Applied Biological Research 19 (2): 172-179; (2017)
DOI: 10.5958/0974-4517.2017.00024.6

DETERMINATION OF SELECTION INDICES FOR WATERLOGGING-STRESS TOLERANCE IN MAIZE (*Zea mays* L.) UNDER FIELD CONDITIONS

S.B. Singh*, R.K. Phagna[1], B. Kumar[2] and Sonu Kumar[2]

Regional Maize Research and Seed Production Centre, ICAR-IIMR, Begusarai – 851 129, Bihar (India)
[1]*Indian Institute of Maize Research, PAU, Ludhiana – 141 004, Punjab (India)*
[2]*Indian Institute of Maize Research, Unit New Delhi (India)*
*e-mail: *singhsb1971@rediffmail.com*

(Received 11 January, 2017; accepted 25 July, 2017)

ABSTRACT

Waterlogging is one of the serious constraints in maize production which affects crop growth and yield in low lying areas. In order to study the waterlogging tolerance in maize 60 line x tester crosses were evaluated during *kharif* 2014 and 2015 under non-stress and waterlogging-stress conditions. Thirteen selection indices including mean productivity (MP); geometric mean productivity (GMP); harmonic mean (HM); tolerance index (TOL); stress susceptibility index (SSI); stress tolerance index (STI); yield index (YI); yield stability index (YSI) and modified tolerance index under non-stress and stress condition (K_iSTI) were calculated using yield in non-stress (Y_P) and stress condition (Y_S). The results showed that it was possible to identify superior combinations for waterlogging tolerance based on above stress indices. Indices STI, SSI, GMP, HM and YI were more accurate criteria for selection of waterlogging-tolerant and high yielding hybrids. Positive and significant correlation of MP, GMP, HM and STI with grain yield under both conditions revealed that these indices were more applicable and efficient for selection of waterlogging tolerant genotypes. On the basis of STI, GMP, HM YI and K_iSTI WNCDMR11R1611 x LM-13, G24QC19-BBB-21-BBB × BML-6, WNCDMR11R1611 × HKI-163 and S99TLYQ-HG-AB*4-47-BBB × BML-7 proved most waterlogging tolerant hybrids and produced good yield under stress and non-stress conditions.

Key words: Maize, stress tolerance, selection indices, waterlogging

INTRODUCTION

Water logging is considered to be one of the major problems in crop production, affecting an estimated 12% of the total cultivated area in world. In Asian countries and other parts of the world water-logging caused by contingent flooding and continuous rainfall coupled with inadequate drainage or a high-water table is one of the most important constraints in maize production. In South and Southeast Asia alone, over 18% of total maize growing areas are frequently affected by floods and water-logging problems (Zaidi *et al*., 2015). Conservative estimates indicate that the annual monetary losses from flooding and waterlogging may increase by up to US $ 1.5 billion by 2100 (Wobus *et al*., 2013). In India water logging is one of the most serious constrains in maize production and productivity particularly in the eastern part of the country. Waterlogging affects the growth and development of maize. Under waterlogging condition, the ear characteristics (grain ear^{-1} and 100-grain weight), plant morphology (plant height, ear height and leaf area index) decreased with maximum decrease in grain felling rate (Ren *et al*., 2014).

Identification and development of genotypes capable of withstanding excess moisture conditions could be an ideal and affordable approach, suitable for resource poor maize-growing farmers in tropics (Shin *et al.*, 2016). Minimization of losses under stress conditions either through breeding efforts or by improving cultural practices is the main thrust area of scientific community so that farmers of such difficult areas could sustain their livelihood. The indices used by several workers (Mitra, 2001) for the identification of tolerant genotypes under stress conditions either for drought stress or water-logging stress, could play a better role in providing immediate relief to the farmers for selecting suitable genotypes for such areas. The best measure for selection in waterlogging condition could enable to separate genotypes which have desirable and similar yield in stress and non-stress conditions from other groups and also the best indices are those which have high correlation with grain yield under both conditions. Several selection criteria have been proposed to select genotypes based on their performance in stress and non-stress environments. These indices are based either on stress resistance or susceptibility of genotypes (Fernandez, 1992). Rosielle and Hamblin (1981) defined tolerance (TOL) as the difference in yield between non-stress (YP) and stress (YS). A low TOL indicates higher tolerance to stress environments. This selection criteria favours genotypes with low yield potential under non-stress condition and high yield under stress conditions but does not separate the genotypes yielding well under stressed conditions from those yielding well under both conditions. Mean productivity (MP) is the average yield of genotypes under stress and non-stress conditions. The geometric mean productivity (GMP) is often used by breeders to find out the relative performance of genotypes. Fischer and Maurer (1978) suggested stress susceptibility index (SSI) for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Guttieri *et al.* (2001) suggested that stress susceptibility index (SSI) >1 indicated above average susceptibility to stress. Stress tolerance index (STI) was defined as a measure of determining high yield and stress tolerance potential of genotypes (Fernandez, 1992). The yield index (YI) suggested by Gavuzzi *et al*. (1997) and yield stability index (YSI) suggested by Bouslama and Schapaugh (1984) too are useful tools for evaluating the stable performance of genotypes in stress and non-stress conditions. Moghadam and Hadizadeh (2000) reported that STI is more important for selection of maize genotypes tolerant to stress than SSI. STI and GMP tend to select hybrids with high yield under stress and non-stress conditions; whereas SSI identifies genotypes yielding well under stress conditions (Khalili *et al*., 2004; Karami *et al*., 2006). For more efficient results of STI a modified stress tolerance index (MSTI) was suggested by Farshadfar and Sutka (2002) which corrects the STI as a weight. Stress susceptibility percent index (SSPI) was suggested by Moosavi *et al* (2008) for screening stress tolerant genotypes in stress and non-stress conditions. Jafri *et al.* (2009) reported that STI, GMP, and harmonic mean indices (HMI), which have the highest correlation with grain yield under both optimal and stress conditions, can be used as the best indices for maize breeding programs to introduce stress tolerant hybrids. The present study was aimed to assess the accuracy of different stress tolerance indices in identifying the maize hybrids for waterlogging tolerance.

