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ASSESSMENT OF DROUGHT TOLERANCE IN MAIZE (Zea *mays* L.) BASED ON DIFFERENT INDICES

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SUMMARY

A study was conducted to identify drought tolerant hybrids. Thirteen maize hybrids were evaluated under stress and non- stress conditions during 2009-10 *kharif* season. Eighteen drought tolerant indices including Tolerance Index (*TOL*), Stress Tolerance Index (*STI*), Stress Susceptibility Index (*SSI*), Harmonic Mean (*HM*), Geometric Mean (*GMP*), Mean Production (*MP*), modified *STI* under optimum conditions (K_1STI) and *STI* under stress condition (K_2STI) were calculated based on grain yield under drought (*Ys*) and irrigated conditions (*Yp*). Grain yield under irrigated conditions was significantly and positively correlated with *TOL* and K_1STI. Yield under stress conditions was having significant and positive correlation with *TOL*, *GMP* and K_2STI. Results of this study showed that the hybrids Bio-9681 and HQPM-7 were having good yield under both stress as well as non-stress environments. Hence, these 2 hybrids are identified as drought tolerant based on different indices. However, before recommending these hybrids for drought prone areas, need further testing over many locations under drought conditions.

Key words: Maize, drought tolerant indices, correlation

Key findings: Identification of drought stress tolerant hybrids and assessing existing level of drought resilience in available germplasm or hybrids in maize using various indices.

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INTRODUCTION

Maize is the third most important food crop of the world. It has food, feed and industrial uses. It is the major component of livestock feed. It is estimated that globally more than 2 billion people derive their dietary calories from maize. It is consumed as food in almost all the countries wherever it is grown. In India maize is grown in 9.07 million-ha area from which 24.26 million tons of maize is harvested. Average productivity of maize in India is 2.68 tons per hectare which is much lower compared to USA, China and Brazil. Though maize is well adapted to different climatic conditions, the yield is adversely affected by various abiotic stresses like drought, heat and water logging in different agro climatic conditions. Among these, drought is an important production constraint and shows huge genotype × environment interaction over years and locations (Bruce *et al.,* 2002; Loffler *et al*., 2005 & Setimela *et al*., 2005).

In India, most of the maize is grown in rainy season under rainfed conditions. The rainy season offers a difficult growing condition for maize. Over the period of time it is observed that maize experiences intermittent drought and water logging stress during the critical growing stages. Mitigating intermittent drought during the major maize growing season is a challenge. In maize, grain yield reduction caused by drought ranges from 10 to 76 %, depending upon severity and stage of drought occurrence (Bolaoos *et al*., 1993). Development of climate resilient hybrids is a viable solution but, may take longer period. Hence through multi-location evaluation under artificial stress condition existing level of tolerance in available cultivars can be determined (Richards *et al*., 2002) and utilized.

The exactness of any stress cannot be assessed rather the confounding effect of stress on the dependent variable (= yield) may be estimated. However, applying complex statistical models may not prove suitable as compared to the indices which can be computed through simplified calculations. There are many indices developed to assess stress and stress tolerance. Broadly, they are either physiological or agronomic indices. Some selection indices based on mathematical equations have been proposed for selection of drought tolerant genotypes by comparing the performance under stress and optimum conditions (Fischer and Maurer, 1978; Rosielle and Hamblin, 1981; Fernandez, 1992 & Gavuzzi *et al*., 1997). Rosielle and Hamblin (1981) define Tolerance index (*TOL*) as difference between crop yields in stress and non- stress conditions and Mean Productivity (*MP*) as the average grain yield over both conditions. Higher *TOL* showed plant susceptibility to water stress and selection should be based on lower *TOL*. High *MP* also showed more tolerance to stress. Fernandez (1992) suggested Geometric Mean Productivity (*GMP*) based on which maize hybrids can be identified with high yield in both stress and non-stress conditions. The Stress Susceptibility Index (*SSI*) is estimated based on mean yield of plants under stress and non-stress conditions (Drivand *et al*., 2012; Ahamadizadeh *et al*., 2012; Guttieri, 2001; Fischer and Maurer, 1978). If the value of *SSI* is more than one, it indicates above average susceptibility and *SSI* less than one indicates below average susceptibility to water stress. Stress Tolerance Index (*STI*) was defined as a useful tool for determining high yield and stress tolerance potential of genotypes (Fernandez, 1992). Genotypes can be categorized into 4 groups based on their performance in stress and non-stress environments: genotypes which express uniform superiority in both stress and non-stress environments (Group A); genotypes which perform favorably only in non-stress environments (Group B); genotypes which yield relatively well only in stress environments (Group C) and genotypes which perform poorly in both stress and non-stress environments (Group D). The optimal selection criteria should distinguish Group A from the other 3 groups (Fernandez, 1992).Therefore, the present study was planned to compare the different drought resistance/ tolerance indices and to know the association of these indices with grain yield for identification of potential genotypes for moisture stress and irrigated conditions.

