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COMBINING ABILITY STUDIES IN RICE THROUGH 6 X 6 DIALLEL CROSS ANALYSIS

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ABSTRACT

A 6 x 6 diallel cross experiment on rice was conducted in saline sodic soil at Soil Salinity Research Institute, Pindi Bhattian, Punjab, Pakistan during 2013-14. The parents F_1 and F_2 generations were grown and data were collected on eight agro-physiological traits for each generation. Six rice genothypes viz. Basmati-370, Super Basmati, Shaheen Basmati, Basmati PB-95, NIAB IRRI-9 and Basmati-385 were tested in the study. The included traits were, days to maturity, plant height, panicle fertility, tillers per plant, panicle length, shoot dry weight, paddy yield per plant and 1000-grain weight. Three chemicals i.e. Na, K and Ca were also determined from both generations. The data were processed for combining ability analysis in both generations. The results revealed that additive effects were preponderance for panicle length, plant height and number of tillers per plant in both generations. For the traits like paddy yield, shoot dry weight, days to maturity and panicle fertility non-additive effects were more prominent. This study further indicated that in both generations non-additive effects were preponderance for sodium content, calcium content and potassium sodium ratio of shoot. The crosses of Basmati 385 x NIAB IRRI-9, Shaheen Basmati x Basmati 385 and Shaheen Basmati x Basmati 370 were better for traits like paddy yeild, salt tolerance and early maturity. The study also revealed that Shaheen Basmati proved to be the best combiner for all traits followed by Basmati PB-95. Moreover, cross combinations of Shaheen Basmati with different genotypes gave SCA effects for most of the traits.

KEYWORDS: Rice; *Oryza sativa;* genotypes; combining ability; cross breeding; agronomic characters; salt tolerance; Pakistan.

INTRODUCTION

Salinity is a major worldwide problem, limiting the crop yield potential. The salt affected area in Pakistan is almost 6.68 million hectares (Khan, 1998). One approach that is largely practiced on samall scale is reclamation of soil but on large scale it is not feasible (Qureshi *et al.,* 1990). Development of salt tolerant crop cultivars for salt affected soil is quite promising and fruitful technique (Qureshi and Barret-Lennard, 1998). Worldwide rice is harvested on 148 million hectares, more than 10% of the earth's arable land (5). In Pakistan, reduction in paddy yield is 40-47% because of salinity and sodicity (Muhammad *et al.,* 1991; Aslam *et al.,* 1994).

Rice (*Oryza sativa* L.) is usually considered as moderately sensitive to salt strss (Shabbir *et al.,* 2001). The threshold (maximum soil salinity level without yield loss) of rice is EC 3 dS/m, beyond this level yield starts decreasing and is drastically reduced at EC 10 dS/m. The most obvious mechanism of salt tolerance is morphological adaptation (Waisel, 1972). Rice adopts two mechanisms to tolerate salinity i.e. osmotic tolerance and ion exclusion (Munns and Tester, 2008). These mechanisms are further categorized into tissue tolerance, osmotic tolerance and ion exclusion (Roy *et al.,* 2014).

The K:Na is considered as a good indicator for salt tolerance of a crop. In a saline environment plants take up excess of Na^+ at the cost of K^+ and Ca^{2+} (Kuiper, 1984). The exchange of shoot K^+ by Na^+ has been noted earlier and this sparing of K^+ by Na^+ has been observed to be closely related to salt tolerance. Ahmad *et al*. (2000) observed that salinity had positive association with Na/K ratio while it had negative association with yield. Salinity stress on yield can be predicted from Na/K ratio in plants during maximum tillering and panicle initiation stages. Better salt tolerance varieties have lower Na/K ratio (Afride *et al.,* 1988).

Hussain *et al.* (2003) studied one salt tolerant fine rice variety (Shaheen Basmati) which was solely developed/evolved as salt tolerant. To dissect the physiological mechanism involved in salt tolerance of this variety an experiment was conducted in water culture. In all levels of salt stress the ionic concentration of K^+ significantly decreased.

Narayanan and Rangaswamy (1990) conducted a 6 x 6 full diallel experiment and observed that there was preponderance of additive and dominance gene effects for days to flowering, number of tillers, plant height, panicle length and number of tillers, panicle length and number of spikelets per panicle, 1000-grain weight and dry matter accumulation under both normal and salinized conditions. The additive genetic effect was significant for grain in salinized media. Salinization suppressed, to a greater extent, the dominance effect of genes contributing to the expression of grain yield and suggested that varieties involving more additive genes for grain yield would perform better in saline soils. High heritability was reported dry matter accumulation, for number of spikelets per panicle and 1000-grain weight. Similarly Mishra (1990) reported that in stress environment for sterility percentage, panicle weight, days to 50 percent flowering, grains per panicle, fertile tillers per plant, plant height, grain and straw yield per plant were under the control of additive gene action . The objective of this study was to see the best combiners for evolution of high yielding, short duration and salt tolerant rice variety.

