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RESEARCH ARTICLE

COMBINING ABILITY AND GENE ACTION FOR PHYSIOLOGICAL PARAMETERS IN QUALITY PROTEIN MAIZE (*Zea mays* L.)

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Abstract

Combining ability analysis was done using 45 F_1 hybrids and their parents obtained from a diallel mating design for eight physiological parameters. Both general and specific combining ability variances were highly significant for almost all the characters. Based on gca effects the parents, P_4 - TQPM 34-1 and P_5 - QPM 10-2 for LAI, P_8 - DMR 274-1, P_{10} - QPM 89E-1 and P_4 - TQPM 34-1for LDW, P_5 - QPM 10-2 for CGR, P_1 - TQPM 178-1 and P_3 - QPM 46-3 for NAR, P_1 - TQPM 178-1, P_2 - PK (C103ae x B 73ae) B-3-6, P_4 - TQPM 34-1 and P_5 - QPM 10-2 for SLW, P_4 - TQPM 34-1, P_5 - QPM 10-2 and P_8 - DMR 274-1 for total biomass, P_1 - TQPM 178-1, P_2 - PK (C103ae x B 73ae) B-3-6 and P_5 - QPM 10-2 for chlorophyll content and P_1 - TQPM 178-1 and P_2 - PK (C103ae x B 73ae) B-3-6 for harvest index were identified as good general combiners, while the crosses *viz.*, P_7 X P_9 and P_4 X P_6 for LAI; P_2 X P_9 and P_1 X P_4 for LDW; P_4 X P_6 and P_2 X P_{10} for CGR; P_5 X P_6 and P_1 X P_{10} for NAR, P_2 X P_3 and P_1 X P_9 for SLW, P_1 X P_{10} and P_2 X P_{10} for biomass, P_1 X P_2 and P_3 X P_7 for chlorophyll content and P_4 X P_6 and P_7 X P_9 for harvest index were found to be the best specific combiners, involving either both the parents or one of the parents as good general combiners. Hence, these crosses could be advanced further for isolation of transgressive segregants and also to develop good inbred lines.

Introduction

Maize is the second most important cereal crop in the world economy. It is globally the top ranking cereal in productivity and has worldwide significance as food, feed and as a good source of starch, protein, fat, oil, sucrose in addition to some of the important vitamins and minerals. Maize area and production have been in increasing trend with the advent of hybrids with higher productivity potential. Hence it is desirable to understand the nature and magnitude of gene action for developing an effective breeding methodology.

Success in plant breeding is largely dependent upon the choice of suitable parents. The value of any population depends on its potential *per se* and its combining ability in crosses (Vacaro *et al*., 2002). Combining ability plays a vital role in identifying the potential inbred lines for obtaining promising segregants. Moreover, combining ability is the quickest method for understanding the genetic nature of quantitative traits. It is well established that combining ability is the relative ability of the genotype to transmit its desirable performance to its crosses. The variance due to general combining ability (GCA) is an attribute of additive gene action whereas specific combining ability (SCA) is the measure of non additive gene action in heterosis breeding. Merits of each inbred line can ideally be determined through diallel crosses and these crosses can be used to study the inheritance of a desired trait among a set of genotypes in order to select the superior parents in hybridization programme. Hence the present investigation was carried out with the main objectives of studying the combining ability and gene action for physiological characters and to identify the parents with high gca and single crosses with high sca for these traits for their further utilization in future breeding programmes.

Material and Methods

Ten promising elite QPM genotypes *viz.*, P_1 - TQPM 178-1, P_2 - PK (C103ae x B 73ae) B-3-6, P_3 - QPM 46-3, P_4 - QPM 34-1, P_5 - QPM 10-2, P_6 - TQPM 42-1, P_7 - TQPM 80-1, P_8 - MR 274-1, P_9 - QPM 35-1 and P_{10} - QPM 89E-1 were mated in diallel fashion without reciprocals to obtain single crosses during *Kharif*, 2002. The resultant 45 crosses along with ten parental lines and two standard checks *viz.*, Madhuri and Shaktiman-2 were evaluated at Rajendranagar and Palem during *Kharif* and *Rabi*, 2003 for studying the magnitude of gene action and combining ability for physiological parameters in Randomized Complete Block design with three replications. The plot size for each entry was a single row of five-meter length, with a spacing of 75 cm and 20 cm between rows and plants respectively. Recommended cultural practices were adopted to maintain a healthy crop.

Data on physiological parameters were recorded from five competitive plants selected at random in each treatment in all replications. LAI (cm^2) was measured by using LI-3100 Area meter (LICOR-Lincoln, Nebraska, USA). Leaf Dry Weight (LDW) at 50 % silking was recorded by taking the weight of the leaves which were dried in hot air oven at 80^oC till constant weight was attained. Crop Growth Rate (CGR), Net Assimilation Rate (NAR) and Specific Leaf Weight (SLW) were calculated as per the formulae given by Gardener *et al*. (1988). Total biomass (Kg/plot) at maturity was recorded by weighing the plants which were dried in hot air oven at 80^oC till constant weight was attained. Total chlorophyll content at 50 % silking was estimated colorimetrically by Dimethyl Sulfoxide method of Hiscox and Stam (1979). Harvest Index (HI) was computed as per the formula given by Gardener *et al*. (1985).

Data recorded on parents and their F_1s were subjected to combining ability analysis following the procedure proposed by Griffing (1956)-Experimental Method-II and Model-I (Fixed effects) with an assumption that there were no reciprocal differences.

