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Original Research Article

Genetic variability of yield and yield-related traits among 27 drought-tolerant maize genotypes

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Abstract

Maize is a valuable crop with high genetic variability, and understanding this variability is essential for improving crop productivity and resilience to environmental stressors. This study evaluated the genetic variability and heritability of yield and yield-related traits among 27 drought-tolerant maize genotypes in a humid climate region of Southwestern Nigeria. The experiments followed rigorous agronomic, soil, and climatic requirements for maize cultivation. Our findings revealed significant genetic variability among the traits of the maize genotypes, particularly in the number of ears per plant, which had the highest genetic advancement as a percentage of the mean (68.25% and 67.83%) under both well-watered and drought conditions, respectively. This suggests that breeding programs targeting this trait could significantly improve maize productivity and resilience to drought stress. Additionally, most of the agronomic traits targeted were highly heritable with heritability values ranging from 0.76 to 0.99 under both environments where the genotypes were evaluated, thus indicating that selective breeding for these traits could lead to consistent improvements in maize yields over time. Overall, this study highlights the importance of evaluating yield-related traits' genetic variability and heritability in maize breeding programs. Findings suggest that targeting the number of ears per plant in drought-tolerant maize genotypes as revealed in the study could be an effective approach for improving crop productivity and resilience in regions with variable moisture regimes.

Keywords: Genotype * environment interaction; genetic advancement; selective breeding; heritability; agronomic traits; moisture regimes; *Zea mays*

INTRODUCTION

Maize (*Zea mays* L.) has one of the highest genetic yield potentials when compared to other cereal crops, earning it the title "queen of grains" (Dinesh et al., 2018). It is a staple crop that is widely used as both human and animal feed in Sub-Saharan Africa (SSA) (Adebayo and Menkir, 2015; Meseka et al., 2018). However, there is a need to maintain an appropriate grain supply for the swarming world population, which is expected to reach roughly nine billion by 2050. The current grain supply is insufficient and might result in unsustainable production techniques in the future (Gong et al., 2015). This change is anticipated to result from an increase in maize demand, which was projected to rise by 50% to 837 million tonnes by 2020 from 558 million tonnes in 1995.

A number of biotic (like diseases, pests, and weeds) and abiotic (like soil and climatic factors) filters have been identified as major constraints on optimal maize productivity during the growing season. Additionally, given the growing demand for maize, its production must be increased to ensure that its demand and supply curve is well balanced (Ramirez-Cabral, 2017). Wossen et al. (2017) emphasised the susceptibility of maize productivity to climate change and how the changing environment would most likely affect the yield potential of maize among the stated biotic and abiotic filters. This may be the cause of the more severe, lengthy, and frequent drought periods that have had a blatantly detrimental impact on maize output. According to Wossen et al. (2017), Africa has roughly 40% of its maize-growing areas experience intermittent drought stress, with corresponding yield losses of between 10% and 25%. By 2050, climate change is also anticipated to cause SSA to produce 22% less maize. This story inspired the creation of irrigation systems to reduce the effects of drought on maize yield, and more recently, the creation of drought-tolerant maize varieties that thrive in moisture-restrictive environments (Sabagh et al., 2018).

A significant portion of Nigeria's maize-growing regions experience drought every year, which often occurs during the crop's reproductive season and reduces grain yields (Adebayo and Menkir, 2015). In addition, high-temperature regimes frequently accompany dry conditions with evapotranspiration, which causes very significant amounts of plant and soil moisture to be lost and reduces the amount of moisture that crops have access to for ideal development and production. Additionally, this is based on the idea that as global temperatures rise, drought impact and intensity would likewise climb (Kinama et al., 2005).

The major source for breeding is still genetic material. The ability of breeders to choose materials and genetically develop such germplasm will unquestionably be impacted by a thorough assessment of the genetic materials, genetic characteristics, and genetic diversity of maize germplasm resources. By utilising association analysis and genetic variance among such characteristics, it will also set the groundwork for the examination of the genetic basis for complex quantitative traits. In future maize breeding operations, knowing which characteristics to load more for an improvement in yield will be possible with a solid grasp of the genetic variability among traits. But this will significantly enhance production for farmers and the supply chain.

