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RESEARCH PAPER

Genetic variation and tolerance indices interactions among wheat (*Triticum aestivum* L.) accessions under drought stress

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Key Message: This study reveals that stress tolerance indices were effective at classifying the accessions of wheat into different groups of drought tolerance. Hence it provides information on genetic variation and heritability of quantitative characteristics in wheat under drought stress.

Abstract: This study was conducted to analyse the level of genetic variability for drought tolerance among wheat (*Triticum aestivum* L.) accessions adopting the technique of stress tolerance indices of quantitative traits. A factorial experiment (10 x 2) in a completely randomised design replicated three times was adopted utilising pots (300 pots in total) filled with 3.5 kg of unfertilised top soil. Two treatments were applied (after irrigating all pots with 500 ml for two weeks after seed sowing): control (irrigated with 500 ml of water per pot at 2 days interval) and drought stress (irrigated with 500 ml of water at 8 days interval). Targeted data were on plant height and number of tillers per pot, number of spikelets per spike, spike length, seeds per spike, 1000 grain weight and grain yield per pot. Analysis of variance revealed significant variability among accessions for all traits in both conditions. Mean morphological reduction ranged from 14.58% in AKAC10 to 45.08% in AKAC06. Heritability estimate was high for all traits under stress except for number of tillers, spike length and grain weight. High loadings were expressed in PC1 among spike length, spikelets per spike, and seeds per spike and grain yield indices. High loadings in PC2 were displayed by THE number of tillers and spikelets per spike indices. Accessions AKAC09 and AKAC03 with the highest mean indices of 0.79 and 0.75, respectively, were classed as highly tolerant and AKAC10 and AKAC07 with the lowest indices of 0.53 and 0.50, respectively, were classed as the least tolerant accessions. The information provided in the present study would be useful for effective selection of wheat genotypes for drought-prone environments in future breeding programs.

Keywords: Drought, Heritability, Tolerance, Variability, Wheat

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Introduction

In the recent time, wheat has gained more acceptance and utilisation over the traditional staples such as tubers and other cereals in Africa (Negassa et al., 2013) as a consequence of increased demand for dietary enhancement due to urbanisation and increased population in regions where staple was predominantly known to come from maize (Jayne et al., 2010). The pressure on wheat has now raised to the level in which local production is grossly overwhelmed by demand, hence the reliance on importation to cater for the deficit in local supply (Negassa et al., 2013). Developing nations in general have therefore progressively become significant net importers of wheat, accounting for 43% of their food imports. Africa's wheat importation is anticipated to increase by 23.1 million metric tonnes by 2050 with both the largest rate of population growth and wheat consumption per person (El Siddig et al., 2013).

Wheat provides 20 and 21% of the protein and nourishment calories respectively in human diet to over three billion individuals residing in ninety countries of the world (Naeem et al., 2015). Global wheat production is estimated to be about 761.5 million tonnes and roughly 21% of the food consumed worldwide depend on wheat as raw material (Food and Agriculture Organization [FAO], 2020). It serves as a major raw material in cakes, animal feeds, pasta, bread, spaghetti, biscuits, semovita and macaroni. The stalks after harvest are used in mulching, construction and bedding for animals (Oyewole, 2016). In Nigeria, wheat cultivation has been going on for millennia (Adegbanke et al., 2019), and there are reports that its cultivation started before 200 BC, although the present cultivated varieties are comparatively latest introductions (Olabanji et al., 2004).

In spite of the heavy consumption pattern, national wheat production in Nigeria has been limited because of restrictions arising from climatic demands, agronomic procedures and the preference for vegetable cultivation in the majority of the wheat producing regions (Oyewole, 2016). Introduction of better agronomic procedures, appropriate land preparation, and other cultural practices revolving around sowing, nourishment, watering regime, crop protection, crop yield and post yield technology have been the main focus of workers (Oyewole, 2016).

Despite the importance of wheat in Nigeria, its productivity can be stunted by drought which according to Ajayi et al. (2018) drought is a state of persistent insufficiency in soil moisture preventing effective crop growth and development, hence significantly reducing yield. Advancement of climatological techniques make it possible to predict an upcoming drought (Haas et al., 2020), nevertheless, its overwhelming effect on the economy persists (Cai et al., 2020; Saha et al., 2020). Adaptation and survival of plants under drought condition requires that plants possess inherent ability to deploy diverse mechanisms which can be morphological, physiological and molecular (Baek et al., 2020; Xiong et al., 2020). Rapid decrease in wheat productivity is a consequence of impeded growth caused by drought (El Siddig et al., 2013). The main cropping season of wheat in Nigeria falls between November and March (the dry season) hence there is a heavy dependence on irrigation which could be expensive to deploy. The drier Northern region is favourable to wheat cultivation being a temperate crop (Olugbemi, 1990) but unfortunately this region is characterised by poor rainfall distribution during the cropping season (Bekele et al., 2002).

Information on genetic variation and heritability of yield characteristics in wheat under drought stress is limited in Nigeria. Adequate genetic information about crop yield characters of wheat will make a positive contribution to its productivity. Grain yield determination under drought stress is hard because its manifestation is a consequence of interactions between many other contributing characters (Richards, 2004). Therefore, the choice of genotypes based on yield traits might be more efficient than the direct selection for yield (Toker & Cargirgan, 2004). Its selection under drought stress is also laborious and time consuming requiring many decades of work (Haas et al., 2020) and evaluation in multiple environments because of its propensity to influence of the genotype by environment interaction (Stahl et al., 2020). Correlation offers information on the linkage between morphological characters and economic characters that allow indirect selection. The Principal Component Analysis (PCA) is an additional multivariate process effective for the analysis of relative contribution of individual features under prevailing conditions. This technique identifies a tiny set of variables which represent a big percentage of the complete variance in the original variable (Ajayi et al., 2017a). Correlation and PCA have been used successfully to select drought tolerant genotypes of many crop species (Ali et al., 2011; Abdou Razakou et al., 2013; Li et al., 2015).