Results and Discussion

The analysis of variance revealed significant differences among the genotypes for all the characters studied indicating the existence of sufficient variability in the material studied. The combining ability analysis (Table 1) revealed significant mean squares due to general and specific combining ability for LAI, LDW, CGR and HI indicating that both additive and non-additive gene actions were important in the inheritance of these characters. The relative importance of additive and non-additive gene action was reported earlier by Muthaiah and Palaniswamy (1989). The estimates of components of variance, $\sigma^2 gca$ and $\sigma^2 sca$, indicated the preponderance of non-additive gene action for the characters studied here. The findings are in consonance with earlier reports for chlorophyll content (Krebs *et al.,* 1996 and Fattakhova *et al.,* 1997) and total biomass (Abdul Shakoor, 1988 and Djisbar and Gardner, 1989). The estimates of *gca* effects (Table 2) enable the breeders to identify the desirable parents for hybridization, while the *sca* effects (Table 3) are useful for the identification of best cross combinations for various desirable traits.

High *per se* performance for LAI was recorded for P_4, P_8 and P_{10} but only P_4 recorded highest *gca* effects for this character in addition to P_5 at all the locations. These parents can be better utilised in breeding programmes for improving LAI. However P_7 X P_9, P_4 X P_6, P_2 X P_7 and P_5 X P_6 were best among the crosses. Majority of the crosses except P_4 X P_6 and P_5 X P_6 were not having good general combiners in their parentage for this character. These two crosses had one good general combiner in their parentage indicating the involvement of additive x dominance type of interaction and they may be advanced for deriving desirable transgressive segregants and homozygous lines in subsequent generations as suggested by Langham (1961). Hence they can be used in heterosis breeding; whereas in, other crosses good general combiners were not involved in parentage and were the resultant of non-additive gene action, which can be improved through suitable population improvement.

High mean values of LDW were recorded for P_4, P_8 and P_{10} among which P_4 and P_8 were good general combiners in addition to P_9 and P_2. The best specific crosses for this trait were P_1 X P_4, P_2 X P_9, P_1 X P_3 and P_5 X P_{10}. Among these crosses, the last two were not having good general combiners in their parentage and were the resultant of non-additive gene action, which can be improved through suitable population improvement programme in addition to utilising them in heterosis breeding. P_1 X P_4 and P_2 X P_9 had one good general combiner in parentage and can be used in heterosis breeding.

In respect of CGR, P_5 and P_2 had high *per se* mean values, both of which were good general combiners for this character in addition to P_1 and P_{10}. These parents can be used in breeding programme aimed at improving the CGR. The best specific crosses were P_4 X P_6, P_2 X P_{10}, P_2 X P_8, P_5 X P_6 and P_7 X P_9. Except P_5 X P_6 all these crosses involved both poor combiners as their parents indicating the presence of dominance type of gene action. Such crosses could be utilised in the production of homozygous lines (Darrah and Hallauer, 1972).

NAR was higher for P_6 and P_3 and both of them were good general combiners in addition to P_1. An examination of *sca* effects of the crosses at all the locations indicated that P_5 X P_6, P_1 X P_{10} and P_3 X P_8 were the best specific crosses for NAR. They were having at least one good general combiner as parent. Hence, they can be used in heterosis breeding.

Higher SLW was observed in P_{10}, P_5, P_4 and P_1. Among these parents P_4, P_5 and P_2 were good general combiners . The crosses P_2 X P_3, P_2 X P_8, P_2 X P_7 and P_5 X P_8 were the best specific crosses involving at least one good general combiner in their parentage. Hence, they can be used in heterosis breeding.

Total biomass was higher for P_8, P_5 and P_4 but only P_4 and P_8 were good general combiners in addition to P_9. Among these parents P_4 and P_8 contributed maximum favourable genes and can be used as donors for increasing biomass. The cross combinations P_1 X P_{10}, P_2 X P_{10}, P_3 X P_7 and P_2 X P_7 were the best specific crosses for this character. All these crosses were the resultant of the combination of poor general combiners and hence any scheme utilizing non additive gene action is suggested. In spite of the involvement of good general combiners in its parentage, the cross P_4 X P_8 did not exhibit significant *sca* effect and can be considered for recombination breeding.

Maximum chlorophyll content was recorded for P_{10}, P_2, P_5 and P_1 where P_{10} and P_2 were good general combiners at all the locations. These two parents contributed maximum favourable genes and can be used for further breeding programme for increasing total chlorophyll content. The cross combinations P_1 X P_2, P_3 X P_7, P_5 X P_8, P_5 X P_9 and P_5 X P_{10} were the best specific crosses. The cross P_2 X P_{10}, which was having good general combiners as both the parents, did not exhibit significant *sca* effect and such cross can be considered for recombination breeding for getting better transgressive segregants with maximum chlorophyll content having favourable genes from both parents.

In respect of harvest index P_1 and P_2 recorded higher mean values and both of them recorded highest *gca* effects at all the locations. The best specific crosses were P_4 X P_6, P_1 X P_9, P_2 X P_8 and P_2 X P_4 over the locations. Since both the parents of the cross, P_4 X P_6, were poor general combiners, any scheme utilizing non additive gene action is suggested. All the remaining crosses can be used in heterosis breeding as they had atleast one good general combiner in their parentage.

From the above findings it was observed that the parent P_4 was good general combiner for LAI, LDW, SLW and biomass whereas P_5 was good combiner for LAI, CGR and SLW. Further it was noticed that P_2 was a good combiner for total chlorophyll content and harvest index.

The cross combinations P_7 X P_9 and P_4 X P_6 were found to be best crosses for LAI; P_1 X P_4 and P_4 X P_6 for LDW; P_4 X P_6, P_2 X P_{10} for CGR; P_1 X P_{10} and P_2 X P_8 for NAR, P_2 X P_3 and P_2 X P_8 for SLW, P_1 X P_{10} and P_2 X P_{10} for biomass, P_1 X P_2 and P_3 X P_7 for chlorophyll content, P_4 X P_6 and P_1 X P_9 for harvest index (Table 4), involving either both the parents or one of the parents as good general combiners. Hence, these crosses could be advanced further for isolation of transgressive segregants and also to develop good inbred lines.

Table 1 : Analysis of variance for combining ability for physiological parameters in QPM at two locations over two seasons (Contd..)

