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Performance of quality protein maize (*Zea mays*) genotypes under different moisture-stress environments

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ABSTRACT

Eightysix genotypes of quality protein maize (*Zea mays* L.) including 12 parents, their 66 crosses and 7 checks were evaluated for morpho-physiological traits in four environments created by withdrawing irrigation at different crop growth stages in winter (*rabi*) season of 2009–10. Hybrids exhibited higher grain yield/plant and low chlorophyll stability index in stress condition, were found good for stress environments. The traits under investigation were governed by additive and non-additive gene action and thus could be improved through selection, followed by hybridization. Among the good general combining inbreds with high *per se* performance for grain yield was P7 and P12. Among the hybrids, P9 × P12 and P4 × P12 were found best for all the environments but P10 × P12, P1 × P7, P1 × P4 were best only in well irrigated environments. The above hybrids also exhibited higher estimates of specific combining ability effects, economic heterosis and *per-se* performance in all the environments for grain yield/plant and chlorophyll stability index (CSI).

Key words: Chlorophyll stability index (CSI), Combining ability, Economic heterosis, Grain yield, Moisture stress, Quality protein maize

Maize (*Zea mays* L.) has worldwide assumed significance as human and animal feed. Also for large number of many other industrial products like glucose, starch, oil etc. The commercial maize varieties usually contain 9-12% protein which is enough to meet the physiological needs of human body. However, the quality of protein is nutritionally poor due to lower contents of two essential amino acids, lysine and tryptophan and an undesirable ratio of leucine and isoleucine. Lysine is important for general growth in human beings and animals. Its deficiency impedes utilization of other amino acids. The maize carrying opaque-2 gene in homozygous condition is referred to as opaque-2 and the hard modified endosperm opaque-2 maize with vitreous kernels is known as quality protein maize (QPM). Such modified opaque-2 mutants contain lysine and tryptophan twice than the normal maize varieties along with low amount of leucine. The opaque-2 gene can be incorporated into any maize population, inbred line or other germplasm through backcross breeding method in selected genetic backgrounds.

In Rajasthan, maize is cultivated as rainfed crop in majority of areas. In semi-arid regions, erratic and uneven distribution of rainfall and terminal drought acutely affects the crop and ultimately yields, full season varieties/hybrids gives drastically reduced grain yield (<1.0 tonnes/ha). Maize crop possess three main growth stages, viz knee height, flowering and grain, filling stage. Among these, flowering is the most critical stages in relation to moisture stress. The improvement in yield potential under drought-prone areas is possible only through development of drought-tolerant/ resistant, high-yielding and early maturing hybrids/varieties. An attempt has been made to develop and recognize superior single cross hybrids and with good general combining inbred lines, which are sustainable for semi-arid rainfed and moisture stress environments. The present study was undertaken to evaluate the combining ability of QPM inbred lines using diallel analysis and to examine the magnitude and directions of mid-parent and standard heterosis of single crosses for grain yield and chlorophyll stability index (CSI).

MATERIALS AND METHODS

Twelve QPM inbred lines selected on the basis of their *per-se* performance and genetic diversity were used in diallel mating design (without reciprocal) for development of 66

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F_1s during the rainy (*kharif*) season of 2009. The experimental material comprised 85 genotypes including 12 parents, their 66 F_1s and seven checks were evaluated under four environments/moisture regimes that were created by withdrawing irrigation at different crop-growth stages during the winter (*rabi*) season of 2009–10, at Instructional Farm, Rajasthan College of Agriculture, Udaipur.

E1, well-irrigated crop (control); E2, irrigation skipped at grain filling; E3, irrigation skipped at flowering; E4, irrigation withheld from knee height stage till maturity.

