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RESEARCH ARTICLE

Evaluation of Water Stress Tolerance Indices for the Selection of Maize Genotypes

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Thirty genotypes of maize were evaluated in RBD with two replications under two regimes (i) no water stress and (ii) water stress during 2009-10 in *Rabi*. Eight water stress tolerance indices viz., stress tolerance (TOL), stress susceptibility index (SSI), stress tolerance index (STI), mean production (MP), geometric mean production (GMP), yield index (YI), stress susceptibility percentage index (SSPI) and modified stress tolerance index(MSTI) were calculated based on grain yield per plant (g) under water stress (Ys) and no water stress (Yp). Yield under Ys had significant positive association with STI, MP, GMP, YI and MSTI. Based upon the mean yield and stress tolerance indices, five genotypes GM-2, PM-3, EH-1731, EC-3160 and EH-1820 were found potentially drought tolerant.

Key Words: Correlation, Grain yield, Maize, Tolerance indices, Water stress

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crop in the world agricultural economy, as food for man and feed for animals and its serves as a source for high fructose, malt dextrin, germ oil, germ meal fibre and gluten products which have application in industries such as alcohol, textile, paper, pharmaceuticals, organic chemicals, cosmetics and edible oil (CRA, 2009). Maize can be grown under a wide range of climatic conditions and is particularly sensitive to water stress from one week before to two weeks after flowering (Grant *et al.,* 1989**).** Therefore, high yielding maize could be achieved through full irrigation at the flowering stage, even if the soil water content is sub-optimal during the vegetative growth and grain filling stages (Igbadun *et al.,* 2007). Drought tolerance is a complex quantitative trait with low heritability. Breeding for tolerant to drought is complicated by the lack of rapid, reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions where large populations can be evaluated efficiently (Ramirez and Kelly, 1998). The most effective selection criterion, among various morphological, physiological, yield and yield related traits, for identifying drought tolerant genotypes is based on mean grain yield (the arithmetic and geometric) under drought stress and non-stress environments (Araus *et al*., 2002; White *et al*., 1994). Loss of yield is the main concern of plant breeders hence they emphasize on yield performance under stress conditions. The relative yield performance of genotypes in drought stressed and favourable environments seems to be a common starting point in the identification of desirable genotypes for drought conditions (Nouri *et al*., 2011). Thus, drought indices which provide a measure of drought based on loss of yield under drought-conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2000). The objective of the present research was to identify drought tolerant maize genotypes on the basis of various quantitative criteria on their yield performance in water stress and no water stress at pre and post flowering stages such as stress tolerance (TOL), stress susceptibility index (SSI), stress tolerance index (STI), mean production (MP), geometric mean production (GMP), yield index (YI), stress susceptibility percentage index (SSPI) and modified stress tolerance index (MSTI).

Materials and Methods

The experiment was laid out with thirty genotypes of maize at Agronomy Farm, B.A. College of Agriculture, Anand 2009-10 in *Rabi*. Seeds of thirty diverse

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genotypes were obtained from Main Maize Research Station, Godhra, Agricultural University, Anand, Gujarat and All India Coordinate Research Project on Maize, Maharana Pratap University of Agriculture and Technology, Udaipur (Rajasthan) (Table1). These genotypes were sown in two replications with two different environments namely no water stress (S_0) and water stress (S_1) conditions at pre and post flowering stage. In each environment/replication, each genotype was sown in a single row plot of 4m length. The row to row and plant to plant distance was maintained 60cm and 20cm respectively. Irrigations were given at the time of seed sowing for establishing the crop in both environments. Till pre flowering stage, which coincides with 50-60 days after sowing, all genotypes were similar. At this stage water stress was created by withholding irrigation S_1while S_0 was given normal irrigation. At post flowering stage (80-90 days after sowing), water stress was created by withholding irrigation in S_1 while remaining so was given normal irrigation. All standard recommended agronomic practices were carried out during entire cropping season except irrigation. The cobs of the sampled plants were harvested seeds were weighed in (g) and recorded as grain yield per plant under both water stress and no water stress conditions at pre and post flowering stages and denoted as Ys and Yp, respectively.