Source of variation	**df**	**Mean sum of squares**											
		Leaf Area Index				**Leaf Dry Weight**				**Crop Growth Rate**			
		Rajendranagar		**Palem**		**Rajendranagar**		**Palem**		**Rajendranagar**		**Palem**	
		Kharif	***Rabi***	***Kharif***	***Rabi***	***Kharif***	***Rabi***	***Kharif***	***Rabi***	***Kharif***	***Rabi***	***Kharif***	***Rabi***
GCA	9	0.97**	1.08**	0.58**	0.40**	1109.84**	1527.03**	945.79**	797.12**	18.40**	26.16**	18.21**	17.57**
SCA	45	0.95**	1.00**	1.03**	1.17**	625.12**	1729.13**	1353.28**	884.86**	27.51**	24.52**	24.86**	23.85**

ERROR	108	0.00	0.00	0.00	0.00	25.63	18.41	26.35	24.20	0.28	0.29	0.31	0.26
σ2gca		0.0002	0.0003	0.0001	0.0001	2.1486	2.0286	2.2092	2.0286	0.0239	0.0247	0.0264	0.0220
σ2sca		0.0022	0.0028	0.0010	0.0015	24.3077	22.9496	24.9926	2.9496	0.0271	0.2794	0.2989	0.2490
σ2gca/sca		0.0909	0.1070	0.1000	0.0660	0.088	0.0880	0.0883	0.0883	0.8820	0.0880	0.0880	0.0880

* - Significant at 5 % level ** - Significant at 1 % level NS – Non significant

Analysis of variance for combining ability for physiological parameters in QPM at two locations over two seasons (Contd…..)

Source of variation	df	Mean sum of squares											
		Net Assimilation Rate				Specific Leaf Weight				Total biomass			
		Rajendranagar		Palem		Rajendranagar		Palem		Rajendranagar		Palem	
		Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
GCA	9	0.53	0.59	0.95	0.57	0.46	0.79	0.88	1.20	0.28	0.15	0.09	0.08
SCA	45	1.17	1.37	1.09	1.06	2.66	1.64	1.62	1.72	0.70	0.77	0.46	0.59
ERROR	108	0.04	0.04	0.04	0.04	0.06	0.06	0.04	0.06	0.04	0.02	0.02	0.05
σ2gca		0.2234	0.0040	0.0031	0.0033	0.0055	0.0047	0.0037	0.0048	0.0031	0.0017	0.0014	0.0041
σ2sca		0.0388	0.0456	0.0356	0.0370	0.0617	0.0528	0.0418	0.0537	0.0349	0.0190	0.0158	0.0460
σ2gca/sca		0.0870	0.0870	0.0870	0.089	0.0890	0.0890	0.0880	0.0890	0.0880	0.0890	0.0886	0.0891

* - Significant at 5 % level ** - Significant at 1 % level NS – Non significant

Analysis of variance for combining ability for physiological parameters in QPM at two locations over two seasons

Source of variation	df	Mean sum of squares							
		Chlorophyll content				Harvest Index			
		Rajendranagar		Palem		Rajendranagar		Palem	
		Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
GCA	9	0.0107	0.0130	0.0100	0.008	11.43**	15.63**	15.74**	22.60**
SCA	45	0.0150	0.0150	0.0140	0.015	19.22**	21.94**	17.47**	15.43**
ERROR	108	0.0008	0.0007	0.0009	0.001	0.23	0.43	1.11	0.98
σ2gca		0.0001	0.0001	0.0001	0.0001	0.0196	0.0365	0.0932	0.0823
σ2sca		0.0007	0.0007	0.0009	0.0007	0.2218	0.4127	1.0549	0.9310
σ2gca/sca		0.1420	0.1420	0.1110	0.1420	0.0880	0.0884	0.0883	0.0883

* - Significant at 5 % level ** - Significant at 1 % level NS – Non significant

Table 2 : Estimates of *gca* effects of ten parents for physiological parameters in QPM at two locations over two seasons (contd..)

Parents	Leaf Area Index				Leaf Dry Weight				Crop Growth Rate			
	Rajendranagar		Palem		Rajendranagar		Palem		Rajendranagar		Palem	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
P_1	0.07**	0.03	-0.20**	-0.15**	-0.07	5.62**	-2.88*	9.17**	0.58**	0.67**	0.86**	0.50**
P_2	0.13**	0.12**	0.13**	0.10**	7.76**	4.44**	-4.90**	-2.78*	0.82**	0.98**	1.01**	0.96**
P_3	-0.38**	-0.36**	-0.11**	-0.14**	-17.41**	-0.14	-20.07**	-5.43**	-0.15	-0.17	-0.13	-0.20
P_4	0.48**	0.44**	0.20**	0.32**	14.83**	16.41**	6.06**	13.30**	-0.07	-0.06	-0.03	-0.05
P_5	0.39**	0.40**	0.36**	0.23**	-7.55**	-15.64**	1.22	0.09	2.33**	2.26**	2.31**	2.29**
P_6	-0.22**	-0.25**	-0.25**	-0.21**	-4.80**	-5.92**	-3.21*	-12.69**	0.47**	1.03**	-0.16	0.54**
P_7	-0.35**	-0.45**	-0.34**	-0.23**	-7.36**	-19.39**	5.68**	-8.13**	-1.42**	-2.42**	-1.34**	-1.55**
P_8	0.01	0.07**	0.11**	0.01	4.85**	12.91**	-1.32	8.31**	-1.73**	-0.97**	-1.56**	-1.64**
P_9	-0.09**	-0.16**	0.05**	0.02*	9.55**	1.48	10.94**	-1.85	-1.35**	-2.12**	-1.43**	-1.13**
P_{10}	-0.04**	0.16**	0.07**	0.05**	0.20	0.25	8.48**	0.03	0.51**	0.83**	0.47**	0.28*
SE(gi)	0.00	0.00	0.00	0.00	1.46	0.73	1.48	1.42	0.14	0.14	0.17	0.14
SE(gi-gj)	0.00	0.00	0.00	0.00	2.18	1.85	2.22	2.12	0.22	0.22	0.24	0.22

* - Significant at 5 % level ** - Significant at 1 % level NS – Non significant

Estimates of *gca* effects of ten parents for physiological parameters in QPM at two locations over two seasons (Contd..)