An effort was made to identify suitable maize hybrids with high drought tolerance using five indices which are broadly agronomic in nature.

MATERIALS AND METHODS

The experimental material consisted of 13 maize hybrids, released through All India Coordinated Maize Research Project (AICRP). The hybrids were evaluated under randomized block design with 3 replications in 2 environments *i.e.* irrigated and moisture stress conditions of *kharif* season [June-September] during 2009-10 at Maharana Pratap University of Agricultural Sciences and Technology, Udaipur, Rajasthan, India (latitude 24.55 ^{o}N, longitude 73.4 ^{o}E and altitude of 572 masl). Main factors considered were normal irrigated (non-stress) and drought stress at pre-flowering stage; the sub factors were 13 hybrids (Table 1).

Table 1. Genotypes of maize used for assessment of drought tolerance.

Hybrid	Source	Maturity group	Recommended for states
Bio 9637	Private	Medium	All India
Bio 9681	Private	Medium	All India
HM 4	CCSHAU, Karnal	Medium	All India
HM 9	CCSHAU, Karnal	Medium	Bihar, Jharkhand & Odisha
HQPM 1	CCSHAU, Karnal	Late	All India
HQPM 5	CCSHAU, Karnal	Late	All India
HQPM 7	CCSHAU, Karnal	Late	Karnataka, AP, TN & Maharashtra
PEHM 2	IARI, New Delhi	Early	Andhra Pradesh, Tamil Nadu, Maharashtra, Karnataka, Rajasthan, Gujarat & MP
PEHM 3	IARI, New Delhi	Early	Punjab, Haryana & Delhi
Prakash	PAU, Ludhiana	Early	All India
Seed Tech 2324	Private	Late	All India
Vivek 17	VPKAS, Almora	Extra Early	All India except hilly region
Vivek 21	VPKAS, Almora	Extra Early	Uttarakhand, HP, J & K and NEH regions, Delhi, Punjab, Haryana, UP, Andhra Pradesh, Tamil Nadu, Maharashtra & Karnataka

These hybrids were grown in 4 rows of 4 meter length with spacing of 70 cm × 20 cm. Recommended package of practices were followed for irrigated conditions whereas, for drought stress, irrigation was stopped 1 week before flowering and it was resumed 1 week after completion of flowering period. Drought tolerant indices were calculated using the following equations:

1. Tolerance index (TOL) and mean productivity (MP) as done by Rosielle & Hamblin (1981):

$TOL = (Yp - Ys)$ and $MP = \frac{(Ys+Yp)}{2}$

Yp and *Ys* were the yield of each cultivars, non-stressed and stressed, respectively.

2. Harmonic mean (HM) (Kristin *et al.*, 1997):

$$HM = \frac{2(Yp * Ys)}{(Yp + Ys)}$$

3. Stress susceptibility index (SSI) (Fischer & Maurer, 1978):

$SSI = \frac{1-\left(\frac{Ys}{Yp}\right)}{SI}$ while, $SI = 1 - \left(\frac{\hat{Y}s}{\hat{Y}p}\right)$

Where, SI is stress intensity and $\hat{Y}s$ and $\hat{Y}p$ are the means of all genotypes under stress and well water conditions, respectively.

4. Geometric mean productivity (*GMP*) and stress tolerance index (*STI*) (Fernandez, 1992; Kristin *et al.*, 1997):

$GMP = \sqrt{(Yp * Ys)}$ and

$STI = \frac{(Yp*Ys)}{\hat{Y}p^2}$

5. Modified stress tolerance index (*MSTI*) as reported by Farshadfar & Sutka, (2002):

$MSTI = kiSTI$ while,

$k1 = \frac{Yp^2}{\hat{Y}p^2}$ and $k2 = \frac{Ys^2}{\hat{Y}s^2}$

Analysis of variance was done for each drought indices through computer program SAS 9.3 version. Correlation coefficients were determined as per Johnson *et al.* (1955).

