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DROUGHT TOLERANCE INDICES: GENETIC PARAMETER ESTIMATION AND APPLICATION IN DISCRIMINATING TOLERANT WHEAT GENOTYPES

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The drought incidence and severity are one of the majors constrain in wheat production and grain yield in Bangladesh. Therefore, this work aimed to evaluate the use of drought tolerance indices for screening spring wheat genotypes with stability for a specific environment. Accordingly, field experiments were conducted with 35 advance wheat genotypes during 2020-2021 at the Bangladesh Wheat and Maize Research Institute, Rajshahi under two field environments: rain-fed and irrigated conditions. The indices Tol, SSI, SSPI, SDI and STI showed moderate to high heritability with genetic advances indicating possible improvement through selection. The genotypic (r_g) and phenotypic (r_p) correlations coupled with principal component analysis (PCA) depicted that the indices MP, HM, GMP, STI, YI and DI could be considered as the better predictor of potential yield under both non stress and drought stress environments. Besides, the indices Tol, SSI, SSPI, SDI, YSI and RDI could screen highly susceptible and low susceptible genotypes that can be recommended for optimum environment and stress environment, respectively. Finally, the genotypes G-10, G-16, G-20 and G-33 were selected as a source of drought tolerance and could be used either in the breeding program for varietal improvement or forwarded to advanced multi-location trial in drought prone areas.

Key words: correlations, drought tolerance, genetic variability, principal component analysis, spring wheat

INTRODUCTION

Wheat (*Triticum aestivum* L.) plays an important role in ensuring food security as its consumption is increasing day by day. In recent years, Bangladesh produces only 1.1 million

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metric ton of wheat in an area of 0.31 million hectares against the increasing demand of around 6.7 million tons annually (USDA, 2023). Therefore, boosting wheat production is very important to meet the demand for wheat which has been increasing every year at the rate of 7-13%. Wheat is one of the most important winter crops grown under various environment and agro-ecosystems of Bangladesh. Among winter crops, wheat is often affected by drought stress during the winter. However, 1.2 million hectares of cropland face droughts of various magnitudes during the winter cropping season. Besides, wheat faces high drought risk in the most northwest districts of Bangladesh especially High Barind Tract of Rajshahi division (ALAMGIR *et al*., 2019). High Barind region represents one of the major wheat producing area of Bangladesh characterized by high water scarcity limiting the expression of wheat yield potential and productivity, leading to increased food scarcity (HABIBA *et al*., 2014). However, the drought prone High Barind region still lacks appropriate drought tolerant wheat cultivars. It has been reported that, Rajshahi division contributes 35 percent of the total land area of wheat cultivation and 44 percent of the total wheat production in Bangladesh. There are around 50,000 hectares of rain-fed land in the High Barind area which has been a bright prospect of bringing the huge land under wheat cultivation to combat food security (DAILY SUN, 2019). Drought tolerant wheat cultivar would be a pioneer crop from this point of view.

There is a need to identify high-yielding region-wise wheat varieties and expand those varieties in drought prone non-traditional areas. These will increase cropping intensity by adapting to regionally sustainable cropping patterns and thus increase total annual yield. Therefore, more emphasis has become necessary for development of drought tolerant wheat variety together with adoption in the farmer’s field. For this reason, developing new wheat cultivars with high grain yield potential through identifying drought tolerant genotypes is of great significance (RAJARAM *et al*., 1996). Wheat has gained special attention in respect to yield potentially affecting drought tolerance. Hence, the grain yield remains the basis of genotypes selection for improving drought tolerance (TALEBI *et al*., 2009; SHIRINZADEH *et al*., 2010; GERAVANDI *et al.*, 2011; FARSHADFAR *et al.*, 2013). Though breeding for drought tolerance is complicated but efficient evaluation of large number of genotypes under non-stress and stress condition is one of the most effective options to overcome this complex stress. Many authors recently proposed non-stress and stress conditioned screening, permits good yield in both environments for the identification of stable, high yielding drought tolerant genotypes (MITRA, 2001; MOOSAVI *et al*., 2008; MOHAMMADI *et al*., 2010; FARSHADFAR *et al*., 2014; SAHAR *et al*., 2016). In these perspectives, drought tolerance indices provide a measure of drought based on yield loss under drought stress conditions in comparison to non- stress conditions which have been used for screening drought tolerant genotypes (MITRA, 2001).

Various quantitative criteria have been proposed for selection of genotypes based on their yield performance in stress condition. Drought selection indices in this regard are to be found pioneer for the development of new varieties adapted to drought and climate instability. Drought indices provide a measure of drought based on yield loss under drought stress conditions in comparison to non-stress condition which have been used for screening drought tolerant genotypes (MITRA, 2001). In order to estimates the drought sensitivity of plant genotypes, some selection indices for instance, Mean Productivity (MP), Stress Tolerance (TOL) (ROSIELLE and HAMBLIN, 1981), Geometric Mean Productivity (GMP), Stress Tolerance Index

(STI) (FERNANDEZ, 1992), Harmonic Mean (HM) (KRISTIN *et al*., 1997), Stress Susceptibility Index (SSI), Relative Drought Index (RDI) (FISCHER and MAURER, 1978), Stress Susceptibility Percentage Index (SSPI) (MOOSAVI *et al*., 2008), Yield Stability Index (YSI) (BOUSLAMA and SCHAPAUGH, 1984), Yield Index (YI) (GAVUZZI *et al*., 1997), Drought Index (DI) (LAN, 1998), Sensitivity Drought Index (SDI) (FARSHADFAR and JAVADINIA, 2011), Modified Stress Tolerance Index 1 (k_1STI), Modified Stress Tolerance Index 2 (k_2STI) (FARSHADFAR and SUKTA, 2002) has been proposed by several authors based on a mathematical relation between stress and non-stress conditions. They have used different methods to evaluate genetic differences in drought tolerance, stated that the relative yield performance of genotypes in different environments can be used as an indicator to identify stress tolerant genotypes. Some of their proposed indices can explain drought tolerant genotypes for screening under both stress and non- stress conditions (BOUSSEN *et al*., 2010; GHOBADI *et al*., 2012; FARSHADFAR *et al.*, 2013) while some others assess genotypes susceptibility to environment suitable for either optimum or stress conditions (GHOBADI *et al*., 2012; ANWAAR *et al*., 2019). Therefore, it has been seen that the indices which can explain tolerance of a genotype, could not judge sensitivity towards the environments. Alternately, susceptibility indices could not refer to a potential genotype. The best tolerance indices, however, are those which are closely related to the grain yield under both non-stress and stress conditions and would be able to identify high yielding drought tolerant genotypes (FERNANDEZ, 1992; MITRA, 2001; BOUSSEN *et al*., 2010; ILKER *et al*., 2011). Genotypic screening by drought tolerance indices in wheat under different environmental conditions were studied by several authors (BOUSSEN *et al*., 2010; GHOBADI *et al*., 2012; FARSHADFAR *et al*., 2013), concluded that a suitable genotype should has high grain yield under both non stress and stress condition but has low variation in its yield between these two conditions.