MATERIALS AND METHODS

In present study, 15 lines were crossed with 4 testers in line × tester design to obtain 60 single crosses. The lines, tester and checks used in this study and their sources were: HKI-142, HKI-163 (tester) and HQPM-1 (check) from HAU, Hisar; CML-41, CML-161, CML-171, CML-338, CML-359 and CML-420 from CIMMYT; HKI-14-1, CML-40B, WNCDMR11R2855, WNCDMR11R1611, WNCDMR11R4782, G24QC19-BBB-21-BBB, S99TLYQ-HG-AB*4-47-BBB and HKI-164-3-(2-1)-1 from WNC, Hyderabad; BML-6 (tester), BML-7 (tester) and DHM-117 (check) from ANGRAU, Hyderabad; LM-13 (tester) from PAU, Ludhiana and P-3441 (check) from M/s Pioneer Hybrid, India. All the crosses were evaluated along with three checks hybrids (HQPM-1, P-3441 and DHM-117) suitable for the *kharif* season in the region, in two sets *viz*., set I (optimum) and set II (waterlogging) during *kharif* 2014 and 2015 at Regional Maize Research and Seed production Centre (IIMR), Begusarai (India). The experiment was laid out in a randomized block design with three replications. Recommended agronomic practices were followed to raise a good crop. The maize was planted in two rows of 4.0 m length with plant spacing of 0.6 x 0.2 m. A uniform plant population of 40 plants was maintained per plot at knee high stage. The water logging treatment was applied to the crop 35 days after sowing at crop stage between knee high to pre-flowering. Strong bunds were constructed around the entire experimental field to impose water logging treatment. Water logging environment was created by flooding of entire field up to 25 cm from soil surface for 7 days and was maintained by continuous application of water. After 7 days, pounding water was relieved from the experimental field through surface drainage and thereafter crop was managed as per normal practices for maize production. Crop was harvested separately in both sets and yield data recorded.

The grain yield data was used to calculate the various indices. Eleven stress tolerance indices including MP, GMP, TOL, HM, SSI, STI, YI, YSI, SSPI, K_1STI and K_2STI were calculated using the following relationships:

Mean productivity (MP)	$= (Ys+Yp)/2$	(Rosielle and Hamblin, 1981)
Geometric mean productivity (GMP)	$= \sqrt{YsYp}$	(Fernandez, 1992)
Tolerance index (TOL)	$= Ys-Yp$	(Rosielle and Hamblin, 1981)
Harmonic mean (HM)	$= 2(Yp \times Ys)/(Yp \times Ys)$	(Kristin *et al.*, 1997)
Stress susceptibility index (SSI)	$= [1-(Ys/Yp)]/[1-(\bar{Y}s/\bar{Y}p)]$	(Fischer and Maurer, 1978)
Stess tolerance index (STI)	$= (Ys \times Yp)/(\bar{Y}p2)$	(Fernandez, 1992)
Yield index (YI)	$= (Ys)/(\bar{Y}\ s)$	(Gavuzzi *et al.*, 1997)
Yield stability index (YSI)	$= Ys/Yp$	(Bouslama and Schapaugh, 1984)
Stress susceptibility percentage index (SSPI)	$= [Yp-Ys/2(\bar{Y}p)] \times 100$	(Moosavi *et al.*, 2008)
Modified stress tolerance index (K_1STI)	$= Yp2/\bar{Y}p2$	(Farshadfar and Sutka, 2002)
Modified stress tolerance index (K_2STI)	$= Ys2/\bar{Y}s2$	(Farshadfar and Sutka, 2002)

In above formulae, Ys, Yp, $\bar{Y}s$ and $\bar{Y}p$ represent yield under stress, yield under non-stress (for each cultivar), mean yield in stress and mean yield under non-stress conditions (for all the cultivars), respectively. Analysis of variance of pooled mean data was performed for each experiment using Indostat computer programme as well as for correlation coefficients.

