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Assessing gene action for yield and its contributing traits in aromatic and non-aromatic rice (*Oryza sativa* L.) under sodic soils

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Abstract
The present investigation entitled "Studies on genetic variability, combining ability and heterosis in aromatic and non-aromatic rice (*Oryza sativa* L.) Uner sodic soil". The present study was based on two related experiments, namely, Germplasm evaluation (Experiment-I) and Combining ability (Experiment-II). These experiments were conducted at Main experimental farm, of the N.D. University of Agriculture & Technology, Narendra Nagar (Kumarganj), Faizabad., during Kharif, 2015 and 2016. The combining ability experiment (Experiment-II) was based on evaluation of a line x tester set of 69 hybrids (F1's) and their 26 parents along with two checks for seven characters under sodic soil condition in randomized complete block design with three replications during Kharif, 2016. The 69 F1's were generated by crossing 23 lines with 3 testers during Kharif, 2015.
The mean squares due to lines x testers interactions, indicating importance of specific combining ability and non-additive gene effects, were found to be highly significant for all the seven characters under study. Twenty-three out of sixty-nine crosses emerged with positive and significant sca effects for grain yield/plant. The five best crosses were Pusa Bas.-1 x Jaya, NDRK-50046 x Jaya, NDRK-50055 x Jaya, NDRK-50054 x CSR-10 and NDRK-50063 x CSR-10 which showed significant and positive sca effects for grain yield/plant as well as some other yield components. The findings of the present investigation have been discussed considering their practical usefulness in relation to overall improvement of rice in sodic soil.

Keywords: Aromatic- rice (*Oryza sativa* L.), gene action, general and specific combining ability, sodic soil.

Introduction
Rice (*Oryza sativa* L. 2n =24), belongs to the family gramineae (Poaceae). Rice is a staple food of developing world as well as majority of Asian countries. More than 90 per cent of the world's rice is grown and consumed in Asia (rice bowl of the world), where 16 per cent of the earth's people and two third of world's poor live (Khush and Virk 2000) [3]. In India, rice is cultivated over an area of about 42.77 million hectares with an annual production of about 106.54 million tonnes with an average productivity of 2490 kg per hectare. (Anonymous, 2014) [1]. However, rapidly increasing demand due to ever increasing Indian population has forced us to search for another quantum jump in rice production. The projection of Indian rice production target for 2020 AD is 115-120 million tonnes, which can be achieved only by increasing the rice production by over 2.0 million tonnes/year in this decade. This has to be done against backdrop of diminishing natural resource bases like land, labour and water, which is a huge challenge (Subbiah, 2006).

Materials and Methods
The technical programme of the present investigation will be based on two experiments as follows:

Genetic variability (Experiment-I) This experiment will involve evaluation of 115 elite aromatic and non-aromatic rice lines along with 3 checks *viz.* Sarjoo 52, FL 478 and CSR 43. The 115 rice lines along with three checks will be evaluated in augmented design during *Kharif*, 2016. The experimental plot will be sub-divided in to 10 blocks of 13 plots each. The three checks will be allotted randomly to three plots in each block, while remaining 10 plots in a block will be used for accommodating the unreplicated test genotypes.

Combining ability analysis (Experiment-II) A line x tester set of 69 hybrids (F_1's) will be derived by crossing 23 rice genotypes /varieties as lines (females) with three testers (males) *viz.,* Jaya, BPT 5204 and CSR 10. The twenty three lines are NDRK 50063, Narendra Usar 2009, NDRK 50051, Narendra 6093, Narendra 6330, Pusa Basmati 1, Improved Pusa

Basmati -1, Narendra 359, NDRK 50054, NDRK 50060, NDRK50046, NDRK50058, NDRK 50055, NDRK 50052, IRSSTN 150, IR-14 T-102, IR-14 T-105, N 80, Usar 1, Narendra 2026, N-3112-1, Narendra Shushk Samrat and Narendra Parag. The 69 F_1s along with their parents and check varieties (Narendra Usar Dhan 3 and IR 28), will be evaluated in randomized complete block design with three replications during *Kharif* 2016. Single row plots of 3m length will be used in both the experiments for transplanting single seedling per hill for each genotype (treatment) following intra-row and inter-row spacing of 15 cm and 20 cm, respectively. Recommended cultural practices will be followed to raise a good crop in both the experiments.