MATERIALS AND METHODS

This study was conducted in the saline sodic soil at Soil Salinity Research Institute, Pindi Bhattian, Punjab, Pakistan. The soil of the required salinity-sodicity level was selected from a salt affected field having sandy loam texture. For the development of plant material to be used in salt tolerance studies, six genotypes of rice viz Basmati-370, Super Basmati, Shaheen Basmati, Basmati PB-95, NIAB IRRI-9 and Basmati-385. These genotypes differed from each other in salinity tolerance and maturity period.

Each parent was grown in glazed pots measuring 30 cm x 25cm during rice growing season i.e. June-November. When six parents started to flower they were crossed according to diallel system of crossing. The experiment was conducted in saline-sodic clay loam soil with EC 7.75 dS/m, SAR 28 mmol/L)$^{1/2}$, and pH 9.0. Soils with EC 4 dS/m is classified as saline and those with SAR.15 (mmol/L) $^{1/2}$ as sodic and saline-sodic soils combine these features (US Salinity Lab Staff, 1954). A site with appropriate chemical properties was selected after intensive sampling from a salt-affected field at the Institute (31 54/N, $73^0$07E). To avoid leaching of salt to maintain a constant salt concentration in the column, artificial salinity blocks were constructed. The beds of blocks were lined with impermeable polythene sheet and the sides were protected by sidewalls. To maintain a uniform salt stress throughout the growth period, a minimum workable soil column 25-cm deep was developed. In a longer column, due to leaching the salt stress become milder in the top layers. Three such blocks measuring 15.6m long, 15.0m wide, and 0.5m deep were built, each serving as one replication. The blocks were constructed adjacent to rice fields, and thus the environmental conditions were similar to the field except that leaching was prevented in the blocks. A depth of 2.5 cm of main water (EC 0.40 dS/m) was maintained in the blocks throughout the growth period.

Six rice accessions, representing the range of tolerance to salinity, were hybridized in a complete diallel, i.e. each accession was used as both female and male parent. Accessions NIAB IRRI-9, Shaheen Basmati, and Basmati PB 95 were salt tolerant or moderately tolerant cultivars, whereas Basmati-370 was sensitive (Aslam, 1987; Muhammad *et al.,* 1991, Aslam *et al.,* 1994; Muhammad and Aslam 1998). Basmati accessions are generally considered as sensitive to salt stress, so Basmati-385 and Super Basmati having a tolerance level equivalent to that of Basmati 370, were used as additional salt sensitive parents in these studies.

Crossed seeds and also the selfed grains from the parents were harvested from the crossing block. In next season, these seeds were germinated under standard conditions (day/night temperature 35/25°C, day length 13.5 hrs) and maternal line confirmed that a plant was indeed a hybrid progeny. The 40-day-old seedlings were transplanted into the salinity blocks. A single plant was transplanted per hill. Plots consisted of 12 plants at 23-cm spacing both within and between rows. At maturity, data from ten plants each of F_1 hybrids and their parents were recorded for the traits viz. plant height, productive tillers, panicle length, panicle fertility, days to maturity, shoot dry weight, paddy yield, 1000-grain weight, Na, Ca and K content of the shoot. Na, Ca and K contents of shoot were determined by wet digestion method and contents were noted from flame photometer (US Salinity Lab Staff, 1954).

K/Na ratio

The determination of K and Na (%) made from shoot of individual plants was used to compute K/Na ratio in individual plants.

Statistical analysis

The data obtained on 12 characters in each of 16 families were averaged and subjected to ordinary analysis of variance technique (Steel and Torrie, 1980) in order to determine whether genotype difference was significant. Only significant genotypic differences for a character allow the use of simple additive-dominance model as advocated by Mather and Jinks (1982).

Combining ability analysis

F1 hybrid data collected were also subjected to analysis of variance technique as outlined by Steel and Torrie (1980) for all characters studied to observe the level of significance among various F1 hybrids and their parental lines. All the characters under observation exhibited highly significant differences. Further analysis for combining ability effects were performed by using Griffing's (1956) Method I, Model II, Combining ability was computed as under:

General combining ability (GCA) effects

$$gi = (Xj + Xi)/2p - X../p2$$

where:

gi = Generalcombining ability effects for line i.

p = Number of parents/varieties.

Xi = Total of mean value of F1's resulting from cressing j line with ith lines.

X.i = Total of mean values of F1's resulting from crossing 1 line with hjth lines.

X.. = Grand total of all the mean values in the table.

Specific combining ability (SCA) effects

$$\hat{S}ij = ½ (X ij - X ji) - ½p (Xi. + X.i + Xj. + X. j) + 1/_{p2}\ X..$$

where

$\hat{S}_{ij}$ = Specific combining ability between ith and jth lines.

x_{ij} = Mean value of the F_1 resulting from crossing the ith and jth lines.

x_{ji} = Mean value of the F_1 resulting from crossing the jth and ith lines.