According to Edmeades (2013), the difference in grain output between the well-watered and drought circumstances during the growing season might be narrowed by genetic modification of maize lines for drought tolerance. Due to this, several varieties of drought-tolerant maize germplasm have been discovered and created (Adebayo et al., 2015). However, the new drought-resistant maize genotypes' performance under drought circumstances must be determined. This is often evaluated against a well-watered environment to gauge how the genotypes perform under various circumstances and compare them to a locally grown variety to see how much better any new maize lines are. As a result, it is crucial to assess newly created maize lines for their intrinsic performance in order to reflect the real idea of crop drought resistance. Twenty-seven drought-tolerant maize genotypes were tested in this study during two growing seasons to better understand how yield and other yield-related parameters varied.

In this study, we investigated the genetic variability amongst drought-tolerant maize (*Zea mays*) using yield and yield-related traits with the null hypothesis: There is no relationship between yield and other agronomic traits amongst drought-tolerant maize for selective breeding programs.

MATERIALS AND METHODS

Experimental sites

The field experiment was carried out at the Teaching and Research Farms, Directorate of University Farms (DUFARMS), Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, (Lat. 7°12′N and Long. 3°20′E) derived savannah zone of South-Western Nigeria. It has a humid climate with a mean annual rainfall of about 1422 mm and a temperature of about 32.0 °C. The relative humidity ranges between 68–84% in the rainy season (late March–October) and 54–82% in the dry season (November–early March), with an annual average of 73.2% (FUNAAB Agrometeorological Station, 2019). The seasonal distribution of yearly rainfall is such that, approximately 52.2 mm occurs in the late dry season (January–March); 190.8 mm in the early wet season (April–June); 90.2 mm in the late wet season (July–September) and 140.7 mm in the early wet season (October–December) (FUNAAB Agrometeorological station, 2019). The field experiments were conducted during the June 2019 – February 2020 growing season (rainy season (Well-watered): June–October 2019; dry season (Drought): November 2019 – February 2020).

Table 1. Means of agrometeorological observations from June 2019 to March 2020

		2019							2020		
		June	July	August	September	October	November	December	January	February	March
Maximum temp. °C		30.9	29.3	29.6	30.1	30	32.1	33.9	35.8	37.2	35.3
Minimum temp. °C		23.2	23.2	23.7	23.1	22.7	23.8	22.1	20.2	21.6	24.8
Mean temp. °C (max/min)		27.1	26.3	26.6	26.6	26.3	27.9	28	26.8	29.4	30.1
Rainfall (mm)		264.5	108.7	65.8	96.3	310	112.3	0	0	0	145.1
Rel. Humidity %		76.9	79.7	73.6	81.1	83.9	82.3	80.5	75	68.2	73.7
Sunshine hours		3.7	2.2	2.5	2	1.7	5.3	5.1	4.2	2.61	7.2
Evaporation (mm)		-	1.4	1.6	2.4	3.2	6	3	4.7	3.9	3.2
Soil temperature °C	10CM	27.3	26.7	26.5	26.7	26.4	26.3	27.6			
	20CM	27.8	27.2	26.7	27.2	26.7	26.7	28.1			
	30CM	28.1	27.4	27.1	27.6	27.3	28.2	28.6			
	50CM	28.1	28	27.6	28.3	27.9	28.9	29.2			

Source: Federal University of Agriculture, Abeokuta, Nigeria , Agro-meteorological Station

Table 2. Description and source of maize genotypes used in this study

Entry	Pedigree	Source	Description
1.	White DT STR Syn/TZL COMP1-W F2	07A04207	Open Pollinated
2.	TZL COMP1-W C6/DT SYN-1-W	07C05409	Open Pollinated
3.	DTSTR-W SYN2	07C05410	Open Pollinated
4.	DTSTR-Y SYN2	07C05411	Open Pollinated
5.	DT SYN2-Y	11A11988	Open Pollinated
6.	Z. DIPLO BC4 C3-W DT C1	12C24117	Open Pollinated
7.	TZL COMP4 C3 DT C2	14C31968	Open Pollinated
8.	TZL COMP3 C3 DT C2	14C31969	Open Pollinated
9.	TZL COMP3 C4	07A04207	Open Pollinated
10.	TZL COMP4 C4	07A04208	Open Pollinated
11.	ACR06 TZL COMP3 C4	11A11895	Open Pollinated
12.	ACR06 TZL COMP4 C4	11A11896	Open Pollinated
13.	AFLATOXIN SYN-W4	11A11990	Open Pollinated
14.	Synldfo/Obantanpa/TZL Comp 3 C3*2	12C24114	Open Pollinated
15.	OBATANPA/IWD-C2 SYN	12C24122	Open Pollinated
16.	AFLATOXIN SYN5	14A21603	Open Pollinated
17.	IWD C3 SYN/DT.STR SYN-W-1	14A21605	Open Pollinated
18.	OBATANPA/TZL COMP3	14A21621	Open Pollinated
19.	TZL COMP3 C5	16A21537	Open Pollinated
20.	TZL COMP4 C5	16A21538	Open Pollinated
21.	TZL COMP4 C3 DT C2/HicoryKing	17A16499	Open Pollinated
22.	DT STR-W SYN12	16A20626	Open Pollinated
23.	IWD C3 SYN/DT SYN-1-W	16A20634	Open Pollinated
24.	IWD C3 SYN F3	MK-Breeder	Open Pollinated
25.	IWD C2 SYN F2	MK-Breeder	Open Pollinated
26.	SAMMAZ 52	IB16A-20625	Open Pollinated
27.	TZB-SR		Open Pollinated