In the current changing climate situation scientists have given much emphasis for breeding drought stress tolerant genotypes. Therefore, we need to determine the best measures for evaluating wheat genotypes responsive to drought stress since using useful stress indices is one of the most important tools for plant breeders to seek for high tolerance genotypes (JAMAATI-E-SOMARIN and ZABIHI-E-MAHMOODABAD, 2012). Although morpho-physiological studies regarding drought tolerance have been studied in different research initiatives in Bangladesh (RAHMAN *et al*., 2017; ARIFUZZAMAN *et al*., 2020), but less is known about the genetic potentiality as influenced by the environment regarding tolerance indices in wheat. This study will estimate the differential response of genotypes towards stress environment achieved through the measurement of their relative performance which could specify the genotypic suitability for a specific environment. Also, establish a judging platform of suitable tolerant genotype. These suitable genotypes could be recommended for cultivation in drought prone areas of High Barind Tract as well as similar areas of Bangladesh.

MATERIALS AND METHODS

Experimental materials

Field experiments were carried out at the Bangladesh Wheat and Maize Research Institute (BWMRI), Rajshahi during 2020-2021 cropping season. Thirty-two diverse advanced genotypes were selected from International Wheat and Maize Improvement Center (CIMMYT) provided stress adaptive international nurseries. These genotypes were previously screened under

Bangladesh environment based on their good phenotype, disease resistant as well as grain quality having potential yield. The selected advance genotypes along with three high yielding cultivars BARI Gom-26, BARI Gom-28 and BARI Gom-30 as check were used for experimentation.

Crop production

The genotypes were grown in two field environments, rainfed which considered as drought stress and irrigated as non-stress condition. The experiment was laid out in Alpha Lattice design (7 × 5) with three replications for each environment. Wheat seeds were sown on 30th November 2020 at field capacity soil moisture level continuously in 5 m long 6-row plots with a row spacing of 20 cm. The soil was fertilized with N: P: K: S: B @ of 120: 26: 50: 20: 2.5 kg ha^{-1}. All the fertilizers were applied before final cultivation for rain-fed environment (stress) whereas, two third urea and rest of all the fertilizers were applied before final land preparation and rest of one third urea was applied after first irrigation for non-stress condition. Recommended three irrigations for the normal water requirement of crop were applied for non-stress condition at the time of crown root initiation stage, heading stage and post anthesis stage. Other standard agronomic cultural practices were followed to ensure a good crop.

Experimental location

The experimental site was situated in Barind region of Rajshahi which in between 24° 22´ N latitude and 088° 39´ E longitude with elevation of 28 m above sea level. The soil of the experimental field was silty clay loam with a pH value of 7.1-8.5 having low fertility level. The experimental area is in the low-rainfall region (< 1500 mm year^{-1}). Every year, this area experiences a dry season of up to seven months starting in November. The average rainfall had been recorded in the wheat growing season was 2.2mm and 43.5mm in the month of January and March, respectively. However, January is the coolest month of the year, later the air temperature rises with a discernible trend and often exceeds 40 °C.

Estimation of drought tolerance indices

Grain yield was recorded by harvesting the total plants in each replicate and then was calculated to convert the final grain yield in kg ha^{-1}. Stress indices were estimated using the mean yield of each genotype. The drought tolerance and susceptibility indices were further calculated for each genotype using the relationships given in Table 1.

Data analysis and genetic parameter estimation

Analysis of variance of yield and drought tolerance indices was calculated according to the formula suggested by STEEL and TORRIE (1980). The collected data on yield and all other indices were subjected to different biometrical analyses to determine variances and genotypic and phenotypic coefficient of variations. The genotypic and phenotypic coefficient of variability, heritability in broad sense (h^2b), genetic advances, genotypic and phenotypic correlations were estimated following SINGH and CHOUDHARY (1985). Principal component analyses were performed to determine the relationships between yield and tolerance indices. All calculations for this article were set up by the software package R version 4.4 (R CORE TEAM, 2024).

Table 1. Drought tolerance indices and their measurement

SL. No.	Tolerance/susceptibility Index	Equation	References	Remark
1	Mean Productivity (MP)	$(Ypi + Ysi) / 2$	ROSIELLE and HAMBLIN, 1981	High value will be desirable index
2	Geometric Mean Productivity (GMP)	$\sqrt{(Ypi \times Ysi)}$	FERNANDEZ, 1992	High value index will be suitable
3	Harmonic Mean (HM)	$2 (Ypi \times Ysi) / (Ypi + Ysi)$	KRISTIN *et al*., 1997	High value index is expected
4	Stress Tolerance (TOL)	$(Ypi - Ysi)$	ROSIELLE and HAMBLIN, 1981	Low value index is more stable
5	Stress Susceptibility Index (SSI)	$[1 - Ysi / Ypi] / SI$	FISCHER and MAURER, 1978	SSI < 1 are more resistant to stress
6	Stress Susceptibility Percentage Index (SSPI)	$[(Ypi - Ysi) / 2Yp]*100$	MOOSAVI *et al*., 2008	Low values are expected index
7	Yield Stability Index (YSI)	Ysi / Ypi	BOUSLAMA and SCHAPAUGH, 1984	High values can be regarded as stable
8	Yield Index (YI)	Ysi / Ys	GAVUZZI *et al*., 1997	High value index is suitable
9	Stress Tolerance Index (STI)	$(Ysi \times Ypi) / (Yp)^2$	FERNANDEZ, 1992	High values will be tolerant to stress
10	Modified Stress Tolerance Index 1 (k_1STI)	$[(Ypi)^2 / (Yp)^2] \times STI$	FARSHADFAR and SUKTA, 2002	High value indicates stress tolerance
11	Modified Stress Tolerance Index 2 (k_2STI)	$[(Ysi)^2 / (Ys)^2] \times STI$	FARSHADFAR and SUKTA, 2002	High value index is tolerant
12	Drought Index (DI)	$Ysi \times (Ysi / Ypi) / Ys$	LAN, 1998	High values are more desirable
13	Relative Drought Index (RDI)	$(Ysi / Ypi) / (Ys / Yp)$	FISCHER and WOOD, 1979	High values found to be suitable
14	Sensitivity Drought Index (SDI)	$(Ypi - Ysi) / Ypi$	FARSHADFAR and JAVADINIA, 2011	Low values will be desirable

Ysi denote yield under stress for i^{th} genotype and *Ypi* yield under non-stress for i^{th} genotype, respectively (i = 1.2.3.4.5…); *Ys* and *Yp* are the mean yields of all genotypes under stress and non-stress conditions, respectively; SI is the stress intensity and calculated as: SI = [1 - *Ys* / *Yp*]

RESULTS AND DISCUSSION

Genetic variability estimates of tolerance indices

Analysis of variance was calculated for grain yield of 35 wheat genotypes under non stress condition (Yp), stress condition (Ys) and studied indices (Table 2). Genetic estimates of variance revealed that genotypes were differing significantly for yield under both growing conditions and all drought tolerance indices (GHOLIPOURI *et al*., 2009; ANWAR *et al*., 2011; GHOBADI *et al.*, 2012; SAHAR *et al*., 2016). High diversity among genotypes indicated the genotypes possess inherent genetic variances that allow extensive selection of genotypes in diverse environments. Hence, substantial improvement may be achieved in these indices through selection under stress conditions. Moreover, the indices showed high heritability ($h^2 > 60$) for Yp, Ys, MP, HM, GMP, YI and STI whereas Tol, YSI, SSI, SSPI, SDI, RDI, and DI had moderate high ($40 \leq h^2 \leq 60$) heritability. Furthermore, the estimated genetic advance displayed high values (> 11) for almost all the indices except YSI and RDI while Tol, SSI, SSPI, SDI and STI had shown very high (> 31) genetic advance.

