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Combining Ability for Morphological and Biochemical Characters in Mulberry (*Morus* spp.) under Salinity Stress

Kunjupillai Vijayan*, Shyama Prasad Chakraborti[1], Subramaniam Gandhi Doss[1], Partha Deb Ghosh[2] and Sezai Ercisli[3]

SeriBiotech Research Laboratory, Central Silk Board, Carmelram Post, Bangalore, Karnataka- 560035, India.
[1]Central Sericultural Research and Training Institute, Berhampore, West Bengal-742 101, India.
[2]Department of Botany, University of Kalyani, Nadia, West Bengal-741 235, India.
[3]Ataturk University, Faculty of Agriculture, Department of Horticulture, Erzurum 25240, Turkey

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A line x tester analysis was carried out in mulberry (*Morus* spp.) under different salinity levels to determine the changes in the genetic interaction of various morpho-biochemical characters. Five mulberry genotypes, 3 females and 2 males, differing in salt tolerance were selected for the study. Clones of these parents along with clones of the F1 hybrids were planted in earthen pots and subjected to different levels of salinity (0.0%, 0.25%, 0.50%, 0.75% and 1.00% NaCl). Data on morphological and biochemical characters were subjected to line x tester analysis. The result revealed significant variation among the parents studied. The prominence of non-additive gene effect under control condition suggests the need for well chalked out breeding program to exploit the non-fixable variance of components for improvement of plant height, leaf size and leaf yield, chlorophyll and photosynthesis in mulberry. However, under salinity stress a shift from non-additive gene effect to additive gene effect for the above said character further suggests the need for a change in breeding strategy. The general combining ability (GCA) analysis has identified English black as the best combiner among the parents and the specific combining ability analysis (SCA) found crosses of English black X C776 and Rotndiloba x Mandalaya were good for Plant height and leaf size and English black X C776 and Rotundiloba x C776 were good for biochemical proline and chlorophyll. From the performance of parents and their crosses under different salinity levels and also under normal cultural conditions it is concluded that in mulberry different approaches are required to develop varieties for the irrigated and saline conditions.

Key words: Mulberry- salinity- specific combining ability- general combining ability.

Introduction

Mulberry (*Morus* spp.) is a tree species that is being cultivated for its leaves to feed silkworms in China, India and other Asian countries where sericulture is practiced to produce silk fibers. A good mulberry plantation is one of the most critical factors that decide the success of sericulture as the cost of mulberry leaf production covers more than 60% of the total cocoon production cost (Das and Krishnaswami, 1965). Many new mulberry varieties with higher leaf yield potential have been developed recently (Chakraborti et al., 1999; Datta, 2000; Jalaja et al., 1994; Vijayan and Chakraborti, 1998; Vijayan et al., 1999; Yadav, 2004) most of these verities are good only in areas where other food crops also grow well. Considering the population explosion and loss of agriculture land due to urbanization, industrialization and faulty irrigation, a major food crisis could be envisioned in the near future. In order to enhance the production of food materials, agriculture has to be expanded in all possible means. One of the area which can help in this regard is the utilization of saline soils which are not being properly used hitherto. A rough estimate reveals that nearly 19.5% of the irrigated agricultural lands are considered saline affected (Flowers and Yeo 1995) and in each year, there is an addition of

*To whom the correspondence addressed
Institute of plant and Microbial Biology, Academia Sinica, Taipei, Taiwan-115, ROC; E-mail: kvijayan01@yahoo.com

about 2 million ha of agricultural lands to salinity (Choukr-Allah, 1995; Kalaji and Pietkiewica, 1993; Syverstein et al., 1989; Tanji 1990). Since mulberry is found to be moderately salt tolerant (Vijayan et al., 2007, 2008), mulberry cultivation can be expanded to saline soils if varieties with greater resistance to salinity can be developed. Keeping this in view, present study was undertaken to work out the combining ability of a few plants that has been selected through *in vitro* culture with different salt concentrations (Vijayan et al., 2003).

