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Behaviour of Quality Protein Maize (QPM) genotypes under well irrigated and water stress conditions in subtropical climate

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Abstract

Drought or water stress is one of the prime problems affecting production of maize at global level. A major objective of QPM breeding programs in semi arid tropics or subtropical climatic conditions is to increase genetic potential of QPM genotypes under water stress conditions. In order to identify drought tolerant single cross QPM hybrids an experiment with 85 genotypes was conducted under well irrigated and water stress conditions. Six drought tolerance indices viz, mean productivity (MP), geometric mean productivity (GMP), yield index (YI), tolerance index (TOL), stress susceptibility index (SSI), and superiority measures (SM) were used on the basis of grain yield in water stress (Ys) and well irrigated (Yp) conditions. Highest significant positive correlations were observed among MP, GMP and YI indices. The hybrids 75, 38, 27, and 50 were more drought tolerant based on drought tolerance indices. Three dimensional plot, bi-plot and cluster analysis confirmed these results. Principal component analysis reduced six indices down to two components with 90.71% proportional cumulative variance. Genotypes were grouped by two ways cluster analysis (using Ward's method) based on Yp, Ys and drought tolerance indices. Also, the results of correlation, 3D graphs, bi-plot and cluster analysis reveals that the most suitable indices to screen QPM genotypes in drought stress conditions were MP, GMP and YI. These indices could be used in QPM breeding programs to introduce drought tolerance in single cross hybrids.

Keywords: QPM, water stress, tolerance indices, principal component analysis

Introduction

Maize (*Zea mays* L) is an important food, feed and industrial crop after wheat and rice at global level. It is a versatile crop grown in diversified ecologies. Maize is the important source of protein (9-12%) (Bressani, 1991) and it supplies 15 % of global human protein requirements. However quality of protein like other cereals lacks sufficient quantities of lysine and tryptophan, which are essential amino acids in human nutrition. Its deficiency impedes utilization of other amino acids. These deficiencies have been corrected by the mutant *opaque-2* (*o2*) gene, which raises the amount of lysine and tryptophan in the endosperm by two times over that of ordinary maize. The maize carrying the *o2* gene in homozygous condition, the hard modified endosperm with vitreous kernels is known as quality protein maize (QPM). An attempt has been made to develop and recognize superior inbred lines and single cross hybrids, which are sustainable for semi-arid rainfed and moisture stress environments in subtropical climate. Thus, the current effort on QPM is to increase its cultivation in the semi-arid rainfed and subtropical climatic region, experiencing problems of malnutrition and where normal maize is the staple food. In these regions, however, maize is frequently produced under environmental stress, among which drought is the most important.

To identify drought resistance genotypes, some selection indices based on a mathematical equations between stress and optimum conditions has been proposed for selection of drought tolerant genotypes (Fischer and Maurere, 1978; Rosielle and Hamblin, 1981; Fernandez, 1992; Gavuzzi et al, 1997). Rosielle and Hamblin (1981) define tolerance index (TOL) as difference between crop yield in both stress and non stress conditions and mean productivity (MP) as the average grain yield in both conditions. High amount of TOL showed plant susceptibility to water stress and selection was based on low TOL. High MP also showed more tolerance to stress. Fernandez (1992) suggested geometric mean productivity (GMP) based on which maize hybrids identified with high yield in both stress and non-stress conditions (Khalili et al, 2004). The stress susceptibility index (SSI) is estimated based on mean yield of plants under suitable and stress conditions (Drivand et al, 2012; Ahmadizadeh et al, 2012; Guttieri et al, 2001; Fischer and Maurere, 1978). If the value of SSI is more than one it indicates above average, susceptibility and SSI less than one indicate below average susceptibility to water stress.

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Lin and Binns (1988) suggested a superiority measure (SM) of genotypes performance in different environmental conditions. Gavuzzi et al (1997) and Lin et al (1986) suggested a Yield Index (YI) for selection of stable genotypes under both water stress and normal conditions. Therefore, the above-mentioned indices were introduced as appropriate indices to identify stress tolerant genotypes. Thus an attempt has been made to recognize superior single cross QPM hybrids & inbred which are sustainable for semi-arid rainfed and moisture stress environments using drought tolerant indices.