Parents	Net Assimilation Rate				Specific Leaf Weight				Total biomass			
	Rajendranagar		Palem		Rajendranagar		Palem		Rajendranagar		Palem	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
P_1	0.29**	0.19**	0.06	-0.08	0.08	0.17**	0.14*	0.40**	-0.34**	-0.20**	-0.12**	0.02
P_2	0.00	0.04	-0.34**	-0.30**	0.16*	0.12	0.22**	0.01	-0.03	-0.04	0.05	-0.01
P_3	0.01	0.22**	0.44**	0.16**	-0.14*	-0.08	-0.36**	-0.55**	-0.15**	-0.08*	-0.08*	0.06
P_4	0.10	-0.15*	0.09	0.27**	0.28**	0.01	0.15**	0.28**	0.17**	0.07	0.15**	-0.05
P_5	0.00	0.07	0.16**	-0.16**	0.16*	0.51**	0.46**	0.30**	-0.01	0.04	0.11**	0.05
P_6	0.28**	0.39**	0.20**	0.39**	-0.07	-0.22**	-0.42**	-0.30**	0.07	-0.06	0.03	-0.06

P_7	-0.25**	-0.33**	-0.36**	-0.04	-0.10	-0.30**	-0.14*	-0.27**	0.04	-0.07	-0.05	-0.14*
P_8	-0.25**	-0.14*	0.00	-0.09	-0.36**	0.20**	-0.04	-0.21**	0.14**	0.13**	0.02	0.14*
P_9	-0.29**	-0.20**	-0.40**	-0.22**	-0.16*	-0.33**	-0.12*	0.15*	0.12*	0.17**	-0.04	-0.06
P_{10}	0.11*	-0.09	0.16**	0.05	0.15*	-0.06	0.12*	0.19**	0.00	0.03	-0.06	0.06
SE(gi)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SE(gi-gj)	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.10	0.00

* - Significant at 5 % level ** - Significant at 1 % level NS – Non significant

Estimates of *gca* effects of ten parents for physiological parameters in QPM at two locations over two seasons

	Chlorophyll content				**Harvest Index**			
	Rajendranagar		**Palem**		**Rajendranagar**		**Palem**	
	Kharif	**Rabi**	**Kharif**	**Rabi**	**Kharif**	**Rabi**	**Kharif**	**Rabi**
P_1	0.01	0.01	0.01	0.03**	1.47**	0.34	0.82**	1.96**
P_2	0.04**	0.04**	0.04**	0.02**	1.58**	1.81**	0.91**	1.58**
P_3	0.01	0.02**	0.01	0.00	-1.33**	-2.28**	0.75**	1.39**
P_4	-0.03**	-0.02**	-0.02**	-0.03**	-0.24	-0.19	-0.95**	-2.38**
P_5	0.01	0.02*	0.01	0.01	0.55**	0.68**	1.40**	-0.20
P_6	-0.03**	-0.04**	-0.03**	-0.03**	-0.29*	1.17**	0.76**	-0.98**
P_7	0.00	0.00	-0.01	0.01	-0.59**	0.30	-0.41	-0.79**
P_8	-0.05**	-0.05**	-0.05**	-0.04**	0.37**	-0.40*	-0.19	-0.06
P_9	-0.01	-0.01*	-0.01	-0.01	-0.61**	-0.74**	-2.37**	-1.04**
P_{10}	0.04**	0.05**	0.05**	0.03**	-0.92**	-0.69**	-0.71*	0.53
SE(gi)	0.00	0.00	0.00	0.00	0.14	0.17	0.30	0.28
SE(gi-gj)	0.00	0.00	0.00	0.00	0.20	0.28	0.45	0.42

* - Significant at 5 % level ** - Significant at 1 % level NS – Non significant

Table 3 : Estimates of *sca* effects of 45 crosses for physiological parameters in QPM at two locations over two seasons (Contd..)

	Leaf Area Index				**Leaf Dry Weight**				**Crop Growth Rate**			
	Rajendranagar		**Palem**		**Rajendranagar**		**Palem**		**Rajendranagar**		**Palem**	
	Kharif	**Rabi**	**Kharif**	**Rabi**	**Kharif**	**Rabi**	**Kharif**	**Rabi**	**Kharif**	**Rabi**	**Kharif**	**Rabi**
P_1 X P_2	-0.37**	-0.33**	-0.97**	-1.02**	4.32	-81.31**	10.75*	2.20	1.73**	1.50**	1.89**	1.60**
P_1 X P_3	1.00**	1.07**	0.63**	0.60**	6.59	-16.63**	80.02**	79.46**	2.20**	2.05**	2.24**	2.45**