Response of plants to soil salinity is a complex phenomenon governed by a number of genes (Akbar and Yabuno, 1975, Akbar et al., 1985). Plant breeders often resort to using several donor parents for contributing characteristics to construct a phenotypically salt-tolerant variety through pyramiding of desirable genes (Yeo and Flowers, 1984). To achieve this, knowledge on the genetic basis of salt tolerance of the crop is a prerequisite and assessing the combining ability of the donor parents is one of the most commonly used method for this. The notion of good combining ability implies the capacity of a parent to produce superior progenies when combined with another parent. In analyzing the combining ability data, the breeder breakdown the average performance of each progeny into components relating to general combining ability (GCA) as main effects and to specific combining ability (SCA) as interactions. GCA is the average performance of a parent estimated on the basis of its salinity tolerance when combined with other parents. GCA effects represent fixable (additive gene effects) genetic components. SCA is used to designate cases in which a certain specific combinations performed better on the basis of the average performance of the parents involved. SCA effects represent pre-dominance or non-additive gene action (Sprague and Tatum, 1942).

In mulberry, baring a single report on the combining ability for leaf yield characters in eight genotypes under irrigated conditions (Vijayan et al., 1997), no report is available on genetic basis of characters under any cultural conditions. Under this circumstances, it is utmost important to work out the genetic influence on important agronomic characters under sanity to take the first step towards developing salt resistant mulberry varieties.

Materials and Methods

Five mulberry genotypes, comprising 3 tolerant, 'English black', 'Rotundiloba' and 'C776' and 2 susceptible 'Tollygung' and 'Mandalaya' were used for a line x tester analysis. Among these genotypes 'English black', 'Rotundiloba' and 'Tollygunj' were considered as lines and 'C776' and 'Mandalaya' as testers. Crosses were made during the normal flowering seasons. Seedlings were raised from these cross combinations and allowed to grow for one year with recommended cultural practices (Ray et al., 1973). After one-year of growth, saplings were raised from stem cuttings of both the hybrids and their parents in a nursery bed. When the saplings attained six-month old, five randomly selected saplings from each set were planted in earthen pots containing about 35 kg of well-sieved sandy loam soil thoroughly mixed with Farm Yard Manure (60 : 40) and treated as it as one replication. In this way, three replications were made and the pots were arranged in Randomised Block Design. In the initial three months, the saplings were maintained under normal cultural practices. Thereafter, the plants were subjected to salinity by applying solutions of NaCl with different concentrations (0.0, 0.25, 0.5, 0.75 and 1.0% NaCl). The electric conductivity (EC) of the soil saturation extract was monitored at one day interval. Once the EC of the soil extraction was found equal to the EC of the applying NaCl solution (1.58, 6.5, 10.1, 14.1, 19.2 dS m^{-1} respectively for 0.0, 0.25, 0.5, 0.75 and 1.0% NaCl), the same EC was maintained by monitoring the EC at one day interval. Under this salinity level, the plants were pruned at 10 cm height from the ground and data on height of the longest shoot, single leaf size and leaf weight were recorded on the 60th day from the pruning as reported earlier (Vijayan et al., 1997). Single leaf weight was calculated by weighing the 7^{th}, 8^{th} and 9^{th} leaves from each twig, as these leaves were found to be physiologically mature and very healthy (Das et al., 1999). Total leaf yield was also recorded by plucking the leaf on 60^{th} day after pruning.

For all biochemical studies, 5^{th} leaf from the top of each twig was collected on the 60^{th} day since pruning. Chlorophyll and proline content of the leaf were estimated following the methods of Arnon et al. (1949) and Bates et al. (1973) respectively. Mineral content of the leaf was estimated from leaves, 9^{th} - 11^{th} positions from top of the twig, dried at 80°C for 48 hours in a hot air oven and digested with tri-acid digestion mixture (Nitric acid, Perchloric acid and Sulphuric acid in 10 : 4 : 1 ratio). The amounts of Na^+ was measured using NaCl as standard, in a flame photo meter.

Combining ability of the parents were calculated using Kempthorne's (1957) methods. Total variance among the hybrids was further partitioned into variance due to lines, testers and their interactions.