Many criteria have been used in crop species for selection under drought stress. Notable among these are markers assisted selection (MAS) (Yang, 2019; Haas et al., 2020), expression profiling of drought responsive genes, biochemical and molecular traits (Baek et al., 2020; Xiong et al., 2020; Zhang et al., 2020), physiological traits (Hirooka et al., 2019; Cai et al., 2020; Stahl et al., 2020), morphological traits, root phenotype and architecture (Yang, 2019; Klein et al., 2020) and stress tolerance index (STI) of yield traits (Al-Rawi, 2016; Batieno et al., 2016). STI was highly appropriate for selecting high yielding tolerant wheat and cowpea genotypes under stress and well-watered conditions (Al-Rawi, 2016; Batieno et al., 2016). In Nigeria, however, there is restricted data on the use of STI for assessment of drought tolerance in wheat genotypes, and no report exists that utilises STI of quantitative traits in selection of wheat genotypes for drought tolerance. This study therefore aimed to evaluate the amount of genetic variation for drought tolerance among genotypes; heritability of suitable characteristics for choice, and association among stress tolerance indices of yield traits which should be useful tools in establishing a breeding programme for drought tolerance in wheat.

Materials and Methods

Collection of plant materials and procedures

The ten accessions of wheat utilized in this study were collected from the Lake Chad Research Institute, Maiduguri, Nigeria. The details of the accessions are presented in Table 1. The study was conducted between September and December, 2018 in a screen house at the Department of Plant Science and Biotechnology, Adekunle Ajasin University, Akungba-Akoko, Nigeria which lies in Latitude 7.2^0 N, Longitude 5.44’ E and 423m above sea level. Three seeds of each accession were sown in pots filled with 3.5 kg of top soil without fertilizer. A factorial experiment (10 x 2) in a Completely Randomised Design (CRD) replicated three times was adopted with five pots per accession per treatment in each replicate. Five hundred millilitres (500 ml) of water was applied to each pot thrice per week for two weeks after seedling emergence. Two watering regimes were adopted for treatments until maturity of plants: watering of each pot with 500 ml of water at two days interval (control treatment or well watered) and watering of each pot with 500 ml at eight days interval (drought stress). At 4 weeks after sowing (4 WAS), data were collected on plant height and number of tillers per pot. Data were also collected on the number of spikelets per spike, spike length, seeds per spike, 1000 grain weight and grain yield per pot at maturity.

Data analysis

Data were subjected to statistical analysis employing SPSS version 20. The Duncan Multiple Range Test (DMRT) at $P \leq 0.05$ was used for mean separation within the environment. Genotypic and phenotypic variances (GV and PV) were estimated according to Prasad et al. (1981); Wricke & Weber (1986). Genotypic and phenotypic coefficient of variations (GCV and PCV) were estimated according to Burton (1952); Damarany (1994) and grouped according to Sivasubramanian & Menon (1973) as: 0 – 10% = low; 10 – 20% = moderate; 20% and above = high. Broad sense heritability (H^2B) was estimated as the proportion of the ratio of VG to VP as defined by Allard (1960) and grouped according to Robinson et al. (1949) as: 0 – 30% = low; 30 – 60% = moderate; 60% and above = high. Genetic advance as percent of the mean (GAM) was calculated according to Johnson et al. (1955) and grouped according to Al-Jibouri et al. (1958) as: 0 – 10% = low; 10 – 20% = moderate; 20% and above = high. All quantitative traits were used for determination of drought tolerance indices as described by Fernadez, (1992); Al-Rawi, (2016): (Ys)*(Yp)/(Grand mean of Yp) ^{2}; where Ys = mean value under stressed condition and Yp = mean value under control condition and higher values of the indices indicated tolerant to drought stress. Based on the mean indices, accessions were ranked into different classes of tolerance. Pearson correlation of tolerance indices was done using SPSS. Tolerance indices were also subjected to Principal Component (PCA) and bi-plot analyses with Palaeontological Statistic Software Package for Education and Data Analysis (PAST), Hammer et al. (2001).