Xi. = Total of mean value of F_1' s resulting from crossing jth line with ith inbred

X.i = Reciprocal value of Xi.

Xj. = Total of mean value of F_1' s resulting from crossing ith line with jth inbred

X.j = Reciprocal value of Xi.

X. = Grand total of observations

Reciprocal effects

$$rij = ½ (Xij - Xji)$$

r_{ij} = Reciprocal effects of ith and jth varieties / lines.

x_{ij} = Mean values for the F_1 resulting from crossing the ith and jth line.

x_{ji} = Reciprocal values of F_1 resulting from Xij.

The variance due to crosses was partitioned into the variance due to general combining ability effects, specific combining ability effects and reciprocal effects, by following formulae for Method I, and Model II (Table 1) (Griffing, 1956).

Table1. Analysis of variance for Method I giving expectations of mean squares for the assumption of Model II.

Source	d. f	Sum of squares	Mean squares	Expectation of mean squares
General combining ability	p - 1	S_g	M_g	$\sigma^2 + \frac{2(p-1)}{p} \sigma^2_s + 2p\sigma^2_g$
Specific combining ability	$p \frac{(q-1)}{2}$	S_s	M_s	$\sigma^2 + \frac{2(p^2-p-1)}{p} \sigma^2_s$
Reciprocal effects	$q \frac{(p-1)}{2}$	S_r	M_r	$\sigma^2 + 2\sigma^2_r$
Error	m	S_e	M_e'	σ^2

where

$$S_g = \frac{1}{2p} \sum_i (X_{i.} + X_{.j}) - \frac{2}{p^2} X^2$$

$$S_s = \frac{1}{2} \sum_i \sum_j x_{ij} (x_{ij} + x_{ji}) - \frac{1}{2p} \sum_i (X_{.i} + X_{i.})^2 + \frac{1}{p^2} X^2$$

$$S_r = \frac{1}{2} \sum_i \sum_j x_{ij} (x_{ij} + x_{ji})$$

P = Number of parents.

M_e' = Mean squares for error.

M_g = Mean squares due to general combining ability effects.

M_s = Mean squares due to specific combining ability effects.

M_r = Mean squares due to reciprocal effects.

σ^2_g = Components of variance for general combining ability.

σ^2_s = Components of variance for specific combining ability.

σ^2_r = Components of variance for reciprocal combining ability.

Variance components were estimated by equating the observed and expected mean squares in Table 1. The estimates are commuted as follows:

$$\sigma 2g = \frac{1}{2p} + \left(Mg - \frac{Me' + p\,(p-1)\,Ms}{c}\right)$$

$$\sigma^2_s = \frac{p^2}{2c} [M_s - M_e']$$

$$\sigma^2_r = \frac{1}{2} [M_s - M_e']$$

where

$c = p^2 - p + 1.$

RESULTS AND DISCUSSION

The estimates of mean squares due to GCA revealed highly significant results for plant height, tillers per plant, panicle length, panicle fertility, shoot dry weight, yield per plant, days to maturity ,1000-grain weight, Na Ca K content of shoot, K/Na ratio of shoot, Ca/Na ratio of shoot and panicle sterility (Table 2). All traits under study had significant SCA and the reciprocal effects.

Table 2. Mean squares due to GCA, SCA and reciprocal effects of various traits in 6×6 diallel cross experiment (F1 generation).

Traits df = 5	GCA df = 5	SCA df = 15	Reciprocals df = 15	Error df = 70
Plant height	151.21294**	91.612417**	0.2043167 ns	9.7770951
Tillers per plant	14.08601**	3.6369797**	0.02123 ns	0.2674686
Panicle length	15.524949**	2.6500009**	0.0424293 ns	0.0817973
Panicle fertility	133.07991**	34.544887**	0.1515474 ns	0.2292149
Shoot dry weight	12198.124**	2575.209**	1.7095915 ns	6.8069215
Yield per plant	1281.322**	317.71379**	0.8830685 ns	4.2915634
Days to maturity	106.12769**	82.43286**	0.1375489 ns	0.5996824
1000-grain weight	4.9859999**	1.3014056**	0.0926 ns	0.1833388
Na content of shoot	0.1405285**	0.0623707**	0.0004226 ns	0.0006165
Ca content of shoot	0.0014284**	0.0019358**	6.48105ns	9.44605
K content of shoot	0.1690381**	0.0348454**	0.0011648 ns	0.0017497
K/Na ratio of shoot F1	1.2016483**	0.2857321**	0.0064101ns	0.0090124
Ca/Na ratio of shoot F1	0.018072**	0.0053427**	0.0001797 ns	0.0003211
Panicle sterility	133.07991**	34.544887**	0.1515474 ns	0.2292149

**Highly significant, NS= Non-significant, Tested against table value of F against error degree of freedom.

For all traits components of variation were estimated to find out the heritability estimate (Table 3). High GCA effects were found for plant height, panicle fertility, shoot dry weight, yield per plant, days to maturity and panicle sterility. As far as SCA is concerned, high values were obtained for plant height, panicle fertility, panicle sterility days to maturity, shoot dry weight, paddy yield, Na, Ca, K content of the shoot and K/Na ratio of shoot. High SCA values indicated high non-additive effects for these characters (Table 3).

