0.17	5.90**	6.17**	-0.16	1.71*	-0.63	-0.07	-0.77*	-0.02	0.00	0.47**
20	CSR 10*CSR 23	-0.75	0.62*	-0.01	0.77**	0.14	-2.46**	0.12	-0.12	-7.47**	-0.85	2.83*	-2.31**	-1.02	-0.12*	-0.28	-0.07**	0.00	-1.32**
21	CSR 10*IR 28	0.14	-0.25	0.03*	-0.46*	0.05	-3.46**	-0.48**	0.30	1.57	-5.32**	-2.68*	0.60	1.66	0.19**	1.06**	0.09**	0.00	0.85**
22	NDRK 5040*Narendra Usar Dhan 3	1.06	0.75**	-0.04**	-0.58**	0.00	-0.62	-0.04	-0.17	3.01*	-0.16	-1.73	1.71*	2.80*	-0.13*	-0.40	0.05**	0.02	1.96**

23	NDRK 5040*CSR 23	-1.97	-0.11	0.02	-0.10	0.38	0.72	0.02	0.48	-0.02	-1.51	-1.05	-1.31	-0.30	0.12*	0.15	0.01	0.01	-0.67**
24	NDRK 5040*IR 28	0.92	-0.64*	0.02	0.68**	-0.38	-0.10	0.02	-0.30	-2.99*	1.68	2.77*	-0.40	-2.51**	0.01	0.24	-0.06**	-0.03	-1.29**
25	Sarjoo 52*Narendra Usar Dhan 3	-0.72	1.33**	0.05**	-0.30	0.31	-0.88	-0.09	0.31	-20.99**	-12.16**	2.15	1.04	-0.37	0.06	-0.19	-0.03*	-0.10**	0.42*
26	Sarjoo 52*CSR 23	-0.75	-0.01	-0.06**	-0.18	0.15	0.39	0.08	-0.31	10.65**	-1.51	-4.95**	-0.97	0.00	-0.01	0.12	0.03	0.19**	-0.39*
27	Sarjoo 52*IR 28	1.47	-1.31**	0.01	0.48	-0.45*	0.50	0.01	0.01	10.34**	13.68**	2.81*	-0.07	0.37	-0.05	0.07	0.01	-0.09**	-0.04
28	NDRK 5062*Narendra Usar Dhan 3	-1.72	-2.21**	0.05**	-0.36	0.07	-0.26	0.39*	-0.49	5.12**	12.28**	4.55**	-2.29**	-2.88**	-0.19**	-0.01	-0.07**	0.09**	-2.21**
29	NDRK 5062*CSR 23	2.25*	1.05**	-0.02	-0.12	-0.07	1.48	-0.64**	0.09	-4.91**	-18.07**	-8.30**	-0.31	0.16	0.14*	-0.22	0.05**	-0.06**	-0.01
30	NDRK 5062*IR 28	-0.53	1.16**	-0.03	0.48*	0.00	-1.21	0.25	0.41	-0.21	5.79**	3.76**	2.60**	2.72**	0.06	0.23	0.02	-0.03	2.22**
31	Narendra 2064*Narendra Usar Dhan 3	0.61	-0.58*	-0.01	0.75**	0.08	-0.27	-0.06	-0.54	-3.54*	-4.83**	-1.62	-0.62	-0.03	-0.12*	0.27	-0.11**	0.00	-0.11
32	Narendra 2064*CSR 23	-0.42	0.15	0.01	-0.19	-0.02	0.73	0.05	0.39	-3.58**	2.15	2.01	-1.31	0.88	-0.01	-0.42	0.11**	-0.01	-0.03
33	Narendra 2064*IR 28	-0.20	0.43	0.00	-0.56**	-0.06	-0.46	0.01	0.14	7.12**	2.68	-0.39	1.93*	-0.85	0.13*	0.15	0.00	0.01	0.14
34	NDRK 5037*Narendra Usar Dhan 3	0.17	-0.83**	0.01	0.35	-0.22	-0.87	0.37*	0.51	2.34	-4.16**	-3.30**	-0.74	-0.16	-0.28**	-0.17	0.05**	0.00	-0.18