Results

Variability among accessions for quantitative traits

Results presented in Table 2 show that there were significant differences among accessions for all traits. Treatment was also significant for all traits and accession by treatment effect was also significant for all traits. The performance of accessions under drought stress and well watered conditions are presented in Table 3. Mean plant heights were 7.17 cm and 6.02 cm under control and drought stress, respectively. Plant height ranged from 5.87 cm in AKAC09 to 7.57 cm in AKAC04 under control, while it ranged from 5.06 cm in AKAC01 to 6.81 cm AKAC09 under drought stress. The mean number of tillers per pot were 5.11 and 3.56 under control and drought stress respectively. Under control, the lowest number of tillers per plant (2.57) was obtained in AKAC10, while the highest (7.60) was obtained in AKAC04. Under drought stress however, the lowest number of tillers (3.20) was obtained in accessions AKAC02 and AKAC04, while the highest (4.10) was obtained in AKAC010. Mean spike lengths per plant were 7.19 cm and 5.18 cm under control and drought stress respectively, ranging from 5.60 cm in AKAC07 to 8.68 cm in AKAC02 in the controls, while under stress the value ranged from 4.77 cm in AKAC09 to 5.60 cm in accessions AKAC02 and AKAC03. Mean values for the number of spikelets per spike under control and drought stress were 40.71 and 17.00 respectively. It ranged from 27.33 in AKAC10 to 61.63 in AKAC09 in the controls, while it ranged between 16.27 in AKAC04 and 18.27 in AKAC10 under drought stress. Mean number of seeds per spike were 22.57 and 6.41 under control and drought stress respectively. The lowest number of seeds (12.73) under control was obtained in AKAC09, while the highest (29.53) was obtained in AKAC05. However, the lowest (5.16) under drought stress was obtained in AKAC02, while the highest (7.47) was obtained in AKAC08. Mean one thousand-grain weight under control and drought stress was 32.90g and 28.30g respectively. The value ranged from 20.67 g in AKAC02 to 42.00 g in AKAC06 in the controls, while it ranged from 18.33 g in AKAC02 to 35.00 g in AKAC05 under drought stress. The mean grain yield per pot was 4.73 g and 2.90 g in the controls and under drought stress respectively. In the controls, the lowest grain yield (2.67 g) was obtained in AKAC05, while the highest (7.23 g) was obtained in AKAC09. Under drought stress, the lowest grain yield (0.53 g) was obtained in AKAC07, while the highest (5.40 g) was obtained in AKAC09. The results show that drought stress significantly reduced the assessed quantitative traits in all the accessions. The rate of reduction of the quantitative traits by drought stress is presented in Table 4.

Table 1 Names of the 10 accessions of wheat used for genetic variability study under well watered and drought stressed conditions

Accession ID	Entry number	Code
REBWAH-13/3/CMH81.38/2*KAUZ//ATTILA/4/URES/BOW//OPATA/3/HD2206/HORKS	28	AKAC01
WBLL1*2/BRAMBLING//SHMIEKH-4	31	AKAC02
VEE/PJN//2*KAU/3/SHUHA-4/FLOW-2	7	AKAC03
PFAU/MILAN//FUNGMAI24/3/ATTILA*2/CROW	8	AKAC04
WBLL1*2/BRAMBLING/3/OPATA/RAYON//KAUZ	6	AKAC05
22SAWSN-142/3/PASTOR//MUNIA/ALTAR84/4/SHAMISS-3	23	AKAC06
SERI.1B*2/3/KAUZ*2/BOW//KAUZ*2/4/MNCH/3*BCN	15	AKAC07
BACANORA T 88/RUTH-2	29	AKAC08
MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/ZAFIR-3	4	AKAC09
VEE/PJN//2*KAUZ/3/SHUHA-4/FOW-2	10	AKAC10

Table 2 Combined mean square values (from ANOVA) of quantitative traits of 10 accessions of wheat under well watered (control) and drought stress conditions

S.O.V	DF	PH (cm)	NT	SPL (cm)	SPS	SDPS	1000-GW (g)	GY (g)
Accession	9	0.57*	2.25*	2.93*	125.31*	39.44*	140.60*	9.62*
Treatment	1	19.63*	36.18*	60.80*	17651.81*	464.26*	317.40*	50.33*
Treatment × Accession	9	1.18*	4.33*	1.73*	131.57*	50.19*	31.21*	6.53*
Error	40	0.08	0.08	0.06	0.09	0.09	18.27	0.07
Total	59							
Coefficient of variation (%)		4.29	6.53	3.96	1.04	2.5	13.97	6.93

*Significant at P ≤ 0.05; DF: Degree of freedom; PH: Plant height; NT: Number of tillers; SPL: Spike length; SPS: Number of spikelet per spike; SDPS: Number of seeds per spike; 1000-GW: One thousand grain weight; GY: Grain yield per pot.

Table 3 Mean performance of 10 accessions of wheat under well watered (control) and drought stress conditions

Accession	Plant height (cm)		Number of tillers		Spike length (cm)		Spikelets per spike	
	Control	Stressed	Control	Stressed	Control	Stressed	Control	Stressed
AKAC01	7.37±0.14[cd]	5.06±0.03[a]	6.20±0.12[f]	3.50±0.06[ab]	8.12±0.64[e]	5.53±0.20[c]	33.30±0.21[b]	16.33±0.33[a]
AKAC02	7.39±0.13[cd]	6.35±0.27[bc]	5.67±0.18[e]	3.20±0.11[a]	8.68±0.09[f]	5.60±0.31[c]	44.53±0.17[h]	16.67±0.14[abc]
AKAC03	7.40±0.14[cd]	6.24±0.12[bc]	4.27±0.18[c]	3.27±0.22[a]	7.38±0.10[d]	5.60±0.29[c]	40.50±0.26[f]	16.63±0.18[abc]
AKAC04	7.57±0.09[d]	5.49±0.22[a]	7.60±0.12[g]	3.20±0.17[a]	6.69±0.15[c]	5.43±0.14[bc]	45.50±0.26[i]	16.27±0.15[a]
AKAC05	7.35±0.08[cd]	6.65±0.12[c]	6.46±0.09[f]	3.23±0.12[a]	8.62±0.60[f]	5.10±0.21[abc]	34.67±0.24[c]	17.07±0.12[bcd]
AKAC06	7.53±0.12[d]	6.20±0.41[bc]	4.70±0.06[d]	3.66±0.19[ab]	8.30±0.58[e]	4.90±0.06[ab]	39.63±0.20[e]	17.50±0.06[de]
AKAC07	7.34±0.07[cd]	6.27±0.19[bc]	3.77±0.20[b]	3.73±0.32[ab]	5.60±0.87[a]	4.83±0.09[ab]	37.33±0.24[d]	16.57±0.12[ab]
AKAC08	7.09±0.06[c]	5.46±0.19[a]	4.90±0.10[d]	4.02±0.11[b]	6.84±0.02[c]	4.87±0.13[ab]	42.80±0.12[g]	17.10±0.06[cd]
AKAC09	5.87±0.09[a]	6.81±0.05[c]	5.00±0.12[d]	3.69±0.21[ab]	5.77±0.09[ab]	4.77±0.18[a]	61.63±0.15[j]	17.63±0.12[e]
AKAC10	6.75±0.10[b]	5.69±0.13[ab]	2.57±0.12[a]	4.10±0.15[b]	5.91±0.06[b]	5.13±0.12[abc]	27.23±0.15[a]	18.27±0.14[f]
GM	7.17±0.09	6.02±0.11	5.11±0.26	3.56±0.08	7.19±0.21	5.18±0.08	40.71±1.63	17.00±0.12