Results

Analysis of variance (ANOVA) was significant for most

Table 1. ANOVA for Line X Tester analysis in mulberry under different salt concentrations (Morphological characters)

Source	.df	Plant height					Leaf size					Leaf Yield				
		NaCl (%)					NaCl (%)					NaCl (%)				
		0.0	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00
Mean Sum of Squares																
Replicates	2	202.17**	120.92	139.45**	9.35	45.09**	12.78	15.23	609.83**	8.07	83.91	29.50*	10.46	9.93	32.93	0.55
Between Parents	4	169.51**	36.59	46.78	162.60**	60.13**	868.01**	271.60**	416.49**	366.60**	209.27**	5.83	26.31	14.64	3.14	2.05
Lines	2	1.18	25.45	6.22	6.16	23.52**	1937.5*	2969.43*	1245.71**	666.99**	764.79**	96.17**	69.76**	60.26**	69.44**	62.85**
Tester	1	17.36	40.20	10.42	63.84**	129.12**	1546.79**	426.03*	1363.46**	224.08**	153.12**	8.93	10.75	14.04	37.85	66.28**
Lines x Testers	2	361.39**	72.89	13.34	12.16	0.44	1597.46**	1365.57**	665.58**	92.58	67.75	328.89**	159.86**	166.59**	100.10**	59.41**
Between Hybrids	5	151.73**	47.39	9.91	20.09	35.21**	1723.32	1819.23**	1037.21**	348.37**	363.70**	171.81**	94.00**	93.53**	75.26**	62.13**
Parents vs Hybrids	1	5.95	1.69	6.09	0.03	0.04	244.75	71.92	42.85	240.91**	5.46	85.71**	84.59**	187.30**	46.92**	84.41**
Error	20	16.13	34.97	17.94	14.44	3.75	85.88	42.51	38.42	43.30	42.77	6.91	9.93	6.72	6.68	3.69
Estimates of components of variances																
Lines		-57.34	-7.9	-1.19	-1.100	3.77	56.66	267.31	96.69	95.63	116.14	-38.79	-15.02	-17.73	-5.16	0.57
Tester		-40.02	-3.63	-0.32	5.74	14.29	-5.63	-104.39	77.54	14.61	9.46	-35.55	-16.57	-16.95	-6.93	0.75
Gca		-46.95	-0.65	-0.66	3.04	10.08	19.28	44.28	85.20	47.01	52.13	-36.84	-15.94	-17.26	-0.06	0.68
Sca		111.25	11.34	1.66	1.25	-1.44	508.52	447.26	210.09	17.39	5.07	106.0	50.76	53.45	5.44	17.69
Gca/Sca		-0.42	-0.06	-0.39	2.43	-8.64	0.03	0.90	0.40	2.70	10.28	-0.34	-0.31	-0.32	-0.01	0.04
Proportional contributions to the total variation.																
Line		4.58	21.52	25.013	12.10	26.15	44.96	65.29	48.05	76.51	84.10	22.45	29.68	25.05	36.76	40.44
Tester		0.15	16.96	21.03	63.80	73.35	17.96	4.68	26.28	12.86	8.43	1.03	2.29	3.90	10.03	21.31
Lines x Testers		95.27	61.51	53.84	24.10	0.50	37.08	30.03	25.67	10.63	7.47	76.52	68.03	71.05	53.21	38.25

*,** significance at $P<0.05$ and $P<0.01$ levels respectively.

Table 2. ANOVA for Line X Tester analysis in mulberry under different salt concentrations (Biochemical characters)