Materials and Methods

Plant material

The experimental material comprised of twelve Quality Protein Maize (QPM) inbred lines selected on the basis of their per se performance and genetic diversity from AICRP on Maize, Department of Plant Breeding and Genetics, Rajasthan College of Agriculture, Udaipur. The crosses were made by intermating twelve parents in diallel mating design (without reciprocal) for development of 66 F_1s during the rainy (kharif) season of 2009. The experimental material comprised of 85 genotypes including 12 parents, their 66 F_1s and 7 checks.

Experimental site and condition

The study was conducted at research farm of Rajasthan college of Agriculture, MPUAT, Udaipur (Rajasthan), India. The site of experiment is situated in NARP-IVA Zone of Rajasthan on latitude of 24°35'North and longitude of 73°42'East at an elevation of 582.17 meters above mean sea level. The soil textural class at the site is clay loam with 34.50% sand, 31.40% silt and 34.10% clay. Soil pH is around 8.2, Electric conductivity 0.48 dS m^{-1} at 25°C, organic carbon 8.50 g kg-1 and available N, P and K are 427.75, 22.4 and 671 kg ha^{-1}, respectively. The meteorological data including relative humidity (RH) and rainfall were collected throughout the experimental period. Relative humidity and rainfall ranged from 12-88.6% and 0-1.6 mm respectively. At Udaipur there was no rainfall just before or during grain filling stage in the Rabi season. Thus there was no interference from rainfall from the viewpoint of managed stress trial.

Experimental design and crop husbandry

This experiment were conducted under well irrigated and water stress (Irrigation skipped at grain filling stage) conditions in a randomized block design and each genotype was accommodated in a single row of 5 m length having 60 × 25 cm crop geometry during the winter (rabi) season of 2009–2010. The parents and hybrids were accommodated in same block randomly. The recommended package of practices was followed to raise the healthy crop in both conditions. Total amount of phosphatic and half amount of nitrogenous fertilizers were applied (@ 120 kg N and 60 kg P_2O_5 kg ha^{-1}) at basal dose and rest of the nitrogenous fertilizers was applied in two equal doses, one at knee high stage and another at flowering stage of the crop. Observations were recorded for grain yield on 10 randomly selected competitive plants for each entry in each replication in both conditions.

Calculate indices

Six drought tolerance indices including Geometric mean productivity (GMP), Yield index (YI), Mean productivity (MP), Stress susceptibility index (SSI), Tolerance index (TOL), Superiority measure (SM) were estimated by the following formula:

Geometric Mean Productivity $GMP = \sqrt{Yp_i \times Ys_i}$

Yield Index $YI = Ys_i / Ys$

Mean Productivity $MP = (Yp_i + Ys_i)/2$

Stress Susceptibility Index

$$SSI = (1 - (Ys_i / Yp_i)) / SI$$

Tolerance Index $TOL = Yp_i - Ys_i$

Superiority Measure $P_i = \left[\sum_{j=1}^{n} \left(X_{ij} - M_j \right)^2 / 2n \right]$

In above mentioned equations, Ys_i and Yp_i are the grain yield of genotypes in water stress and well watered condition; SI is stress intensity, where $SI = 1-(Ys/Yp)$; Ys = Total grain yield mean in stress condition; Yp = total grain yield mean in normal condition; n = number of environments; X_{ij} = Grain yield of i^{th} genotype at the j^{th} environment, and M_j = Grain yield of the genotype with maximum yield at j^{th} environment.

To represent the genotype by trait two way data in biplot, a principal component analysis is essential. The biplot graph of Principal component analysis was used to select suitable stress tolerant indices, stress tolerant and high yielding genotypes. Principal component analysis reveals relationships that were not

Table 1 - Mean value of best performing five QPM genotypes based on drought tolerant indices.

Genotypes	YP	YS	MP	GMP	TOL	SSI	YI	SM
P3 x P8	102.67	91.33	97.00	96.83	11.34	-1.39	1.85	5.68
P2 x P6	102.33	80.00	91.16	90.48	22.33	-1.10	1.62	37.33
P4 x P12	103.67	75.00	89.34	88.18	28.66	-0.95	1.52	71.92
P9 x P12	104.00	90.00	97.00	96.75	14.00	-1.33	1.83	27.18
P10 x P12	108.67	64.00	86.34	83.40	44.67	-0.58	1.30	236.36

Table 2 - Correlation coefficient between Ys,Yp and drought tolerance indices.