Table 3. Estimates of components of genetic parameters.

Traits	GCA	SCA	Reciprocals	Error	Total	Additive variance	Non-additive variance
Plant height	11.78632	81.835322	-4.7863892	9.7770951	98.612348	180.858 (15.743)	9.5402 (6.009)
Tillers per plant	1.1515	3.369	-0.1231	0.2674686	4.6648686	12.433 (0.3861)	0.272 (0.147)
Panicle length	1.2869293	2.5682035	-0.019684	0.0817973	3.9172461	5.8779639 (0.5681795)	0.0890361 (0.2168886)
Panicle fertility	11.070891	34.315673	-0.0388337	0.2292149	45.576945	48.814259 (5.9527527)	0.227408 (2.272317)
Shoot dry weight	1015.9431	2568.402	-2.548665	6.8069215	3588.6034	1518.6186 (442.55522)	6.9061889 (168.93457)
Yield per plant	106.4192	313.422	-1.7042	4.2915634	422.42856	615.09168 (46.900925)	4.4797651 (17.903275)
Days to maturity	8.7940008	81.833177	-0.2310668	0.5996824	90.995793	183.0008 (18.220375)	0.6008049 (6.95518)
1000-grain weight	0.4002218	1.1180668	-0.0453694	0.1833388	1.656258	3.2735602 (0.2735455)	0.1802176 (0.1044193)
Na content of shoot	0.0116593	0.0617542	-9.69405	0.0006165	-9.62002	0.0307734 (0.0127401)	0.0006207 (0.0048632)
Ca content of shoot	0.0001112	0.0018413	-1.482	9.446	7.9659525	0.00152549 (0.000135)	9.41358 (5.1628)
K content of shoot	0.0139407	0.0330958	-0.0002924	0.0017497	0.0484938	0.1029914 (0.0073171)	0.0030253 (0.0027931)
K/Na ratio of shoot	0.09938	0.2767198	-0.0013	0.00901	0.3838098	0.4006466 (0.048275)	0.0099926 (0.0184278)
Ca/Na ratio of shoot	0.0014792	0.0050215	-7.06905	0.0003211	-7.062228	0.0068761 (0.0014136)	0.0003239 (0.0005396)
Panicle sterility	11.070891	34.315673	-0.0388337	0.2292149	45.576945	48.814259 (5.9527527)	0.227408 (2.272317)

GCA effects

For each trait the parental genotypes values for general combining ability effects and critical differences are presented in Table 4. Maximum positive value of GCA effects was recorded for plant height in Shaheen Basmati whereas minimum and negative GCA effects were noted for NIAB IRRI-9. Positive GCA effects in descending order were revealed by Shaheen Basmati, Basmati PB-95 and Super Basmati, respectively. Negative GCA effects in descending order were revealed by Basmati-385, Basmati-370 and NIAB IRRI-9.

The positive highest GCA effects for tillers per plant were recorded in Shaheen Basmati whereas minimum and negative GCA effects were noted for Basmati-370. Positive GCA effects in descending order were revealed by Shaheen Basmati, Basmati PB-95 and NIAB-IRRI-9. Negative GCA effects in descending order were revealed by Basmati-385, Super Basmati and Basmati-370.

Basmati PB-95 had the highest value for GCA effects followed by Shaheen Basmati for panicle length and Basmati-370 exhibited the minimum value Positive GCA effects in descending order were exhibited by Basmati PB-95, Shaheen Basmati and NIAB IRRI-9. Negative GCA effects in descending order were revealed for Basmati-385, Super Basmati and Basmati-370.

For panicle fertility Shaheen Basmati had the highest value for GCA effects followed by Shaheen Basmati and Basmati-370 exhibited the minimum value. Positive GCA effects in descending order were indicated by Shaheen Basmati and Basmati PB-95. Negative GCA effects in descending order were exhibited by NIAB IRRI-9, Basmati-385, Super Basmati and Basmati-370.

In case of shoot dry weight, Shaheen Basmati displayed the highest value of positive GCA effects and Bamati-370 displayed the lowest negative GCA effects. Positive GCA effects in descending order were presented by Shaheen Basmati and Basmati PB-95. Negative G.C.A. effects in descending order were shown by NIAB IRRI-9, Super Basmati, Basmati-385 and Basmati-370.