35	NDRK 5037*CSR 23	0.47	-0.15	0.03*	-0.14	-0.48*	0.73	-0.77**	0.32	0.65	2.49	0.47	-0.08	-0.13	0.04	0.60	0.07**	0.00	-0.06
36	NDRK 5037*IR 28	-0.64	0.98**	-0.04**	-0.21	0.70**	0.14	0.40*	-0.83*	-2.99*	1.68	2.83*	0.82	0.30	0.24**	-0.44	-0.11**	0.00	0.24
37	NDRK 5025*Narendra Usar Dhan 3	0.17	-0.28	0.00	-0.19	0.67**	-0.85	0.17	-0.25	-2.21	-4.94**	-1.99	0.82	-3.03**	0.04	-0.12	0.11**	-0.01	-1.05**
38	NDRK 5025*CSR 23	-0.86	0.03	-0.03*	0.46*	-0.72**	1.49	0.31	0.13	2.76*	0.71	-0.98	-2.86**	-1.31	0.23**	0.07	0.02	0.00	-1.62**
39	NDRK 5025*IR 28	0.69	0.26	0.03*	-0.27	0.05	-0.64	-0.49**	0.12	-0.54	4.23**	2.97*	2.04*	4.34**	-0.27**	0.04	-0.13**	0.00	2.67**
40	NDRK 5059*Narendra Usar Dhan 3	1.06	-0.22	0.02	0.60**	0.10	0.29	-0.06	0.35	6.57**	3.06*	-1.86	-1.96*	-1.40	-0.03	0.27	0.05**	0.00	-1.36**
41	NDRK 5059*CSR 23	-1.64	0.49	-0.02	-0.25	-0.31	-0.20	0.08	0.03	0.20	-3.96**	-2.58*	-1.64	-1.00	-0.22**	-0.11	-0.04**	-0.01	-1.05**
42	NDRK 5059*IR 28	0.58	-0.27	-0.01	-0.35	0.20	-0.09	-0.02	-0.38	-6.77**	0.90	4.43**	3.60**	2.39**	0.25**	-0.16	-0.01	0.01	2.40**
43	NDRK 5081*Narendra Usar Dhan 3	1.06	-0.82**	0.00	-0.20	-0.46*	0.10	-0.04	-0.48	-0.21	-1.61	-0.89	-2.07*	-1.51	-0.17**	0.15	0.03	0.00	-1.44**
44	NDRK 5081*CSR 23	1.69	0.38	0.02	-0.09	0.34	-0.82	0.12	-0.14	0.09	-1.62	-1.16	0.58	-0.15	0.19**	-0.04	0.09**	-0.01	0.22
45	NDRK 5081*IR 28	-2.75*	0.44	-0.02	0.29	0.13	0.72	-0.08	0.62	0.12	3.23*	2.05	1.49	1.66	-0.02	-0.11	-0.12**	0.01	1.22**

S.N.	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*Narendra Usar Dhan 3	-1.39	3.13**	-0.01	0.09	-0.24	-1.77*	0.00	0.00	-3.21*	6.95**	6.49**	-0.18	1.77*	0.22**	0.03	0.02	-0.02	0.81**
2	NDRK 5004*CSR 23	-0.75	-1.72**	-0.02	1.96**	0.77**	4.50**	0.07	0.10	-2.24	-4.40**	-1.84	-0.20	-4.51**	0.01	0.11	-0.02	0.01	-2.02**
3	NDRK 5004*IR 28	2.14	-1.41**	0.03*	-2.05**	-0.52*	-2.73**	-0.07	-0.10	5.46**	-2.54	-4.65**	0.38	2.74**	-0.23**	-0.14	0.00	0.01	1.20**
4	FL478* Narendra UsarDhan 3	-1.05	2.48**	-0.01	-0.84**	-0.16	6.67**	0.00	0.02	-5.88**	-5.39**	0.76	0.93	1.04	0.07	0.19	-0.04*	0.00	0.88**
