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Research Article

Drought tolerance assessment and trait associations in two wheat accessions under varying water stress conditions

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Abstract **–** This study aimed to assess drought tolerance in two wheat accessions (ATTILA-7 and RYENA-28) under different water stress conditions and examine trait associations. The accessions were subjected to well-watered, moderately watered, and drought-stressed treatments. Various yield and yield-determining traits were measured, including plant height, number of tillers, days to heading, spikelets per spike, seeds per plant, and grain yield. Significant differences were observed among accessions and treatments for most traits. RYENA-28 (AC2) performed better under drought stress. Correlation analysis revealed consistent negative correlations between the number of days to heading and the number of seeds per plant across treatments (-0.93, -0.89, and -0.93), while the number of seeds per plant consistently showed significantly positive correlations with grain yield per plant (0.96, 0.97, and 0.82) across treatments. Plant height exhibited negative correlations with the number of tillers and days to heading but positive correlations with grain yield. Notably, the number of spikelets per spike consistently correlated positively with the number of seeds per plant across treatments. These findings provide insights for breeding programs focused on drought tolerance in wheat, emphasizing the selection of accessions with shorter stature, increased spikelets, and higher seed production to develop drought-tolerant wheat varieties with improved yield potential.

Keywords – Accessions, Correlation Analysis, Drought Tolerance, Wheat Production, Yield-Determining Traits

I. INTRODUCTION

Wheat (*Triticum aestivum* L.) is a crucial cereal crop, providing vital nutrition and protein to billions of people worldwide [1]. With global production estimated at 761.5 million tonnes, wheat serves as a fundamental raw material for various food products and animal feed [2]. Its versatile uses range from baked goods and pasta to mulching and animal bedding.

Drought stress poses a significant challenge to wheat production in various agro-climatic environments, affecting millions of hectares globally [3]. In Nigeria, wheat cultivation has a long history, but it heavily relies on costly irrigation due to the dry season cropping period from November to March [4]. The Northern region, suitable for wheat cultivation, suffers from inadequate rainfall during the cropping season. These limitations, along with climatic demands, agronomic practices, and a preference for vegetable cultivation, have hindered national wheat production in Nigeria [5].

Drought imposes significant limitations on crop productivity worldwide, causing various detrimental effects on plant morphology, biochemistry, physiology, and molecular processes. Identifying drought-tolerant traits is crucial for assessing the impact of drought stress on plants and distinguishing between tolerant and susceptible genotypes [3], [6]. Improving both drought tolerance and yield simultaneously is essential for farmers to achieve profitable agricultural production under drought conditions [3]. Selecting genotypes based on yield-contributing traits can be more efficient than direct yield selection, although it requires extensive evaluation across multiple environments due to genotype-environment interactions [7], [8].

Limited information exists on the impact of drought stress on yield-determining traits in wheat in Nigeria [5], [9]. However, understanding the effects of drought stress on these traits and their correlation with yield is crucial for effective selection in wheat breeding programs. This study aimed to assess drought tolerance in wheat under varying levels of drought stress and analyze the strength of trait associations in the crop.

II. Materials and Method

The study was conducted at the Department of Plant Science and Biotechnology, Adekunle Ajasin University, Akungba-Akoko, Nigeria (Latitude 7.20 N, Longitude 5.44' E, and 423 m above sea level) between July 2017 and January 2018. Seeds of two wheat accessions (AC1: ATTILA-7 and AC2: RYENA-28) obtained from the Lake Chad Research Institute were used. The experiment included three watering regimes: well-watered (WW) (watered three times per week), moderately watered (MW) (watered two times per week), and drought-stressed (DS) (watered once per week) with 250 ml of water per pot. Topsoil was used (3.5 kg/pot), with 5 pots per treatment per accession in 3 replications (total of 90 pots) in a Completely Randomized Design (CRD). Five seeds were sown per pot, and data on plant height, and number of tillers were collected four weeks after sowing. Data on the number of days to heading were collected as plants flowered. However, data on the number of spikelets per spike, spike length, grain yield, 1000-grain weight, seeds per plant, and number of grains per spike were collected at maturity.