Table 4. Estimates of general combinability effects for different traits in rice (*Oryza sativa*) in a 6×6 diallel cross experiment

S.O.V	Plant height	Tillers/ plant	Panicle length	Panicle fertility	Shoot dry weight	Yield/ plant	Days to maturity	1000-grain weight	Panicle sterility
Basmati-370	-2.8233	-1.73546	-1.37907	-4.3536	-45.0143	-8.19278	3.77019	-1.0653	4.3536
Super Basmati	1.01389	-0.64046	-0.72824	-2.2433	-7.34019	-6.06639	-0.57231	-0.3345	2.2433
Shaheen Basmati	5.43472	1.24926	0.82287	4.30750	47.89787	11.74417	-2.68343	0.32241	-4.3075
Basmati PB-95	2.27778	0.88370	1.74759	3.48083	21.65287	13.63917	-3.70815	0.79491	-3.4808
NIAB IRRI-9	-3.9155	0.31648	0.08315	-0.3919	-1.83519	-10.2597	2.94352	0.30685	0.3919
Basmati-385	-1.9875	-0.07352	-0.54630	-0.7994	-15.3610	-0.86444	0.25019	-0.0242	0.7994
CD (gi-gj)	1.62951	0.0445781	0.013632	0.03820	1.1344	0.7152	0.0999	0.0305	0.0382025
					Na	**Ca**	**K**	**K/Na**	**Ca/Na**
Basmati-370					0.05972	-0.0151	-0.1658	-0.35666	-0.0441
Super Basmati					0.17944	0.0041	0.01667	-0.34546	-0.0470
Shaheen Basmati					-0.0991	-0.0073	0.04750	0.277931	0.0228
Basmati PB-95					-0.1116	0.0152	0.09000	0.352786	0.0523
NIAB IRRI-9					-0.0205	0.0071	0.13278	0.193625	0.0090
Basmati-385					-0.0077	-0.0040	-0.1211	-0.12221	0.0070
CD (gi-gj)					0.00010	1.57405	0.00029	0.00150	0.000053

In term of days to maturity, Basmati-370 gave maximum positive GCA effects and Basmati PB-95 revealed the lowest negative value for GCA effects. Positive GCA effects in descending order were shown by Basmati-370, NIAB IRRI-9 and Basmati-385. Negative GCA effects in descending order were observed for Super Basmati, Shaheen Basmati and Basmati PB-95.

As far as yield per plant in concerned, maximum value for GCA effects were recorded for Basmati PB-95 and minimum negative effects were noted for NIAB IRRI-9. Positive GCA effects in descending order were given by Basmati PB-95, and Shaheen Basmati. Negative GCA effects in descending order were demonstrated by Basmati-385, Super Basmati, Basmati-370 and NIAB IRRI-9.

With regards to 1000-grain weight Basmati PB-95 depicted the highest positive GCA effects and Basmati-370 depicted minimum negative effects. In descending order the positive GCA effects were revealed by Basmati PB-95, Shaheen Basmati and NIAB IRRI-9. In descending order the negative GCA effects were demonstrated by Basmati-385, Super Basmati and Basmati-370.

In case of panicle sterility, Basmati-370 surpassed for positive GCA effects and Shaheen Basmati surpassed for negative GCA effects. In descending order positive GCA effects were moted for Basmati-370, Super Basmati, Basmati-385 and NIAB IRRI-9. In descending order negative GCA effects were shown by Basmati-PB-95 and Shaheen Basmati

In terms of Na content of shoot, Super Basmati had maxium positive GCA effects and Basmati PB-95 showed minimum negative GCA efects. In descending order the positive GCA effects were shown by Super Basmati and Basmati-370. Negative GCA effects in descending order were revealed by Basmati-385, NIAB IRRI-9, Shaheen Basmati and Basmati PB-95.

For Ca content of shoot highest positive GCA effects and lowest negative GCA effects effects were recorded for Basmati PB-95 and Basmati-370 respectively. Positive G.C.A. effects in descending order were given by Basmati PB-95, NIAB IRRI-9 and Super Basmati. Negative GCA effects in descending order were displayed by Basmati-385, Shaheen Basmati and Basmati-370.

For K content of shoot the highest positive GCA effects and lowest negative GCA effects effects were recorded for NIAB IRRI-9 and Basmati-370, respectively. Positive GCA effects in descending order were depicted by NIAB IRRI-9, Basmati PB-95, Shaheen Basmati and Super Basmati. Negative GCA effects in descending order were recorded for Basmati-385 and Basmati-370.

In case of K/Na ratio of shoot, Basmati PB-95 had maximum positive GCA effects and Basmati-370 showed minimum negative GCA efects. Positive

GCA effects in descending order were depicted by Basmati PB-95, Shaheen Basmati and NIAB IRRI-9. Negative GCA effects in descending order were indicated by Basmati-385, Super Basmati and Basmati-370.