Table 2. Mean, GCV, PCV, Heritability in broad sense (h^2) and Genetic Advance as percentage of mean (GA%) of Yp, Ys and different drought tolerance indices in wheat

Sl. no.	Drought Index	Mean ± Std	GCV	PCV	h^2	GA%
1	YLDIR (Yp)	2899.35 ± 344.8**	104878.7	132930.4	78.90	17.46
2	YLDRF (Ys)	2287.21 ± 304.2**	70536.03	114539.5	61.58	16.04
3	MP	2593.28 ± 300.7**	78129.49	102723.5	76.06	16.54
4	HM	2548.84 ± 302.3**	76957.69	105864.8	72.69	16.33
5	GMP	2570.89 ± 301.1**	77447.85	103946.7	74.51	16.44
6	Tol	612.14 ± 247.3**	38311.47	84045.99	45.58	38.00
7	YI	1.00 ± 0.13**	0.014	0.022	63.64	16.61
8	YSI	0.79 ± 0.07**	0.0035	0.0085	41.18	8.46
9	SSI	0.98 ± 0.36**	0.0785	0.1895	41.42	32.39
10	SSPI	10.55 ± 4.26**	11.3975	24.9975	45.59	38.03
11	SDI	0.21 ± 0.07**	0.0035	0.0085	41.18	32.12
12	RDI	1.00 ± 0.09**	0.0055	0.0135	40.74	8.33
13	DI	0.79 ± 0.15**	0.016	0.033	48.48	19.62
14	STI	0.79 ± 0.18**	0.0275	0.0375	73.33	31.64
15	k_1STI	1.02 ± 0.22*	0.0195	0.0815	23.93	11.79
16	k_2STI	1.02 ± 0.24*	0.0245	0.0935	26.20	13.83

GCV: Genotypic co-efficient of variation, PCV: Phenotypic co-efficient of variation, CV: Co-efficient of variation, std: Standard deviation, YLDIR: Grain yield under irrigated condition (kg ha^{-1}) as yield potential (Yp), YLDRF: Grain yield under rain-fed condition (kg ha^{-1}) as stress yield (Ys), **, * – significant at 1% and 5% probability level, respectively

The high heritability and genetic advance for the indices Tol, SSPI, SSI, SDI and STI offer chances of expected response to selection. So, drought tolerance in wheat could be improved through indirect selection of these indices. ANWAR *et al*. (2011) find high heritability (> 64) for yield under both stress and non-stress conditions and all the studied indices when experimented on wheat genotypes for studying their drought tolerance. Additionally, the coefficient of variation varied between 5.78% (Yp) and 34.94% (Tol, SSPI) confers high influence of environment for each index. The coefficient of variation also expressed that all genotypes had exploitable genetic variability for the studied indices. These findings also agreed with the results of YAGDI and SOZEN (2009) in durum wheat.

Evaluation of the genotypes based on tolerance indices

Grain yield of genotypes under both non-stress and stress conditions were used for estimating drought sensitivity and stress tolerance indices (Table 3) to identify suitable indices that can discriminate genotypes under target environment conditions. Regarding tolerance indices, the genotypes with high values of MP, HM, GMP, YI, YSI, DI, RDI, STI, k_1STI and k_2STI are more desirable index whereas low values are expected for the indices Tol, SSI, SSPI and SDI while judging the genotypes for drought tolerance (GHOBADI *et al*., 2012; NAGHAVI *et al*., 2013; KHAN and DHURVE, 2016; ANWAAR *et al.,* 2019; BONEA, 2020). The results revealed that estimated percent yield reduction (% R) from potential yield varied from 6.50 to 34.12 indicated a wider variation when imposed by the drought stress condition.

Table 3. Estimates of drought tolerance indices and grain yield (kg ha^{-1}) with their reduction for 35 bread wheat genotypes

Genotype code	YLDIR (Yp)	YLDRF (Ys)	Reduction (%)	MP	HM	GMP	Tol	YI	YSI	SSI	SSPI	SDI	RDI	DI	STI	k_1STI	k_2STI
G-1	2977.5	2347.5	21.16	2662.5	2621.8	2642.1	630.0	1.03	0.795	0.98	10.86	0.207	1.01	0.82	0.84	1.03	0.96
G-2	3537.5	2737.5	22.61	3137.5	3085.2	3111.2	800.0	1.20	0.775	1.07	13.80	0.224	0.99	0.93	1.15	1.43	1.16
G-3	3320.0	2460.0	25.90	2890.0	2826.0	2857.9	860.0	1.08	0.740	1.23	14.83	0.259	0.94	0.80	0.98	0.79	0.89
G-4	3142.5	2390.0	23.95	2766.3	2709.0	2737.4	752.5	1.05	0.765	1.13	12.98	0.236	0.97	0.80	0.90	0.90	1.13
G-5	3197.5	2587.5	19.08	2892.5	2860.3	2876.4	610.0	1.13	0.810	0.91	10.52	0.190	1.03	0.92	0.99	0.94	0.98
G-6	2910.0	2537.5	12.80	2723.8	2711.0	2717.4	372.5	1.11	0.870	0.61	6.43	0.128	1.11	0.97	0.88	0.93	1.18
G-7	3305.0	2392.5	27.61	2848.8	2768.2	2808.1	912.5	1.05	0.725	1.29	15.74	0.273	0.92	0.77	0.94	0.88	1.15
G-8	2902.5	2265.0	21.96	2583.8	2542.1	2562.8	637.5	0.99	0.780	1.05	11.00	0.222	0.99	0.78	0.79	1.01	0.99
G-9	2295.0	2127.5	7.30	2211.3	2207.2	2209.2	167.5	0.93	0.930	0.34	2.89	0.071	1.18	0.87	0.58	0.81	0.87
G-10	3125.0	2590.0	17.12	2857.5	2830.1	2843.7	535.0	1.13	0.830	0.81	9.23	0.170	1.05	0.94	0.96	1.20	1.23
G-11	3185.0	2105.0	33.91	2645.0	2524.3	2583.7	1080.0	0.92	0.670	1.58	18.63	0.332	0.85	0.62	0.80	1.06	1.17
G-12	2482.5	1937.5	21.95	2210.0	2176.1	2193.0	545.0	0.85	0.780	1.05	9.40	0.221	0.99	0.66	0.58	0.99	0.86
G-13	2655.0	2402.5	9.51	2528.8	2521.3	2525.0	252.5	1.05	0.900	0.46	4.36	0.097	1.15	0.96	0.76	1.10	1.34
G-14	3072.5	2282.5	25.71	2677.5	2619.1	2648.2	790.0	1.00	0.740	1.22	13.63	0.258	0.94	0.74	0.84	1.04	0.84
G-15	3052.5	2212.5	27.52	2632.5	2558.9	2595.4	840.0	0.97	0.725	1.31	14.49	0.276	0.92	0.71	0.81	1.06	0.92
G-16	3085.0	2695.0	12.64	2890.0	2875.6	2882.8	390.0	1.18	0.875	0.59	6.73	0.124	1.11	1.03	0.99	1.37	1.20
G-17	2497.5	1752.5	29.83	2125.0	2049.6	2086.8	745.0	0.77	0.700	1.42	12.85	0.299	0.89	0.55	0.52	0.98	0.64
G-18	2775.0	2040.0	26.49	2407.5	2349.9	2378.5	735.0	0.89	0.730	1.27	12.68	0.267	0.93	0.66	0.68	0.91	0.65
G-19	2612.5	2290.0	12.34	2451.3	2440.7	2446.0	322.5	1.00	0.880	0.59	5.56	0.124	1.11	0.88	0.72	0.81	0.78
G-20	3500.0	2907.5	16.93	3203.8	3176.3	3190.0	592.5	1.27	0.835	0.80	10.22	0.169	1.06	1.06	1.22	1.38	1.38
G-21	2855.0	2527.5	11.47	2691.3	2678.9	2685.1	327.5	1.11	0.885	0.55	5.65	0.115	1.12	0.98	0.86	1.06	1.30
G-22	2897.5	2275.0	21.48	2586.3	2547.8	2566.9	622.5	0.99	0.785	1.02	10.74	0.215	1.00	0.78	0.79	1.34	0.83
G-23	2915.0	2467.5	15.35	2691.3	2671.0	2681.1	447.5	1.08	0.845	0.73	7.72	0.153	1.08	0.92	0.86	1.00	1.23
G-24	2500.0	2337.5	6.50	2418.8	2415.5	2417.2	162.5	1.02	0.935	0.31	2.80	0.065	1.19	0.96	0.70	0.86	1.14
G-25	2882.5	2027.5	29.66	2455.0	2379.5	2417.0	855.0	0.89	0.710	1.40	14.75	0.294	0.90	0.63	0.70	0.97	0.89
G-26	3045.0	2332.5	23.40	2688.8	2634.7	2661.5	712.5	1.02	0.770	1.10	12.29	0.231	0.98	0.79	0.84	1.11	1.05
G-27	2795.0	2387.5	14.58	2591.3	2573.9	2582.6	407.5	1.05	0.860	0.68	7.03	0.142	1.09	0.90	0.80	0.73	0.86
G-28	2330.0	1600.0	31.33	1965.0	1896.4	1930.4	730.0	0.70	0.680	1.50	12.59	0.316	0.87	0.48	0.45	0.46	0.52
G-29	2330.0	1567.5	32.73	1948.8	1866.1	1906.8	762.5	0.69	0.670	1.57	13.15	0.330	0.85	0.47	0.44	0.93	0.52
G-30	2507.5	2060.0	17.85	2283.8	2260.7	2272.2	447.5	0.90	0.825	0.84	7.72	0.176	1.05	0.74	0.62	0.86	1.04
G-31	2887.5	2152.5	25.45	2520.0	2465.8	2492.8	735.0	0.94	0.745	1.21	12.68	0.256	0.94	0.71	0.74	1.36	1.23
G-32	2500.0	2025.0	19.00	2262.5	2237.5	2250.0	475.0	0.89	0.810	0.90	8.19	0.190	1.03	0.72	0.61	1.01	1.05
G-33	3030.0	2740.0	9.57	2885.0	2875.0	2880.0	290.0	1.20	0.905	0.45	5.00	0.095	1.15	1.09	0.99	1.02	1.26
G-34	2760.0	2112.5	23.46	2436.3	2387.2	2411.6	647.5	0.92	0.770	1.10	11.17	0.231	0.98	0.72	0.69	1.00	1.23
G-35	3612.5	2380.0	34.12	2996.3	2867.5	2931.1	1232.5	1.04	0.660	1.61	21.26	0.339	0.84	0.69	1.03	1.61	1.56
std	344.825	304.2	-	300.71	302.343	301.16	247.343	0.13	0.0774	0.366	4.2658	0.077	0.098	0.156	0.181	0.224	0.24