Parameter	YP	YS	MP	GMP	TOL	SSI	YI	SM
YP	1							
YS	0.560**	1						
MP	0.883**	0.883**	1					
GMP	0.804**	0.941**	0.988**	1				
TOL	0.469**	-0.470**	0.000	-0.147*	1			
SSI	0.101	-0.759**	-0.373**	-0.501**	0.916**	1		
YI	0.559**	1.000**	0.882**	0.940**	-0.470**	-0.759**	1	
SM	-0.739**	-0.917**	-0.938**	-0.958**	0.190**	0.543**	-.0917**	1

**. Correlation is significant at the 0.01 level (2-tailed).

previously predicated and, thereby, allows interpretations that would not generally result (Johanson and-Wichern 1996). The genotypes categorized into four group based on their performance in well irrigated and water stress conditions: genotype express good performance in both water stress and non stress conditions (Group 1), genotypes with good performance only in well irrigated conditions (Group 2), genotypes relatively gave higher yield in water stress conditions (Group 3), and genotypes with low performance in both conditions (Group 4). The three dimensional plot among the Ys, Yp and GMP, MP showed the interrelationships among these variables to differentiate genotype of Group 1 from others groups (Fernandez, 1992).

Statistical Analysis

Analysis of variance, correlation (SPSS, version 11) among the indices and grain yield in both conditions, three dimensional plots drawing (R, version 2.15), principal component analysis (SAS, version 9.3), biplot drawing ('R', versions 2.15) and cluster analysis (SAS, version 9.3) were performed with the help of different software as mentioned in parenthesis.

Results and Discussion

Analysis of variance

Analysis of variance for various yield based drought tolerance indices for all the parents, hybrids and checks were carried out. The result of analysis of variance for yield in well irrigated and water stress conditions and stress tolerance indices showed significant differences among the genotypes in Ys, Yp and stress tolerance indices. It indicated that genetic variation exists among genotypes. These finding of significant difference for all the criteria among the QPM genotypes are in consistence with those reported by Ahmadizadeh et al (2012) and Drikvand et al (2012) in the evaluation of wheat genotypes. The hybrid P1 x P7 (18), P2 x P12 (33) and P7 x P8 (64) had highest grain yield only in well watered conditions. The best performing genotypes in stress and non stress condition with different drought tolerance

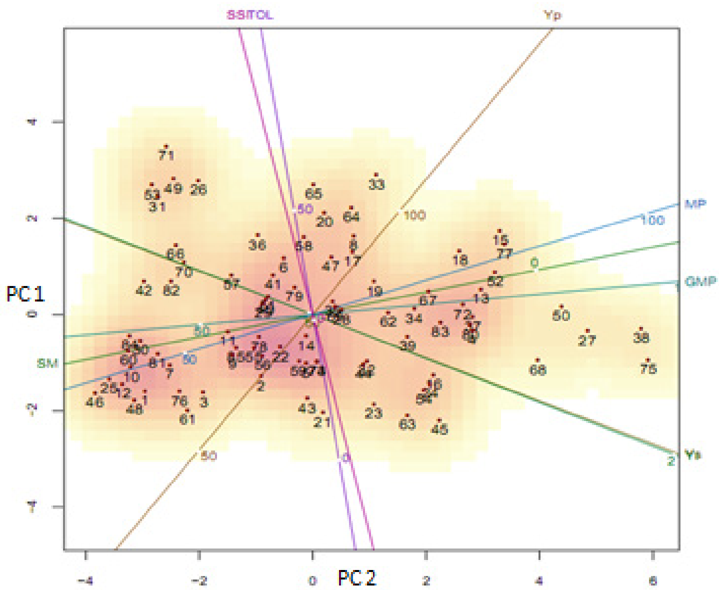

Figure 1- The biplot of 85 QPM genotypes and 6 drought tolerance indices based on PC1 and PC2.

indices given in Table 1. The hybrid P4 x P12 (50), P3 x P8 (38), P2 x P6 (27), P10 x P12 (77), and P9 x P12 (75) had the highest grain yield in both water stress and well watered conditions. Among the inbreds or parents P4 and P8 had highest grain yield in both conditions. The ranking of genotypes on the basis of drought indices GMP, MP, YI, and SM were identical and almost correspondence to the ranking for Ys and Yp. On the other hand, TOL and SSI exhibited different ranking than the others indices.