Results

The understanding of inheritance of various characters and identification of superior parents are important pre-requisites for launching an effective and efficient breeding programme (Dhillon, 1975). Combining ability analysis is useful technique for understanding of genetic worth of parents and their crosses for further exploitation in breeding programmes. Among the various techniques of combining ability analysis, line x tester analysis (Kempthorne, 1957) has been widely utilized for screening of germplasm to identify valuable donor parents and promising crosses in many crops including rice (Satheesh *et al.*, 2010; Saidaiah *et al.*, 2011; Devi *et al*., 2017) [5, 2].

The significant and positive GCA effects for grain yield/plant were exhibited by ten lines, NDRK-50052 (1.79), Pusa Basmati-1, NDRK-50060 (1.24), NDRK-50055 (1.23), Usar-1(1.07), NDRK-50046 (1.06), NDRK-50058 (0.94), NDRK-50063 (0.51), IR-92831-22-BAY-2-1 (0.36) and NDR-359 (0.29) The parent with highest GCA effects for grain yield, NDRK 50052, also showed significant GCA effects in desirable direction forspikeletes/panicle, spikelet fertility, biological yield/plant, harvest-index and 1000 grain weight. Tester CSR-10 showed good general combiner for grain yield/plant and exhibited significant and positive GCA effect for biological yield/plant, harvest index and L/B ratio under sodic soil. The eleven parents showing positive and significant GCA effects for grain yield and other important traits as mentioned above may serve as valuable parents for hybridization programme or multiple crossing programme for obtaining high yielding hybrid varieties or transgressive segregants for developing pure line varieties of rice sodic soil. The significant GCA effects for grain yield in positive direction resulted from similar GCA effects of some other yield components suggesting that the combining ability for grain yield was influenced by the combining ability of its components. Therefore, simultaneous improvement in important yield components and other associated traits along with grain yield may be better approach for raising yield potential in rice under sodic soil. These findings are similar to those of Verma and Srivastava (2004) [8].

Specific combining ability effects

The specific combining ability (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 of sixty-nine crosses for thirteen characters are given in Table 3. Seventeen out of sixty-nine crosses emerged with positive and significant SCA effects for grain yield/plant. The top ten crosses were Pusa Bas.-1 x Jaya, NDRK-50046 x Jaya, NDRK-50055 x Jaya, NDRK-50054 x CSR-10, NDRK-50063 x CSR-10, IR 14 T 102 x BPT 5204, NDRK 50058 x CSR 10, Usar 1 x CSR 10, IR 14 T 105 x BPT 5204 and NDRK 50060 x CSR 10 showed significant and positive SCA effects for grain yield/plant as well as some other yield components. The cross having highest positive and significant SCA effects for grain yield/plant Pusa Basmati-1 x Jaya also recorded significant SCA effects in desirable direction for spikelets/panicle, spikelet fertility, biological yield/plant and 1000-grain weight. The second ranking cross for higher positive and significant SCA effect for grain yield/plant, NDRK-50046 x Jaya showed significant and desirable SCA effects for spikelets/panicle, spikelet fertility, biological yield/plant, harvest-index, L/B ratio and 1000-grain weight. Similarly, remaining fifteen crosses having significant and positive SCA effects for grain yield/plant also possessed significant SCA effects in desirable direction for some other characters also. The twenty crosses having positive and desirable SCA effects for grain yield and some of its component traits merit attention in breeding programme for exploitation of hybrid cultivars. The twenty-three crosses having significant and positive SCA effects for grain yield/plant also showed positive and desirable significant SCA effects for some other characters, most commonly biological yield/plant, 1000-grain weight, harvest-index and spikelet fertility. This suggested that manifestation of SCA effects for grain yield is related with higher SCA effects for important yield components.

The foregoing observation clearly 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. Verma and Srivastava, (2004 [8]), Singh and Kumar (2004) [6] and Devi *et al*., (2017) [2] have also found that crosses having high order positive SCA effects for grain yield resulted from parents having high x high as well as high x low GCA effects for grain yield.