The genotypes G-10, G-16, G-20 and G-33 received high values for the indices MP, HM, GMP, YI, DI, STI, k_1STI and k_2STI along with lower yield reduction (< 17%). Hence, these genotypes might be considered as drought tolerant. Results also displayed that the genotypes G-2, G-7, G-11 and G-35 received high indices values of Tol, SSI, SSPI and SDI simultaneously, low values of YSI and RDI. Consequently, it can be assumed their sensitivity towards environmental stress. Among them, the genotypes G-11 showed high yield reduction (33.9%) with moderate high yield under non stress condition. Thus, it can be considered as susceptible to drought stress only suitable for optimum condition.

On the other hand, the genotypes G-13 and G-24 got low values of Tol, SSI, SSPI and SDI while high values of MP, HM, GMP and STI with the lowest yield reduction (< 9%). These genotypes also gave potential yield under stress condition rather than non-stress condition. So, they were regarded as tolerant genotypes adjusted for only stress environment. Moreover, the genotypes G-17, G-28 and G-29 expressed low indices values of MP, HM, GMP, YI, YSI, DI, RDI, STI, k_1STI and k_2STI indicates their non-potentiality and high indices values of Tol, SSI, SSPI and SDI denoted high yield reduction (≥ 30%). Thus, they might be considered as yield non potential susceptible.

Genotypic screening by drought tolerance indices in wheat under different environmental conditions were studied by many authors (BOUSSEN *et al*., 2010; GHOBADI *et al*., 2012; FARSHADFAR *et al*., 2013), concluded that a suitable genotype should has high grain yield under both non stress and stress condition but has low variation in its yield between these two conditions. In all aspects, tolerance should be determined considering yield potentiality over environments and intensity of yield loss. Thus MP, HM, GMP, STI, YI, DI, k_1STI and k_2STI could be established as good index suitable in all environments while applied on studied genotypes. Besides, genotypic evaluation through the indices revealed Tol, SSI, SSPI, SDI, YSI and RDI associated with the discrimination of susceptible genotypes suitable for either optimum or stress environment. GHOBADI *et al*. (2012) and ANWAAR *et al*. (2019) separated the most tolerant genotypes in wheat based on Tol and SSI, which their low quantity is indication of tolerant genotypes. In another study, while judging on some wild diploid populations, tetraploid and hexaploid cultivars of wheat by using stress tolerance indices KHOSRAVI *et al*. (2020) find STI, MP, GMP and HM indices were appropriate for screening drought tolerant and high yield genotypes. MEVLUT and SAIT (2011) and NAGHAVI *et al*. (2013) discriminated tolerant genotypes having high STI as well as MP, GMP in oat and corn cultivars, respectively and suggested that these three parameters are equal for selecting tolerant genotypes.

Results implied that some genotypes for instance, the genotypes G-2, G-7 and G-35 received high indices values of Tol, SSI, SSPI and SDI which denoted their susceptibility. On the contrary, seemed to be tolerant as they got high values from the indices MP, HM, GMP, YI, DI, STI, k_1STI and k_2STI which creates contradiction when to judge a genotype for selection. This inconsistency depends on the conditions of the environment in which the genotypes grown and how the indices interrelated with each other. It occurred even though their yield potentiality under both growing conditions, they showed stress sensitivity measured from high yield reduction (22-34%). In fact, the effectiveness of selection indices depends on stress severity. Therefore, genotypic selection should be performed considering potentiality over stress and non-stress environments with minimum yield loss. These studies revealed a single index is not enough to judge properly when subjected tolerance estimation. NAGHAVI *et al*. (2013) and SAEIDI *et al*. (2013) find contradiction in identification of drought tolerant cultivars when judged by a single criterion of estimates indicators of drought tolerance. BONEA (2020) suggested applying a combination of indices that may provide a useful criterion for selecting drought tolerant maize hybrids genotypes.