Correlation analysis

Correlation analysis between drought tolerant indices on the basis of grain yield under well irrigated and a water stress condition was performed (Table 2). Indices which had high correlation with grain yield in both stressed and non stressed conditions had been selected as best ones, because these were able to separate and identify genotypes with high grain yield in both conditions. We observed that indices GMP, MP and YI had significant positive correlation with grain yield under two conditions. Therefore genotypes which showed high amount of these indices were identified as most tolerant QPM genotypes. The observed positive correlation between GMP and MP are in accordance with the results of Ahmadizadeh et al (2012), Drikvand et al (2012) in durum wheat and Khalili et al (2004) in maize, respectively. In water stress conditions TOL had significant negative correlation with grain yield, while in well irrigated condition it had significant positive correlation. Hence it cannot be a proper index for selecting the genotypes, which have a high yield in both stress and normal conditions (Jabbari et al, 2008). Superiority measure (SM) had significant negative correlation with Yp, Ys, MP, GMP and YI and significant positive correlation with TOL and SSI. So that it can be used as an index for screening of drought tolerance genotype with high grain yield in both conditions with low indices value. The correlation coefficient indicated that GMP, MP and YI are the best criteria for selection of high yielding QPM genotypes both under well irrigated and water stress conditions.

Principal component analysis

In order to find out relationship among genotypes and drought tolerance indices, principal component analysis was performed that reduced six indices down to two components. The horizontal axis was related to first component and the vertical axis was related to the second component. Principal component analysis (PCA) reported that the first component explained 67.13% of the variations with Ys, YI, Yp, MP and GMP. Considering the positive value of principal component first on biplot, selected genotypes will be high yielding with stable performance in different water stress conditions. The PCA 2 explained 23.58% of the total variation and had the positive correlation with Yp, TOL and SSI. Thus, selection of genotypes that have high PCA1 and Low PCA2 are suitable for water stress and well watered conditions. These findings in consistence with the result of investigation of Golabadi et al (2006) and Zabet et al (2003) in wheat and mungbean, respectively.

The relationship between the genotypes and drought tolerant indices can be plotted in same graph (the biplot). The biplot is a useful tool for data analysis and interpretation. If the angle and directions between vectors or lines which indicated yield in two conditions and indices are less than 90oc, it represents a positive correlation and if the angles between the lines are more than 90oc, then the correlation is negative. According to the biplot there was positive correlation between indices MP, GMP and YI and grain yield in both conditions confirming the simple correlation results. Therefore, these three indices (GMP, MP, and YI) were the most appropriate indices to screening QPM genotypes. The results of this study are in accordance with Dadbakhsh and YazanSepas (2011), Ahmadizadeh et al (2012), and Drikvand et al (2012). According the biplot, genotypes with high PC1 and low PC2 gave high grain yield (stable genotypes), and genotypes with low PC1 and high PC2 score gave low grain yield (unstable genotypes). Therefore, ac-