P_1 X P_4	-0.74**	-0.55**	0.18**	-0.04	60.65**	61.62**	70.19**	49.93**	-0.58	-0.56	-0.36	-0.39
P_1 X P_5	0.11*	0.12*	-1.49**	-1.46**	-8.28	87.67**	-20.27**	-18.07**	-3.18**	-2.78**	-3.41**	-2.33**
P_1 X P_6	1.31**	0.88**	-0.36**	-0.47**	-7.72	-25.65**	-34.85**	-26.48**	-1.42**	-1.75**	-0.53	-1.18*
P_1 X P_7	0.07	-0.45**	-0.13**	-0.35**	5.54	19.62**	0.26	19.66**	3.97**	5.10**	3.64**	3.90**
P_1 X P_8	-0.93**	-0.80**	0.27**	0.26**	5.13	20.62**	1.17	-4.68	1.19*	0.35	1.17*	1.20*
P_1 X P_9	0.89**	1.22**	0.49**	1.41**	17.72**	27.35**	-4.89	15.48**	3.10**	4.00**	3.04**	2.68**
P_1 X P_{10}	0.87**	0.83**	1.86**	1.77**	10.47*	18.48**	-7.04	3.99	6.05**	4.85**	5.44**	5.18**
P_2 X P_3	-0.95**	-0.82**	-1.28**	-1.25**	-2.75	70.05**	-11.46*	-18.60**	0.05	0.14	-0.11	-0.70
P_2 X P_4	0.13**	0.09	0.80**	0.87**	-2.59	-7.10	2.40	3.07	-0.93	-0.78	-0.81	-0.44
P_2 X P_5	0.99**	1.12**	1.48**	1.50**	24.69**	-14.65**	16.75**	37.38**	-2.93**	-2.90**	-2.76**	-2.98**
P_2 X P_6	-0.21**	-0.21**	-0.80**	-0.86**	-14.35**	83.63**	-28.33**	-21.34**	-1.97**	-2.66**	-1.28*	-2.03**
P_2 X P_7	1.43**	1.65**	1.53**	1.40**	19.60**	30.70**	-1.82	24.10**	-0.18	0.69	-0.21	-0.35
P_2 X P_8	1.02**	0.94**	0.54**	0.63**	-2.90	-2.90	9.89*	5.76	8.64**	7.74**	8.32**	7.95**
P_2 X P_9	-0.83**	-0.69**	-1.53**	-1.54**	64.59**	-9.77*	71.83**	4.92	0.85	1.19*	0.59	0.63
P_2 X P_{10}	0.52**	0.36**	0.59**	0.57**	28.24**	29.45**	14.28**	30.23**	9.79**	9.54**	9.29**	9.63**
P_3 X P_4	-0.05	-0.05	0.28**	0.07*	-0.41	-17.52**	-8.02	-19.77**	-0.36	-0.22	-0.37	0.11
P_3 X P_5	1.32**	1.28**	0.81**	1.00**	11.06*	4.53	16.92**	60.03**	-3.06**	-3.04**	-3.41**	-3.03**
P_3 X P_6	0.53**	0.56**	0.88**	0.82**	-10.48*	-35.99**	-23.45**	-18.88**	-0.50	-1.50**	-0.14	-0.88
P_3 X P_7	0.17**	-0.04	-0.37**	-0.49**	-6.62	83.88**	-32.05**	-30.24**	1.49**	2.95**	1.64**	2.20**
P_3 X P_8	0.20**	0.43**	0.50**	0.57**	20.47**	-6.82	24.76**	4.82	1.51**	0.50	1.46**	1.60**
P_3 X P_9	0.37**	0.47**	0.56**	0.61**	18.46**	16.01**	7.70	20.48**	1.23*	2.45**	1.03*	1.38**
P_3 X P_{10}	-0.59**	-0.84**	-0.45**	-0.45**	-10.39*	-35.96**	-35.05**	-33.61**	6.97**	5.90**	6.43**	5.97**
P_4 X P_5	0.00	0.27**	0.61**	0.57**	5.92	23.38**	5.59	9.90*	5.16**	4.85**	4.19**	4.82**
P_4 X P_6	1.52**	1.58**	0.97**	1.54**	32.18**	29.56**	15.21**	28.98**	10.82**	10.18**	11.36**	10.58**
P_4 X P_7	0.07	-0.77**	-0.65**	-0.99**	20.14**	16.83**	-8.18	22.43**	-3.19**	-1.97**	-3.16**	-3.34**
P_4 X P_8	-0.48**	-0.29**	-0.72**	-0.77**	-14.57**	3.03	1.33	-3.52	-2.27**	-2.92**	-1.84**	-2.34**

P_4 X P_9	0.31**	0.45**	-0.09**	0.81**	-17.38**	-10.14*	-14.03**	0.94	-3.46**	-2.47**	-3.77**	-3.56**
P_4 X P_{10}	0.37**	0.27**	1.26**	1.14**	-50.43**	-52.31**	-55.98**	-55.14**	6.69**	5.58**	5.93**	5.83**
P_5 X P_6	1.44**	1.59**	1.87**	1.65**	14.35**	30.31**	-3.05	15.69**	6.52**	-0.24	6.62**	6.23**
P_5 X P_7	-0.68**	-0.85**	-0.43**	1.58**	-22.89**	-0.52	-47.74**	-24.57**	5.81**	6.31**	5.99**	4.32**
P_5 X P_8	1.16**	1.18**	1.20**	0.42**	34.60**	30.68**	13.67**	19.39**	6.73**	3.56**	6.22**	6.62**
P_5 X P_9	-0.15**	-0.03	0.25**	-1.60**	-24.40**	-16.49**	-53.59**	-33.65**	3.64**	6.91**	4.29**	3.30**
P_5 X P_{10}	-1.14**	-1.48**	-1.24**	-1.11**	7.95	24.24**	93.86**	-0.93	0.79	6.46**	0.79	0.69
P_6 X P_7	-0.50**	-0.35**	-0.64**	-0.81**	2.77	-65.34**	59.09**	-6.48	-4.33**	-3.65**	-3.33**	-4.13**
P_6 X P_8	-0.72**	-0.66**	-0.34**	-0.08*	11.36*	5.16	7.90	12.38**	-4.11**	6.30**	-3.91**	-4.23**
P_6 X P_9	-0.92**	-0.85**	-0.23**	-0.27**	2.85	8.50*	-16.16**	7.73	-3.00**	-2.85**	-2.64**	-2.95**
P_6 X P_{10}	-1.34**	-1.55**	-1.05**	-0.99**	-27.00**	-28.18**	48.09**	-24.35**	-6.36**	-6.80**	-5.14**	-5.36**
P_7 X P_8	-1.02**	-1.06**	-1.18**	-1.21**	-24.38**	-16.67**	-51.30**	-32.48**	-1.92**	-1.65**	-1.83**	-1.55**
P_7 X P_9	1.89**	0.49**	2.17**	1.88**	17.31**	23.16**	-13.15**	23.08**	9.59**	-0.90	8.34**	8.93**
P_7 X P_{10}	-0.42**	1.83**	-0.04	-0.29**	9.06	23.29**	-18.30**	18.59**	-3.96**	-3.65**	-3.76**	-3.88**
P_8 X P_9	0.66**	0.67**	0.67**	0.77**	-27.30**	-24.74**	-31.55**	-19.77**	-1.59**	-1.95**	-1.44**	-2.17**
P_8 X P_{10}	-1.25**	-1.63**	-1.09**	-1.01**	-9.05	-14.21**	-7.10	-0.85	-3.15**	-4.50**	-3.14**	-2.98**
P_9 X P_{10}	0.01	0.15**	0.06	0.26**	5.15	11.92**	-9.55*	27.01**	-3.23**	-2.75**	-3.07**	-2.89**
SE sij	0.05	0.05	0.03	0.04	4.93	4.18	4.99	4.79	0.52	0.53	0.55	0.49