Source	.df	Proline					Total Chlorophyll					Na^+ content in the leaf				
		NaCl (%)					NaCl (%)					NaCl (%)				
		0.0	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00
Mean Sum of Squares																
Replicates	2	0.00	0.06	0.39	1.26	1.75	0.01	0.00	0.00	0.00	0.002	8313	3091	69244*	72479*	10516
Between Parents	4	0.18**	0.50**	1.52**	2.54**	11.57**	0.63**	0.47**	0.72**	0.47**	0.95**	60962**	204794**	473412**	168285**	836286**
Lines	2	0.31**	1.76**	4.97**	6.06**	6.90**	0.76	0.89**	0.15	1.32**	1.03**	80525**	363848**	742875**	316312**	116089
Tester	1	0.58**	3.44**	0.43	0.20	0.01	0.49**	0.02	0.00	0.21**	0.00	21799	945442**	34055	2948310**	2175948**
Lines x Testers	2	0.39**	0.55	0.78	18.57**	1.81**	0.01**	0.89**	0.01	0.50**	0.92**	355998**	110398**	50857	211008	139407
Between Hybrids	5	0.40**	0.16	2.38**	9.89**	3.49*	0.38**	0.69**	0.51**	0.78**	0.78**	178969**	378787**	32430	724630**	537388**
Parents vs Hybrids	1	0.02	0.65**	0.02	7.86**	0.00	0.11	0.00	0.00	0.05**	0.18**	47516	139115**	36302	1607030**	41296
Error	20	0.02	0.07	0.17	0.52	0.60	0.05	0.00	0.00	0.00	0.005	9178	13017	15846	14773	39677
Estimates of components of variances																
Lines		-0.01	0.02	0.70	-2.08	0.85	0.11	-0.01	-0.16	0.14	0.02	-45912	42241	115336	49200	-3886
Tester		0.02	0.32	-0.04	-2.04	-0.20	0.05	-0.10	-0.12	-0.03	-0.10	-37133	92782	-1866	325244	226282
Gca		0.00	0.27	0.25	-2.05	0.22	0.07	-0.06	-0.14	0.04	-0.05	-40644	72566	45014	214827	134214
Sca		0.15	0.14	0.18	5.90	0.30	0.00	0.29	0.36	0.17	0.29	116090	31312	13108	872	29686
gca/sca		0.00	1.93	1.39	0.35	0.73	70.00	-0.20	0.38	0.24	-0.17	-0.35	2.31	0.34	246.36	4.52
Proportional contributions to the total variation																
Line		31.50	43.59	83.25	24.53	78.92	20.84	47.56	12.25	67.43	52.56	17.99	38.44	91.63	17.46	8.64
Tester		29.00	42.75	3.60	0.42	0.15	25.53	0.56	0.00	6.93	0.01	2.44	49.91	2.10	81.37	80.98
Lines x Testers		39.50	13.66	13.15	75.05	20.93	53.63	51.88	87.75	25.64	47.43	79.57	11.65	6.27	1.17	10.38

*, ** significance at P<0.05 and P<0.01 levels respectively

of the traits among lines and testers (Table 1-2). The mean sum of squares between parents for plant height was significant under control, 0.75% and 1.0% NaCl, whereas the same for lines and testers were significant only under higher salinity. The proportions of mean sum of squares due to lines and testers were of lower magnitude than their interactions under low salinity levels. The variance for SCA increased with salinity. GCA/SCA ratio was less under control conditions than those in different salinity levels. Variations among the parents for leaf size under different salinity levels were highly significant ($p<0.01$) at all the salinity levels. While the variation between lines and between testers decreased with salinity. Estimates of components of variance for leaf size revealed that under higher salinity the variance for SCA reduced significantly. This is further corroborated by the low contributions made by line x tester interaction for the total variance. The ANOVA for leaf yield showed existence of highly significant variations ($p<0.01$) among the parents and hybrids under different salinity levels. Higher proportional contribution of line x tester interaction and low GCA/SCA ratio were observed for leaf yield in mulberry under all levels of salinity.

ANOVA for proline, total chlorophyll and Na^+ content in the leaf (Table 2) revealed that variance due to lines was more prominent than due to testers. The variance between parents was significant for all characters under all salinity levels. The mean sum of squares for parents and their interactions were significant in all the salinity levels for total chlorophyll contents. The Na^+ content in the leaf on the other hand showed an increase in the GCA/SCA ratio under higher salinity.

General combining ability for plant height (Table 3) at different salt concentrations showed that GCA of the salt tolerant genotypes English black and C776 increased with increasing salinity. However, in case of the susceptible genotypes, Tollygunj and Mandalaya, the GCA decreased with increasing salinity. Thus, English black and C776 were found to be the best general combiner for plant height under saline conditions. In case of leaf size the GCA was found decreasing with increasing salinity in all genotypes. For leaf yield the GCA was higher in English black under all salinity conditions.