Interrelationship among the indices coupled with non-stress and stress environments

Genotypic (r_g) and phenotypic (r_p) correlation coefficients between Yp, Ys and other quantitative indices of drought tolerance were calculated to get a suitable index for screening the best genotypes used in the experiments (Table 4). Several authors (MITRA, 2001; GHOBADI *et al.*, 2012; NAGHAVI *et al.*, 2013) had shown correlation analysis between grain yield and drought tolerance indices as a good criterion for screening the best cultivars. Moreover, they emphasized the significant relationship of the indices with grain yield under both non-stress and stress environments to be a suitable criterion. The present study showed the necessity of phenotypic correlation (r_p) to find out how the genotypes were correlated with the environment. Phenotypic correlation (r_p) in these aspects allowed precious interpretation of the relations between grain yield and the estimated indices. Result displayed the significant positive relation between Yp and Ys both at genotypic and phenotypic levels (r_g = 0.79**; r_p = 0.66**) depicted that though the genotypes significantly inherited their potentiality but also highly influenced by the environmental conditions. Genotypes having yield potentiality might be able to yield under stress condition, but its yield reduction will be determined by the intensity of the stress environment. These findings are in concurred with those studied by DEHBALAEI *et al.* (2013) and ALI and EL-SADEK (2016) in wheat for its drought tolerance.

The correlations also showed that MP, HM, GMP, STI had very strong positive correlation with Yp and Ys at genotypic and phenotypic levels (0.86** ≤ r_g, r_p ≤ 0.96**), considered as the better predictor of potential yield under both environments. Several authors reported MP, HM, GMP, and STI can be used as convenient parameters to introduce drought tolerance genotypes (KARIMIZADEH and MOHAMMADI, 2011; GHOBADI *et al.*, 2012; DEHBALAEI *et al.*, 2013; ALI and EL-SADEK, 2016). Besides, YI and DI showed strong positive relationship (r_g ≥ 0.89**; r_p ≥ 0.90**) under stress environment rather than relatively low under non stress condition (r_g = 0.78**, 0.44**; r_p = 0.66**, 0.30 respectively). However, k_1STI and k_2STI had a very strong positive relationship with both sowing condition (Yp, Ys) only at genotypic levels (0.82** ≤ r_g, r_p ≤ 1). Whereas k_1STI was found to be highly related with Yp and k_2STI with Ys, as indicating by their perfect (r_g = 1) correlations. Thus, the association of YI, DI, k_1STI and k_2STI with Yp and Ys also offer good index to screen genotypes under both environments. The observed relations were also consistent with those reported by KHALILI *et al.* (2012) and NAGHAVI *et al.* (2013) stated such significant correlations with Yp, Ys and indices YI, k_1STI and k_2STI that can be used as the most suitable indicators for screening drought tolerant genotypes. Moreover, Tol and SSPI are mostly correlated with Yp rather than Ys. Tol and SSPI showed significant positive correlation (r_g = 0.57**; r_p = 0.48**) both at genotypic and phenotypic levels with yield under optimum condition (Yp). There was almost no correlation (r_g = -0.03) found at genotypic level between Tol, SSPI and yield under stress condition (Ys). Therefore, selection by these indices under stress condition may not provide good result.

Table 4. Genotypic (r_g) and phenotypic (r_p) correlation between different drought tolerance indices

Index	r	Yp	Ys	MP	HM	GMP	Tol	YI	YSI	SSI	SSPI	SDI	RDI	DI	STI	k_1STI
Ys	r_g	0.797**														
	r_p	0.662**														
MP	r_g	0.958**	0.937**													
	r_p	0.918**	0.905**													
HM	r_g	0.934**	0.960**	0.997**												
	r_p	0.866**	0.948**	0.993**												
GMP	r_g	0.947**	0.949**	0.999**	0.999**											
	r_p	0.893**	0.928**	0.998**	0.998**											
Tol	r_g	0.573**	-0.038	0.314	0.243	0.278										
	r_p	0.485**	-0.335*	0.099	-0.018	0.040										
YI	r_g	0.783**	0.985**	0.921**	0.945**	0.934**	-0.040									
	r_p	0.662**	0.999**	0.904**	0.947**	0.928**	-0.335*									
YSI	r_g	-0.198	0.423*	0.087	0.158	0.123	-0.902**	0.420*								
	r_p	-0.205	0.589**	0.194	0.304	0.251	-0.946**	0.589**								
SSI	r_g	0.199	-0.428*	-0.088	-0.160	-0.124	0.910**	-0.423*	-0.994**							
	r_p	0.208	-0.587**	-0.192	-0.302	-0.248	0.947**	-0.587**	-1.001**							
SSPI	r_g	0.573**	-0.038	0.314	0.243	0.278	1.000**	-0.041	-0.902**	0.910**						
	r_p	0.485**	-0.335*	0.099	-0.018	0.040	1.000**	-0.335*	-0.946**	0.947**						
SDI	r_g	0.200	-0.429*	-0.088	-0.160	-0.124	0.912**	-0.426*	-0.996**	1.003**	0.913**					
	r_p	0.207	-0.584**	-0.190	-0.300	-0.247	0.942**	-0.584**	-0.995**	0.996**	0.942**					
RDI	r_g	-0.199	0.437*	0.0919	0.165	0.129	-0.922**	0.432*	1.009**	-1.016**	-0.922**	-1.019**				
	r_p	-0.208	0.587**	0.1917	0.302	0.248	-0.947**	0.587**	1.001**	-1.000**	-0.947**	-0.997**				
DI	r_g	0.444**	0.894**	0.6820**	0.735**	0.709**	-0.478**	0.881**	0.776**	-0.782**	-0.479**	-0.786**	0.795**			
	r_p	0.304	0.909**	0.6527**	0.733**	0.695**	-0.679**	0.909**	0.856**	-0.855**	-0.679**	-0.850**	0.855**			
STI	r_g	0.955**	0.950**	1.0047**	1.004**	1.005**	0.292	0.935**	0.106	-0.108	0.292	-0.108	0.112	0.702**		
	r_p	0.899**	0.918**	0.9959**	0.993**	0.996**	0.059	0.917**	0.225	-0.222	0.059	-0.221	0.222	0.679**		
k_1STI	r_g	1.005**	0.825**	0.9740**	0.947**	0.961**	0.543**	0.817**	-0.162	0.161	0.543**	0.164	-0.173	0.495**	0.993**	
	r_p	0.449**	0.331*	0.4300*	0.411	0.421*	0.179	0.326	-0.042	0.043	0.179	0.042	-0.044	0.176	0.419*	
k_2STI	r_g	0.956**	1.038**	1.0467**	1.057**	1.052**	0.173	1.027**	0.303	-0.301	0.173	-0.300	0.298	0.835**	1.049**	0.862**
	r_p	0.428*	0.582**	0.5506**	0.560**	0.556**	-0.142	0.579**	0.335*	-0.338*	-0.142	-0.335*	0.338*	0.528**	0.537**	0.541**

**, * – significant at 1% and 5% probability level, respectively

Hence, the indices Tol and SSPI are good indicators to discriminate highly susceptible genotypes only suitable for optimum environment. On the other hand, the indices SSI, SDI, YSI and RDI had shown very low correlation ($0.19 \leq r_g$, $r_p \leq 0.20$) with yield under non-stress condition (Yp). It also revealed that the indices SSI, SDI, YSI and RDI had significant correlation with Ys at phenotypic level and their phenotypic correlations were found greater than genotypic correlations. Their phenotypic association indicated that the indices SSI, SDI, YSI and RDI were highly influenced by the environment, and they were least involved with suitable environment rather than stress environment. Therefore, genotypes screened by the indices SSI, SDI, YSI and RDI will indicate their low susceptibility towards stress environment. Thus, highly stress susceptible and low susceptible genotypes could be identified which might be recommended for optimum environment and stress environment, respectively.