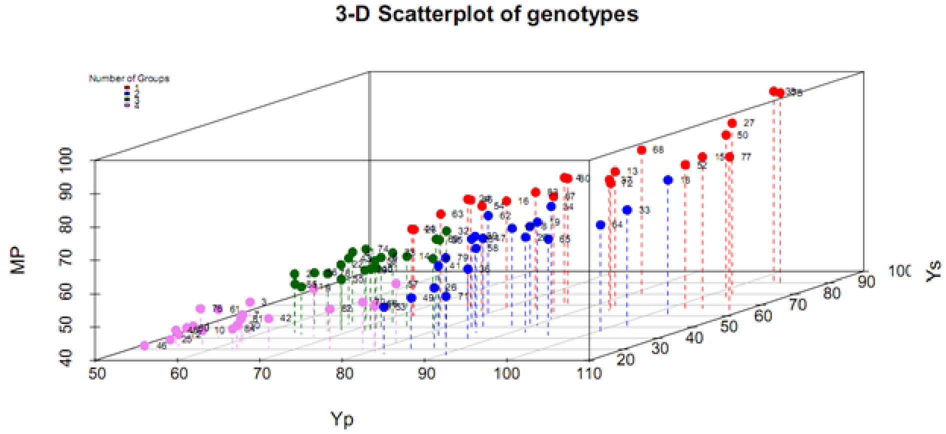

Figure 2 - The 3-D plots among the MP, Yp, Ys..

cording to biplot (Figure 1), genotype 75, 38, 27 and 50 had stable and high grain yield in both water stress and well watered conditions with high PC1 score.

Three dimensional plots

To select drought or water stress tolerant genotypes three dimensional plot were drawn (Figure 2). In three dimensional plots the genotypes were divided in four groups and marked by different colours. These plots can be used effectively to differentiate the high yielding genotypes under both stress and non stress conditions.

Three dimensional plot (Ys,Yp, and MP) are presented to show the interrelationship among the variables to separate the genotypes of group 1(high yielding in both water stress and well watered conditions) from the other groups (2, 3, and 4), and to inform the advantage of MP,GMP and YI indices as selection criterion for selecting high yielding and water stress tolerant genotypes. These results are supported by the finding of the Jamshidimoghadam et al (2007), Pouresmael et al (2009), and Ahmadizadeh et al (2012). According to three-dimensional plots genotypes 38, 75, 27, and 50 were in Group 1. These genotypes had high yield in both water stress and well irrigated conditions. Genotypes 18, 33, 64, 65 etc were in Group 2 and performed favorably only in well irrigated conditions. Genotypes 32, 74, 21, etc were in Group 3 that performed in water stress conditions only. Genotypes 76, 9, 3, 61, 57, etc were in Group 4 that performed poorly in both conditions.

Cluster analysis

To describe the genetic diversity and grouping based on similar characteristics cluster analysis has been widely used (Golestani et al, 2007; Malek-shahi et al, 2009; Ahmadizadeh et al, 2012). Separate two-way cluster analysis (using Ward's methods) based on Yp, Ys and other quantitative indices of drought tolerance were performed for QPM genotypes (Figure 3). The discriminate function analysis allowed the highest difference among groups when genotypes were categorized into 9 groups. Mean value of QPM genotypes groups in cluster analysis are presented in Table 3. Group 9 with Ys, Yp and most of other drought tolerance indices exhibited maximum deviance of total means and this group may be recommend as superior groups. Cluster analysis supported the result of principal component analysis because genotypes 75, 38, 27, 50, and 68 were in this group. These results are in consistence with the findings of Golabadi et al (2006), Ahmadizadeh et al (2011), Ahmadizadeh et al (2012), and Drikvand et al (2012). On the basis of another way MP, GMP, Ys, Yp and YI are grouped in first group and TOL, SM and SSI into second group.

Conclusion

When a breeder is looking for the genotypes well adapted for water stress and well irrigation conditions, selection of genotypes should be based on different available drought tolerant indices calculated from the grain yield under both water stress and water availability conditions. In present investigation it was found that statistical methods including correlation between grain yield and indices, biplot analysis, three dimensional analysis and cluster analysis have represented the same genotypes as drought or water stress tolerant. Thus, these statistical methods are useful for selection of drought tolerant QPM genotypes. Also it was observed that MP, GMP and YI are the best indices for selecting drought tolerant genotypes of QPM and genotypes 77, 38, 27, 50, and 68 can be recommended for cultivation in water stress or drought prone rainfed areas of subtropical climatic conditions or else, may be used in the future hybridization/ breeding programme.