RESULTS AND DISCUSSION

The analysis of variance showed significant differences among hybrids for all indices (Table 1). Based on the performance in stress and non-stress conditions hybrids were grouped as: i) hybrids which expressed uniform superiority in both stress and non-stress conditions (group A), ii) hybrids which performed favourably only in non-stress conditions (group B), iii) hybrids which gave relatively higher yield in stress conditions (group C); and iv) hybrids which performed poorly in both conditions (group D). Among all the hybrids, highest grain yield under optimum conditions was by ‘G24QC19-BBB-21-B BB × BML-7’ (68.82 q ha^{-1}), followed by ‘WNCDMR11R1611 × LM-13’ (68.16 q ha^{-1}) whereas under waterlogging stress condition the highest grain yield was noticed in hybrid ‘G24QC19-BBB-21-BBB × BML-6’ (34.83 q ha^{-1}); followed by hybrid ‘WNCDMR11R1611 × LM-13’ (34.17 q ha^{-1}). The hybrids ‘G24QC19-BBB-21-BBB × BML-6’ (66.99 and 34.83 q ha^{-1}), ‘WNCDMR11R1611× LM-13’ (68.16 and 34.17 q ha^{-1}) and ‘WNCDMR 11R1611×HKI-163’ (62.16 and 33.60 q ha^{-1}) produced high yield under both stress and non-stress environments (group A). The hybrids ‘G24QC19-BBB-21-BBB × BML-7’, ‘WNCDMR11R4782

Table 1: Analysis of variance of stress tolerance indices and yield in water logging stress and non-stress conditions in maize

Source of variation	Degree of freedom	Mean squares											
		Y_P	Y_S	MP	GMP	TOL	HM	SSI	STI	YI	YSI	SSPI	K1STI
Replicates	2	1.248	10.611	5.540	9.702	24.390	4.687	0.002	0.008*	0.002	0.005	7.238	0.007
Treatments	62	330.2**	223.6**	162.0**	253.1**	461.0**	185.5**	0.14**	0.09**	0.12**	0.07**	217.3**	0.15**
Error	124	10.25	7.19	4.47	7.18	16.98	6.24	0.01	0.01	0.01	0.01	5.95	0.01

* and ** significant at 5 and 1% levels, respectively. Y_P = Yield in non-stress condition; Y_S = Yield in stress condition; MP = Mean productivity; GMP = Geometric mean productivity; TOL = Tolerance index, HM = Harmonic mean tolerance index; SSI = Stress susceptibility index; STI = Stress tolerance index; YI = Yield index; YSI = Yield stability index; K_1STI = Modified tolerance index under non-stress condition; and K_2STI = Modified stress tolerance index under stress condition.

× LM-13', 'G24QC19-BB B-21-BBB × HKI-163', 'WNCDMR11R2855 × BML-7', 'CML-359 × BML-6' and 'CML-171 × LM-13' produced high grain yield under non-stress condition but produced poor yield under stress condition (group B). Two hybrids 'CML-359 × LM-13' and 'CML-420 × LM-13' produced intermediate yield under non-stress condition but high yield under stress conditions. The hybrid 'WNCDMR11R1611 × BML-6' showed smallest yield gap between stress and non-stress conditions but poor yield under non-stress condition. Hybrid 'HKI-142 × BML-7' and 'WNCDMR11R1611 × BML-6' produced relatively higher yield under stress condition (group C) whereas, hybrid 'CML-40BBB × BML-6' produced low yield under both environments (group D).