The relationship among the indices exposed that the indices MP, HM, GMP, STI, YI, k_1STI and k_2STI were positively and strongly correlated with each other both at genotypic and phenotypic levels. Simultaneously, Tol, YSI, SSI, SSPI, SDI and RDI showed strong relationship among each other both at genotypic and phenotypic levels. Additionally, the indices Tol, SSI, SSPI and SDI were related in positive direction but negative with YSI and RDI, while YSI and RDI possess positively. It was also observed that the indices MP, HM, GMP and STI differed from the indices Tol, SSPI, SSI, SDI, YSI and RDI since their insignificant lower association. These bunches of indices were independent of each other but inside the groups showed strong relationship among them. Thus, the strong perfect genotypic and phenotypic relationship among the indices suggested Tol and SSPI, SSI and SDI, YSI and RDI could be used interchangeably as an alternative for the others. These results support the finding of ALI and EL-SADEK (2016), noticed perfect positive correlations between Tol and SSPI, SSI and SDI while perfect negative with SSI/SDI and YSI suggested using interchangeably.

Principal component analysis for drought tolerance indices

The principal component analysis (PCA) was performed to understand the relationship, similarities and dissimilarities among drought tolerance indices which reflect the importance of the largest contributor to the total variation. The principal component analysis showed the proportion of total variance explained by three principal components and their correlations with estimated indices (Table 5). The analysis revealed that the first two principal components (PC1 and PC2) were the most influential and explained 55.85% and 37.37% of the total variation, respectively. The indices Tol, SSI, SSPI and SDI showed high positive coordination with the first principal component (PC1). This component had negative correlation with yield under non-stress (Yp) and stress (Ys) condition while the loading was higher under stress condition, indicated that they have much influence during selection under stress condition. Similarly, the indices YSI, RDI and DI had high positive loading into the second principal component (PC2). This component had a high negative correlation with yield under non-stress condition (Yp) while the loading was negligible (0.071) under stress condition (Ys). Hence, those indices were influential in selecting genotypes under non stress condition.

Furthermore, the PCA also revealed that the indices MP, HM, GMP, YI, STI, k_1STI and k_2STI exhibited negative loading into both the PC1 and PC2 indicating these indices do not have direct influence to discriminate stress tolerant genotypes. Another component, the third principal component (PC3) played an influential role though it accounts for only 4.64% of the total variation. The indices MP, HM, GMP, YI and STI showed high positive loading into the third principal component while Yp and Ys also correlated with the same pattern. Therefore, this component can be considered as yield potential and separates tolerant genotypes with high yield under both stress and non-stress environments. FARSHADFAR *et al.* (2013) and ALI and EL-SADEK (2016) showed the first two principal component axes justify more than 98% of total variation, mainly distinguished the indices in different groups. Several authors (SANJARI-PIREIVATLOU and YAZDANSEPAS, 2008; KARIMIZADEH and MOHAMMADI, 2011; GHOBADI *et al.*, 2012; ALI and EL-

SADEK, 2016) by their experiments identified MP, HM, GMP, and STI appropriate indices to select drought tolerance genotypes.

Table 5. Principal components for drought tolerance indices

Tolerance indices	PC1	PC2	PC3
YLDIR (Yp)	-0.19326	-0.33059	0.12306
YLDRF (Ys)	-0.32743	-0.07149	0.115348
MP	-0.27643	-0.22569	0.128886
HM	-0.29328	-0.19056	0.133622
GMP	-0.28536	-0.20814	0.131581
Tol	0.133269	-0.37296	0.029697
YI	-0.32706	-0.07215	0.122907
YSI	-0.22679	0.299412	-0.02617
SSI	0.226451	-0.30002	0.026724
SSPI	0.13324	-0.37298	0.029494
SDI	0.226435	-0.30007	0.024706
RDI	-0.22662	0.299702	-0.02645
DI	-0.3225	0.103067	0.06529
STI	-0.28061	-0.21497	0.141334
k_1STI	-0.14569	-0.21269	-0.76463
k_2STI	-0.24451	-0.1001	-0.53973
Standard deviation	2.9894	2.4451	0.8616
Proportion of variance	0.5585	0.3737	0.0464
Cumulative proportion	0.5585	0.9322	0.9786
Eigen values	8.9367	5.9785	0.7425

The relationship among different indices was graphically illustrated (Fig. 1) in a biplot using PC1 and PC2. The PC1 and PC2 mainly distinguish the indices in different groups. FARSHADFAR *et al*. (2013) applied principal component analysis (PCA) to distinguish the indices in different groups stated each PCA statistics can be assigned to one group only. Assuming the indices Yp, Ys, MP, HM, GMP, YI, STI, k_1STI and k_2STI refer to one group. The indices of this group exhibited strong correlation among them and with Ys, Yp because of the angles between those indices were well below 90° (acute angle). So, they might be considered the most desirable indices to discriminate drought tolerant genotypes with high grain yield under both non-stress and stress conditions. Inside this group, an overlapping of vectors was found between Ys and YI ($0.98^{**} \leq r_g, r_p < 1.0$) and between MP, HM, GMP and STI ($0.99^{**} \leq r_g, r_p \leq 1$) showing very high correlations and similarities in ranking the genotypes.

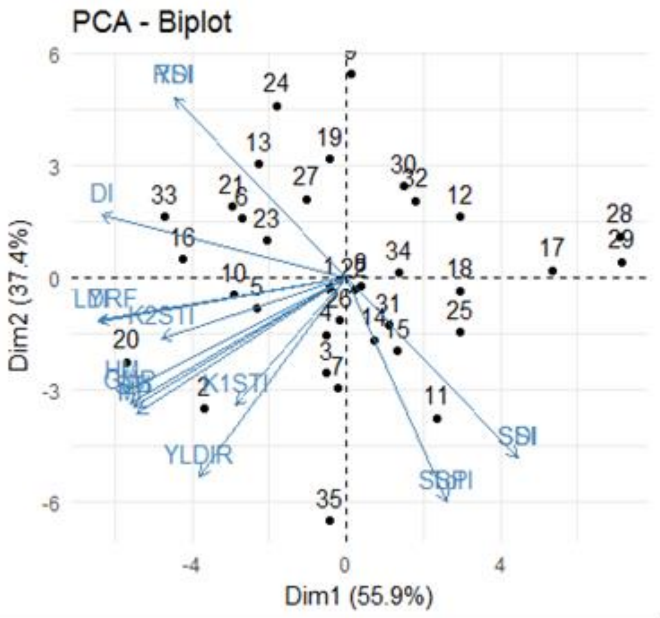

Fig. 1. Biplot of the first two principal component axes for 35 bread wheat genotypes

The PCs axes separated Tol, SSI, SSPI and SDI into another group within an acute angle. A zero angle was found between the vectors of Tol & SSPI (r_g, $r_p = 1$) and between SSI & SDI ($0.99^{**} \leq r_g$, $r_p \leq 1$), indicating that they could rank similarly the genotypes. Biplot also revealed that the indices YSI, RDI and DI were separated into a third group as well with an angle below 90°. Furthermore, the results showed strong perfect negative correlation ($-0.99^{**} \leq r_g$, $r_p \leq -1$) between YSI or RDI with SSI or SDI as indicated by ≈ 180° angle between their vectors. Among them, a zero angle between YSI and RDI showed the same ranking genotypes basis. In contrast, the indices YSI and RDI can discriminate genotypes almost same as SSI and SDI but in a reverse way since their perfect negative relations. Consequently, perfect association and PCA biplot of the indices revealed (Table 4, Fig. 1) Tol and SSPI, SSI and SDI, YSI and RDI had a chance of interchangeably application as an alternative for the others which supported by ALI and EL-SADEK (2016).