Regarding the GCA of the genotypes for biochemical

Table 3. General combining ability effects on mulberry under different salt concentrations (Morphological characters)

Parents	Plant height					Leaf size					Leaf yield				
	NaCl (%)														
	0.0	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00
Lines															
E. black	-1.73*	1.99	0.98	0.12	1.43	20.52*	25.69*	15.53*	11.51*	12.65*	3.72	3.19	3.24	3.86	3.61
Rot.	0.07	0.13	0.07	-1.07	0.80	-7.58*	-12.96	-12.94	-9.17	-9.04	0.52*	0.41	-0.16	-1.35	-0.99
Toll.	1.67*	-2.12	-1.05	0.95	-2.23	-12.93	-12.73	-2.59	-2.34*	-3.61*	-4.24	-3.60	-3.09	-2.51	-2.63
SE	1.05	1.53	0.71	0.98	0.53	2.09	1.20	1.46	1.37	1.79	0.78	0.75	0.61	0.74	0.62
Testers															
C776	-0.26	-1.49	-0.76	1.88	2.68	90.27**	4.87	8.70	3.53	2.92	-0.79	-0.77	-0.88	1.45	1.92
Mand.	0.26	1.49	0.76	-1.88	-2.68	-90.27**	-4.87	-8.70	-3.53	-2.92	0.79	0.79	0.88	-1.45	-1.92
SE	0.74	1.08	0.50	0.69	0.37	1.48	0.85	1.03	1.11	1.26	0.55	0.53	0.43	0.53	0.44

*, *.*- significant at $P<0.05$ and $p<0.01$ levels respectively.

Table 4. General combining ability effects on mulberry under different salt concentrations (Biochemical characters)

Parents	Proline					Total Chlorophyll					Na^+ content in the leaf				
	NaCl (%)														
	0.0	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00
Lines															
E. black	0.23**	-0.14*	0.97*	-0.98	1.06	-0.20**	0.41**	-0.19**	-0.33	-1.39**	-127.59	-147.79	-260.98	-262.24	116.57
Rot.	-0.23**	-0.46	-0.84	1.03	0.0*	0.39**	-0.12*	0.11**	0.53**	-0.04**	29.00*	284.28*	-139.19	97.34	-153.98
Toll.	0.00**	0.60*	-0.13*	-0.04	-1.08	-0.19**	-0.03**	0.08**	-0.18**	0.43**	98.59	-136.48	400.17**	164.90	37.41
SE	0.04	0.08	0.12	0.22	0.24	0.01	0.02	0.01	0.02	0.02	21.84	31.59	26.44	33.48	55.21
Testers															
C776	-0.18	-0.44	0.16	0.11	0.04	-0.17*	0.03	0.00*	-0.12	0.00	-34.80	-229.18*	-43.50	404.72*	-347.69
Mand.	0.18	0.44	-0.16	-0.11	-0.04	0.17*	-0.03	0.00*	0.12	-0.00	34.80	229.18*	43.50	-404.72*	347.69
SE	0.03	0.06	0.06	0.16	0.17	0.01	0.01	0.01	0.02	0.02	15.44	22.33	18.70	23.67	39.56

*, *.*- significant at $P<0.05$ and $p<0.01$ levels respectively.

Table 5. Specific combining ability effects on mulberry under different salt concentrations (Morphological characters)

Crosses	Plant height					Leaf sizel					Leaf yeild				
	NaCl (%)														
	0.0	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00
EB x C776	0.76**	-1.01	-1.57	-0.55	0.16	16.98	17.31**	11.51**	4.53	-1.63*	8.39**	4.72*	6.06**	4.63**	3.13**
EBx Man	-0.76**	1.01	1.57	0.55	-0.16	-16.98	-17.31**	-11.51**	-4.53	1.63*	-8.39**	-4.72*	-6.06**	-4.63**	-3.13**
ROTx C776	-8.11**	-2.87	0.18*	-1.07	-0.31	-15.58	-10.35	-2.35**	-2.53	-2.24	-5.63	-5.51**	-2.56**	-1.52**	-3.17**
ROTx Man	8.11**	2.87	-0.18*	1.07	0.31	15.58	10.35	2.35**	2.53	2.24	5.63	5.51**	2.56**	1.52**	3.17**
TOL X C776	7.36**	3.88	1.39	1.62	0.16	-1.43*	-6.93**	-9.16	-1.99	3.87**	-2.75**	0.79**	-3.50	-3.11	0.04**
TOL x Man	-7.36**	-3.88	-1.39	-1.62	-0.16	1.43*	6.93**	9.16	1.99	-3.87**	2.75**	-0.79**	3.50	3.11	-0.04
SE	1.05	1.53	0.71	0.96	0.53	2.09	1.20	1.46	1.57	1.79	0.75	0.75	0.61	0.74	0.62

*, *.*- significant at $P<0.05$ and $p<0.01$ levels respectively.