The experiment was conducted in a randomized block design with three replications in four environments. Each genotype was accommodated in a single row of 5 m length having 60 cm × 25 cm crop geometry under four different environmental conditions during the winter (*rabi*) season of 2009–10. The recommended package of practices was followed to raise the healthy crop in all the environments. Observations were recorded for all traits on 10 randomly selected competitive plants for each entry in each replication for various traits except for days to 50% tasseling, days to 50% silking, days to 50% maturity, leaf senescence and leaf rolling where observations were recorded on plot basis. The observations of morpho-physiological traits were taken during the early hours, i e 9–12 AM.

RESULTS AND DISCUSSION

Analysis of variance (Tables 1, 2) revealed that mean squares due to genotypes were significant for all the characters in all the environments. The genotypic variance was further partitioned into parents, F_1s and parents vs F_1s. Mean squares due to parents and F_1s were significant for all the characters under study in all the environments. This indicated that among the parental lines and hybrids considerable amount of genetic variability existed. Mean squares due to parents v/s F_1s were significant for all characters in all the environments, whereas it was non-significant for days to 50% silking (E2 and E3), anthesis-silking interval (E1), days to 50% maturity (E3), vapour pressure deficit (E2), plant height (E3) and for leaf senescence (E4), indicating the presence of heterosis for most of the traits.

Table 1 Analysis of variance for 13 characters in individual environment in quality protein maize

Character	Environment	Source						
		Rep [2]	Genotype [77]	Parent [11]	F_1 [65]	P vs F_1 [1]	Error [154]	Bartle test
Days to 50% silking	1	104.20**	36.74**	7.54*	41.82**	27.75**	3.69	
	2	113.23**	35.56**	13.83**	39.64**	9.15	3.33	
	3	100.72**	34.61**	19.30**	37.62**	7.54	3.93	1.05
ASI	1	0.26	4.53**	1.36**	5.14**	0.05	0.10	
	2	0.03	2.12**	0.57**	2.40**	1.37**	0.12	
	3	0.81*	4.527**	4.67**	4.44**	8.32**	0.20	19.58**
Days to 50% maturity	1	166.78**	32.80**	28.13**	33.05**	68.31**	6.28	
	2	168.00**	53.17**	29.52**	56.48**	98.20**	6.30	
	3	166.48**	32.70**	24.99**	34.50**	0.50	5.83	0.29
Cob height (cm)	1	79.83	1 317.38**	2 055.68**	1 197.73**	972.96**	49.06	
	2	97.65	1 322.35**	2 142.27**	1 195.07**	576.94**	54.65	
	3	53.10	1 359.04**	2 117.29**	1 243.50**	528.45**	56.28	0.80
100-seed weight	1	4.73	33.69**	29.74**	34.48**	25.57**	2.90	
	2	3.56	29.92**	17.36**	32.36**	8.96*	1.86	
	3	3.73	21.53**	16.91**	22.25**	24.97**	2.50	7.69*
Grain yield	1	53.74	656.65**	432.79**	625.45**	5 146.78**	32.08	
	2	18.17	667.74**	339.16**	710.84**	1 480.43**	13.80	
	3	8.74	572.42**	188.17**	622.20**	1 564.21**	7.90	76.79**
CSI	1	0.00	0.02**	0.02**	0.02**	0.01**	0.00	
	2	0.00*	0.02**	0.01**	0.02**	0.00**	0.00	
	3	0.00	0.02**	0.01**	0.01**	0.03**	0.00	77.82**
Desiccation injury	1	2.21	139.48**	58.44**	151.80**	230.97**	2.59	
	2	9.05	206.28**	65.65**	222.54**	696.31**	4.85	
	3	4.92	207.17**	91.38**	223.58**	414.05**	4.88	18.81**

*P = 0.05; **P = 0.01

Table 2 Analysis of variance for three characters in individual environment in quality maize protein