Table 1: Analysis of variance for combining ability following line × tester mating design for 7 characters in rice under sodic soil

Characters	Sources of variation				
	Replications	Lines	Testers	Lines × Testers	Error
d.f.	2	22	2	44	136
Spikelets / panicle	1.22	1004.89	916.99	841.99**	1.19
Spikelet fertility (%)	0.17	3.19	0.99	3.08**	0.23
Biological yield / plant (g)	0.00	35.15	96.10*	26.18**	0.85
Harvest index (%)	0.04	2.22	5.19	2.93**	0.12
L/B ratio	0.01	0.48	1.26	0.44**	0.02
1000-grain weight (g)	0.01	7.01	4.09	4.87**	0.02
Grain yield / plant (g)	0.04	8.56	23.70*	5.37**	0.05

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

Table 2: Estimates of general combining ability (GCA) effects of parents (lines and testers) for 7 characters in rice under sodic soil

S. No.	Lines	Spikelets / panicle	Spikelet fertility (%)	Biological yield /plant (g)	Harvest-index (%)	L/B Ratio	1000-Grain wt. (g)	Grain yield / plant (g)
1	NDRK - 50055	1.68**	-0.19	2.31**	0.54**	-0.23**	0.06	1.23**
2	Imp. Pusa Bas. -1	-9.34**	0.21	-0.2	0.30**	-0.03	-0.41**	-0.33**
3	Narendra - 359	20.06**	0.93**	0.3	0.33**	-0.1	0.56**	0.29**
4	NDRK - 50051	5.12**	-0.36*	-1.15**	-0.74**	-0.36**	1.01**	-0.85**
5	Narendra - 6330	-9.62**	0.90**	-2.53**	-0.93**	-0.36**	-0.17**	-1.49**
6	NDRK - 50063	12.80**	0.61**	1.19**	0	0.21**	0.01	0.51**
7	IR - 14 T -102	3.23**	0.61**	-2.30**	-0.62**	0.40**	-2.07**	-1.22**
8	N. Usar - 2009	15.19**	0.23	-1.42**	-0.39**	-0.24**	0.91**	-0.76**
9	IR - 14 T -105	13.89**	0.56**	-0.99**	-0.30**	0.31**	-0.29**	-0.54**
10	NDRK - 50054	0.18	-0.3	0.15	-0.70**	0	0.42**	-0.25**
11	NDR – 2026	5.61**	-1.25**	-3.23**	-0.49**	0.01	0.74**	-1.53**
12	Narendra - 3112 - 1	-24.14**	-0.59**	-1.04**	0.05	-0.1	0.41**	-0.39**
13	NDRK - 50046	-7.20**	-0.34*	2.68**	-0.1	0.04	0.14**	1.06**
14	Usar – 1	-2.97**	0.23	2.58**	-0.02	0.09	-1.93**	1.07**
15	N – 80	-7.61**	0.28	-1.52**	-0.30**	-0.1	-1.83**	-0.74**
16	IR-92831-22-BAY 2-1	1.25**	-1.10**	-0.05	0.73**	0.31**	0.46**	0.36**
17	N. Parag	-2.72**	-0.91**	-1.91**	-0.06	-0.08	0.41**	-0.79**
18	Pusa Bas. – 1	2.67**	0.31	2.13**	0.71**	0.28**	0.96**	1.24**
19	NDRK - 50058	-13.50**	0.18	1.40**	0.63**	0.02	-0.70**	0.94**
20	N. ShushkSamrat	-10.94**	-0.07	-1.16**	0.06	-0.21**	0.27**	-0.45**
21	NDRK - 50052	6.41**	0.51**	3.65**	0.55**	-0.09	0.31**	1.79**
22	N – 6093	-8.83**	-0.31	-1.67**	0.57**	-0.21**	0.67**	-0.39**
23	NDRK - 50060	8.78	-0.15	2.78**	0.18	0.41**	0.06	1.24**
SE (gi) Lines		0.84	0.33	0.6	0.2	0.1	0.1	0.15
SE(gi – gj)		1.19	0.47	0.84	0.29	0.14	0.14	0.22
Tester								
1	CSR – 10	-2.83**	-0.12*	1.36**	0.31**	0.15**	-0.25**	0.68**
2	BPT – 5204	-1.29**	0.01	-0.79**	-0.11**	-0.11**	0.24**	-0.37**
3	Jaya	4.11**	0.12	-0.56**	-0.20**	-0.03	0.01	-0.31**
SE(gi) Tester		0.3	0.12	0.21	0.07	0.04	0.04	0.06
SE(gi – gj)		0.43	0.17	0.3	0.1	0.05	0.05	0.08