Table 6. Specific combining ability effects on mulberry under different salt concentrations (Biochemical characters)

Crosses	Proline					Total Chlorophyll					Na^+ content in the leaf				
	NaCl (%)														
	0.0	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00	0.00	0.25	0.50	0.75	1.00
EB x C776	-0.29	-0.31*	-0.18	-0.94**	0.01**	0.06**	-0.4**1	-0.30**	-0.10**	0.44**	-104.29**	72.59	104.39*	30.26	-173.41*
EB x Man	0.29	0.31*	0.18	0.94**	-0.01**	-0.06**	0.4**1	0.30**	0.10**	-0.44**	104.29**	-72.59	-104.39*	-30.26	173.41*
ROTx C776	0.12	0.02**	-0.23	2.03**	0.55	-0.03**	0.25	-0.19**	0.32**	0.14**	-173.49	-156.40	-34.80*	-68.34	60.61*
ROTx Man	-0.12	-0.02**	0.23	-2.03**	-0.55	0.03**	-0.25	0.19**	-0.32**	0.14**	173.49	156.40	34.80*	68.34	-60.61*
TOL X C776	0.18	0.29	0.42	-1.09*	-0.56	-0.03**	0.06**	0.49**	-0.23	-0.30	278.38**	83.90	-69.59	38.08	112.80
TOL x Man	-0.18	-0.29	-0.42	1.09*	0.56	0.03**	-0.06**	-0.49**	0.23	0.30	-278.38**	-83.90	69.59	-38.08	-112.80
SE	0.04	0.08	0.12	0.22	0.24	0.01	0.07	0.01	0.02	0.02	21.84	31.59	26.44	33.48	35.24

*, *.*- significant at $P<0.05$ and $p<0.01$ levels respectively.

characters, the GCA for proline (Table 4) was found increasing in tolerant genotypes with higher salinity, where as the GCA of the susceptible genotypes decreased with increasing salinity. The GCA for total chlorophyll decreased with increasing salinity in all genotypes irrespective of their tolerant levels. The GCA for Na^+ accumulation in the leaf was also found decreasing with increasing salinity.

The SCA for plant height decreased with increasing salinity. Under normal conditions the cross between Rotundiloba and Mandalaya showed the highest specific combining ability (Table 5). The SCA for leaf size was found decreasing with increasing salinity. Under control condition the highest SCA was found in English black X C776 cross but at 1.00 NaCl the highest SCA was observed in the cross between Tollygunj and C776. The SCA for leaf yield was also found decreasing with increasing salinity. Under control condition the highest SCA was observed in the cross English black x C776 and at 1.00% NaCl both English black x C776 X Rotundiloba and Mandalaya showed higher SCA.

The SCA for proline (Table 6) was found decreasing with salinity in almost all crosses. Under control condition the highest SCA was found in English black x Mandalaya but at 1.00% the highest SCA was observed in Tollygunj X Mandalaya. The SCA for chlorophyll was found increasing in crosses like English black x C776, Rotundiloba X C776, Tollygung X Mandalaya. The SCA for Na^+ accumulation in the leaf did not show any distinct pattern as the highest SCA under control condition was observed in Tollygunj x C776 but the highest SCA at 1.00% NaCl was observed in English black x Mandalaya.

Discussion

The present study clearly demonstrates that in mulberry under ideal cultural conditions non-additive genes control expression of most of the traits studied in this experiment. However, when the plants were subjected to salinity, effect of non-additive gene action reduces and the actions of additive genes become more prominent. Plant heights and leaf size were under the control of non-additive gene actions in normal cultural conditions, which were also reported earlier in mulberry (Vijayan et al., 1997). However, when the salinity increased the additive gene action became stronger than the non-additive gene actions. Thus, under stress conditions, the non-fixable components of variance give way to fixable components of variance in mulberry. This in turn, suggests the need of a change in the breeding strategy for salinity tolerance in mulberry For the development of salt tolerant genotypes less cum-