In case of Ca/Na ratio of shoot, Basmati PB-95 had maximum positive GCA effects and Super Basmati showed minimum negative GCA efects. Positive GCA effects in descending order were depicted by Basmati PB-95, Shaheen Basmati, NIAB IRRI-9 and Basmati-385. Negative GCA effects in descending order were indicated by Basmati-370 and Super Basmati

The data (Table 4) further revealed that the parent Shaheen Basmati proved to be the best combiner for plant height, tillers per plant, panicle length, panicle fertility, shoot dry weight yield per plant, 1000-grain weight, Na, Ca and K content of shoot followed by Basmati PB-95. Also for days to maturity and panicle sterility both these parents showed desirable trend i.e. minimum days to maturity and panicle sterility. Since high general combining ability effect is related to additive or additive x additive interaction (Griffing 1956; Sprague 1966) and represents the fixable genetic component of variation, parents Shaheen Basmati and Basmati-95 appeared worthy of exploitation for most other traits under consideration. Therefore it is suggested that these parents for specific characters can be used as donor parent in hybridization.

SCA effects

Data for only those crosses are given in Table 5 which have shown significantly positive and negative SCA effects for different traits. For plant height the best cross combination was Super Basmati x NIAB IRRI-9 followed by Shaheen Basmati x NIAB IRRI-9. The cross combination of Basmati PB-95 x Basmati-385 revealed the lowest SCA effect. For plant height more than half cross combinations gave positive SCA effects while negative effects were exposed by less than one third of the combinations.

In case of tillers per plant, the best cross combination was Basmati PB-95 × Shaheen Basmati, while the cross combination of NIAB IRRI-9 x Shaheen Basmati had the lowest SCA effects. For tillers per plant around half of the cross combinations unfurled positive SCA effects whereas more than half of the combinations gave negative SCA effects.

For panicle length, the cross combination of Shaheen Basmati × Basmati PB-95 had the highest SCA effects whereas the cross combination Super Basmati x Basmati-370 revealed minimum SCA effects. More than half of the cross combinations gave negative SCA effects and less than half of the combinations revealed positive SCA effects in case of panicle fertility.

With regards to panicle fertility, cross combination Shaheen Basmati × Super Basmati gave maximum SCA effect. The cross combination Basmati-385 x Basmati-370 exhibited the lowest SCA effect. More than half of the cross combinations gave negative SCA effects and less than half gave positive effects for panicle fertility.

As far as days to maturity are concerned, the cross of Shaheen Basmati × Basmati-370 had the highest estimate of SCA effect. The minimum SCA effects was recorded for cross combination of Basmati -370 x Super Basmati. More than half of the cross combinations exhibited positive SCA effects for primary days to maturity while less than half showed negative effects.

In case of shoot dry weight, NIAB IRRI-9 × Basmati PB-95 had the highest estimate of SCA effect and minimum SCA effects were recorded for Basmati-370 x Basmati PB-95. Majority of the cross combinations gave positive SCA effects for shoot dry weight.

For paddy yield, cross combination Basmati-385 × NIAB IRRI-9 gave maximum value of SCA effects and the cross combination of Shaheen Basmati x Basmati-370 had the lowest SCA effect. More than half of the cross combinations gave negative SCA effects for paddy yield.

Table 5. Estimates of specific combinability effects for different traits in rice (*Oryza sativa*) in a 6×6 diallel cross.

Sr. No.	Trait	Crosses	Values (SCA)
1.	Plant height	Super Basmati x NIAB IRRI-9	7.97972222
		Shaheen Basmati x NIAB IRRI-9	6.715556
		Basmati PB-95 x Basmati-385	-8.7972
2.	Tillers per plant	Basmati PB-95 x Shaheen Basmati	1.1660
		NIAB IRRI-9 x Shaheen Basmati	-1.5118
3.	Panicle length	Shaheen Basmati x Basmati PB-95	2.620185
		Super Basmati x Basmati-370	-1.28203
4.	Panicle Fertility	Shaheen Basmati x Super Basmati	5.4552778
		Basmati-385 x Basmati-370	0.3241667
5.	Days to maturity	Shaheen Basmati x Basmati-370	8.2156481
		Basmati-370 x Super Basmati	-7.97712
6.	Shoot dry weight	NIAB IRRI-9 x Basmati PB-95	50.731852
		Basmati-370 x Basmati PB-95	-40.1589
7.	Yield per plant	Basmati-385 x NIAB IRRI-9	15.296667
		Shaheen Basmati x Basmati-370	-16.1455
8.	1000-grain weight	Shaheen Basmati x Super Basmati	1.2150926
		Basmati-370 x Shah x een Basmati	-0.66240
9.	Na-content of shoot	Basmati-385 x Super Basmati	0.2730556
		Super Basmati x Basmati PB-95	-0.24472
10.	Ca-content of shoot	Basmati PB-95 x Basmati-385	0.0534259
		Super Basmati x Basmati PB-95	-0.00962
11.	K-content of shoot	Basmati-385 x Basmati PB-95	0.2444444
		Shaheen Basmati x NIAB IRRI-9	0.1613889
		Nayyab IRRI-9 x Basmati-385	-0.13277
12.	K / Na ratio of shoot	Basmati-370 x NIAB IRRI-9	0.6486903
		Shaheen Basmati x Basmati-385	0.4879181
		NIAB IRRI-9 x Basmati-385	0.0542764
13.	Ca / Na ratio of shoot	Shaheen Basmati x Basmati-385	0.12377771
		Super Basmati x Basmati-370	0.0211269