* - Significant at 5 % level ** - Significant at 1 % level NS – Non significant

Estimates of *sca* effects of 45 crosses for physiological parameters in QPM at two locations over two seasons (Contd..)

	Net Assimilation Rate				Specific Leaf Weight				Total biomass			
	Rajendranagar		Palem		Rajendranagar		Palem		Rajendranagar		Palem	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
P_1 X P_2	-1.43**	-1.16**	-1.47**	-1.50**	0.17	-0.10	-0.74**	0.94**	-0.93**	-1.15**	0.34**	0.57**
P_1 X P_3	-0.12	0.59**	-0.31	-	-	0.79**	0.84**	-	-0.29	0.31*	0.25*	-0.07

				0.63**	0.92**			0.58**				
P_1 X P_4	-0.62**	-0.36	-0.57**	0.60**	0.37	-0.74**	1.18**	-0.29	0.14	0.41**	0.56**	0.35
P_1 X P_5	-0.06	-0.38	-0.45*	-0.33	0.07	-0.16	-0.22	-0.03	-0.92**	-0.59**	-0.18	0.40
P_1 X P_6	0.08	-0.29	-0.07	0.62**	0.33	1.18**	-0.68**	0.19	0.15	0.48**	0.71**	0.37
P_1 X P_7	1.74**	-0.09	1.56**	1.17**	1.73**	-0.67**	0.54**	0.89**	0.14	0.39**	0.46**	0.87**
P_1 X P_8	0.32	0.82**	0.79**	1.21**	-0.32	0.47*	0.55**	1.20**	0.90**	0.55**	0.19	0.30
P_1 X P_9	1.05**	1.42**	0.74**	1.03**	1.39**	1.60**	2.16**	1.50**	0.68**	0.66**	0.01	0.31
P_1 X P_{10}	2.33**	2.16**	1.62**	-0.01	0.88**	0.52*	-0.62**	0.43	1.34**	1.20**	0.70**	0.78**
P_2 X P_3	0.04	-0.26	-0.50**	-0.17	2.29**	1.85**	1.29**	1.06**	-0.85**	-0.32*	0.01	0.29
P_2 X P_4	0.81**	1.40**	0.85**	0.48**	1.58**	1.00**	0.20	1.14**	0.54**	0.50**	0.38**	-0.50*
P_2 X P_5	0.17	-1.13**	1.26**	-0.22	0.80**	1.04**	1.75**	1.05**	0.57**	0.56**	0.17	0.11
P_2 X P_6	0.24	-0.16	0.35*	0.54**	-1.74**	-1.06**	0.83**	-0.65**	0.43*	0.42**	0.50**	0.61**
P_2 X P_7	0.95**	1.11**	0.62**	1.29**	2.05**	1.30**	1.45**	0.43	1.01**	1.12**	0.50**	0.52**
P_2 X P_8	0.18	0.33	-0.63**	-0.62**	2.21**	1.20**	0.50*	1.56**	0.72**	0.94**	0.52**	0.34
P_2 X P_9	0.23	0.23	-0.60**	0.55**	0.52*	0.81**	-0.07	1.19**	0.30	0.22	0.56**	0.73**
P_2 X P_{10}	0.45*	1.26**	0.84**	1.20**	0.10	0.17	0.83**	-0.24	1.15**	1.01**	0.26*	0.51*
P_3 X P_4	-1.08**	-0.44*	1.01**	1.29**	-0.63**	-0.29	-0.66**	-0.62**	0.83**	0.26*	0.43**	-0.19
P_3 X P_5	1.62**	2.41**	0.03	0.62**	1.59**	1.79**	0.53**	-0.30	-0.82**	-0.37**	0.42**	0.63**
P_3 X P_6	0.36	0.67**	0.95**	1.16**	0.22	1.00**	-0.45*	0.81**	0.52**	0.46**	0.25*	0.55**
P_3 X P_7	0.29	-0.36	-0.09	1.00**	-1.35**	-1.91**	-0.86**	-0.83**	1.02**	0.71**	0.25*	0.48*
P_3 X P_8	1.43**	1.10**	2.05**	0.65**	1.21**	0.31	0.85**	0.67**	0.03	0.25	0.35**	0.30
P_3 X P_9	0.62**	0.37	-0.35*	-1.17**	0.61**	0.11	1.12**	1.44**	1.02**	0.64**	0.49**	0.15
P_3 X P_{10}	1.10**	0.63**	0.89**	0.45*	1.00**	0.78**	0.78**	2.01**	-0.38*	-0.17	0.15	0.51*
P_4 X P_5	0.41*	-0.19	1.12**	1.02**	0.97**	1.33**	0.73**	0.94**	0.99**	0.85**	0.24*	0.78**
P_4 X P_6	1.49**	1.33**	0.66**	1.28**	1.81**	1.07**	0.94**	0.70**	0.96**	1.05**	0.10	0.46*
P_4 X P_7	-0.19	0.17	-0.98**	-0.20	0.23	0.14	1.76**	2.48**	0.26	0.51**	0.55**	0.06