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

Table 3: Estimates of specific combining ability (SCA) effects of crosses for 7 characters in rice under sodic soil

S. No.	Crosses	Spikelets / panicle	Spikelet fertility (%)	Biological yield / plant (g)	Harvest-index (%)	L/B ratio	1000-grain wt. (g)	Grain yield / plant (g)
1	NDRK-50055 X CSR-10	-1.53*	0.06	-1.26*	-1.71**	-0.08	-0.45**	-1.38**
2	NDRK-50055 X BPT-5204	-14.17**	-1.07**	-3.07**	0.84**	-0.05	-0.87**	-0.87**
3	NDRK-50055 X Jaya	15.70**	1.02**	4.33**	0.87**	0.13	1.33**	2.24**
4	Imp. Pusa Bas. 1 X CSR-10	-1.37	0.39	-1.08*	0.62**	0.38**	0.11	-0.92**
5	Imp. Pusa Bas. 1 X BPT-5204	-6.14**	1.23**	0.77	0.07	-0.35**	-0.94**	0.76**
6	Imp. Pusa Bas. 1 X Jaya	7.52**	-1.62**	0.31	-0.70**	-0.03	0.83**	0.16
7	Narendra-359 X CSR-10	10.86**	-0.42	3.22**	-0.23	-0.42**	-0.79**	1.26**
8	Narendra-359 X BPT-5204	-6.81**	0.71*	-2.69**	1.09**	0.61**	-0.04	-0.60**
9	Narendra-359 X Jaya	-4.05**	-0.29	-0.53	-0.85**	-0.20*	0.83**	-0.66**
10	NDRK-50051 X CSR-10	-1.91*	-0.70*	-0.89	-0.3	-0.12	-1.34**	-0.46**
11	NDRK-50051 X BPT-5204	-7.48**	-0.13	3.53**	-0.58**	0.05	0.30**	1.11**
12	NDRK-50051 X Jaya	9.39**	0.83**	-2.64**	0.88**	0.07	1.04**	-0.65**
13	Narendra-6330 X CSR-10	-7.20**	0.63*	-1.28*	1.29**	-0.28**	-0.20*	0.11
14	Narendra-6330 X BPT-5204	20.90**	0.4	2.37**	-1.69**	0.08	-0.65**	0.12
15	Narendra-6330 X Jaya	-13.70**	-1.04**	-1.09*	0.40*	0.20*	0.85**	-0.24
16	NDRK-50063 X CSR-10	3.78**	0.49	4.83**	-0.04	0.11	1.86**	1.98**
17	NDRK-50063 X BPT-5204	2.81**	0.26	-1.12*	0.67**	0.20*	-0.26**	-0.14
18	NDRK-50063 X Jaya	-6.59**	-0.75*	-3.72**	-0.63**	-0.31**	-1.60**	-1.84**
19	IR-14 T-102 X CSR-10	1.91*	0.69*	-1.34*	-2.12**	-0.08	-1.30**	-1.56**
20	IR-14 T-102 X BPT-5204	-5.76**	0.06	2.01**	2.03**	-0.29**	1.28**	1.81**
21	IR-14 T-102 X Jaya	3.84**	-0.75*	-0.66	0.09	0.37**	0.02	-0.25
22	N. Usar-2009 X CSR-10	-10.04**	1.31**	1.08*	-0.39*	-0.24**	0.36**	0.28*
23	N. Usar-2009 X BPT-5204	7.99**	-0.95**	-0.41	0.96**	0.43**	0.67**	0.29*
24	N. Usar-2009 X Jaya	2.05**	-0.36	-0.67	-0.57**	-0.19*	-1.03**	-0.57**
25	IR-14 T-105 X CSR-10	-5.74**	1.18**	-0.69	-0.71**	-0.49**	-0.08	-0.61**
26	IR-14 T-105 X BPT-5204	0.52	-0.49	2.03**	1.04**	0.14	0.70**	1.33**
27	IR-14 T-105 X Jaya	5.22**	-0.69*	-1.34*	-0.33	0.36**	-0.63**	-0.73**
28	NDRK-50054 X CSR-10	26.60**	0.13	3.98**	0.76**	0.38**	1.51**	2.04**
29	NDRK-50054 X BPT-5204	-8.73**	-0.3	-2.64**	-0.89**	-0.05	-0.51**	-1.52**