Maximum value of SCA effects for 1000-grain weight was recorded in cross combination of Shaheen Basmati × Super Basmati while the bottom most SCA effects were recorded for Basmati-370 x Shaheen Basmati. Near half of the cross combinations displayed positive and remaining lot gave negative SCA effects for this trait.

For Na content of shoot, cross combination Basmati-385 x Super Basmati gave the highest SCA effects while the bottom most SCA effects were recorded for Super Basmati x Basmati PB-95. Half of the cross combinations displayed positive and other half gave negative SCA effects for this trait.

In case of Ca content of shoot, cross combination Basmati PB-95 x Basmati-385 gave the highest SCA effects whereas minimum SCA effects were recorded for Super Basmati x Basmati-385. More than half of the cross combinations gave negative SCA effects for this character.

For K content, cross combination of Basmati-385 × Basmati PB-95 had the highest value for SCA effects followed Shaheen Basmati x NIAB IRRI-9. Minimum value was recorded for cross combination of NIAB IRRI-9 x Basmati-385. More than half of the cross combinations gave negative SCA effects for K content of the shoot.

In case of K:Na ratio of shoot, cross combination of Basmati-370 x NIAB IRRI-9 exhibited the highest SCA effects followed by Shaheen Basmati x Basmati-385 and minimum value was recorded for cross combination of NIAB IRRI-9 x Basmati-385 . Half of the cross combinations gave positive SCA effects for K:Na ratio of the shoot.

In case of Ca:Na ratio cross combination of Shaheen Basmati x Basmati-385 had the highest and cross combination Super Basmati. x Basmati-370 had the lowest SCA effects. Half of the cross combinations gave positive SCA effects for Ca: Na ratio of the shoot.

The results given in Table 5 clearly indicate that cross combinations of Shaheen Basmati with different genotypes gave SCA effects for most of the plant characters. Therefore crosses of parent Shaheen Basmati were more successful than any other parent in aggregate for SCA.

Positive association was found between sodium content and sodium/potassium ratio of shoot. The role of these traits have been assessed in exclusion of Na from rice plant shoot. Further, the Na content of shoot at grain filling stage were found associated with grain yield (Selamat, 2010) and percentage of plants surviving after 90-days of salt stress was associated with potassium/sodium ratio (Gupta and Huang, 2014), suggesting that both selection criteria are reliable for salinity tolerance in rice. Zeng *et al.* (2003) reported a very strong association between Na-Ca selectivity and on the basis of this association they ranked the accessions for grain yield potential. Their final conclusion was that Na-Ca selectivity could be a promising selection criteria for screeing salt tolerance in rice plant.

Once the available genetic variation and heritability of different morpho-physiological traits is known then these paremeters could be a promising one's in breeding salt tolerance genotypes. The complex nature of salt tolerance mechansism in rice plant is a major hindrance in breeding salt tolerance (Rahman *et al.,* 2016).

REFERENCES

Afridi, M.M.R.K., A. Qudar and R. S. Dwivedi. 1988. Effect of salinity and sodicity on growth and ionic composition of *Oryza sativa* L. and *Diplachne fusa.* J. Indian. Bot. Soc.67(1-2): 166-182.

Agarwal R.P., J.S.P Yadav and R.N. Gupta 1979. Saline and alkali soils of India (Indian Council of Agricultural Research: New Delhi, India).

Ahmad, I.N., M. Iqbal, Z. Alam and E. Rasool. 2000. Germination and seedling growth of rice (*Oryza sativa* L.) under saline condition. Pak. J. Biol. Sci., 3:350-351.

Aslam, M. 1987 Mechanisms of salt tolerance in rice (*O. sativa* L.). Ph.D. Thesis, Department of Soil Science, University of Agriculture, Faisalabad, Pakistan.

Aslam, M., I. Ahmad, I.A. Mahmood, J. Akhtar and S. Nawaz. 1994. Physiological basis of differential tolerance in rice to salinity. Pak. J. Soil. Sci. 9: 96-99.

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel mating systems. Aust. J. Biol. Sci. 9: 463-493.