P_4 X P_8	0.28	-0.13	0.11	0.02	0.39	0.49*	1.02**	0.37	-0.21	-0.29*	-0.12	-0.33
P_4 X P_9	-0.46*	-0.42*	-0.88**	-1.11**	1.80**	0.87**	0.17	0.93**	-0.13	0.02	0.32**	0.82**
P_4 X P_{10}	0.77**	0.03	0.48**	-0.28	-2.02**	-1.24**	-1.83**	-1.92**	-0.17	-0.05	0.11	0.13
P_5 X P_6	1.45**	2.46**	1.58**	1.40**	1.92**	1.24**	0.30	0.46*	0.62**	0.53**	0.24*	-0.10
P_5 X P_7	0.07	-1.56**	0.12	0.23	-1.16**	-1.37**	-1.89**	-1.67**	-0.83**	-0.63**	-0.01	-0.06
P_5 X P_8	0.98**	1.09**	1.03**	1.19**	2.01**	1.13**	0.35	0.57**	0.84**	0.71**	0.34**	0.69**
P_5 X P_9	-0.86**	-0.31	-0.19	0.41*	-1.49**	-1.62**	-1.74**	-0.10	0.58**	0.47**	-0.09	0.26
P_5 X P_{10}	-0.96**	-1.48**	-0.04	-0.86**	-0.71**	-0.61**	-0.13	-0.43*	0.51**	0.53**	0.55**	0.43*
P_6 X P_7	-1.49**	-1.37**	-0.65**	-1.22**	-0.52*	0.75**	1.09**	0.56*	0.05	0.42**	-0.01	0.65**
P_6 X P_8	0.27	-0.25	0.15	-0.37*	1.55**	0.26	0.79**	0.87**	0.16	0.29*	-0.14	0.58**
P_6 X P_9	-0.48**	-0.61**	-0.37*	-0.99**	0.18	0.18	-0.50*	-0.44*	-0.32	-0.22	-0.44**	-0.51*
P_6 X P_{10}	-1.12**	-0.67**	-1.39**	-0.70**	-1.15**	-1.55**	-1.07**	-0.42	-0.61**	-1.12**	0.32**	0.08
P_7 X P_8	-0.67**	0.29	-0.85**	0.06	-0.11	-0.21	-1.06**	0.75**	-0.30	-1.05**	0.03	-0.19
P_7 X P_9	1.04**	1.76**	1.99**	1.31**	1.19**	1.44**	1.03**	0.40	0.86**	0.82**	0.60**	-0.37
P_7 X P_{10}	1.04**	1.49**	0.26	-0.08	0.95**	1.00**	2.16**	0.00	-0.16	-0.25	-0.70**	-0.66**
P_8 X P_9	0.21	0.48*	-0.25	-0.49**	-3.15**	-1.35**	-1.69**	-1.77**	-0.39*	0.70**	0.07	0.21
P_8 X P_{10}	-1.01**	-0.68**	-0.57**	-0.26	-1.48**	-1.19**	-0.22	-1.60**	-0.26	0.39**	0.80**	0.47*
P_9 X P_{10}	-0.16	-0.90**	0.21	1.30**	1.62**	0.83**	-0.38*	0.42	0.53**	0.33*	0.41**	0.15
SE sij	0.19	0.21	0.20	0.20	0.26	0.22	0.20	0.22	0.20	0.14	0.14	0.22

* - Significant at 5 % level ** - Significant at 1 % level NS – Non significant

Estimates of *sca* effects of 45 crosses for physiological parameters in QPM at two locations over two seasons

	Chlorophyll content				Harvest Index			
	Rajendranagar		Palem		Rajendranagar		Palem	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
P_1 X P_2	0.20**	0.21**	0.22**	0.20**	-0.54	1.48*	-2.31*	-2.88**
P_1 X P_3	0.00	0.01	-0.01	0.00	-0.71	-5.90**	-5.79**	-7.34**
P_1 X P_4	-0.11**	-0.11**	-0.12**	-0.06*	1.93**	1.19	-0.96	-3.05**