Table 2. Analysis of variance for different Indices of drought tolerance in maize genotypes.

Source of Variation	Degree of freedom	Ys	Yp	TOL	MP	GMP	HM	SSI	STI	K$_1$STI	K$_2$STI
Genotypes	12	2524394.80*	2076683.05*	2339017.77*	584754.479*	1757251.83*	1831863.39*	0.572*	0.098*	0.159*	0.334*
Replication	2	129240.66	215919.07	540201.28	135050.258	34872.70	35043.84	0.001	0.007	0.000	0.000
Errors	24	117041.28	125734.61	3738914.36	38947.012	84296.54	87544.61	0.045	0.004	0.008	0.016

*Significant at 0.01 probability level.

(Ys) Yield under stress; (Yp) Yield under optimal condition; (TOL) Tolerance Index; (MP) Mean Production; (GMP) Geometric Mean Production; (HM) Harmonic Mean; (SSI) Stress Susceptibility Index; (STI) Stress Tolerance Index; (K$_1$STI) Modified Stress Tolerance Index under Optimal condition; (K$_2$STI) Stress Tolerance Index under stress condition.

Table 3. Estimates of stress tolerance attributes from potential yield and stress yield of maize genotypes.

Genotypes	Ys	Yp	TOL	MP	GMP	HM	SSI	STI	K$_1$STI	K$_2$STI
Bio9637	5297.161	7484.540	1084.255	1084.255	6288.472	6196.891	1.234	0.724	1.021	0.885
Bio9681	6787.259	8230.932	722.3603	722.360	7461.230	7413.512	0.703	1.024	1.241	1.459
HM4	4592.832	5596.773	735.6723	735.672	5273.085	5218.432	0.992	0.509	0.674	0.665
HM9	5359.199	6428.656	712.8876	712.888	6028.541	5985.347	0.877	0.665	0.843	0.906
HQPM1	5016.084	8725.303	2026.403	2026.403	6743.590	6457.541	1.902	0.833	1.508	0.797
HQPM5	4999.988	6556.190	745.4015	745.401	5695.092	5645.288	0.955	0.596	0.776	0.790
HQPM7	6725.953	8158.883	869.7532	869.753	7545.182	7495.009	0.870	1.043	1.314	1.428
PEHM2	4735.821	7401.532	1254.717	1254.717	5857.345	5727.142	1.465	0.630	0.963	0.707
PEHM3	6669.415	7501.635	420.8929	420.893	7077.444	7064.605	0.469	0.917	1.033	1.402
Prakash	6663.618	7722.000	522.445	522.445	7166.434	7146.866	0.567	0.940	1.088	1.400
SeedTech2324	5070.864	7005.189	936.9722	936.972	5927.818	5849.162	1.122	0.647	0.884	0.814
Vivek17	6725.296	7302.703	280.782	280.782	7002.272	6996.472	0.323	0.900	0.975	1.426
Vivek21	4601.008	6860.988	1103.445	1103.445	5596.253	5490.138	1.377	0.575	0.852	0.668

(Ys) Yield under stress (kg/ha); (Yp) Yield under optimal condition (kg/ha); (TOL) Tolerance Index; (MP) Mean Production; (GMP) Geometric Mean Production; (HM) Harmonic Mean; (SSI) Stress Susceptibility Index; (STI) Stress Tolerance Index; (K$_1$STI) Modified Stress Tolerance Index under Optimal condition; (K$_2$STI) Stress Tolerance Index under stress condition

Table 4. Genotypic correlation (r_g) for yield and different stress indices in maize.