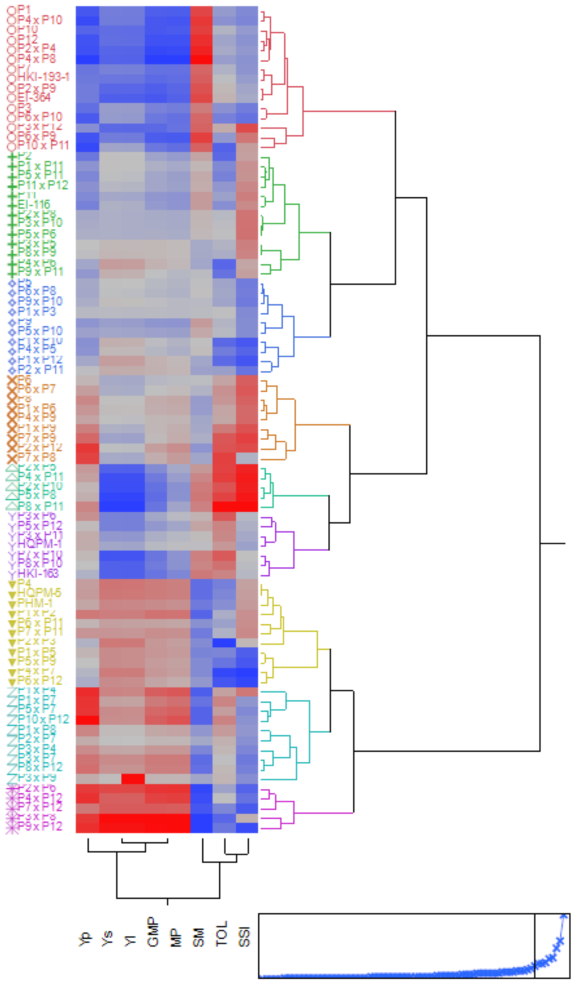

Figure 3 - Clustering of QPM genotypes using ward's method based on Yp,Ys and six indices.

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Table 3 - Grain yield mean and drought indices values of QPM genotypes groups issued from cluster analysis

Group	Genotype		Yp	Ys	SM	YI	GMP	MP	TOL	SSI
1	1,3,7,10,12,25,30,42, 46,48,60,61,76,81,84	Mean difference	57.889	34.356	6.776	1464.486	0.697	44.476	46.123	23.532
		%	-26.202	-30.264	89.101	88.113	-30.935	-27.852	-27.769	-19.342
2	2,11,22,29,35,40,44 51,56,69,74,78,85	Mean difference	69.59	49.23	3.877	836.948	0.999	58.452	59.41	20.36
		%	-11.286	-0.075	8.212	7.506	-1.036	-5.179	-6.961	-30.216
3	5,9,14,21,23,32, 43,55,59,73	Mean difference	71.566	50.434	3.577	772.775	1.023	59.988	61	21.132
		%	-8.767	2.368	-0.176	-0.736	1.384	-2.689	-4.471	-27.570
4	6,8,17,20,23, 47,58,64,65	Mean difference	91.26	46.555	2.685	591.273	0.944	65.094	68.907	44.704
		%	16.338	-5.503	-25.0715	-24.050	-6.412	5.594	7.912	53.222
5	26,31,49,53,71	Mean difference	85.334	26.934	5.332	1176.524	0.546	47.901	56.134	58.4
		%	8.784	-45.330	48.800	51.124	-45.856	-22.296	-12.091	100.163
6	36,41,57,66,70,79,82	Mean difference	81.19	34.62	4.571	1003.816	0.702	52.908	57.905	46.57
		%	3.501	-29.729	27.564	28.940	-30.405	-14.174	-9.318	59.616
7	4,13,16,24,45,54, 62,63,67,80,83	Mean difference	82.029	66.181	1.615	347.059	1.343	73.614	74.105	15.847
		%	4.571	34.332	-54.921	-55.420	33.041	19.415	16.052	-45.684
8	15,18,19,28,34, 37,39,52,72,77	Mean difference	95.467	59.168	1.502	329.960	1.283	75.119	77.317	36.299
		%	21.702	20.096	-58.082	-57.616	27.115	21.857	21.082	24.413
9	27,38,50,68,75	Mean difference	101.134	82.466	0.230	50.018	1.673	91.262	91.8	18.668
		%	28.926	67.385	-93.571	-93.575	65.776	48.042	43.762	-36.016
	Total	Mean	78.443	49.267	3.583	778.512	1.009	61.645	63.855	29.176

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