Data Analysis

Statistical analysis was performed using SPSS version 20, employing LSD for mean separation for accession by treatment interaction and DMRT for mean separation for the treatment effect at $P \leq 0.05$.

III. RESULTS

The mean square values for the yield-determining traits are presented in Table 1. The accession of wheat showed significant effects on most of the traits except 1000-grain weight. The watering regimes significantly affected all traits except the number of spikelets per spike. However, the interaction between accession and treatment showed significant effects on all traits but not significantly influenced the number of days to heading, number of spikelets per spike, and 1000-grain weight.

Table 2 presents the effect of the accession × treatment interaction on yield and yield-determining traits of wheat accessions under differential drought stress. The well-watered treatment resulted in the tallest plants, with a maximum height (71.57 cm) for AC2. The shortest plants were observed under the drought-stressed treatment, with a minimum height of 48.60 cm for AC1. The well-watered treatment resulted in the highest number of tillers (17.13) for AC1 while the lowest number of tillers (7.28) was observed under the drought-stressed treatment for AC2. The drought-stressed treatment significantly reduced the number of days to heading, with a minimum of 9 days for AC1 and 7 days for AC2. The well-watered treatment had the maximum number of days to heading. The well-watered treatment resulted in the highest number of spikes per plant, with a maximum of 10.67 for AC2. The drought-stressed treatment had the lowest number of spikes per plant, with a minimum of 3.07 for AC1 and 4.13 for AC2. Also, the spike length was the highest (7.40 cm) under the well-watered treatment for AC2 while the lowest (6.37 cm) was observed for AC1 in the drought-stressed treatment. While no significant differences were observed among treatments and accessions for the number of spikelets per spike, the well-watered treatment resulted in a higher number of seeds per plant compared to the drought-stressed treatment, with a maximum of 132.80 g for AC1. The minimum values for both accessions were observed under the drought-stressed treatment. The well-watered treatment produced a significantly higher 1000-grain weight and grain yield compared to the other treatments, with a maximum of 6.77 g and 5.63 g, respectively for AC1. The drought-stressed treatment had the lowest 1000-grain weight and grain yield.

Table 3 presents the effect of different treatments (well-watered, moderately watered, and drought-stressed) on various yield and yield-determining traits of wheat accessions. The well-watered treatment resulted in the best performance for all the traits followed by the moderately watered treatment and drought-stressed treatment except for the number of days to heading where the drought-stressed treatment was the best, followed by moderately-watered, and well-watered treatment. There were significant differences in plant height among the treatments, indicating that water availability influenced plant height. However, the number of days to heading, number of spikelets per spike, and 1000-grain weight did not vary significantly among the treatments.

Table 4 presents Pearson's correlation coefficients among various yield and yield-determining traits of wheat accessions under different treatments. The number of days to heading exhibited consistently significant negative correlations across the treatments (-0.93, -0.89, and -0.93) with the number of seeds per plant while the number of seeds per plant consistently had a significantly high positive correlation across treatments (0.96, 0.97, and 0.82) with grain yield per plant.

Table 1. Mean square values of yield and yield determining traits of accessions of wheat screened under differential drought stress

Source of variation	DF	PH (cm)	NT	NDH	NS	SL	NSPS	NSDS	GW (g)	GY (g)
Accession (A)	1	640.82*	47.21*	69.62*	42.94*	2.35*	72.80*	5122.41*	0.50^{ns}	5.06*
Treatment (T)	2	214.83*	89.39*	5.21*	29.09*	0.41*	9.15^{ns}	13706.6*	8.17*	13.37*
A × T	4	14.31*	3.43*	0.74^{ns}	6.88*	0.21*	9.77^{ns}	705.57*	3.50^{ns}	0.49*
Error	12	12.56	2.22	2.63	1.27	0.11	9.99	368.33	5.39	0.31

*: ***Significant at 5%; ns: Not significant.***

PH: Plant height; NT: Number of tillers; NDH: Number of days to heading; NS: Number of spikes per plant; SL: Spike length; NSPS: Number of spikelets per spike; NSDS: Number of seeds per plant; GW: 1000-grain weight; GY: Grain yield per plant.