Ranking of genotypes

Ranking genotypes according to all indices (Table 6) has been found to be an efficient screening method. It was observed that a single criterion is not sufficient to explain in discriminating tolerant genotypes. This might be the conditions of the environment in which the genotypes grow and how the indices interrelated with each other. NAGHAVI *et al.* (2013) found contradiction in identification of drought tolerant cultivars when judged by a single criterion of estimates indicators of drought tolerance.

Table 6. Rank, rank mean and standard deviation of ranks of drought tolerance indices

Genotype code	YLDIR (Yp)	YLDRF (Ys)	MP	HM	GMP	Tol	YI	YSI	SSI	SSPI	SDI	RDI	DI	STI	k_1STI	k_2STI	Mean	std
G-1	15	16	16	15	16	18	16	16	16	18	16	16	15	16	14	22	16.56	2.03
G-2	2	3	2	2	2	29	2	20	20	29	20	18	9	2	2	13	10.81	10.18
G-3	4	10	5	8	7	32	10	25	26	32	26	24	17	7	33	24	17.25	10.71
G-4	8	13	10	11	10	26	12	23	23	26	23	23	16	10	27	16	16.69	6.79
G-5	6	6	4	6	6	16	5	14	15	16	14	14	10	5	23	21	11.75	6.54
G-6	17	7	11	10	11	7	7	8	8	7	8	6	5	11	25	11	11.31	6.57
G-7	5	12	9	9	9	33	13	28	28	33	28	28	21	9	28	14	17.94	10.10
G-8	18	22	21	20	21	19	21	18	19	19	19	19	20	20	16	20	19.44	1.50
G-9	35	25	31	31	31	2	25	2	2	2	2	2	14	31	31	26	20.25	13.58
G-10	9	5	8	7	8	13	6	12	12	13	12	12	8	8	7	6	9.88	4.60
G-11	7	27	17	21	18	34	26	33	34	34	34	33	32	18	10	12	22.44	10.84
G-12	32	32	32	32	32	14	32	19	18	14	18	20	29	32	20	27	25.00	7.43
G-13	26	11	22	22	22	3	11	4	4	3	4	3	6	22	9	3	12.75	9.90
G-14	11	20	15	16	15	28	19	26	25	28	25	25	22	14	13	29	19.81	6.39
G-15	12	23	18	18	17	30	23	29	29	30	29	29	26	17	11	23	21.38	7.37
G-16	10	4	6	3	4	8	4	7	6	8	6	7	3	4	4	10	7.25	6.23
G-17	31	33	33	33	33	25	33	31	31	25	31	31	33	33	21	33	29.00	7.38
G-18	24	29	28	28	28	23	29	27	27	23	27	27	30	28	26	32	26.13	5.16
G-19	27	19	25	24	24	5	20	6	7	5	7	8	13	24	32	31	18.69	9.98
G-20	3	1	1	1	1	15	1	11	11	15	11	11	2	1	3	2	6.50	7.28
G-21	22	8	12	12	12	6	8	5	5	6	5	5	4	12	12	4	10.25	7.26
G-22	19	21	20	19	20	17	22	17	17	17	17	17	19	21	6	30	18.81	4.68
G-23	16	9	13	13	13	10	9	10	10	10	10	10	11	13	18	7	12.38	4.57
G-24	29	17	27	25	25	1	17	1	1	1	1	1	7	26	30	15	16.13	12.43
G-25	21	30	24	27	26	31	31	30	30	31	30	30	31	25	22	25	26.25	6.38
G-26	13	18	14	14	14	21	18	21	21	21	21	21	18	15	8	17	16.75	3.82
G-27	23	14	19	17	19	9	14	9	9	9	9	9	12	19	34	28	16.94	7.84
G-28	33	34	34	34	34	22	34	32	32	22	32	32	34	34	35	34	30.25	8.07
G-29	34	35	35	35	35	27	35	34	33	27	33	34	35	35	24	35	30.94	8.24
G-30	28	28	29	29	29	11	28	13	13	11	13	13	23	29	29	19	22.19	7.52
G-31	20	24	23	23	23	24	24	24	24	24	24	26	27	23	5	8	20.75	6.43
G-32	30	31	30	30	30	12	30	15	14	12	15	15	24	30	17	18	22.50	7.61
G-33	14	2	7	4	5	4	3	3	3	4	3	4	1	6	15	5	7.00	7.96
G-34	25	26	26	26	27	20	27	22	22	20	22	22	25	27	19	9	22.38	4.99
G-35	1	15	3	5	3	35	15	35	35	35	35	35	28	3	1	1	15.69	15.23

To get desirable rank of the genotypes depending upon the indices, high values of Yp, Ys and the indices MP, HM, GMP, YI, YSI, DI, RDI, STI, k_1STI and k_2STI while low values of the indices Tol, SSI, SSPI, and SDI were applied (Table 1 and 3) for estimating genotypic tolerance levels (GHOBADI *et al.*, 2012; NAGHAVI *et al*., 2013; KHAN and DHURVE, 2016). The results exhibited close relations among some indices as indicated by their almost identical ranking. For instance, Ys and YI, Tol and SSPI, YSI-RDI-SSI and SDI were found to be almost same in their ranking, suggests their interchangeably application in ranking genotypic. Similarly, the ranks of the genotypes for MP, HM, GMP and STI were almost identical which supported by the work Anwar et al. (2011) in wheat and POUR-SIAHBIDI and POUR-ABOUGHADAREH (2013) in chickpea. These relations were previously established in correlation and biplot study (Table 4, Fig. 1).

Considering all indices, the genotypes G-2, G-10, G-16, G-20, G-21 and G-33 that received mean rank ≤ 10 having 4-10 standard deviation of rank might be regarded as potential genotypes in different environments. On the other hand, the genotypes G-12, G-17, G-18, G-25, G-28 and G-29 which exhibited mean rank ≥ 25 having > 5 standard deviations of rank might be considered as non-potential genotypes. In recent years, researchers suggest genotypic ranking based on all different types of indices to determine the most desirable drought tolerant cultivar. In a study of drought tolerant indices in maize hybrids, BONEA (2020) found none of the used indices could identify the high yielding hybrids under drought and non-stress conditions rather than ranking based on indices. The ranking method based on the indices for discrimination and identification of suitable drought stress tolerant genotypes was also supported by KHALILI *et al.* (2012) while working in spring canola cultivars, NAGHAVI *et al*. (2013) in corn cultivars and EID and SABRY (2019) in wheat genotypes.