Values with similar superscript within a column are not significantly different from one another at P ≤ 0.05 using Duncan Multiple Range Test (DMRT). Values are means of measurements ± standard error (SE) of mean; GM = Grand mean

Table 3 continued

Accession	Seeds per spike		1000-Grain weight (g)		Grain yield (g)	
	Control	Stressed	Control	Stressed	Control	Stressed
AKAC01	22.63±0.15[e]	7.20±0.20[d]	28.00±0.57[b]	23.33±1.67[ab]	4.37±0.03[c]	3.23±0.15[d]
AKAC02	24.13±0.19[f]	5.16±0.13[a]	20.67±1.20[a]	18.33±1.67[a]	3.67±0.12[b]	3.53±0.23[d]
AKAC03	21.50±0.26[d]	6.43±0.15[c]	35.33±0.88[c]	30.00±2.89[bc]	6.30±0.21[e]	4.80±0.06[e]
AKAC04	29.47±0.29[h]	5.67±0.15[b]	28.33±1.20[b]	31.67±4.41[bc]	5.47±0.17[d]	1.50±0.26[b]
AKAC05	29.53±0.12[h]	7.30±0.10[d]	34.67±0.67[c]	35.00±2.89[c]	2.67±0.15[a]	2.27±0.15[c]
AKAC06	19.27±0.18[c]	6.50±0.36[c]	42.00±1.15[d]	30.00±5.77[bc]	6.55±0.14[e]	0.90±0.06[a]
AKAC07	19.73±0.12[c]	6.43±0.31[c]	34.67±2.60[c]	25.00±2.89[abc]	3.60±0.12[b]	0.53±0.09[a]
AKAC08	28.27±0.15[g]	7.47±0.25[d]	36.00±2.08[c]	29.67±2.60[bc]	4.77±0.09[c]	2.40±0.17[c]
AKAC09	12.73±0.15[a]	6.30±0.30[c]	36.00±1.73[c]	29.00±2.08[bc]	7.23±0.15[f]	5.40±0.23[f]
AKAC10	18.40±0.23[b]	5.63±0.25[b]	33.33±1.76[c]	31.00±2.08[bc]	2.70±0.12[a]	4.43±0.18[e]
GM	22.57±0.96	6.41±0.76	32.90±1.11	28.30±1.18	4.73±0.29	2.90±0.29

Values with similar superscript within a column are not significantly different from one another at P ≤ 0.05 using Duncan Multiple Range Test (DMRT); Values are means of measurements ± standard error (SE) of mean; GM = Grand mean

Table 4 Percentage reduction (%) in quantitative traits of 10 accessions of wheat under drought well watered (control) and drought stress conditions

ACCESSION	PH	NT	SPL	SPS	SDPS	GW	GY	Mean
AKAC01	31.34	43.55	31.89	50.96	68.18	16.68	26.09	38.38
AKAC02	14.07	43.56	35.48	62.96	78.61	11.32	3.81	35.69
AKAC03	15.68	23.42	24.12	58.94	70.09	15.09	23.81	33.02
AKAC04	27.48	57.89	18.83	64.24	80.76	-11.79	72.58	44.28
AKAC05	9.52	50.00	40.84	50.76	75.28	-0.95	14.98	34.35
AKAC06	17.66	22.13	40.96	55.84	66.27	28.57	86.26	45.38
AKAC07	14.58	1.06	13.75	55.61	67.41	27.89	85.28	37.94
AKAC08	22.99	17.96	28.8	60.05	73.58	17.58	49.69	38.66
AKAC09	-16.01	26.20	17.33	71.39	50.51	19.44	25.31	27.74
AKAC10	15.70	-59.53	13.19	32.90	69.40	6.99	-64.07	14.58

PH: Plant height; NT: Number of tillers; SPL: Spike length; SPS: Number of spikelet per spike; SDPS: Number of seeds per spike; 1000-GW: One thousand grain weight; GY: Grain yield per plant