Table 2. Effect of accession × treatment interaction on yield and yield-determining traits of wheat accessions screened under differential drought stress

Treatment	PH (cm)		NT		NDH		NS		SL (cm)	
	AC1	AC2	AC1	AC2	AC1	AC2	AC1	AC2	AC1	AC2
WW	57.87^{b}	71.57^{b}	17.13^{b}	14.00^{b}	47.33^{b}	42.90^{a}	$5. 33^{b}$	10.67^{c}	$6. 77^{a}$	$7. 40^{b}$
MW	52.67^{b}	66.40^{b}	16.20^{b}	11.40^{b}	45.70^{ab}	41.47^{a}	4.20^{ab}	7.07^{b}	6.20^{a}	7.33^{ab}
DS	48.60^{a}	56.97^{a}	9.07^{a}	7.28^{a}	45.00^{a}	41.87^{a}	3.07^{a}	4.13^{a}	6.37^{a}	6.77^{a}
±SE	2.05		0.86		0.94		0.65		0.19	
LSD	6.32		2.65		2.88		2.01		0.59	

Mean values followed by similar superscripts within a column are not significantly different from one another at $P \leq 0.05$ using LSD. Values are means of measurements ± standard error. PH: Plant height; NT: Number of tillers; NDH: Number of days to heading; NS: Number of spikes per plant. WW: Well-watered; MW: Moderately watered; DS: Drought-stressed.

Table 2 cont'd.

Treatment	NSPS		NSDS		GW (g)		GY (g)	
	AC1	AC2	AC1	AC2	AC1	AC2	AC1	AC2
WW	24.33^{a}	17.47^{a}	132.80^{b}	85.87^{b}	31.33^{a}	30.33^{a}	4. 14^{b}	5. 63^{c}
MW	21.20^{a}	17.93^{a}	85.87^{a}	123.73^{c}	32.00^{a}	32.00^{a}	2.67^{a}	3. 94^{b}
DS	19.40^{a}	17.47^{a}	58.93^{a}	69.22^{a}	28.67^{a}	30.67^{a}	1.70^{a}	2.11^{a}
±SE	1.83		11.08		1.34		0.32	
LSD	ns		34.16		ns		1.00	

Mean values followed by similar superscripts within a column are not significantly different from one another at $P \leq 0.05$ using LSD. Values are means of measurements ± standard error. SL: Spike length; NSPS: Number of spikelets per spike; NSDS: Number of seeds per plant; GW: 1000-grain weight; GY: Grain yield per plant. WW: Well-watered; MW: Moderately watered; DS: Drought-stressed.

Table 3. Effect of treatment on yield and yield-determining traits of wheat accessions screened under differential drought stress

Treatment	PH (cm)	NT	NDH	NS	SL (cm)	NSPS	NSDS	GW (g)	GY (g)
WW	64.72^{c}	15.57^{b}	45.12^{a}	8. 00^{c}	7. 08^{b}	20.90^{a}	159.33^{c}	32.00^{a}	4.89^{c}
MW	59.53^{b}	13.80^{b}	43.58^{a}	5.63^{b}	6.77^{ab}	19.57^{a}	104.80^{b}	30.83^{a}	3.30^{b}
DS	52.78^{a}	8.18^{a}	43.43^{a}	3.60^{a}	6.57^{a}	18.43^{a}	64.08^{a}	29.67^{a}	1.90^{a}
±SE	1.45	0.61	0.66	0.46	0.14	1.29	7.84	0.95	0.23

Mean values followed by similar superscripts within a column are not significantly different from one another at $P \leq 0.05$ using DMRT. Values are means of measurements ± standard error. PH: Plant height; NT: Number of tillers; NDH: Number of days to heading; NS: Number of spikes per plant. SL: Spike length; NSPS: Number of spikelets per spike; NSDS: Number of seeds per plant; GW: 1000-grain weight; GY: Grain yield per plant. WW: Well-watered; MW: Moderately watered; DS: Drought-stressed.