Based on MP index, the hybrids 'WNCDMR11R1611×LM-13', 'G24QC19-BBB-21-BBB× BML-6' and 'WNCDMR11R1611×HKI-163' were identified as water logging tolerant. Therefore, it appears that the selection based on MP will improve mean yield under both conditions, but it does not allow to discriminate lines of group A (high yield under both conditions) and B (high yield under non-stress and low yield under stress condition). The study of GMP showed comprehensive results. Based on this index 'WNCDMR11R1611 × HKI-163', 'WNCDMR11R1611 × LM-13', 'G24QC19-BBB-21-BBB × BML-6' and 'S99TLYQ-HG-AB*4-47-BBB × BML-7' were identified as high water logging tolerant. The ability to separate group A genotypes from others using GMP index is consistent with those of Khalili *et al.* (2004) and Khodarampour *et al.* (2011) in maize. TOL index allow us to discriminate 'HKI-142 × BML-7', 'WNCDMR11R1611 × BML-6', 'HKI-142 × BML-6', 'WNCDMR11R1611 × BML-7' and 'S99TLYQ-HG-AB*4-47-BBB × HKI-163' hybrids as water logging tolerant genotype (Table 2). All these genotypes were low to intermediate yielding under both conditions. This is due to low yield differences between the two environments that decreased the value of TOL index. Therefore, low TOL does not mean high yielding, and genotype yield should be taken in consideration in addition to this criterion. Similar results were reported by Khodarahmpour *et al.* (2011). Although low TOL has been used for selecting genotypes with tolerance to stress, the likelihood of selecting low yielding genotypes can be anticipated. On the basis of SSI, hybrids 'HKI-142 × BML-7', 'WNCDMR11R1611 × BML-6', 'S99 TLYQ-HG-AB*4-47-BBB × HKI-163', 'CML-359 × LM-13' and 'CML-420 × LM-13' were tolerant to water logging stress. Hybrids 'CML-359 × LM-13', 'CML-420 × LM-13' and 'S99TLYQ-HG-AB*4-47-BBB × HKI-163' yielded intermediate in non-stress and relatively high yield under stress condition, whereas hybrids 'HKI-142 × BML-7' and 'WNCDMR11R1611 × BML-6' yielded poor under non-stress and intermediate under stress condition. Therefore, this index discriminated group (A) genotypes from others. These results are in conformity with Moghaddam and Hadizadeh (2000). The results of STI showed that hybrids 'G24QC19-BBB-21-BBB × BML-6' was highest tolerant to water logging followed by hybrids 'WNCDMR11R1611 × LM-13', 'WNCDMR11R1611 × HKI-163' and 'S99TLYQ-HG-AB*4-47-BBB × BML-7'. All these hybrids produced high yield under both conditions. This index also separates genotypes of group A from genotypes of other groups.