Character	Environment	Source					
		Rep [2]	Genotype [77]	Parent [11]	F1 [65]	P vs F_1 [1]	Error [154]
Plant height(cm)	1	263.26	2 256.29**	1 285.65**	2 439.86**	1 001.35*	177.80
	2	308.52	2 002.82**	933.27**	2 199.72**	969.79*	194.90
	3	202.36	1 904.77**	1 019.66**	2 078.67**	337.37	188.74
	4	93.80	1 519.69**	478.85**	1 707.36**	769.94**	86.60
Leaf senescence	1	0.00	0.30**	0.23**	0.31**	0.47**	0.02
	2	0.05	0.62**	0.54**	0.63**	0.70**	0.03
	3	0.11	0.36**	0.47**	0.32**	1.72**	0.04
	4	0.09	1.01**	0.98**	1.03**	0.09	0.05
Leaf rolling	1	0.03	0.29**	0.13**	0.33**	0.10*	0.02
	2	0.07	0.80**	0.89**	0.79**	0.48**	0.04
	3	0.05	0.72**	0.85**	0.70**	0.40**	0.04
	4	0.03	0.58**	0.52**	0.59**	0.60**	0.04

Mean square in E4 environment was not calculated for days to 50% silking, anthesis-silking interval, days to 50% maturity, cob height, test weight and grain yield because most of the genotype showing 0 value for these characters and also not calculated for all the physiological characters due to leaf firing/complete dryness of leaves. Since Bartlett's tests indicated that error variance was not homogenous for all the characters, pooled analysis was not carried out.

Table 3 Combining ability mean square and expected mean square for thirteen characters in quality protein maize

Characters	Environment	Source			Var Model I		
		GCA [11]	SCA [66]	Error [154]	GCA	SCA	Error
Days to 50% silking	1	8.09**	12.94**	1.23	1.80	257.63	1.23
	2	22.51**	10.08**	1.11	5.60	197.25	1.11
	3	15.32**	10.91**	1.30	3.67	211.16	1.30
ASI	1	1.18**	1.56**	0.03	0.30	33.67	0.03
	2	0.25**	0.78**	0.04	0.06	16.32	0.04
	3	1.06**	1.58**	0.07	0.26	33.31	0.07
Days to 50% maturity	1	8.26**	11.38**	2.09	1.61	204.27	2.09
	2	9.75**	19.05**	2.10	2.00	372.95	2.10
	3	12.29**	10.67**	1.94	2.71	191.94	1.94
Cob height (cm)	1	1 037.80**	339.35**	16.35	267.52	7 105.91	16.35
	2	1 103.01**	330.41**	18.22	284.11	6 868.23	18.22
	3	1 165.75**	334.22**	18.76	300.40	6 940.18	18.76
100-seed weight	1	17.03**	10.26**	0.97	4.20	204.47	0.97
	2	13.41**	9.40**	0.62	3.35	193.13	0.62
	3	7.45**	7.13**	0.83	1.73	138.61	0.83
Grain yield	1	236.60**	215.93**	10.70	59.17	4 515.21	10.69
	2	193.90**	227.36**	4.60	49.58	4 900.65	4.60
	3	221.75**	185.65**	2.63	57.39	4 026.32	2.63
CSI	1	0.01**	0.01**	0.00	0.00	0.17	0.00
	2	0.01**	0.01**	3.83	0.00	0.13	3.84
	3	0.01**	0.00**	2.61	0.00	0.07	2.62
Desiccation injury	1	45.53**	46.65**	0.86	11.70	1 007.38	0.86
	2	37.34**	73.99**	1.62	9.35	1 592.31	1.62
	3	37.40**	74.33**	1.63	9.37	1 599.51	1.63

*P = 0.05; **P = 0.01

Table 4 Combining ability mean square and expected mean square for three characters in quality protein maize