Calculation of Water Stress Indices

Eight water stress tolerance indices were calculated using the following relationships:

- Stress tolerance (TOL) = Yp - Ys (Rosielle and Hamblin, 1981). The genotypes with low values of this index considered more stable in two different conditions.
- Stress susceptibility index (SSI) = [1 - (Ys/Yp)]/

Table 1. Details of genotypes with sources and pedigree used in study

S. No.	Genotypes	Maturity	Source/Pedigree
1	PM-3		AICRP on Maize, MPUA &T, Udaipur
2	EC-3135 (Forage)		AICRP on Maize, MPUA &T, Udaipur
3	EC- 3160 (Y)		AICRP on Maize, MPUA &T, Udaipur
4	EC-3157(NP-2)		AICRP on Maize, MPUA &T, Udaipur
5	GWC-9611	EE	Local collection in 96 (Panchmahals)
6	GYC-9646	M	Suwan-3 x Composite-74
7	GWC-9103	EE	A Cross-8223 x FMS
8	GWC-9701	M	Local collection in 97 (Panchmahals)
9	GYC-0402	M	IC-9414 (GDRM-188)
10	EH-1491		AICRP on Maize, MPUA &T, Udaipur
11	GWC-9101	EE	GM-1 x Pool-31
12	EH-1389		AICRP on Maize, MPUA &T, Udaipur
13	GYC-9325	EE	DTS-19
14	GYC-9837	M	Local collection in 98 (Sabarkantha)
15	GWC-9604	EE	Local collection in 96 (Panchmahals)
16	GWC-9626	EE	Local collection in 96 (Panchmahals)
17	GYC-9005	EE	MMH-42 x GM-2
18	GYC-9327	M	DTS-26
19	GWC-9631	M	LGC-40 x EH-2922
20	GWC-9413	EE	GDRM-187
21	GYC-9535	M	A Cross-8731 x DRM-6
22	GYC-0401	M	IC-9414 (GDRM-188)
23	GM-6 (White)		Released cultivar
24	GM-2 (Yellow)		Released cultivar
25	EC-3154		AICRP on Maize, MPUA &T, Udaipur
26	Texpeno Sequia		AICRP on Maize, MPUA &T, Udaipur
27	EH-1820		AICRP on Maize, MPUA &T, Udaipur
28	GYC-9315	EE	Harsh-10
29	EH-1731		AICRP on Maize, MPUA &T, Udaipur
30	GWC-0204	EE	Mandvi Gwritoli, Mwrigrol

E = Early, M = Medium, EE = Extra Early,\

[1 - ($\bar{Y}s/\bar{Y}p$)] (Fischer and Maurer, 1978). The genotypes with SSI< 1 considered more resistant to water stress conditions.

- Stress tolerance index (STI) = [Yp x Ys / $\bar{Y}^2p$] (Fernandez, 1992). The genotypes with high STI values considered tolerant to water stress.
- Mean productivity (MP) = (Ys + Yp) / 2 (Rosielle and Hamblin, 1981). The genotypes with high value considered more desirable.
- Geometric mean productivity (GMP) = $\sqrt{Ys \times Yp}$ (Fernandez, 1992). The genotypes with high value considered more desirable.
- Yield index (YI) = (Ys)/($\bar{Y}s$) (Gavuzzi *et al.,* 1997). The genotypes with high value considered suitable for water stress condition.
- Stress susceptibility percentage index (SSPI) = [Yp – Ys/2($\bar{Y}p$)] × 100 (Moosavi *et al.,* 2008). The genotypes with low values considered stable in two different conditions.
- Modified stress tolerance index (MSTI) = KiSTI, K1 = $Yp^2/\ \bar{Y}p^2$ and K2= $Ys^2/\ \bar{Y}s^2$ (Farshadfar and Sutka, 2002). The genotypes with high value considered more desirable.