5	FL 478*CSR 23	1.92	-1.83**	0.01	2.27**	-0.27	-1.72*	0.00	0.16	6.09**	0.26	-4.20**	-1.08	0.48	0.08	-0.19	-0.10**	-0.01	-0.26
6	FL 478*IR 28	-0.86	-0.66*	0.01	-1.43**	0.44	-4.95**	0.00	-0.18	-0.21	5.12**	3.45**	0.15	-1.53	-0.15*	0.00	0.14**	0.01	-0.62**
7	NDRK 5093*Narendra U sar Dhan 3	-0.61	0.34	-0.04**	0.28	0.24	-1.01	0.09	0.72	-5.88**	0.95	5.00**	3.04**	0.37	0.07	0.17	0.01	0.00	1.46**
8	NDRK 5093*CSR 23	-0.97	-0.40	0.00	-0.65**	0.11	-1.87*	0.02	-0.20	-3.91**	4.26**	5.66**	-1.97*	-1.66	0.09	-0.16	0.00	0.00	-1.46**
9	NDRK 5093*IR 28	1.58	0.05	0.04**	0.37	-0.36	2.87**	-0.11	-0.52	9.79**	-5.21**	-10.66**	-1.07	1.30	-0.17**	0.00	-0.01	0.00	-0.01
10	Sushk Samrat*Narendra Usar Dhan 3	1.28	0.16	0.00	0.38	0.22	0.05	-0.17	-0.15	5.79**	2.50	-1.17	-4.29**	-1.65	-0.15**	-0.49	0.02	0.00	-2.53**
11	Sushk Samrat*CSR 23	-1.42	0.14	-0.03	2.35**	-0.55*	-2.25**	0.13	-0.47	3.42*	5.15**	1.74	7.03**	1.41	-0.20**	0.35	-0.02	-0.01	3.56**
12	Sushk Samrat*IR 28	0.14	-0.30	0.02	-2.73**	0.33	2.20**	0.03	0.62	-9.21**	-7.66**	-0.58	-2.74**	0.25	0.35**	0.14	0.00	0.01	-1.03**
13	IR 85897*Narendra Usar Dhan 3	-0.50	0.11	0.04**	1.06**	0.17	-1.05	-0.06	0.16	4.79**	0.95	-2.05	-2.07*	0.09	-0.06	-0.07	0.02	0.00	-0.88**
14	IR 85897*CSR 23	-0.86	-0.10	-0.01	0.06	-0.24	0.89	-0.02	-0.29	0.76	-1.07	-1.27	0.25	2.73**	0.22**	0.15	-0.02	-0.01	1.20**
15	IR 85897*IR 28	1.36	-0.01	-0.02	-1.11**	0.07	0.16	0.08	0.13	-5.54**	0.12	3.32**	1.82*	-2.83**	-0.16**	-0.08	0.00	0.00	-0.32
16	Pant 10*Narendra Usar Dhan 3	0.50	-0.67*	0.03*	-1.11**	-0.33	-4.42**	-0.06	0.04	0.68	-3.28*	-2.39*	0.93	3.18**	-0.13*	0.16	-0.02	0.00	1.71**
17	Pant 10*CSR 23	-0.20	0.34	-0.03*	-1.14**	0.37	-3.75**	-0.09	0.42	1.65	2.71	0.82	-0.42	-2.11*	0.01	-0.17	0.04*	-0.01	-1.06**
18	Pant 10*IR 28	-0.31	0.32	0.00	2.25**	-0.04	8.16**	0.14	-0.46	-2.32	0.57	1.57	-0.51	-1.07	0.12*	0.02	-0.01	0.01	-0.66**
19	CSR 10*Narendra Usar Dhan 3	0.61	-0.37	-0.01	-0.30	-0.19	5.92**	0.36*	-0.17	5.90**	6.17**	-0.16	1.71*	-0.63	-0.07	-0.77*	-0.02	0.00	0.47**
20	CSR 10*CSR 23	-0.75	0.62*	-0.01	0.77**	0.14	-2.46**	0.12	-0.12	-7.47**	-0.85	2.83*	-2.31**	-1.02	-0.12*	-0.28	-0.07**	0.00	-1.32**