Character	Environment	Source			Var Model I			Bartlet test
		GCA [11]	SCA [66]	Error [154]	GCA	SCA	Error	[3]
Plant height(cm)	1	1 273.67**	665.17**	59.28	238.54	9 997.38	59.27	
	2	1 225.47**	574.63**	64.97	227.96	8 409.43	64.97	
	3	1 063.66**	563.46**	62.91	196.58	8 259.08	62.91	
	4	676.48**	478.24**	28.87	127.21	7 414.65	28.87	30.15**
Leaf senescence	1	0.11**	0.10**	0.01	0.02	1.51	0.01	
	2	0.24**	0.20**	0.01	0.05	3.16	0.01	
	3	0.11**	0.12**	0.01	0.02	1.80	0.01	
	4	0.40**	0.33**	0.02	0.07	5.12	0.02	41.87**
Leaf rolling	1	0.13**	0.09**	0.01	0.02	1.46	0.01	
	2	0.26**	0.30**	0.01	0.05	4.20	0.01	
	3	0.23**	0.24**	0.01	0.04	3.77	0.01	
	4	0.16**	0.20**	0.01	0.03	3.07	0.01	33.86**

On account of heterogeneous error variance, combining ability was calculated only in individual environment. Analysis of variance for combining ability (Tables 3, 4) revealed that mean squares due to general combining ability (GCA) and specific combining ability (SCA) were significant for all the characters in all the environments. It indicated the presence of additive and non-additive gene action in the material. Further, the relative magnitudes of SCA variances were considerably higher than magnitude of GCA variances for all the characters in all the environments.

It revealed that non-additive gene action was predominant as compared to additive gene action. The preponderance of non-additive gene effects for grain yield in maize was also reported by Kumar *et al*. (2008), Bello and Olaoye (2009), Shanthi *et al*. (2010), Vivek *et al.* (2010), Apraku *et al*.(2011) and Mhike *et al*.(2011). Analysis of variance for combining ability were not calculated for days to 50% silking, anthesis-silking interval, days to 50% maturity, cob height, test weight and grain yield because most of the genotypes showing 0 value for these characters, and also not calculated for all the physiological characters due to leaf firing/complete dryness of leaves. Out of 12 parental lines, the parents exhibited highest magnitude of positive significant GCA effects for grain yield/plant with good *per-se* performance were P7 and P12 in all environments (Table 5). The results revealed that out of the total hybrids, five best hybrids exhibiting highest magnitude of *per-se* performance, significant and high positive economic heterosis and high significant SCA effects for grain yield/plant in different environments (Table 6). Among the five hybrids, P9 × P12 and P4 × P12 best for all the environments but P10 × P12, P1 × P7, P1 × P4 were best for well-irrigated environments. It could not perform well in stress conditions. Performance of hybrids P3 × P8 and P7 × P12 was best in stress environments. The best hybrids for stress P3 × P8 and P7 × P12 were also significantly superior from best check in well-irrigated environments. Similar findings for identification of superior inbred lines and hybrids based on GCA and SCA effects for grain yield and its components in maize were also reported by Lee *et al.* (2005), Singhal *et al.* (2006), Bajaj *et al*. (2007), Dhliwayo *et al*. (2009), Souza *et al.* (2009), Fan *et al*. (2010), Shanthi *et al*. (2010), Singh *et al.* (2010), Apraku *et al*. (2011) and Mhike *et al*. (2011).

Table 5 Promising inbred line identified on the basis of GCA effects for grain yield per plant in different environments.

	Hybrids	GCA effects	Grain yield/plant
E1	*Well irrigated crop(control)*		
1	P7	7.20	61.33
2	P8	5.01	90.33
3	P12	3.58	55.00
E2	*Irrigation skipped at grain filling*		
1	P12	5.35	32.33
2	P4	3.45	70.33
3	P1	3.14	35.00
4	P7	2.19	35.67
5	P3	1.64	41.00
E3	*Irrigation skipped at flowering*		
1	P12	6.90	24.00
2	P7	4.16	19.00
3	P4	3.14	44.67
4	P3	2.59	29.67
5	P1	1.52	30.00

The results revealed that out of the total hybrids, five best hybrids exhibiting lower mean value for CSI, high magnitude of negatively significant economic heterosis and significant negative SCA effects for CSI in different environment were different (Table 7). Hybrid P7 × P12 was