Table 4. Pearson's correlations among yield and yield-determining traits of wheat accessions screened under differential drought stress

Trait	Treatment	PH (cm)	NT	NDH	NS	SL (cm)	NSPS	NSDS	GW (g)	GY (g)
PH (cm)	**WW**	1	-0.78	-0.81*	0.74	-0.79	-0.85*	0.72	-0.19	0. 70
	MW	1	-0.97**	-0.83*	0.73	0.95**	-0.86*	0.68	0.03	0.76
	DS	1	-0.47	-0.20	0.52	0.89*	-0.05	0.16	0.82*	0.58
NT	**WW**		1	0.43	-0.79	0.42	0.78	-0.34	0. 37	-0.24
	MW		1	0.84*	-0.65	-0.93**	0.73	-0.63	-0.07	-0.72
	DS		1	0.47	-0.19	-0.77	-0.20	-0.63	-0.69	-0.83*
NDH	**WW**			1	-0.57	0.65	0.48	-0.93**	0.48	-0.85*
	MW			1	-0.87*	-0.88*	0.72	-0.89*	0.19	-0.91*
	DS			1	-0.81*	0.33	0.27	-0.93**	0.04	-0.62

*****: Significant at P ≤0.01; *: Significant at P ≤0.05.*** PH: Plant height; NT: Number of tillers; NDH: Number of days to heading; NS: Number of spikes per plant. SL: Spike length; NSPS: Number of spikelets per spike; NSDS: Number of seeds per plant; GW: 1000-grain weight; GY: Grain yield per plant. WW: Well-watered; MW: Moderately watered; DS: Drought-stressed.

Table 4 cont'd.

Trait	Treatment	NS	SL (cm)	NSPS	NSDS	GW (g)	GY (g)
NS	**WW**	1	-0.73	-0.85*	0.33	-0.51	0. 18
	MW	1	0.85*	-0.86*	0.96**	-0.53	0.91*
	DS	1	0.21	-0.78	0.57	-0.27	0.23
SL (cm)	**WW**		1	0.86*	-0.43	-0.03	0.45
	MW		1	-0.84*	0.83*	-0.23	0.87*
	DS		1	0.03	0.49	0.81	0.81
NSPS	**WW**			1	-0.26	0.01	-0.25
	MW			1	-0.72	0.28	-0.72
	DS			1	0.07	0. 39	0. 29
NSDS	**WW**				1	-0.42	0. 96**
	MW				1	-0.48	0. 97**
	DS				1	0.22	0. 82*
GW (g)	**WW**					1	-0.16
	MW					1	-0.28
	DS					1	0.73
GY (g)	**WW**						1
	MW						1
	DS						1

*****: Significant at P ≤0.01; *: Significant at P ≤0.05.***

PH: Plant height; NT: Number of tillers; NDH: Number of days to heading; NS: Number of spikes per plant. SL: Spike length; NSPS: Number of spikelets per spike; NSDS: Number of seeds per plant; GW: 1000-grain weight; GY: Grain yield per plant. WW: Well-watered; MW: Moderately watered; DS: Drought-stresse

IV. DISCUSSION

Cereal crops face significant challenges due to drought, impacting agricultural productivity worldwide. Drought-induced yield loss is a major concern in agriculture. In this study, the effects of wheat accession and watering regime on various traits were examined. Significant effects of both factors were observed, and interactions between accession and treatment were evident, indicating accession-specific responses to drought stress. These findings highlight the potential of certain accessions with traits associated with drought tolerance, offering valuable prospects for breeding programs focused on developing drought-tolerant wheat varieties. Similar findings have been reported in wheat and other crop species, emphasizing the significance of these results [10], [11], [12].