Ys and Yp represented yield for each genotype in water stress and no water stress conditions, respectively. Also, Ys and Yp were mean yield in water stress and no water stress conditions at pre and post flowering stages, respectively (for all genotypes). Statistically, efficiency of the water stress tolerance indices were evaluated based on their ability to discriminate between genotypes, correlation with grain yields of both the environments and their efficiency to identify the best high yielding and stable genotypes.

Statistical Analysis

Pooled analysis of variance was used to compute genotypes x environment interactions. Ranks were assigned to genotypes for each index. A genotype with least rank total was considered to be the best genotype. Based on indices, the genotype with the highest value for Ys, Yp, MP, GMP, STI, MSTI (K1), MSTI (K2) and YI and the lowest value for SSI, TOL and SSPI received the first rank. Besides, the most desirable water stress tolerance measures, the correlation coefficient between Yp, Ys and other quantitative indices of water stress tolerance were estimated using SPSS 20.0 statistical software (SPSS 2011).

Table 2. Pooled analysis of variance for grain yield per plant (g)

Source of variance	d. f.	Grain yield per plant (g)
Environment	1	3049.49
Genotype	29	220.80
G x E	29	117.35
Pooled Error	58	42.05

Results and Discussion

Pooled analysis of variance revealed significant differences among the environment, genotypes and environment × genotype interactions for grain yield per plant (g). This indicated differential/non-linear response of genotypes to the stress. The environment effect was the most important source of yield variation (Table 2). Mean grain yield per plant under S_0 was 49.14 g and ranged from 29.97 g (Texpeno Sequia) to 74.52 g (GWC-0204). While mean grain yield per plant under S_1 was 39.05 g and ranged from 17.07 g (Texpeno) to 56.64 g (EH-1731). Thus the result indicated that mean grain yield per plant (g) decreased under water stress and the range was wider in S_0 as compared to S_1. The genotypes GWC-0204, EH-1389, EH-1731, EC-3160, GWC-9101 and EC-3157 showed higher grain yield per plant (g) in S_0. Whereas, genotypes EH-1731, GM-2, EH-1820, PM-3, EC-3160 and GYC-9325 recorded higher grain yield per plant (g) in S_1 (Table3). To identify water tolerant genotypes using TOL index, higher value of TOL demonstrates more changes of genotype yield in water stress and no water stress conditions (Fernandez, 1992). Rosielli and Hamblin (1981) stated that selection based on TOL index leads to selection of genotypes with low yields in no water stress condition and have lower mean productivity (MP). The results of this experiment showed that GWC-9631, GYC-9325, GM-2, PM-3 and GWC-9611 were tolerant whereas GWC-0204, GWC-9101, GYC-9837and EH-1389 were sensitive to the water stress based on TOL index. For SSI, the higher value refers to more susceptibility to stress, indicating that GWC-9631, GYC-9325,GM-2, PM-3 and GWC-9611 were more tolerant genotypes. The SSPI resulted in the same genotype ranking as TOL. MP, GMP and STI showed similar ranking of genotypes relative to water stress tolerance. Based on STI, the greater the difference between the yields found in no water stress and water stress conditions at pre and post flowering stages, the smaller amount of water stress tolerance index and vice versa. Thus, genotypes EH-1731, GM-2, EC-3160, EH-1820, EC-3135 and PM-3 were found water stress tolerant with high STI and high grain yield per plant (g) under no water stress and water stress conditions at pre and post flowering stages, whereas genotypes Texpeno Sequia, GWC-9103, GWC-9101 and GWC-9701 displayed the lowest amount of STI and grain yield per plant (g) under water stress condition at pre and post flowering stage. GMP showed the same genotype ranking as STI. For MP, the higher value refers to more tolerant to water stress condition. Therefore EH-1731, GM-2, GWC-0204, EC-3160 and EH-1820 were listed as tolerant whereas, the genotypes Texpeno Sequia, GWC-9103, GWC-9701 and GWC-9611 were susceptible to drought stress. YI can be used as a selection criterion, although it only ranks cultivars on the basis of Ys. Based on YI, genotypes EH-1731, GM-2, EH-1820, PM-3 and EC-3160 had the highest YI and Ys, hence were more tolerant whereas, Texpeno Sequia, GWC-9101, GYC-9837 and GWC-9103 had the lower YI and Ys. According to K1STI, the genotypes GWC-0204, EH-1389, EH-1731, EC-3160 and GWC-9101were the most tolerant whereas, the genotypes Texpeno Sequia, GWC-9611, GWC-9631 and GWC-9701 were the most sensitive. According to K2STI, the genotypes EH-1731, GM-2, EH-1820, PM-3, EC-3160 and GYC-9325 were the most tolerant whereas, the genotypes Texpeno Sequia, GWC-9101, GYC-9837, GWC-9103 and GWC-9701were the most sensitive (Table 3). It was concluded that MP, GMP and STI values are convenient parameters to select high yielding genotypes in both the water stress and no water stress conditions at pre and post flowering stages whereas relative decrease in yield under water stress, TOL, SSI and SSPI values are better indices to determine drought tolerance levels.