	Yp	Ys	TOL	MP	HM	SSI	GMP	STI	K_1STI	K_2STI
Yp	1.00000	0.49398 (0.0862)	0.84967 (0.0002**)	0.42907 (0.1435)	0.00017 (0.9996)	0.16950 (0.5799)	0.79388 (0.0012)	-0.19072 (0.5325)	0.99792* (<.0001)	0.48844 (0.0903)
Ys		1.00000	0.87821* (<.0001)	-0.57342 (0.0405)	0.73926 (0.0039)	-0.76951 (0.0021)	0.92054* (<.0001)	0.75534 (0.0028)	0.45961 (0.1141)	0.99916* (<.0001)
TOL			1.00000	-0.11174 (0.7163)	0.44844 (0.1243)	-0.37345 (0.2088)	0.99498* (<.0001))	0.35319 (0.2365)	0.82768 (0.0005)	0.87465* (<.0001)
MP				1.00000	-0.76784 (0.0022)	0.95913* (<.0001)	-0.20828 (0.4947)	-0.96441* (<.0001)	0.46282 (0.1113)	-0.57776 (0.0386)
HM					1.00000	-0.86704* (0.0001)	0.50649 (0.0774)	0.86344* (0.0001)	-0.03061 (0.9209)	0.74326 (0.0036)
SSI						1.00000	-0.46016 (0.1136)	-0.99959* (<.0001)	0.20422 (0.5034)	-0.77136 (0.0020)
GMP							1.00000	0.44069 (0.1318)	0.76859 (0.0021)	0.91741* (<.0001)
STI								1.00000	-0.22521 (0.4594)	0.75724 (0.0027)
K_1STI									1.00000	0.45439 (0.1188)
K_2STI										1.00000

The P valued are given in parenthesis; *significant at 0.05 probability level; **significant at 0.01 probability level.

RESULTS AND DISCUSSION

The analysis of variance (Table 2) showed highly significant differences for yield under both stress (*Ys*) and optimal condition (*Yp*), presented in Table 2. Using the adjusted yield means, various drought tolerance indices were calculated (Table 3). The variations in the indices infer that genotypes vary for genes controlling yield under optimal and stress conditions (Khodarahmpour and Hamidi, 2011).

Greater the value of *TOL* and *SSI,* larger is the yield reduction under stress condition indicating higher sensitivity to drought. Vivek-21 was most sensitive genotype (1103.44) followed by Bio-9637 (1084.25) whereas Vivek-17 (280.72) was least sensitive to drought. But the genotypes Bio-9681 (8230.93 kg/ha and 6787.25 kg/ha) and HQPM-7 (8158.88 kg/ha and 6725.95 kg/ha) were good yielders under both irrigated and stress conditions. It is also important to note that the early maturing hybrids in general have performed better with respect to magnitude of yield difference under optimal and stress conditions. The yield under irrigated conditions (*Yp*) has a very weak association with yield under stress conditions (*Ys*) depicting that high yield potential under best possible conditions does not anticipate superior yield under stress conditions in general. The genotype HQPM-1 (8725.30) was found highest yielder under irrigated conditions but under stress conditions yield (5016.08) was very low as compared to Bio-9681 and HQPM-7. Therefore, indirect selection for stress environments under irrigated conditions would not be effective however; it is advisable to select best genotype on the basis of indices. In the present study high *GMP* coupled with high *STI* was observed for HQPM-7 and Bio-9681. These 2 genotypes have also recorded good yield with less *SSI* under both situations, so these 2 genotypes can be considered as drought stress tolerant genotypes.

Correlation analysis between grain yield and other drought tolerant indices can be a good criterion for screening best cultivars and indices used. Hence association between *Yp*, *Ys* and other drought tolerant indices were estimated to determine the most desirable criteria for drought tolerance (Table 4). Yield under irrigated conditions was significantly and positively correlated with tolerance index and K_1STI. Yield under stress conditions showed significant and positive correlation with *TOL*, *GMP* and K_2STI meaning thereby *TOL* is high under higher stress conditions. Yield under stress conditions has negative but non-significant correlation with *SSI*. This means if value of *SSI* is more than genotype/s will be more susceptible to stress and will yield less under such conditions. Therefore, *TOL* and *SSI* are most suitable factors to identify drought tolerant genotypes. Dehbalaei *et al*., (2013) has also reported that grain yield in non-stress conditions were significant and positive correlations with *STI*, *GMP*, *MP*, *HM*, *TOL*, K_1STI and K_2STI. *TOL* has positive and significant correlation with *GMP* and K_2STI whereas *MP* has negative and significant correlation with *STI*; *HM* was having negative correlation with SSI and positive and significant correlation with *STI* whereas *SSI* has negative and significant correlation with *STI*. *GMP* has significant and positive correlation with K_2STI, *Ys* and *TOL*. Toorchi *et al*., (2012) in canola; Golabadi *et al.* (2006) in durum wheat and Farshadfar *et al*. (2012) in bread wheat also reported almost similar results. According to Fernandez (1992), model genotypes under study can be divided into 4 groups based on their performance under stress and non- stress environments. A 3-dimensional plots (Figure 1) presented to shows the inter-relationship among *STI* and yields under stress and non - stress environments.