30	NDRK-50054 X Jaya	-17.87**	0.16	-1.34*	0.14	-0.33**	-1.01**	-0.51**
31	NDR-2026 X CSR-10	25.67**	-0.04	0.29	0.44*	0.47**	0.82**	0.35*
32	NDR-2026 X BPT-5204	-20.23**	-1.07**	0.84	-0.50**	-0.40**	-0.66**	0.09
33	NDR-2026 X Jaya	-5.44**	1.12**	-1.13*	0.06	-0.08	-0.16	-0.44**
34	Narendra-3112-1 X CSR-10	14.53**	-0.44	-1.53**	-0.59**	0.15	-0.78**	-0.89**
35	Narendra-3112-1 X BPT-5204	-2.98**	0.03	1.18*	-0.64**	-0.12	0.74**	0.16
36	Narendra-3112-1 X Jaya	-11.55**	0.42	0.35	1.23**	-0.03	0.04	0.73**
37	NDRK-50046 X CSR-10	-11.35**	-0.32	-3.69**	-0.41*	-0.02	-0.94**	-1.68**
38	NDRK-50046 X BPT-5204	-20.39**	-0.25	-0.94	-0.46*	-0.35**	-1.00**	-0.63**
39	NDRK-50046 X Jaya	31.74**	0.57*	4.63**	0.87**	0.37**	1.94**	2.31**
40	Usar-1 X CSR-10	-23.75**	1.18**	3.44**	-0.26	0.36**	-0.50**	1.35**
41	Usar-1 X BPT-5204	26.58**	0.58*	-1.27*	-0.44*	0.09	2.12**	-0.78**
42	Usar-1 X Jaya	-2.83**	-1.76**	-2.17**	0.69**	-0.46**	-1.62**	-0.57**
43	N-80 X CSR-10	7.86**	-1.18**	1.01	0.92**	-0.32**	-0.06	0.89**
44	N-80 X BPT-5204	-16.68**	1.13**	-1.11*	-1.46**	-0.22*	0.68**	-1.17**
45	N-80 X Jaya	8.82**	0.05	0.09	0.54**	0.53**	-0.62**	0.27*
46	IR-92831-22-BAY 2-1 X CSR-10	-11.13**	-0.57	0.01	-0.27	0.31**	-1.52**	-0.08
47	IR-92831-22-BAY 2-1 X BPT-5204	-11.90**	-0.2	-0.41	0.59**	-0.36**	-0.34**	0.1
48	IR-92831-22-BAY 2-1 X Jaya	23.03**	0.76**	0.39	-0.32	0.06	1.86**	-0.03
49	N. Parag X CSR-10	19.04**	-1.19**	0.27	0.29	0.20*	1.26**	0.28*
50	N. Parag X BPT-5204	-13.77**	1.15**	1.08*	0.27	0.06	-0.23**	0.56**
51	N. Parag X Jaya	-5.27**	0.04	-1.35*	-0.56**	-0.26**	-1.03**	-0.84**
52	Pusa Bas.-1 X CSR-10	-23.29**	-1.98**	-4.60**	0.28	-0.33**	-1.25**	-1.72**
53	Pusa Bas.-1 X BPT-5204	19.94**	1.16**	-2.22**	-0.24	0.30**	0.23*	-1.04**
54	Pusa Bas.-1 X Jaya	3.34**	0.82**	6.82**	-0.04	0.02	1.03**	2.76**
55	NDRK-50058 X CSR-10	-15.62**	1.19**	3.62**	0.37*	0.13	-0.63**	1.75**
56	NDRK-50058 X BPT-5204	18.21**	-0.77**	-1.99**	-1.18**	-0.44**	-0.32**	-1.44**
57	NDRK-50058 X Jaya	-2.59**	-0.42	-1.63**	0.82**	0.31**	0.95**	-0.30*
58	N. Shushk Samrat X CSR-10	-7.71**	-0.52	-3.41**	1.10**	0.36**	0.67**	-0.83**
59	N. Shushk Samrat X BPT-5204	17.56**	-0.62*	2.07**	-0.48**	-0.17*	0.52**	0.61**
60	N. Shushk Samrat X Jaya	-9.85**	1.14**	1.34*	-0.62**	-0.19*	-1.18**	0.22
61	NDRK-50052 X CSR-10	-0.26	-0.58*	-3.79**	0.31	-0.59**	-0.11	-1.34**
62	NDRK-50052 X BPT-5204	17.57**	0.59*	4.73**	-0.17	0.94**	1.27**	1.83**
63	NDRK-50052 X Jaya	-17.30**	-0.02	-0.94	-0.14	-0.34**	-1.16**	-0.49**
64	N-6093 X CSR-10	-7.75**	-0.05	-0.8	0.32	0.16	1.07**	-0.12
65	N-6093 X BPT-5204	7.44**	-1.02**	-0.85	0.77**	0.13	-0.38**	0.02
66	N-6093 X Jaya	0.31	1.07**	1.65**	-1.10**	-0.29**	-0.68**	0.1
67	NDRK-50060 X CSR-10	18.40**	0.72*	2.61**	0.34	-0.06	2.28**	1.31**
68	NDRK-50060 X BPT-5204	-4.50**	-0.41	-1.91**	0.40*	-0.23**	-2.31**	-0.61**
69	NDRK-50060 X Jaya	-13.90**	-0.32	-0.71	-0.74**	0.29**	0.03	-0.70**
	SE (S_{ij})	1.46	0.57	1.03	0.35	0.17	0.17	0.27
	SE ($S_{ij} – S_{kl}$)	2.06	0.81	1.46	0.5	0.24	0.24	0.38