Correlation Coefficient

To determine the most desirable water stress tolerance index, the correlation coefficient between Yp, Ys and water stress indices were calculated The best indices are those which have positive correlation with grain yield per plant (g) in both S_0 and S_1 conditions at pre and post flowering stages and would be able to identify high yielding and drought tolerant genotypes (Talebi *et al*., 2007). Grain yield per plant (g) under water stress condition (Ys) had a weak positive association ($r = 0.311$) with grain yield per plant (g) under no water stress condition (Yp), indicating that high potential yield under optimal conditions does not necessarily result in improved yield in a water stress condition (and the opposite is true) because the genes controlling yield and drought tolerance are different (Rosielle and Hamblin, 1981). Similar findings were reported by Fernandez, 1992; Mohammadi *et al*., 2010; Farshadfar *et al*., 2014; Sahar *et al*., 2016. The grain yield per plant (g) under no water stress (Yp) had significant positive association with TOL (0.559), STI (0.701), MP (0.799), GMP (0.709), SSPI (0.558) and K1STI (0.990), whereas non-significant and positive association with SSI (0.358), YI (0.308) and K2STI (0.313). The grain yield per plant (g) under water stress (Ys) had significant positive association with STI (0.884), MP (0.820), GMP (0.889), YI (1.000) and K2STI (0.987), while K1STI (0.254) exhibited non-significant and positive character association. In addition, TOL (-0.615), SSI (-0.755) and SSPI (-0.615) showed significantly negative association with grain yield per plant (g) under water stress (Ys). The indices STI, MP and GMP exhibited good correlation with grain yield per plant (g) under both the S_0 and S_1 conditions, therefore, selection based on MP, GMP and STI will result in the selection of genotypes with higher drought stress tolerance and yield potential in both S_0 and S_1 conditions, while TOL, SSI, YI and SSPI exhibited good correlation with grain yield per plant under water stress conditions at pre flowering and post flowering stages. Similar findings were also reported by Siahsar *et al*., 2010 in lentil, Zare, 2012 and Saeidi *et al*., 2013 in barley, Singh *et al*., 2015 and Mohammed and Kadhem, 2017 in wheat. Thus, these indices may be used as selection criteria in breeding programme for water stress tolerance at pre and post flowering stages.