bersome pedigree method can be of much use than the more cumbersome recurrent selection as suggested by Sheikh & Singh (1998). The low variability observed in the line x tester interactions for plant height and leaf size was due to the control of additive genes on these characters under higher salinity as reported earlier (Cheralu et al., 1999). Further, the increased GCA/SCA ratio from below unity to significantly higher levels under higher salinity points to the fact that under salinity the fixable components of variance can be exploited through conventional breeding methods to improve the leaf size in mulberry. Unlike the other two morphological characters, leaf yield in mulberry appeared to be under very strong control of non-additive genes as the variance of SCA was higher in all salinity levels. This shows that in mulberry the fixable components of variance has already been fully utilized, hence it would be worth while to resort to breeding methodology which exploits the non–fixable components as suggested by Singh and Murty (1980). This finding was in total agreement with the earlier observations in mulberry under irrigated cultural conditions (Vijayan et al., 1997).

Estimation of components of variance and the proportional contributions of lines, testers and their interactions towards the total variance revealed that both additive and non additive genes play significant roles in governing proline content in the leaf under normal as well as stress conditions, which in turn reveals that the fixable components of variance are yet to be exploited fully in mulberry for this character. Higher accumulation of proline under salinity is considered as a mechanism of protection against the salt injury. Since the additive gene action is more prominant under saline conditions, traditional breeding methods such as pedigree methods followed by selection can be used for screening and selection. The higher proportional contribution of line x tester interaction and low GCA/SCA ratio reveals that leaf chlorophyll contents in mulberry under higher salinity is controlled by non-additive genes. The Na^+ content on the other hand showed an opposite trend of changes as additive genes became more prominent in controlling Na^+ uptake in mulberry under salinity. In an earlier report Dabnolkar and Saxena (1987) showed importance of general combining ability variance and specific combining ability variance for the expression of cation and anion exchange capacity in Sorghum. In mulberry, leaf is the main economic product and the same is used for feeding the silkworms. Therefor, varieties which can yield good quality leaf under salinity would be a better choice for cultivation under saline affected areas as leaf quality has a good impact on the cocoon productivity (Sarkar et al., 2000). Since Na^+ accumulation is a negative character, the poor combiner could be of much use in breeding for salt tolerant genotypes in mulberry. The genotype English black was found to have negative GCA in all treatments except in 1.00% NaCl.

The general combing ability of the parents revealed that English black is a good general combiner for both morphological as well as biochemical characters under saline conditions. Since English black is a salt tolerant genotype with good leaf yielding potential it can be used for extensive breeding programs aimed at developing mulberry varieties adaptable for salinity stress. Regarding specific crosses, the SCA of the various crosses tested under different salinity levels revealed that English black x C776 and Rotundiloba X Mandalaya could be of much use in harnessing the heterosis together with salinity tolerance for morphological characters as well as the biochemical traits. Thus, from the study it could be concluded that through selective breeding, salt tolerant mulberry varieties can be developed in mulberry. The two tolerant mulberry genotypes namely English black and C776 can be used for developing salt tolerant varieties in mulberry.

References

Akbar, M. and T. Yabuno (1975) Breeding for saline resistant varieties of rice III. Response of F1 hybrids to salinity in reciprocal crosses between "Jhone 349" and "Magnolia". Japan J. Bredding **25**, 215-220.

Akbar, M., G. S. Khush, H. Ris, D. Lambers (1985) Genetics of salt tolerance in Rice. In: Rice Genetics, IRRI, Los. Banos, Laguna, Phillippine.. pp. 399-409.

Arnon, D. I, (1949) Copper enzyme in isolated chloropasts. Polyphenol oxidases in Beta vulgaris. Plant Physiol. **24**, 1-15.

Bates, L. S., R. P.Waldren and L. D.Teare, (1973) Rapid determination of free proline for water stress studies. Plant and Soil **39**, 205-207.

Chakraborti S. P., S. K. Sen, K. Vijayan, B. N. Roy and B. Saratchandra (1999) Mulberry cultivation on coastal saline soil of West Bengal. India Silk **38**: 5-7.

Choukr-Allah R. (1995) The potential of halophytes in the development and rehabilitation of arid and semi-arid zones. In: Choukr-Allah, R., Malcolm, C.V., Hamdy, A. (Eds.), Halophytes and Biosaline Agriculture. Marcel Dekker, Inc., New York, pp. 1-13.