Table 3: Mean comparison of stress tolerance indices of maize hybrids

Cross combination	Y_P	Y_S	MP	GMP	TOL	HM	SSI	STI	YI	YSI	SSPI	K_1STI	K_2STI
HKI-14-1(1+2+3) × HKI-163	48.72	19.63	36.90	32.40	34.50	28.816	0.900	0.303	1.119	0.363	29.210	0.840	1.253
HKI-14-1 (1+2+3× BML-6	52.38	17.10	37.63	31.20	41.13	26.433	1.000	0.280	0.975	0.294	34.798	0.971	0.950
HKI-14-1(1+2+3) × BML-7	49.89	26.30	40.87	38.07	29.17	35.674	0.743	0.417	1.499	0.474	24.666	0.881	2.248
HKI-14-1(1+2+3) × LM-13	67.65	22.10	48.63	40.67	53.07	34.157	1.007	0.477	1.260	0.294	44.930	1.620	1.587
HKI-141 × HKI-163	58.68	19.23	42.20	35.30	46.00	29.704	1.003	0.357	1.096	0.295	38.919	1.219	1.202
HKI-141 × BML-6	39.57	23.30	33.63	32.03	20.63	30.459	0.670	0.293	1.328	0.530	17.498	0.554	1.764
HKI-141 × BML-7	37.89	27.23	34.70	33.83	14.87	33.073	0.500	0.330	1.552	0.647	12.587	0.508	2.410
HKI-141 × LM-13	43.38	18.73	33.50	29.53	29.50	26.980	0.867	0.257	1.068	0.389	24.949	0.666	1.140
CML-40B BB× HKI-163	44.40	9.90	29.60	22.07	39.43	16.491	1.137	0.143	0.564	0.201	33.387	0.698	0.319
CML-40BBB × BML-6	37.08	8.53	24.83	18.73	32.67	14.138	1.127	0.100	0.486	0.207	27.658	0.487	0.237
CML-40BBB × BML-7	42.06	10.43	28.60	21.67	36.27	17.058	1.100	0.140	0.595	0.223	30.734	0.626	0.354
CML-40BBB × LM-13	60.69	7.63	37.57	22.53	59.83	13.714	1.260	0.147	0.435	0.113	50.631	1.304	0.189
CML-41 × HKI-163	57.36	11.33	37.53	26.77	52.40	19.244	1.173	0.207	0.646	0.178	44.365	1.165	0.417
CML-41 × BML-6	40.41	6.43	25.67	16.73	38.50	11.254	1.220	0.083	0.367	0.143	32.569	0.578	0.135
CML-41 × BML-7	45.72	7.10	28.97	18.63	43.67	12.459	1.217	0.100	0.405	0.140	36.999	0.740	0.164
CML-41 × LM-13	43.26	5.63	26.83	16.40	42.43	10.085	1.260	0.077	0.321	0.117	35.927	0.662	0.103
CML-161 × HKI-163	53.22	4.00	31.57	15.20	55.13	7.493	1.327	0.070	0.228	0.068	46.680	1.003	0.052
CML-161 × BML-6	64.35	5.10	38.27	18.97	66.43	9.521	1.320	0.107	0.291	0.071	56.219	1.466	0.085
CML-161 × BML-7	48.24	4.23	28.90	14.70	49.33	7.847	1.307	0.063	0.241	0.079	41.797	0.824	0.058
CML-161 × LM-13	64.68	8.73	40.30	24.93	63.13	15.574	1.250	0.177	0.498	0.122	53.453	1.481	0.248
CML-171 × HKI-163	42.39	10.00	28.53	21.70	37.13	16.497	1.123	0.137	0.570	0.212	31.411	0.636	0.325
CML-171 × BML-6	58.68	8.93	37.07	24.07	56.33	15.714	1.230	0.167	0.509	0.137	47.639	1.219	0.259
CML-171 × BML-7	60.36	4.60	35.83	17.50	62.47	8.609	1.327	0.090	0.262	0.069	52.889	1.290	0.069
CML-171 × LM-13	66.00	8.93	41.13	25.43	64.47	15.926	1.250	0.183	0.509	0.122	54.525	1.542	0.259
CML-338 × HKI-163	57.54	10.77	37.37	26.23	53.13	18.430	1.183	0.197	0.614	0.168	45.014	1.172	0.377
CML-338 × BML-6	42.39	10.17	28.63	21.80	36.93	16.724	1.117	0.137	0.580	0.216	31.270	0.636	0.336
CML-338 × BML-7	42.06	12.47	29.60	24.07	34.27	19.683	1.040	0.167	0.711	0.267	29.012	0.626	0.505
CML-338 × LM-13	37.41	10.40	25.97	20.73	31.17	16.637	1.063	0.123	0.593	0.250	26.388	0.495	0.351
CML-359 × HKI-163	54.03	11.33	35.70	26.07	48.70	19.067	1.153	0.197	0.646	0.189	41.233	1.033	0.417
CML-359 × BML-6	63.99	12.83	41.97	30.20	58.30	21.742	1.163	0.263	0.732	0.180	49.333	1.450	0.535
CML-359 × BML-7	54.39	26.97	43.67	40.27	33.47	37.293	0.783	0.463	1.537	0.446	28.335	1.047	2.363
CML-359 × LM-13	53.22	33.40	46.27	44.40	25.73	42.688	0.617	0.563	1.904	0.565	21.788	1.003	3.625
CML-420 × HKI-163	45.06	19.43	34.73	31.17	30.67	27.999	0.870	0.280	1.108	0.388	25.936	0.719	1.227
CML-420 × BML-6	45.06	21.77	35.90	32.97	28.27	30.342	0.800	0.313	1.241	0.435	23.961	0.719	1.540
CML-420 × BML-7	57.36	17.90	40.80	33.73	45.90	27.950	1.023	0.327	1.020	0.281	38.806	1.165	1.041
CML-420 × LM-13	52.38	32.67	45.43	43.60	25.53	41.846	0.623	0.547	1.862	0.561	21.618	0.971	3.468
WNCDMR11R2855 × HKI-163	60.18	15.17	41.03	31.77	51.70	24.725	1.097	0.290	0.865	0.227	43.773	1.282	0.748
WNCDMR11R2855 × BML-6	52.38	9.33	33.80	23.27	48.87	16.087	1.190	0.157	0.532	0.160	41.374	0.971	0.283
WNCDMR11R2855 × BML-7	63.18	13.07	41.63	30.23	57.17	22.032	1.157	0.267	0.745	0.186	48.373	1.413	0.555
WNCDMR11R2855 × LM-13	60.69	10.37	38.90	26.37	57.07	17.971	1.203	0.200	0.591	0.154	48.316	1.304	0.349
WNCDMR11R1611 × HKI-163	62.16	33.60	51.33	48.10	35.47	45.207	0.727	0.663	1.915	0.486	30.029	1.368	3.669
WNCDMR11R1611 × BML-6	36.60	24.00	32.33	31.20	16.67	30.186	0.580	0.280	1.368	0.590	14.111	0.474	1.872
WNCDMR11R1611 × BML-7	42.39	25.40	36.23	34.57	21.70	33.002	0.657	0.343	1.448	0.539	18.373	0.636	2.097
WNCDMR11R1611 × LM-13	68.16	34.17	54.97	50.83	41.57	47.089	0.783	0.740	1.948	0.451	35.193	1.645	3.794
WNCDMR11R4782 × HKI-163	46.41	13.97	32.73	26.77	37.60	21.980	1.040	0.210	0.796	0.271	31.835	0.762	0.634
WNCDMR11R4782 × BML-6	36.75	14.63	27.70	24.30	26.20	21.545	0.913	0.170	0.834	0.358	22.183	0.478	0.696
WNCDMR11R4782 × BML-7	56.52	27.03	44.93	41.17	35.77	37.796	0.813	0.490	1.541	0.430	30.283	1.131	2.375
WNCDMR11R4782 × LM-13	64.68	23.67	47.77	41.20	48.20	35.607	0.957	0.490	1.349	0.329	40.809	1.481	1.820
G24QC19-BBB-21-BBB × HKI-163	63.99	19.63	45.37	37.23	51.53	30.770	1.027	0.397	1.119	0.276	43.575	1.450	1.253
G24QC19-BBB-21-BBB × BML-6	66.99	34.83	54.67	50.90	39.60	47.457	0.753	0.743	1.986	0.468	33.528	1.589	3.943
G24QC19-BBB-21-BBB × BML-7	68.82	16.33	46.40	35.27	60.17	26.917	1.117	0.357	0.931	0.214	50.913	1.677	0.867
G24QC19-BBB-21-BBB × LM-13	50.37	20.13	38.07	33.50	35.83	29.614	0.913	0.323	1.148	0.360	30.339	0.898	1.317
S99TLYO-HG-AB*4-47-BBB × HKI-	47.40	30.90	41.80	40.30	21.77	38.949	0.590	0.467	1.762	0.587	18.429	0.795	3.103
S99TLYQ-HG-AB*4-47-BBB × BML-6	47.07	22.33	37.30	34.17	29.97	31.301	0.813	0.337	1.273	0.427	25.372	0.784	1.621