Table 6 Promising hybrids identified in each environment on the basis of grain yield/plant quality protein maize

	Hybrid	Grain yield/ plant (g)	Economic heterosis (%)	SCA effects
E1 Well irrigated crop(control)				
1	P10 × P12	108.67	25.39	34.36
2	P1 × P4	104.33	20.38	24.78
3	P9 × P12	104.00	20.00	22.61
4	P4 × P12	103.67	19.62	22.00
5	P1 × P7	103.33	19.23	15.81
E2 Irrigation skipped at grain filling				
1	P3 × P 8	91.33	18.47	42.79
2	P9 × P12	90.00	29.19	34.75
3	P2 × P6	80.00	14.83	30.51
4	P7 × P12	76.00	9.09	18.84
5	P4 × P12	75.00		16.58
E3 Irrigation skipped at flowering				
1	P3 × P8	79.00	49.06	40.93
2	P7 × P12	75.33	42.13	29.27
3	P4 × P12	61.33	15.71	19.02
4	P1 × P5	60.33	13.83	24.17
5	P9 × P12	59.67	12.58	19.01
E4 Irrigation withheld from knee height stage till maturity				
1	P3 × P8	25.00		
2	P7 × P12	22.33		
3	P9 × P12	20.67		
4	P4 × P 12	20.67		
5	P10 × P12	20.00		

best for all the environments for this trait but P7 × P8 and P1 × P4 best for stress conditions. The hybrid P1 × P4 also showed positive significant SCA for grain yield/ plants in all the environments while it exhibited negative significant SCA for CSI in all environments.The negative significant SCA effects for CSI also reported by Nayeem and Veer (2000), Kumari *et al*. (2004) and Lukose and Godawat (2007). Hence this hybrid appear to be very promising combination for actual exploitation and could be recommended for intensive study for possible inclusion in regular breeding trails. The study under discussion finally revealed that parent P7 and P12 showed considerably good *per se* performance and high GCA effects for grain yield and hence they could be used for the development of short duration single cross hybrids.

The selected single cross hybrids P10 × P12, P1 × P7 and P1 × P4 have been identified for superior performance under well-irrigated conditions with respect to yield, specific combining ability and economic heterosis over the best check. At the same time hybrids P9 × P12, P4 × P12, P3 × P8 and P7 × P12, which have been identified for superior performance under moisture-stress conditions along with good specific combining ability for yield and other drought- adaptive traits like chlorophyll-stability index could be used for the development of genotypes for moisture-limited conditions.

Table 7 Promising hybrids identified in each environment on the basis of chlorophyll stability index in quality protein maize

	Hybrid	CSI(mean value)	Economic heterosis (%)	SCA effects
E1 Well-irrigated crop(control)				
1	P2 × P6	0.11	–54.17	–0.11
2	P7 × P12	0.11	–54.17	–0.05
3	P1 × P4	0.12	–50.00	–0.13
4	P2 × P12	0.12	–50.00	–0.04
5	P8 × P9	0.12	–50.00	–0.10
E2 Irrigation skipped at grain filling				
1	P7 × P 12	0.04	–75.00	–0.04
2	P5 × P7	0.05	–68.75	–0.07
3	P1 × P4	0.06	–62.50	–0.12
4	P7 × P8	0.06	–62.50	–0.09
5	P4 × P12	0.06	–62.50	–0.04
E3 Irrigation skipped at flowering				
1	P4 × P11	0.04	–72.73	–0.05
2	P5 × P6	0.04	–72.73	–0.06
3	P7 × P8	0.04	–72.73	–0.08
4	P7 × P11	0.04	–75.00	–0.05
5	P7 × P12	0.05	–65.91	–0.04

These can also be involved in the development of drought tolerant and productive single cross hybrids which can be directly used for general cultivation after confirming its potential through multilocational testing.

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