Cheralu, C., S. N. Kulkarni and K. Jagadishwar and M. S. S. Reddy, (1999) Combining ability analysis for resistance to preharvest sprouting in mungbean (*Vigna radiata* L.) Indian J Genet. **59**, 465-472.

Dabholkar, A. R. and M. Saxena (1987) Combining ability analysis for cation and anion exchange capacity in Sorghum. Indian J. Agril. Sci. **57**, 5-8.

Das, B. C. And S. Krishnaswami (1965) Some observations on iterspecific hybridization in mulberry. Indian J Seric. **4**, 1-4.

Das, C., T. Sengupta, P. K. Sahu, A. K. Mishra, S. K. Sen and B. Saratchandra (1999) Quantitative analysis of photosynthetic parametrs in mulberry leaf. Indian J Plant Physio. **4**, 171-174.

Datta, R. K. (2000) Mulberry Cultivation and Utilization in India. FAO Electronic conference on mulberry for animal production (*Morus*-L) (http://www.fao.org/DOCREP/ 005/ X9895E/x9895e04.htm#TopOfPage).

Jalaja, S. K, A. Sarkar and R. K. Datta, (1994) A breakthrough in mulberry breeding for sustainable cocoon production. In Global Silk Scenario: *Proceedings of International conference on Sericulture,* India, Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi, Calcutta, pp. 241-247.

Kalaji M. H. and S. Pietkiewica (1993) Salinity effects on plant growth and other physiological processes. Acta Physiol. Plant. **15**, 89-124.

Kempthorne, O. (1957) An introduction to genetic statistics. John Willey and Sons. New York.

Ray, D., L. N. Mondal, A. K. Pain and S. Mondal (1973) Effect of NPK and Farm Yard Manure on the yield and nutritive values of mulberry leaf. Indian J Seric. **12**, 7-12.

Sheikh, I. A. and J. N.Singh (1998) Combining ability analysis of seed yield and oil content in *Brassica juncea* (L) . Indian J Genet. **58**, 507-511

Singh, J. N., and B. R. Murty (1980) Combining ability and maternal effect in *Brassica campestris* (L) ver. Yellow sarson. Theor Appl Genet. **56**, 265-272.

Sprague, G. F. and L. A. Tatum (1942) General vs specific combining ability crosses of corn. J. Amer. Soc. Agron. **34**, 932-942.

Syverstein J. P., B. Boman and D. P. H. Tucker (1989) Salinity in Florida citrus production. Proc. Florida State Hort. Soc. **102**, 61-64.

Taji T., C. Ohsumi, S. Iuchi, M,Seki, M. Kasuga, M. Kobayashi, KYamaguchi-Shinozaki and K. Shinozaki (2002) Important roles of drought- and cold-inducible genes for galactinol synthase in stress tolerance in Arabidopsis thaliana, Plant J. **29**, 417-426

Vijayan, K., S. Chauhan, N. K. Das, S. P. Chakraborti, B. N. Roy (1997) Leaf yield combining ablities in mulberry (*Morus* spp.). Euphytica **98**, 47-52.

Vijayan K and SP Chakraborti (1998). Breeding for triploid mulberry varieties in India. Indian J. Seric. **37**, 1-7.

Vijayan K, S. P. Chakraborti, K. K. Chatterjee, S. G. Doss, B. N. Roy and B Saratchandra (1999) S1635- a variety with high promise for Eastern and North-Estern India. Indian Silk **38**, 22-24.

Vijayan K, S. P. Chakraborti and P. D. Ghosh (2007) Foliar application of *Azatobactor chroococcum* increases leaf yield under saline conditions in mulberry (*Morus* spp.) Scientia Horticulturae **113**, 307-31

Vijayan K., S. P. Chakraborti, S. Ercisli and P. D. Ghosh (2008) NaCl-induced morpho-biochemical and anatomical changes in mulberry (*Morus* spp.). Plant Growth Regulation. (In Press).

Yeo A. R. and T. J. Flowers (1984) Mechanisms of salinity resistance in rice and their role as physiological criteria in plant breeding. In; Staples R. C., Tonniessen G. H. (eds) Salinity tolerance in plants strategies for crop improvement . John Wiley and Sons, New York. pp. 151-170.