S99TLYQ-HG-AB*4-47-BBB × BML-7	62.16	30.70	49.87	46.00	38.37	42.506	0.790	0.610	1.750	0.444	32.484	1.368	3.063
S99TLYQ-HG-AB*4-47-BBB × LM-13	50.73	22.87	39.60	35.73	33.50	32.535	0.840	0.370	1.304	0.406	28.363	0.911	1.699
HKI-164-3-(2-1)-1 × HKI-163	55.71	22.00	41.93	36.90	39.87	32.462	0.917	0.393	1.254	0.355	33.782	1.099	1.573
HKI-164-3-(2-1)-1 × BML-6	60.36	23.53	45.30	39.70	43.53	34.841	0.923	0.453	1.342	0.351	36.858	1.290	1.800
HKI-164-3-(2-1)-1 × BML-7	65.01	29.60	50.93	46.17	42.63	41.992	0.840	0.613	1.687	0.410	36.096	1.496	2.847
HKI-164-3-(2-1)-1 × LM-13	57.36	17.67	40.73	33.50	46.07	27.665	1.027	0.323	1.007	0.277	39.003	1.165	1.014

((Y_P) yield in non-stress condition; (Y_S) yield in stress condition; (MP) Mean Productivity; (GMP) Geometric Mean Productivity; (TOL); (HM) Harmonic Mean Tolerance Index; (SSI) Stress Susceptibility Index; Stress Tolerance Index (STI); (YI) Yield Index; (YSI) Yield Stability Index; (K_1STI) Modified tolerance index under non-stress condition and (K_2STI) Modified stress tolerance index under stress condition.

The SSPI discriminated the hybrid 'CML-359 × LM-13' which was intermediate under non-stress and high yielding under stress condition. Modified stress tolerance index K_1STI K_2STI identified two hybrids 'WNCDMR11R1611 × LM-13' and 'G24QC19-BBB-21-BBB × BML-6' as most waterlogging tolerant. These hybrids yielded high under both the conditions. On the basis of GMP, HM, STI, YI and KiSTI indices hybrids 'WNCDMR11R1611 × HKI-163', 'WNCDMR11R1611 × LM-13', 'G24QC19-BBB-21-BBB × BML-6' and 'S99TLYQ-HG-AB*4-47-BBB × BML-7' were identified as high waterlogging tolerant. Therefore, selection indices GMP, HM, STI, YI and KiSTI proved to be important in identifying tolerant genotypes whereas selection indices TOL and SSI selected the genotypes with intermediate yield under both conditions.