Gupta, B. and B. Huang. 2014. Mechanisms of salinity tolerance in plants: physiological, biochemical and molercular characterization. Int. J. Genom. 2014:1-18

Hussain, N., A. Ali, G. Sarwar, F. Mujeeb and M. Tahir. 2003. Mechanism of salt tolerance in rice. Pedosphere. 13(3): 233-238.

IRRI. 1994. Rice Facts. Jan, 1994. P.O. Box 933, Manila, Philippines.

Khan, G.S. 1998. Soil Salinity/Sodicity Status in Pakistan. Soil Survey of Pakistan, Lahore. p. 59.

Kramer, D., A. Lauchli, A.R. Yeo and J. Gullasch. 1997 Transfer cells in roots of *Phaseolus connineus*: Ultra-structure and possible function in eclusion of sodium from the shoot. Annals of Botany. 41:1031-1040.

Kuiper P.J.C. 1984. Functioning of plant cell membranes under saline copndition:Membrane lipid composition and ATPases. *In:* Salinity Tolerance in Plants. Staples, R. G. and G. H. Toeniessen (eds.). p.77-91 (Wiley-Interscience:New York, NY).

Mather,K. and J.C. Jinks. 1982. Biomaterial Genetics. 3rd Edition. Published by Chapman and Hall, 11 New Fetter Lane, London, Ec 4P 4EE.

Mishra, B. 1990. Combining ability and heterosis for yield and yield components related to reproductive stage salinity and sodicity tolerance in rice (*Oryza sativa* L.). *In:* Rice Genetics II. Pp. 761. Proc. International Rice Genetics Symposium, 14.18 May, 1990, Manila, Philippines.

Muhammad, S. and M. Aslam. 1998. Screening of rice for salt tolerance. Pak. J. Soil. Sci. 14: 96-98.

Muhammad, S., M.T. Chaudhary and T. Hussain. 1991. Inter-varietal selection for salt tolerance in rice. Pak. J. Soil. Sci. 6: 13-16.

Munns, R. and M. Tester. 2008. Mechanisms of salinity tolerance. Annu. Rev. Plant Biol. 59: 651-681.

Narayanan, K.K. and S.R. Rangaswamy. 1990. Genetic for salt tolerance in rice. *In:* Rice Genetics. Proc. Int. Rice Gen. Symp. 14-18 May, 1990, Manila, Philippines.

Qureshi, R.H. and E.G. Barret-Lennard. 1998. Saline Agriculture for Irrigated Land in Pakistan. A Hand Book, ACIAR, Canberra, Australia. p. 19-24.

Qureshi, R.H., A. Rashid and N. Ahmad. 1990. A procedure for quick screening of wheat cultivars for salt tolerance. p:315-324. *In:* Elbasam, N., M. Damborth and B.C. Laughman (eds.). Genetic Aspect of Plant Mineral Nutrition, Kluwer Acad. Pub., Dordecht, The Netherlands.

Rahman, M.A., M. J. Thomson, M. Shah-e-Alam, M. De Ocampo, J. Egdane and A. M. Ismail. 2016. Expolring novel genetic sources of salinity tolerance in rice through molecular and physiological characterization. Ann. Bot. 117 (6): 1083-1097.

Roy,S.J., S.Negrao and M.Tester. 2014. Salt resistant crop plants. Curr. Opin Biotechnol. 26: 115-124.

Selamat, A. 2010. Effect of salt stress on germination and early seedling growth on rice (*Oryza sativa* L.). Afr. J. Biotechnol. 9(13): 1911-1918.

Shabbir, G., N. Hussain, M.K. Bhatti, A. Ahmad, M.A. Javed and M.A. Shakir. 2001b. Salt tolerance potential of some selected fine rice cultivars. Online J. Biol. Sci. 1 (2): 1175-1177.

Sprague, G. F.1966. Plant Breeding. p.315-354. The Iowa State University Press, Ames, Iowa.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics, A Biological Approach, Second Edition, McGraw Hill Book Co. Inc. New York, Toronto, London.

United States Salinity Lab. Staff. 1954. Diagnosis and improvement of saline and alkali soils. U.S.D.A. Hand Book No. 60. (Indian Ed.) Oxford and I.B.U. Publishing Company Pvt. Ltd. New Delhi. p.127-147.

Waisel, W. 1972. Biology of Halophytes. Acaemic Press. New York. Pp.395.

Yeo, A. R., M. E Yeo, S. A. Flowers and T. J. Flowers. 1990. Screening of rice (*Oryza sativa* L.) genotypes for physiological characters contributing to salinity resistance and their relationship to overall performance. Theoretical and Applied Genetics. 79: 377-384.

Zeng, L.H., J.A. Poss, C. Willson, A.S.E. Draz, G.B. Gregorio and C.M. Grieve. 2003. Evaluation of salt tolerance in rice genotypes by physiological characters. Emphatic. 129 (3):281-292.

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