Stress tolerance indices of quantitative traits

Stress tolerance indices based on all quantitative traits are presented in Table 5. The lowest index (0.73) and the highest (0.95) for plant height was obtained in AKAC01 and AKAC05 respectively. For the number of tillers per pot, indices ranged from 0.40 in AKAC10 to 0.93 in AKAC04. Tolerance index was lowest (0.52) in AKAC07 and highest (0.94) in AKAC02 for spike length. It ranged between 0.30 in AKAC10 to 0.66 in AKAC09 for number of spikelets per spike. The lowest (0.16) for number of seeds per spike was obtained in AKAC09, while the highest (0.41) was obtained in AKAC08. The lowest index (0.35) for one thousand grain weight was obtained in AKAC02, while the highest (1.16) was obtained in AKAC06. Index for grain yield was lowest (0.09) in AKAC07, while the highest (1.75) was obtained in AKAC09. Mean drought tolerance index was lowest (0.50) in AKAC07 and highest (0.79) in AKAC09. Three groups of tolerance level were formed based on the mean tolerance index. Accessions in group 1 were the most tolerant accessions with mean indices between 0.75 (AKAC03) and 0.79 (AKAC09). Accessions in group 2 were moderately tolerant accessions; and they included AKAC02, AKAC01, AKAC04, AKAC06, AKAC08 and AKAC05 with tolerance indices of 0.60, 0.62, 0.63, 0.64, 0.64 and 0.68 respectively. The least tolerant accessions were placed in group 3. They included accessions AKAC07 and AKAC10 with tolerance indices of 0.50 and 0.53 respectively. Results of the Pearson correlation analysis of the tolerance indices are presented in Table 6. The only significant positive correlation (0.67*) was obtained between indices of number of spikelets per spike and grain yield per pot.

Table 5 Stress tolerance indices based on all the quantitative traits of 10 accessions of wheat under well watered (control) and drought stress conditions

Accession	PHI	NTI	SPLI	SPSI	SDPSI	1000-GWI	GYI	Mean	Rank
AKAC01	0.73	0.83	0.87	0.33	0.32	0.60	0.63	0.62	2
AKAC02	0.91	0.69	0.94	0.45	0.24	0.35	0.58	0.60	2
AKAC03	0.90	0.53	0.80	0.41	0.27	0.98	1.35	0.75	1
AKAC04	0.81	0.93	0.70	0.45	0.33	0.83	0.37	0.63	2
AKAC05	0.95	0.80	0.85	0.36	0.42	1.12	0.27	0.68	2
AKAC06	0.91	0.66	0.79	0.42	0.25	1.16	0.26	0.64	2
AKAC07	0.90	0.54	0.52	0.37	0.25	0.80	0.09	0.50	3
AKAC08	0.75	0.75	0.64	0.44	0.41	0.99	0.51	0.64	2
AKAC09	0.78	0.71	0.53	0.66	0.16	0.96	1.75	0.79	1
AKAC10	0.75	0.40	0.59	0.30	0.20	0.95	0.53	0.53	3

PHI: Plant height index; NTI: Number of tillers index; SPLI: Spike length index; SPSI: Number of spikelet per spike index; SDPSI: Number of seeds per spike index; 1000-GWI: One thousand grain weight index; GYI: Grain yield per index

Table 6 Pearson correlation of the stress tolerance indices of quantitative traits of 10 accessions of wheat under well watered (control) and drought stressed conditions

	PHI	NTI	SPLI	SPSI	SDPSI	1000-GWI	GYI
PHI	1	-0.09	0.38	-0.06	0.08	0.12	-0.25
NTI		1	0.35	0.27	0.57	-0.14	-0.11
SPLI			1	-0.28	0.35	-0.35	-0.15
SPSI				1	-0.35	0.04	0.67*
SDPSI					1	0.18	-0.46
1000-GWI						1	0.03
GYI							1

*Significant at $P \leq 0.05$; PHI: Plant height index; NTI: Number of tillers index; SLI: Spike length index; SPSI: Number of spikelet per spike index; SDPSI: Number of seeds per spike index; 1000-GWI: One thousand grain weight index; GYI: Grain yield per pot index

Estimates of genetic parameters

The results of the estimates of genetic parameters of the ten accessions under control and drought stress conditions are presented in Table 7. GV and PV were higher under drought stress for plant height (0.28 and 0.41) and grain yield (2.74 and 2.83). They were lower under drought stressed conditions for number of tillers per pot (0.08 and 0.18), spike length (0.08 and 0.19), spikelets per spike (0.57 and 0.63) and number of seeds per spike (0.38 and 0.46). GV was lower (13.07) under drought stress and PV was higher (42.70) under stress for one thousand grain weight. GCV was low for plant height under control (0.25%) and under drought stress (0.28%). GCV was low for number of tillers (7.95%), spike length (5.46%), spikelets per spike (4.44%) and seeds per spike (9.62%) under drought stressed condition; and moderate for spike length (16.63%) under control, and one thousand grain weight (12.77%) under stress and (17.20%) under control. GCV was high (28.09%) for number of tillers per pot under control, spikelets per spike (22.65%) under control, number of seeds per spike (24.04%) under control and grain yield (34.02%) under control and (57.08%) under stress. PCV was low for Plant height (7.51%) under control, spike length (8.41%) and spikelets per spike (4.67%) under drought stressed condition. However, it was moderate for plant height (10.64%), number of tillers (11.92%) and seeds per spike (14.71%) under stress; moderate for spike length (16.74%) and one thousand-grain weight (18.96%) under control. It was high for number of tillers (28.43%), spikelets per spike (22.66%), and seeds per spike (24.08%) under control; high for one thousand-grain weight (23.09%) under stress, and grain yield (34.42%) under control and (58.01%) under stress. Heritability in the broad sense was high for all the quantitative traits under both control and drought stressed conditions, except for number of tillers, spike length and one thousand-grain weight which had moderate heritability under stress. The highest (99.85%) under control was obtained in spikelets per spike, while the lowest under control (82.27%) was obtained in one thousand-grain weight. The highest under drought stress (96.82%) was obtained in grain yield, while the lowest (30.61%) was obtained in one thousand-grain weight. Drought stress reduced heritability in all the quantitative traits. GAM was low in spike length (7.30%) and spikelets per spike (8.70%) under control. Moderate for plant height (13.34 and 14.96%) under both conditions, number of tillers (10.91%), seeds per spike (18.01%) and one thousand-grain weight (14.56%) under stress. It was high for number of tillers (57.17%), spike length (34.02%), spikelets per spike (46.62%), seeds per spike (49.42%) and one thousand-grain weight (32.14%) under control, and grain yield (69.29%) under control and (115.70%) under stress. Stress reduced GAM in all traits except in plant height and grain yield.