Table 3: Phenotypic correlation coefficients between maize hybrids in stress and non-stress conditions and waterlogging tolerance indices

	Y_P	Y_S	MP	GMP	TOL	SSI	STI	HM	YI	YSI	SSPI	K_1STI	K_2STI
Y_P	1.00	0.16	0.81**	0.43*	0.73**	0.25	0.41*	0.45*	0.16	-0.21	0.73**	0.99**	0.19
Y_S		1.00	0.71**	0.95**	-0.56*	-0.99**	0.91**	0.94**	0.99**	0.91**	-0.56**	0.16	0.98**
MP			1.00	0.87**	0.18	0.77**	-0.39	0.88**	0.71**	0.39	0.18	0.81**	0.72**
GMP				1.00	-0.30	0.98**	-0.76**	0.99**	0.95**	0.76**	-0.30	0.43*	0.92**
TOL					1.00	-0.48*	0.82**	-0.28	-0.56*	-0.81**	0.99**	0.72**	-0.52*
SSI						1.00	-0.86**	0.97**	0.99**	0.86**	-0.48*	0.26	0.95**
STI							1.00	-0.72**	-0.91**	-0.99**	0.82**	0.21	-0.87**
HM								1.00	0.94**	0.72**	-0.28	0.45*	0.94**
YI									1.000	0.91**	-0.56**	0.16	0.98**
YSI										1.00	-0.82**	-0.21	0.87**
SSPI											1.00	0.72*	-0.52*
K_1STI												1.00	0.20
K_2STI													1.00

* and **, significant at 5% and 1% levels, respectively.

(Y_P) yield in non-stress condition; (Y_S) yield in stress condition; (MP) Mean Productivity; (GMP) Geometric Mean Productivity; (TOL); (HM) Harmonic Mean Tolerance Index; (SSI) Stress Susceptibility Index; Stress Tolerance Index (STI); (YI) Yield Index; (YSI) Yield Stability Index; (K_1STI) Modified tolerance index under non-stress condition and (K_2STI) Modified stress tolerance index under stress condition.

To determine the most desirable stress tolerant criterion, the correlation coefficients between all these indices were calculated (Table 4). There was significant and positive correlation between Y_p and (MP, GMP, TOL, HM, SSPI and K_1STI) and Y_s and (MP, GMP, STI, HM, YI, YSI and K_2STI). The relationship between Y_p, Y_s, and MP, GMP, HM were consistent with those reported by Farshadfar and Sutka (2002) and Khodarampour *et al* (2011) in maize. In present study, the correlation coefficient between SSI and Y_s was negative (-0.990) and highly significant. Thus selection for decreased SSI should give increased yield under waterlogging stress conditions. The correlation coefficient between STI and Y_p was (0.913) positive and highly significant. Thus, selection for increased STI should give positive response under non-stressed conditions. A high positive correlation coefficient between Y_s and STI and a negative correlation coefficient between Y_s and SSI indicated that selection for tolerance based on STI and SSI would be worthwhile when the target condition is waterlogging. These results are similar to those reported by Khalili *et al.* (2004) and Khodarampour *et al.* (2011). The correlation coefficients between GMP and yield in stress and non-stress environments were highly positive and significant, especially under stressed conditions. Hence, selection for high GMP should give positive response in both environments. Jafari *et al.* (2009) found that STI and GMP indices which showed highest correlation with grain yield under both optimal and stress conditions, can be used as the best indices for maize breeding programs. The correlation coefficients of MP and HM with Y_p and Y_s were high and positive. Therefore, selection for MP and HM should give positive response in both environments. The positive and highly significant correlation coefficient between Y_s and K_2STI indicated that selection index K_2STI was useful in selecting water logging tolerant genotypes. Farshadfar *et al.* (2001) believed that the most suitable indices for selection of drought tolerant cultivars are indicators which show a relatively high correlation with grain yield in both stress and non-stress conditions.

Conclusion: The study revealed that the use of indices STI, GMP, HM and YI help to identify genotypes with more waterlogging tolerance as these indices showed high positive significant correlations with grain yield under optimum and waterlogging environment. Therefore, selection based on a combination of indices (MP, GMP, HM and STI) may provide a useful criterion for selection of waterlogging stress tolerant genotypes in maize. In present study, on the basis of STI, GMP, HM YI and K_iSTI combinations ‘WNCDMR11R1611 × LM-13’, ‘G24QC19-BBB-21-BBB × BML-6’, ‘WNCDMR11R1611 × HKI-163’ and ‘S99TLYQ-HG-AB*4-47-BBB ×BML-7’ were recorded as the most waterlogging tolerant which produced good yield both under non-stress and stressed conditions. However, to validate these results there is need for further evaluation of the selected combinations at large scale.

REFERENCES

Bouslama, M. and Schapaugh, W.T. 1984. Stress tolerance in soybean Part 1: Evaluation of three screening techniques for heat and drought tolerance. *Crop Science,* **24**: 933-937.