Ranking Method

The estimated values of various stress tolerance indices indicated that the identification of water stress tolerant genotypes based on a single criterion was contradictory. Different indices introduced different or same genotypes as water stress tolerant. To determine the most desirable drought stress tolerant genotype according to the all indices, mean rank of all indices were calculated and based on this criterion the most desirable and water stress tolerant genotypes were identified (Table 3). The genotypes GM-2, PM-3, EH-1731and EC-3160 were identified as the most tolerant genotypes for drought stress and genotypes EH-1820, GYC-9325 and EC-3135 were found moderately tolerant for drought stress, while genotypes Texpeno Sequia, GWC-9101, GWC-9103, GWC-9701 and GYC-9837 as the most sensitive for drought stress. Such strategies of using different tolerance indices and ranking pattern for identifying tolerant genotypes were used by several other workers

Table 3. Grain yield per plant (g) and water tolerance indices of maize genotypes in response to no water stress (S_0) and water stress (S_1) conditions at pre and post flowering stages

Genotypes	Grain yield per plant (g)				TOL	Rank	SSI	Rank	STI	Rank	MP	Rank	GMP	Rank	YI	Rank	SSPI	Rank	MSTI (K1)	Rank	MSTI (K2)	Rank	Sum	Overall Rank
	Yp	Rank	Ys	Rank																				
PM-3	50.4	15	49.55	27	0.85	4	0.08	4	1.03	25	49.98	24	49.97	25	1.27	27	0.86	4	1.05	15	1.61	27	197	18
EC-3135	53.1	18	47.96	24	5.14	12	0.46	11	1.05	26	50.53	25	50.46	26	1.23	24	5.23	12	1.17	18	1.51	24	220	22
EC-3160	58.07	27	49.42	26	8.65	16	0.71	13	1.19	28	53.75	27	53.57	28	1.27	26	8.80	16	1.40	27	1.60	26	260	29
EC-3157	54.97	25	41.98	19	12.99	21	1.13	20	0.95	21	48.48	22	48.04	21	1.08	19	13.21	21	1.25	25	1.16	19	233	26
GWC-9611	37.13	2	36.04	13	1.09	5	0.14	5	0.55	5	36.59	4	36.58	5	0.92	13	1.11	5	0.57	2	0.85	13	72	1
GYC-9646	54.57	23	44.93	23	9.64	19	0.84	18	1.01	23	49.75	23	49.52	23	1.15	23	9.80	19	1.23	23	1.33	23	240	27
GWC-9103	43.05	9	26.36	4	16.69	26	1.85	25	0.47	2	34.71	2	33.69	2	0.68	4	16.97	26	0.77	9	0.46	4	113	7
GWC-9701	38.28	4	32.02	5	6.26	13	0.78	15	0.51	4	35.15	3	35.01	4	0.82	5	6.37	13	0.61	4	0.67	5	75	3
GYC-0402	50.72	16	34.89	10	15.83	25	1.49	24	0.73	15	42.81	15	42.07	15	0.89	10	16.10	25	1.06	16	0.80	10	181	17
EH-1491	42.81	8	41.2	18	1.61	6	0.18	6	0.73	14	42.01	14	42.00	14	1.06	18	1.64	6	0.76	8	1.11	18	130	10
GWC-9101	55.42	26	21.52	2	33.90	29	2.91	30	0.49	3	0	6	34.53	3	0.55	2	34.48	29	1.27	26	0.30	2	158	14
EH-1389	60.82	29	34.5	8	26.32	27	2.06	27	0.87	17	47.66	19	45.81	17	0.88	8	26.77	27	1.53	29	0.78	8	216	21
GYC-9325	47.12	14	49.35	25	-2.23	2	-0.23	2	0.96	22	48.24	21	48.22	22	1.26	25	-2.27	2	0.92	14	1.60	25	174	16
GYC-9837	54.16	21	25.18	3	28.98	28	2.55	28	0.56	6	39.67	9	36.93	6	0.65	3	29.47	28	1.21	21	0.42	3	156	13
GWC-9604	47.11	13	32.56	6	14.55	24	1.47	23	0.63	10	39.84	11	39.17	10	0.83	6	14.80	24	0.92	13	0.70	6	146	11
GWC-9626	44.97	11	37.08	14	7.89	15	0.84	17	0.69	13	41.03	13	40.83	13	0.95	14	8.02	15	0.84	11	0.90	14	150	12
GYC-9005	51.27	17	42.32	21	8.95	17	0.83	16	0.90	19	46.80	17	46.58	19	1.08	21	9.10	17	1.09	17	1.18	21	202	19
GYC-9327	54.8	24	40.92	17	13.88	22	1.21	21	0.93	20	47.86	20	47.35	20	1.05	17	14.12	22	1.24	24	1.10	17	224	24
GWC-9631	37.98	3	43.23	22	-5.25	1	-0.66	1	0.68	12	40.61	12	40.52	12	1.11	22	-5.34	1	0.60	3	1.23	22	111	6
GWC-9413	39.53	5	35.59	11	3.94	11	0.47	12	0.58	7	37.56	5	37.51	7	0.91	11	4.01	11	0.65	5	0.83	11	96	4
GYC-9535	45.84	12	42.01	20	3.83	10	0.40	10	0.80	16	43.93	16	43.88	16	1.08	20	3.90	10	0.87	12	1.16	20	162	15
GYC-0401	54.23	22	39.92	16	14.31	23	1.26	22	0.90	18	47.08	18	46.53	18	1.02	16	14.55	23	1.22	22	1.05	16	214	20
GM-6	43.95	10	34.54	9	9.41	18	1.02	19	0.63	9	39.25	8	38.96	9	0.89	9	9.57	18	0.80	10	0.78	9	128	9
GM-2	53.8	19	54.83	29	-1.03	3	-0.09	3	1.22	29	54.32	29	54.31	29	1.41	29	-1.05	3	1.20	19	1.97	29	221	23
EC-3154	42.54	7	35.62	12	6.92	14	0.77	14	0.63	8	39.08	7	38.93	8	0.91	12	7.04	14	0.75	7	0.83	12	115	8
Texpeno	29.97	1	17.07	1	12.90	20	2.05	26	0.21	1	23.52	1	22.62	1	0.44	1	13.12	20	0.37	1	0.19	1	74	2
EH-1820	53.86	20	51.36	28	2.50	8	0.22	9	1.14	27	52.61	26	52.60	27	1.32	28	2.54	8	1.20	20	1.73	28	229	25
GYC-9315	40.65	6	38.86	15	1.79	7	0.21	7	0.65	11	39.76	10	39.74	11	1.00	15	1.82	7	0.68	6	0.99	15	110	5
EH-1731	59.27	28	56.64	30	2.63	9	0.21	8	1.39	30	57.96	30	57.94	30	1.45	30	2.67	9	1.45	28	2.11	30	262	30
GWC-0204	74.52	30	33.28	7	41.24	30	2.64	29	1.03	24	53.90	28	49.80	24	0.85	7	41.94	30	2.30	30	0.73	7	246	28