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

Discussion

The analysis of variance for combining ability revealed non-significant mean squares due to testers and lines for all the characters under study except significant mean squares observed for testers for plant height. This indicated less importance of general combining ability and additive gene effects in expression of out of 7 characters. The mean squares due to lines x testers interactions, indicating importance of specific combining ability and non-additive gene effects, were found to be highly significant for all the thirteen characters under study.

The estimates of SCA variance were higher than the corresponding estimates of GCA variance for all the traits. On the basis of general combining ability effects, NDRK 50052 and Pusa Basmati 1, NDRK 50060 showed desirable and significant GCA effects for grain yield/plant and some of the yield contributing traits to emerge as valuable donor parents for hybridization programme for obtaining high yielding hybrid varieties or transgressive segregants for developing pure line varieties of rice under sodic soil. Twenty-three out of sixty-nine crosses emerged with positive and significant SCA effects for grain yield/plant. The top ten crosses were Pusa Bas.-1 x Jaya, NDRK-50046 x Jaya, NDRK-50055 x Jaya, NDRK-50054 x CSR-10, NDRK-50063 x CSR-10, IR 14 T 102 x BPT 5204, NDRK 50058 x CSR 10, Usar 1 x CSR 10, IT 14 T105 x BPT 5204 and NDRK 50060 x CSR 10 which showed significant and positive SCA effects for grain yield/plant as well as some other yield components. The twenty-three crosses having positive and desirable SCA effects for grain yield and some of its component traits merit attention for exploitation as hybrid varieties in breeding materials for developing superior aerobic rice genotypes under salt affected soil.

The twenty-three crosses having significant and positive SCA effects for grain yield per plant also showed desirable and significant SCA effects for some other characters, most commonly biological yield/plant, 1000-grain weight, harvest-index, flag leaf area and spikelet fertility suggested that manifestation of SCA effects for grain yield is related with higher SCA effects for important yield components. 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 indicating thereby lack of any relationship between positive and significant SCA effects of crosses with GCA effects of their parents for the characters under study.

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