Farshadfar, E., Ghannadha, M.R., Sutka, J. and Zahravi, M. 2001. Genetic analysis of drought tolerance in wheat. *Plant Breeding,* **114**: 542-544.

Farshadfar, F. and Sutka, J. 2002. Screening drought tolerance criteria in maize. *Acta Agronomica Hungarica,* **50**: 411-416.

Fernandez, G.C.J. 1992. Effective selection criteria for assessing plant stress tolerance. pp. 257-270. **In**: *Proceedings of the International Symposium on Adaptation of Vegetables and other Food Crops in Temperature and Water Stress*. 13-16 August, 1992, Taiwan.

Fischer, R.A. and Maurer, R. 1978. Drought resistance in spring wheat (*Triticum aestivum* L.) cultivars. I. Grain yield response. *Australian Journal of Agricultural Research,* **29**: 897-912.

Gavuzzi, P., Rizza, F., Palumbo, M., Campaline, R.G., Ricciardi, G.L. and Borghi, B. 1997. Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Canadian Journal of Plant Science,* **77**: 523-531.

Guttieri, M.J., Stark, J.C., Brien, K. and Souza, E. 2001. Relative sensitivity of spring wheat grain yield and quality parameters to moisture deficit. *Crop Science,* **41**: 327-335.

Jafri, F., Paknejad, F. Jami, M. and Ahmadi, A.L. 2009. Evaluation of selection indices for drought tolerance of corn (*Zea mays* L.) hybrids. *International Journal of Plant Production,* **3**(4): 33-38.

Karami, A.A., Ghanadha, M.R., Naghavi, M.R. and Mardi, M. 2006. Identification drought tolerance varieties in Barley (*Hordeum vulgare* L.). *Iranian Journal of Crop Science,* **37**: 371-379.

Khalili, M., Kazemi, H. and Shakiba, M. R. 2004. Evaluation of drought resistance indices in growth different stages of maize late genotypes. pp. 41. **In**: *The 8th Iranian Crop Production and Breeding Congress,* 25-27 August 2004, Gilan, Iran.

Khodarampour, Z., Choukan, R., Bihamta, M.R. and Hervan, E.M. 2011. Determination of best heat stress tolerance indices in maize (*Zea mays* L.) inbred lines and hybrids under Khuzestan province conditions. *Journal of Agricultural Science and Technology,* **13**: 111-121.

Kristin, A.S., Senra, R.R., Perez, F.I., Enriquez, B.C., Gallegos, J.A.A., Vallego, P.R., Wassimi, N. and Kelley, J.D. 1997. Improving common bean performance under drought stress. *Crop Science,* **37**: 43-50.

Mitra, J. 2001. Genetics and genetic improvement of drought resistance in crop plants. *Current Science,* **80**: 758-762.

Moghadam, A. and Hadizadeh, M.H. 2000. Study use of compression stress in drought stress tolerance varieties selection in maize (*Zea mays* L.). *Journal of. Crop Science,* **2**(3): 25-38.

Moosavi, S.S., Yazdi, Samadi, B., Naghavi, M.R., Zali, A.A., Dashti, H. and Pourshahbazi, A. 2008. Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. *DESERT,* **12**: 165-178. [*http://www.jdesert.ut.ac.ir]*.

Ren, B., Zhang, J., Li, X., Fan, X., Dong, S., Liu, P. and Zhao, B. 2014. Effects of waterlogging on the yield and growth of summer maize under field conditions. *Canadian Journal of Plant Science,* **94**: 23-31.

Rosielle, A.A. and Hamblin, J. 1981. Theoretical aspects of selection for yield in stress and non-stress environments. *Crop Science*. **21:** 943-946.

Shin, S., Kim, S.G., Jung, G.H., Kim, C.G., Son, B.Y., Kim, J.T., Yang, W., Know, Y., Sim, K.B. and Woo, M.O. 2016. Evaluation of waterlogging tolerance with the degree of foliar senescence at early vegetation stage of maize (*Zea mays* L.). *Journal of Crop Science and Biotechnology,* **19**: 393-400.

Wobus, C., Lawson, M., Jones, R., Smith, J. and Martinich, J. 2013. Estimating monetary damages from flooding in the United States under a changing climate. *Journal of Flood Risk Manage*. **10.**1111r3.12043.

Zaidi, P.H., Rashid, Z. Vinayan, M.T. Almeida, G.D., Phagna, R.K. and Babu, R. 2015. QTL mapping of agronomic waterlogging tolerance using recombinant inbred lines derived from tropical maize (*Zea mays* L.) germplasm. *PLOS One,* **10**(4): e0124350.