Cluster analysis and screening genotypes

The dendrogram obtained from cluster analysis illustrated several clusters for classification of genotypes based on their tolerance to stress. The cluster analysis as well as genotypic distribution in the PCA-biplot and their relationship to the plotted indices tended to group into four groups (Fig. 2). These discriminations of genotypes based on their suitability under different environments was first cited by FERNANDEZ (1992), later reported by GHOBADI *et al*. (2012), DEHBALAEI *et al.* (2013) and FARSHADFAR *et al.* (2013). Based on indices MP, HM, GMP, YI, DI, STI, k_1STI and k_2STI the genotypes G-2, G-3, G-5, G-7, G-10, G-16, G-20, G-33 and G-35 exhibited high values with good yield performance under both growing conditions, tended to be the most desirable group and can be considered as stress tolerant (Group-A). DEHBALAEI *et al.* (2013) and FARSHADFAR *et al.* (2013) reported from cluster analysis that MP, HM, GMP, YI, DI, STI, k_1STI and k_2STI indices can identify tolerant genotypes for both stress-non stress growing conditions.

It also implied from cluster analysis and PCA-biplot that the genotypes G-8, G-11, G-14, G-15, G-18, G-22, G-25, G-31 and G-34 associated with Tol, SSI, SSPI and SDI, possessed of high index value. It seems Tol, SSI, SSPI and SDI had succeeded in selection of genotypes with high yield under non stress condition but had failed to select genotypes with potential yield under both conditions. Therefore, they could identify drought susceptible genotypes. Accordingly, the mentioned genotypes can be defined by those indices and could be considered as drought susceptible only suitable for optimum environment (Group-B). Simultaneously, the genotypes G-6, G-13, G-19, G-21, G-23, G-24 and G-27 had high value for the indices YSI and RDI, had shown some ability to adjust for good yield under stress environment than non-stress environment. Consequently, mentioned genotypes can be considered as moderate susceptible/tolerant only adjusted for stress/poor environment (Group-C). On the other hand, the genotypes G-9, G-12, G-17, G-28, G-29, G-30 and G-32 showed low values for MP, HM, GMP, YI, DI, STI, k_1STI and k_2STI while almost high values for Tol, SSI, SSPI, and SDI together with poor performance under both stress-non stress conditions indicating their non-suitability in two different environments. These genotypes were considered as yield non potential drought susceptible (Group-D). The analysis concluded that Tol, SSI, SSPI, SDI, YSI and RDI are good indicators to discriminate stress susceptible genotypes while MP, HM, GMP, YI, DI, STI, k_1STI and k_2STI can discriminate tolerant one. The results obtained from cluster analysis were also confirmed by PCA-Biplot.

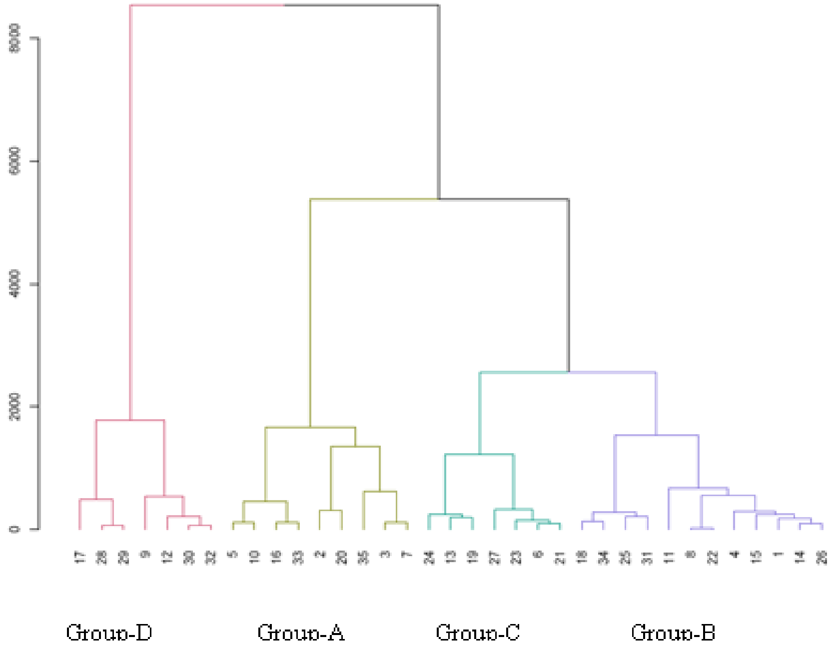

Fig. 2. The Dendrograms resulted from cluster analysis showing classification of genotypes based on stress tolerance

CONCLUSIONS

Identification of stable high yielding wheat genotypes has a substantial benefit to the drought prone areas in Bangladesh. The present works justify the need to evaluate genotypes by the tolerance indices under a representative environment. Moreover, to generate information for strengthening regional wheat breeding program focusing drought stress is of great necessity. Taking all the views into account, we can assume that MP, HM, GMP, STI, YI, DI, k_1STI and k_2STI could be a good index to screen genotypes compared with both non-stress and stress environments. The screened genotypes by those indices might be recommended for suitable in all environments. Besides, the indices Tol, SSI, SSPI, SDI, YSI and RDI are associated with the discrimination of susceptible genotypes. The indices YSI, RDI, SSI and SDI considered as effective indices in identifying tolerant genotypes under drought stress condition while the indices Tol and SSPI are good indicators to discriminate drought susceptible genotypes only suitable for optimum environment. Considering good yield performance under both stress and non-stress growing conditions the genotypes G-10, G-16, G-20 and G-33 might be recommended as highly drought tolerant since they exhibited high values for the indices MP, HM, GMP, YI, DI, STI, k_1STI and k_2STI along with low mean rank (< 10) as well as lower yield reduction (< 17%). These tolerant genotypes might be suggested for advanced multi-location trial in drought prone areas of Bangladesh. Also, the selected materials from this study will be utilized as parents in hybridization program to create new genetic variability for the improvement of drought tolerance.

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INDEKSI TOLERANCIJE NA SUŠU: PROCENA GENETSKIH PARAMETARA I PRIMENA U RAZDVAJANJU TOLERANTNIH GENOTIPOVA PŠENICE

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Izvod

Učestalost i jačina suše jedno su od glavnih ograničenja u proizvodnji pšenice i prinosu zrna u Bangladešu. Stoga je cilj ovog rada bio da se proceni upotreba indeksa tolerancije na sušu za skrining genotipova prolećne pšenice sa stabilnošću za određeno okruženje. Shodno tome, poljski eksperimenti su sprovedeni sa 35 genotipova pšenice tokom 2020-2021. godine u Bangladeškom istraživačkom institutu za pšenicu i kukuruz u Radžšahiju u dva okruženja: uslovima napajanja kišom i navodnjavanja. Indeksi Tol, SSI, SSPI, SDI i STI pokazali su umerenu do visoku heritabilnost, a genetski napredak ukazuje na moguće poboljšanje kroz selekciju. Genotipske (rg) i fenotipske (rp) korelacije, zajedno sa analizom glavnih komponenti (PCA), pokazale su da se indeksi MP, HM, GMP, STI, YI i DI mogu smatrati boljim prediktorom potencijalnog prinosa i u okruženjima bez stresa i u okruženjima sa stresom od suše. Pored toga, indeksi Tol, SSI, SSPI, SDI, YSI i RDI mogli bi da razdvoje visoko osetljive i nisko osetljive genotipove koji se mogu preporučiti za optimalno okruženje, odnosno stresno okruženje. Konačno, genotipovi G-10, G-16, G-20 i G-33 su odabrani kao izvor tolerancije na sušu i mogli bi se koristiti ili u programu oplemenjivanja za poboljšanje sorti ili prosleđivati na napredna višelokaciona ispitivanja u područjima sklonim sušama.

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