Table 7 Estimates of genetic parameters of quantitative traits of 10 accessions of wheat under well watered (control) and drought stress conditions

Trait	Treatment	Grand Mean	Range	GV	PV	GCV (%)	PCV (%)	H^2B (%)	GAM (%)
Plant height (cm)	Control	7.17	5.70 - 7.76	0.25	0.29	6.97	7.51	86.21	13.34
	Stressed	6.02	2.40 - 7.50	0.28	0.41	8.79	10.64	68.29	14.96
Number of tillers	Control	5.11	2.40 - 7.80	2.06	2.11	28.09	28.43	97.63	57.17
	Stressed	3.56	2.90 - 4.40	0.08	0.18	7.95	11.92	44.44	10.91
Spike length (cm)	Control	7.19	5.45 - 8.80	1.43	1.45	16.63	16.74	98.62	34.02
	Stressed	5.18	4.50 - 6.10	0.08	0.19	5.46	8.41	42.11	7.30
Spikelets per spike	Control	40.71	27.00 - 61.90	85.00	85.13	22.65	22.66	99.85	46.62
	Stressed	17.00	16.00 - 18.50	0.57	0.63	4.44	4.67	90.48	8.70
Seeds per spike	Control	22.57	12.50 - 29.90	29.43	29.54	24.04	24.08	99.63	49.42
	Stressed	6.41	5.07 - 7.70	0.38	0.46	9.62	14.71	82.61	18.01
1000-Grain weight (g)	Control	32.90	19.00 - 44.00	32.02	38.92	17.20	18.96	82.27	32.14
	Stressed	28.30	15.00 - 40.00	13.07	42.70	12.77	23.09	30.61	14.56
Grain yield (g)	Control	4.73	2.40 - 7.50	2.59	2.65	34.02	34.42	97.74	69.29
	Stressed	2.90	0.40 - 5.80	2.74	2.83	57.08	58.01	96.82	115.7

GV: Genotypic variance; PV: Phenotypic variance; GCV: Genotypic coefficient of variation; PCV: Phenotypic coefficient of variation; H^2B: Broad sense heritability; GAM: Genetic advance as percent of mean

Principal component analysis (PCA)

The results of the Principal Component Analysis (PCA) of the stress tolerance indices of the quantitative traits are presented in Table 8. Four PCs with Eigen values higher than 1 and representing 88.71% of the total variations were extracted out of the 10 PCs. More than thirty three percent (33.73%) and 21.78% of the total variability were represented in PCs 1 and 2 respectively. High positive contributors in PC1 included seeds per spike index (0.78), spike length index (0.66) and number of tillers index (0.42), while the negative contributors included grain yield index (-0.76) and spikelets per spike index (-0.65). High positive contributors in PC2 included number of tillers index (0.82), spikelets per spike index (0.60) and grain yield index (0.40). The bi-plot of the PCs 1 and 2 is presented Fig. 1. The bi-plot captured 55.51% of the total variations and divided the accessions into four major groups based on their relationships with the stress tolerance indices. Accessions in group 1 included AKAC04, AKAC01, AKAC02 and AKAC08. Accessions in group 2 included AKAC05 and AKAC06. Accessions in group 3 included AKAC07 and AKAC10 and AKAC03. The only accession in group 4 was AKAC09. The vertex accessions in group 1 were AKAC04 and AKAC01, and were the moderately tolerant accessions which were highly correlated with the number of tillers index. The vertex accession in group 2 was AKAC05, correlating with plant height index which was also a moderately tolerant accession. The vertex accessions in group 3 were AKAC07 and AKAC10 which were the least tolerant accessions and correlated with one thousand-seed weight index. AKAC09 was a vertex accession in group 4 and the most tolerant accession correlating with spikelets per spike index and grain yield index. Number of tillers index, seeds per spike index and spike length index were correlated and Spikelets per spike index was highly correlated with grain yield index.

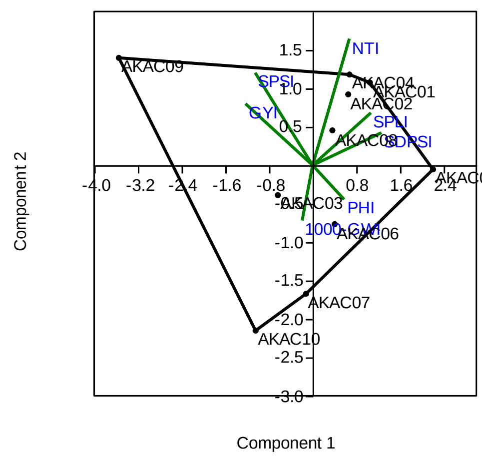

Fig. 1 Bi-plot of stress tolerance indices of quantitative traits of 10 accessions of wheat under well watered (control) and drought stress conditions

Table 8 Principal component analysis (PCA) of stress tolerance indices of quantitative traits of 10 accessions of wheat under well watered (control) and drought stress conditions