Ys = Grain yield per plant under water stress condition at pre and post flowering stages, Yp = Grain yield per plant under no water stress conditions at pre and post flowering stages, TOL=Stress tolerance, SSI=Stress susceptibility index, STI=Stress tolerance index, MP= Mean production, GMP=Geometric mean production, YI=Yield index, SSPI=Stress susceptibility percentage index and MSTI=Modified stress tolerance index.

such as Farshadfar *et al*., 2013 and Mohammed and Kadhem, 2017 in wheat.

Conclusion

Based upon the mean grain yield per plant (g) and various stress tolerance indices, the genotypes GM-2, PM-3, EH-1731 and EC-3160 were found most tolerant to water stress and genotypes EH-1820, GYC-9325 and EC-3135 were found moderately tolerant to water stress and genotypes Texpeno Sequia, GWC-9101, GYC-9837, GWC-9103 and GWC-9701 were found susceptible to water. The indices STI, MP and GMP exhibited good correlation with grain yield per plant (g) under both the water stress conditions while TOL, SSI, YI and SSPI exhibited good correlation with grain yield per plant (g) under water stress condition. Hence, these genotypes may be used in breeding maize for water stress at pre and post flowering stage. However, genotypes identified as tolerant to water stress in the present study should be further tested in multi-location trials for the development of superior synthetic and composite varieties/hybrids in maize.

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