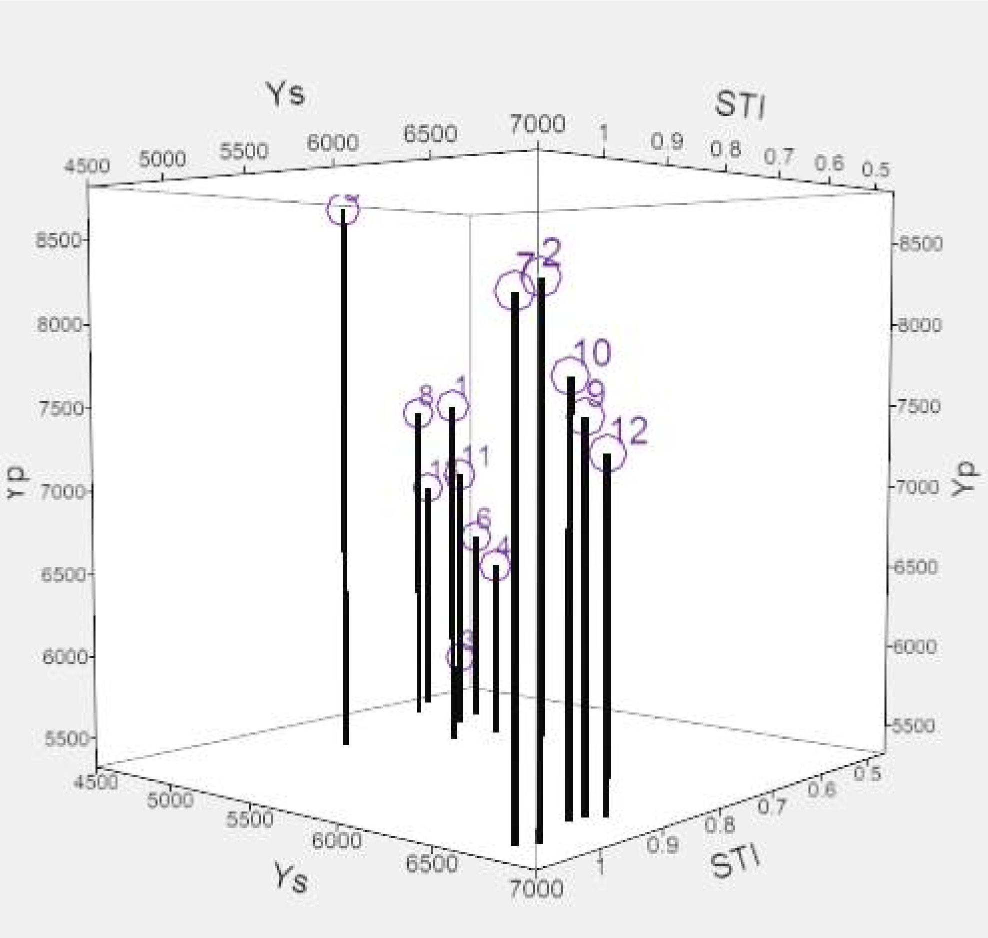

Figure 1. Three-dimensional representation of interaction among genotype and STI, Yp and Ys.

The hybrids namely Bio 9681, HQPM 7, Prakash, PEHM 3 and Vivek 17 having high yield under both stress as well non- stressed environments fall under group A whereas, HQPM-1, PEHM-2 and Bio 9637 performed good under irrigated conditions only and HM 4 and HM 9 performed poorly under both environments falls under group D. Kiani (2013) also used 3-D plot analysis for screening maize genotypes for drought tolerance and reported the most desirable genotypes. Hence, by using this model the genotypes Bio 9681 and HQPM 7 have been identified as potential genotypes for drought prone areas. There is further need for rigorous testing of these genotypes in multi-location trials under rainfed conditions in drought prone areas before recommending as drought tolerant genotypes. An initial study of this kind will help in understanding the confounding effect of stress on yield.

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