The accession × treatment interaction influenced most of the traits in wheat. Well-watered conditions generally led to better performance in terms of seeds per plant, plant height, number of spikes per plant, 1000-grain weight, number of tillers, and grain yield per plant. Drought stress had negative effects on most of these traits but significantly enhanced the number of days to heading among the wheat accessions. However, some traits, such as the number of spikelets per spike and 100-grain weight, did not show significant differences among the treatments and accessions. Based on these observations, AC2 generally showed better performance in terms of plant height, number of days to heading, number of spikes per plant, spike length, and grain yield per plant, while AC1 showed better performance in terms of the number of tillers per plant. The results also demonstrate the significant impact of water availability on various yield traits of wheat. The well-watered treatment consistently resulted in better performance for most traits, including plant height, number of tillers, number of spikes, number of spikelets, 1000-grain weight, and grain yield per plant. These findings emphasize the importance of adequate water supply for maximizing wheat productivity and highlight the negative effects of drought stress on these traits. These results are similar to the findings of [13] in barley, [14] and [15] in wheat.

Drought stress leads to reduced plant height and tiller number, attributed to osmotic shock and impaired photosynthetic activities [14], [15]. Similarly, the present study observed decreased grain yield, 1000-grain weight, and yield-related traits under drought stress, consistent with findings by [16] and [17]. Drought-sensitive genotypes exhibited early heading and a shortened life cycle, while drought-tolerant varieties showed no significant difference in heading time [18], suggesting AC2 as a drought-tolerant genotype. Reductions in spike number, spike length, spikelets per spike, and seeds per plant align with the impact of drought on pollen sterility, disrupted photosynthesis, and nutrient transfer to grains [16]. Impaired photosynthesis and nutrient uptake efficiency are commonly associated with decreased 1000-grain weight and grain yield under drought stress [3], [19], [20].

The consistent correlations among traits such as seeds per plant with days to heading, and grain yield with seeds per plant suggest strong associations between these traits, regardless of the water availability conditions. They can provide valuable insights for breeding programs, as targeting one trait may have a predictable impact on the associated trait. For example, selecting wheat accessions with fewer days to heading may result in an increased number of seeds across different water availability conditions. Similarly, improving seeds per plant may lead to higher grain yield in wheat varieties under both well-watered and drought-stressed conditions. Correlation between yield and its component has also been reported by other researchers [5], [21], [22], [23].

The results revealed significant variations in most traits among the accessions under different treatments. Accessions with taller plant height tended to have fewer tillers, indicating an inverse relationship between these traits. Additionally, the number of days to heading was consistently negatively correlated with seeds per plant while seeds per plant consistently positively correlated with grain yield across treatments. Notably, the number of spikelets per spike exhibited consistent positive correlations with the number of seeds per plant across all treatments. These findings highlight the importance of considering specific trait associations in wheat breeding programs to enhance yield and stress tolerance. Selecting accessions with desirable trait combinations, such as earliness to heading, shorter plant height, and increased spikelet and seed production, could contribute to the development of improved wheat varieties capable of withstanding drought conditions and maximizing productivity.

V. CONCLUSION

The results revealed significant variations in most traits among the accessions under different treatments. Accessions with taller plant height tended to have fewer tillers, indicating an inverse relationship between these traits. Additionally, the number of days to heading was consistently negatively correlated with seeds per plant while seeds per plant consistently positively correlated with grain yield across treatments. Notably, the number of spikelets per spike exhibited consistent positive correlations with the number of seeds per plant across all treatments. These findings highlight the importance of considering specific trait associations in wheat breeding programs to enhance yield and stress tolerance. Selecting accessions with desirable trait combinations, such as earliness to heading, shorter plant height, and increased spikelet and seed production, could contribute to the development of improved wheat varieties capable of withstanding drought conditions and maximizing productivity.

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