	Principal components			
	PC1	PC2	PC3	PC4
Eigen value	2.36	1.52	1.24	1.08
Cumulative Eigen value	2.36	3.88	5.12	6.20
Variability (%)	33.73	21.78	17.73	15.47
Cumulative variability (%)	33.73	55.51	73.24	88.71
Variables	PC1	PC2	PC3	PC4
PHI	0.36	-0.22	-0.26	0.83
NTI	0.42	0.82	0.29	-0.03

SPLI	0.66	0.34	-0.47	0.23
SPSI	-0.65	0.60	0.11	0.34
SDPSI	0.78	0.21	0.49	-0.02
1000-GWI	-0.12	-0.36	0.77	0.42
GYI	-0.76	0.40	-0.09	0.19

PHI: Plant height index; NTI: Number of tillers index; SPLI: Spike length index; SPSI: Number of spikelet per spike index; SDPSI: Number of seeds per spike index; 1000-GWI: One thousand grain weight index; GYI: Grain yield per pot index

Discussion

The essentiality of genetic variability in establishing a proper breeding scheme in crops can never be overemphasized. This study delved into analysing genotypic differences for drought tolerance among accessions of wheat adopting estimates of genetic parameters and multivariate techniques on tolerance indices. Here, accessions had different responses to water deficit, hence the significant differences shown by Analysis of Variance (ANOVA). This study showed that environmental effects (treatments) were significant and also highlighted significant interaction between treatment and accession, indicating that selection for drought tolerance among the accessions will be effective. These are similar to the findings of Al-Rawi (2016); Mkhabela et al. (2019); Patel et al. (2019).

Drought stress reduced all the quantitative traits of the accessions of wheat in accordance, although in few cases, some accessions performed better under the stressed condition than control for some traits. These included AKAC09 for plant height, AKAC10 for number of tillers and grain yield, AKAC04 and AKAC05 for grain weight. The highest grain yielder (AKAC09) under the control was the highest yielder under the stressed environment contrary to the findings of Zebarjadi et al. (2012); Al-Rawi (2016), but in support of the findings of Sareen et al. (2014); Patel et al. (2019). Some of the findings are in accordance with the reports of workers that have analysed drought tolerance in cereals. For instance, morphological attributes of sorghum and sweet corn were reduced respectively, by drought stress (Bibi et al., 2010; 2012; Nemeskeri et al., 2019), shoot length was negatively affected by drought stress in wheat (El Siddig et al., 2013) and yield attributes were significantly reduced at highest drought in wheat (Farnia & Tork, 2015; Boussakouran et al., 2019). According to Tardieu (2013), the main effects of moisture deficit of soil on crops include reduced growth in somatic and reproductive tissues, impingement of leaf area and plant biomass; stomata closure in conserving moisture with adverse consequence of reduced photosynthesis; and premature senescence. Genotypic differences for these traits have been reported for many crops including sorghum (Borrell et al., 2000) and corn (Tardieu, 2012).

The extent of stress tolerance indices among the accessions indicated that the greatest overall values were attributed to accessions AKAC09 and AKAC03 making them the highest tolerant accessions, while the least tolerant ones were AKAC10 and AKAC07 with the lowest overall stress tolerance indices. Pearson Correlation of the stress tolerance indices of all the quantitative parameters however did not reveal any significant correlations among them except for the positive correlation between the number of spikelet per spike index and grain yield index. This indicated that selection for number of spikelets per spike under stress will result in increase in yield and improve tolerance in wheat accessions. Stress tolerance indices have been reported to be very effective in the selection of wheat cultivars under stress (Al-Rawi, 2016) and very powerful at spotting high yielding genotypes of cowpea under drought stress (Batieno et al., 2016).

Genotypic coefficient of variations (GCV) was low under the control for plant height and ranged from moderate to high among other quantitative traits. GCV was also low for all quantitative traits under drought stress except for grain weight (moderate) and grain yield (high). Phenotypic coefficients of variation (PCV) was also low for plant height under control and ranged from moderate to high in other traits, while PCV was mainly moderate to high under stress for all traits except spike length and number of spikelets per spike. Drought stress reduced the GCV and the PCV in all parameters except for plant height, grain weight (PCV only), and grain yield. Our findings are in agreement with those conveyed by Hefny (2013) who opined that morphological traits of lupin were under genetic control irrespective of the environmental condition, hence making selection effective. The results of this work also agree with the findings of Naeem et al. (2015) who reported that growth and physiological parameters of wheat displayed lower GCV and PCV under drought stress. Just as in this study they also affirmed that PCV was slightly higher in all parameters compared to the corresponding GCV indicating a slight influence of the environments on these traits. If these traits are exploited in breeding programmes for drought tolerance, positive returns are highly expected.

Heritability in the broad sense was high for all parameters under both control and drought stress conditions, except in the number of tillers per plant, spike length, and grain weight which had moderate heritability under the drought stress condition. Furthermore, heritability was reduced by drought stress in all the characters studied in agreement with the findings of Hefny (2013) in lupin, Li et al. (2015) in maize and Naeem et al. (2015) in wheat. Heritability estimates show the comparative significance of gene in character expression. High levels of heritability in most traits especially in grain weight and grain yield suggest that selection based on them will be effective for wheat improvement programmes under drought stress. High heritability alone does not do the job effectively if considered in isolation; it is far more effective for breeding objectives if measured with GAM. High heritability complemented with high GAM display additive genetic effects leading to effective selection, high heritability with low GAM indicates non-additive genetic effects, whereas, low heritability accompanied by high GAM and low heritability with low GAM indicates additive gene action and high environmental influences with consequence ineffective selection, respectively (Ajayi et al., 2017b). Genetic advance as percent of mean (GAM) ranged from moderate to high in most traits except in spike length and spikelets per spike where it was low under drought stress. Therefore, grain yield with high heritability under both stress and control conditions with similarly high GAM in both conditions will be perfect for selection of better wheat cultivars under drought stress. Selection for grain weight, number of seeds per spike, number of tillers and plant height will contribute positively to wheat improvement under drought stress. This agrees with the findings of some workers in lupin (Hefny, 2013), in rice (Sathya & Jebaraj, 2013), in wheat (Kumar et al., 2017) and in sorghum (Rajarajan et al., 2018).