P_1 X P_5	-0.01	-0.03	-0.02	0.01	-3.44**	-7.49**	-1.35	1.80*
P_1 X P_6	0.10**	0.11**	0.07*	0.12**	0.37	-1.63**	1.15	-0.30
P_1 X P_7	0.09**	0.11**	0.11**	0.13**	1.71**	0.56	-0.34	2.60**
P_1 X P_8	-0.05*	-0.04	-0.04	-0.04	-2.47**	0.07	-0.53	-1.14
P_1 X P_9	-0.07**	-0.08**	-0.07*	-0.04	2.62**	2.56**	4.88**	4.60**
P_1 X P_{10}	-0.08**	-0.09**	-0.09**	-0.17**	3.95**	3.83**	0.86	0.13
P_2 X P_3	0.16**	0.16**	0.16**	0.13**	-3.91**	-6.91**	-1.64	-2.18*
P_2 X P_4	0.17**	0.16**	0.17**	0.13**	2.13**	3.32**	3.59**	4.41**
P_2 X P_5	0.09**	0.05*	0.09**	0.06*	0.62	0.88	1.47	2.80**
P_2 X P_6	0.07**	0.08**	0.05*	0.05*	0.03	-1.13	-3.85**	-3.01**
P_2 X P_7	0.01	0.02	0.01	0.03	2.49**	0.66	-1.69	1.84*
P_2 X P_8	0.02	0.03	0.01	0.05*	2.32**	2.28**	4.01**	2.20*
P_2 X P_9	-0.09**	-0.06**	-0.10**	-0.10**	1.42**	0.83	-1.54	-4.09**
P_2 X P_{10}	-0.05*	-0.05	-0.08**	-0.03	2.78**	2.78**	2.67**	1.25
P_3 X P_4	0.06*	0.07**	0.05	0.05*	-1.89**	1.14	3.81**	1.71
P_3 X P_5	-0.11**	-0.12**	-0.11**	-0.13**	-15.78**	-14.89**	-0.29	1.47
P_3 X P_6	-0.05*	-0.04	-0.03	-0.06*	-0.62	-0.13	-0.80	0.30
P_3 X P_7	0.17**	0.18**	0.20**	0.22**	2.21**	3.78**	0.56	0.31
P_3 X P_8	0.12**	0.11**	0.11**	0.15**	4.32**	3.06**	1.21	-0.40
P_3 X P_9	0.11**	0.11**	0.10**	0.08**	2.42**	5.27**	1.51	2.04*
P_3 X P_{10}	0.11**	0.11**	0.10**	0.08**	-4.06**	-5.28**	-2.50*	-0.99
P_4 X P_5	-0.15**	-0.15**	-0.14**	-0.16**	2.46**	5.27**	0.45	5.11**
P_4 X P_6	-0.10**	-0.09**	-0.07*	-0.12**	4.06**	3.24**	6.16**	9.05**
P_4 X P_7	-0.05	-0.03	-0.03	-0.10**	2.26**	1.43*	5.13**	-2.58**
P_4 X P_8	-0.03	-0.05	-0.03	-0.02	-2.64**	-3.94**	-6.26**	-0.87
P_4 X P_9	0.05	0.05*	0.03	0.06*	0.07	-1.96**	4.90**	-3.20**
P_4 X P_{10}	0.01	0.01	0.01	0.03	-1.35**	-2.74**	3.52**	2.19*
P_5 X P_6	-0.11**	-0.11**	-0.12**	-0.10**	2.24**	1.75**	1.67	2.18*
P_5 X P_7	0.04	0.04	0.04	0.02	-3.51**	-5.47**	-5.08**	-6.37**
P_5 X P_8	0.17**	0.17**	0.17**	0.14**	1.63**	2.22**	-0.26	1.29
P_5 X P_9	0.17**	0.17**	0.18**	0.17**	2.17**	1.68**	-4.29**	-3.90**
P_5 X P_{10}	0.16**	0.16**	0.15**	0.19**	1.20**	1.57**	-3.79**	-0.59
P_6 X P_7	-0.08**	-0.08**	-0.07*	-0.11**	-1.55**	-5.31**	-2.92**	0.57
P_6 X P_8	0.06*	0.07**	0.04	0.06*	0.78	-0.42	-1.84	2.59**
P_6 X P_9	0.00	0.02	0.01	-0.01	-2.25**	-3.48**	-6.75**	-8.17**

P_6 X P_{10}	0.11**	0.07**	0.12**	0.12**	-7.21**	-1.19*	-0.24	-2.93**
P_7 X P_8	0.04	0.04	0.05	0.01	-8.47**	-1.03	-2.42*	-6.16**
P_7 X P_9	-0.08**	-0.07**	-0.04	-0.09**	1.70**	2.06**	10.48**	2.98**
P_7 X P_{10}	0.00	0.01	0.04	0.03	-1.79**	-1.15	-7.18**	-6.02**
P_8 X P_9	-0.12**	-0.13**	-0.11**	-0.13**	0.88*	-4.25**	-1.50	-1.92*
P_8 X P_{10}	-0.14**	-0.14**	-0.13**	-0.12**	-5.89**	-8.12**	0.85	-1.03
P_9 X P_{10}	-0.02	-0.01	-0.03	-0.03	-0.18	1.04	1.73	1.05
SE sij	0.00	0.00	0.00	0.00	0.47	0.64	1.02	0.96

* - Significant at 5 % level ** - Significant at 1 % level NS – Non significant

Table 4 : *Per se* performance, *gca* and *sca* effects of superior crosses for physiological parameters in QPM at two locations over two seasons

Character	Cross	*Per se* performance of F_1	*Per se* performance of parents		*sca* effect	*gca* effects	
			Parent 1	Parent 2		Parent 1	Parent 2
Leaf Area Index	P_5 X P_6	3.99	1.45	1.10	1.44**	0.39*	-0.22**
	P_2 XP_5	3.98	1.93	1.10	0.99**	0.13**	0.39**
	P_4 X P_6	3.78	1.97	1.10	1.52**	0.48*	-0.22**
Leaf Dry Weight	P_1 X P_4	316.08	192.91	249.40	60.65**	-0.07	14.83**
	P_2 X P_9	278.93	196.03	241.72	64.59**	7.76**	9.55**
	P_4 X P_6	272.35	249.40	226.85	32.18**	14.83**	-4.80**
Crop Growth Rate	P_4 X P_6	38.02	21.02	21.80	10.18**	-0.06	1.03**
	P_2 X P_{10}	37.90	21.55	21.27	9.54**	0.98**	0.83**
	P_2 X P_8	34.50	21.55	21.23	7.74**	0.98**	-0.97**
Net Assimilation Rate	P_5 X P_6	11.60	8.13	9.58	1.45**	0.00	0.28**
	P_1 X P_{10}	11.25	8.53	8.75	2.33**	0.29**	0.11*
	P_4 X P_6	11.13	8.75	9.58	1.49**	0.10	0.28**
Specific Leaf Weight	P_1 X P_9	13.23	10.14	10.10	1.60**	0.17**	-0.33**
	P_2 X P_5	13.12	8.39	11.33	1.04**	0.12	0.51**
	P_4 X P_5	13.01	10.04	11.33	1.33**	0.01	0.51**
Total biomass	P_1 X P_{10}	4.25	1.77	2.31	1.20**	-0.20**	0.03
	P_2 X P_7	4.13	1.80	2.40	1.12**	-0.04	-0.07
Chlorophyll content	P_1 X P_{10}	1.61	1.35	1.40	-0.09**	0.01	0.05**
	P_4 X P_6	1.59	1.39	1.28	-0.09**	-0.02**	-0.04**

	P_5 X P_6	1.55	1.36	1.28	-0.11**	0.02**	-0.04**
Harvest Index	P_4 X P_6	51.18	38.56	49.10	3.24**	-0.19	1.17**
	P_2 X P_8	50.43	47.69	50.17	2.28**	1.81**	-0.40*
	P_2 X P_4	50.22	47.69	38.56	3.32**	1.81**	-0.19

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