The Principal components 1 to 4 consisted of more than 88% of the total variability among the wheat accessions evaluated, based on the tolerance indices of the quantitative traits. PCs 1 and 2, the most important components, included indices such as spike length index and seeds per spike index make high positive contribution in PC1; spikelets per spike index and grain yield index making high negative contribution in PC1. High positive contributors in PC2 include indices such as number of tillers index and spikelets per spike index. Selection based on indices with high positive and negative contribution will be effective for selection of wheat under drought stress. Relationships of accessions in the bi-plot of the PC1 and PC2 with stress tolerance indices varied accordingly. The GT bi-plot in this study netted 56% of the total variation with regards to genotype, and genotype by tolerance indices of traits interactions. According to Abdou Razakou et al. (2013), selection of genotypes based on high drought susceptibility index indicates high susceptibility, since stress susceptibility indices were employed in contrast to this work which employed stress tolerance indices. Here, high tolerance indices will indicate high drought tolerance for any accessions of wheat. A big question regarding the bi-plot is which index vector should be chosen since different accessions would be strongly linked to different index profiles? Associations among indices are defined by the Cosine of the angle between two indices as visualized in the GT bi-plot. Positive correlation between two indices is inferred if the angle between their vectors is acute ($< 90^0$); if the angle is obtuse ($>90^0$), indices are negatively correlated; but no correlations exist if angle is exactly at right angle (Yan & Tinker, 2006; Atnaf et al., 2017).

In this study, the number of tillers index was positively correlated with spike length index and seeds per spike index, while spikelets per spike index was highly positively correlated with grain yield index, as also confirmed by Pearson correlation coefficients between grain yield index and spikelets per spike index. On the contrary, grain yield index and spikelets per spikes index had significant negative correlation with plant height index and grain weight index. Ability of an index for discrimination among accessions depends on its vector length from the origin of the bi-plot. Consequently, number of tillers, spikelets per spike, grain yield, pike length and seeds per spike indices had longer projections, therefore greater discrimination influence, while plant height and grain weight indices had shorter trajectories indicating their inability to discriminate accessions effectively under drought stress.

It has been recommended that selection of genotypes must be based on multiple traits that are regarded as breeding objectives (Yan, 2014). Tolerance indices of these traits under drought stress will lead to effective selection of genotypes. The bi-plot recognized the best accession for a specific index or a group of indices, for instance, Accessions AKAC09, AKAC04, AKAC01, AKAC05, AKAC07 and AKAC10 were vertex accessions. Vertex accessions are the strongest accessions for any traits or indices which fall in similar sectors in the bi-plot (Yan et al., 2007; Atnaf et al., 2017). Therefore, in the present study, there were four major sectors resulting from the bi-plot. In the number of tillers index sector, the vertex accessions there were AKAC04 and AKAC01, high tolerant accessions. The vertex accessions in the plant height sector were AKAC05, a high tolerant accession. The vertex accessions in the grain weight index sector included AKAC07 and AKAC10, the least tolerant accessions. The vertex accession in the grain yield and spikelets per spike indices sector was AKAC09, the highest tolerant accession. AKAC09 was the highest grain yielder, and with the highest number of spikelets per spike under drought stress and control conditions, while the yields and spikelets per spike of AKAC07 and AKAC10 were consistently low. According to Batieno et al. (2016), stress tolerance index (STI) was the best index for screening for drought tolerance. The use of bi-plot analysis has proved effective for selection of accessions under drought stress by Li et al. (2015) in maize, Abdou Razakou et al. (2013), Tapia et al. (2016) in tomatoes, Batieno et al. (2016) and Ajayi et al. (2017a) in cowpea, Marcinska et al. (2017) in oat; Qaseem et al. (2019) in wheat.

Conclusion

The tested accessions exhibited high levels of genetic variability for all traits under drought stress. Stress tolerance indices identified three major categories of accessions: highly tolerant accessions (AKAC09 and AKAC03); the moderately tolerant accessions (AKAC05, AKAC06, AKAC08, AKAC04, AKAC01 and AKAC02) and the least tolerant accessions (AKAC10 and AKAC07). Four major groups of accessions were displayed by the bi-plot of stress tolerance indices. Groups I and II consisted of the moderately tolerant accessions, with only accessions AKAC04, AKAC01 and AKAC05 as vertex accessions. Group III consisted mainly of the least tolerant accessions (AKAC10 and AKAC07) as stable and a high tolerant accession as unstable. The last group consisted of the most tolerant accession (AKAC09) as highly stable, with the highest yield under both stressed and unstressed conditions. Stress tolerance indices were very efficient at identifying the different levels of tolerance among accessions. Grain yield, spikelets per spike and number of tillers tolerant indices were the strongest at discriminating accessions under drought stress. This information would be useful for effective selection of wheat genotypes for drought-prone environments in future breeding programs.

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