*Local Check Oba Super

Twenty-seven open-pollinated, drought-tolerant maize genotypes were used for the study, and they were sourced from the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. In addition, a local check genotype was sourced from the open market and used as the control genotype (Table 2).

The twenty-seven (27) maize genotypes were evaluated under two different environments (Natural rain-fed and Natural Drought environments). The experiment was laid out in a Randomised Complete Block Design (RCBD) with three replicates in single-row plots in each environment during each season. The maize genotypes (the treatments) were randomised within each replicate (representing the blocks). The materials were evaluated between June 2019 and February 2020. Before planting, soil samples were collected randomly from representative spots of the entire experimental field using a diagonal sampling method at a depth of 0–15 cm using a soil auger. The samples were bulked per replicate, mixed thoroughly and sub-samples taken for analysis to determine the pre-planting nutrient status of the soil.

Agronomic practices

Following conventional tillage operations, the experimental land area was cleared, plowed, and allowed to rest for two weeks before harrowing. An experimental land area measuring 18.5 m × 17.25 m (320 m^2) was mapped out after harrowing so that each plot measured 0.75 m × 7.5 m with a one metre avenue between plots and blocks. In the second year of the field experiment, manual clearing of weeds in the experimental land area was the only land preparation exercise before re-planting the maize seeds.

The maize genotypes were planted manually. The maize seeds were planted at two per hill with a spacing of 0.75 m (inter-row) × 0.50 m (intra-row) spacing with an established plant density of 53,333 plants/ha. The plots were adequately labelled to indicate the maize genotypes. During the rainy season environment (well-watered condition), the maize genotypes were planted in the second week of June 2019, while planting of the maize in the drought season was done in the first week of October 2019. Planting followed recommended soil, climatic and agronomic standards for maize.

Twelve (12) plants were randomly selected per plot (genotype), tagged, and used for data collection; the grains dried on the stalks were harvested at physiological maturity. Data were recorded on nineteen (19) agro-morphological characters, namely: Plant and ear heights were recorded on selected plants, as the distance from the ground to the base of the tassel and the upper ear, respectively, number of ears per plant (EPP) was computed as the proportion of the total number of ears harvested divided by the total number of plants at harvest. The plant aspect was visually scored on a scale of 1 to 5, where 1 = excellent overall phenotypic appeal and 5 = poor overall phenotypic appeal. Similarly, the ear aspect was scored on a scale of 1 to 5, where 1 = clean, uniform, large, and well-filled ears and 5 = rotten, variable, small, and partially filled ears. All ears harvested from each plot were shelled and used to determine the percentage of grain moisture and grain weight. Grain yield adjusted to 15% moisture was computed from each plot's grain weight. The number of leaves was recorded as the number of open green leaves at anthesis, leaf blade length, and leaf blade width were recorded in cm as the length and width of the longest and widest leaf of the plant, respectively. Leaf area was the multiplication of the leaf blade length and leaf blade width. *Rust polysora* and *Blight maydis* were scored visually on a scale of 1–5, where 1 is no rust, and no blight, and 5 is severe rust and severe blight. The cob weight, which was the weight of harvested cobs per kg, was also obtained. Days to anthesis and silking were recorded as the number of days from planting to when 50% of the plants in a plot were shedding pollen and had emerged silks, respectively. Leaf death and whole cob were recorded on a scale of 1–10, where 1 is dead leaf and poorly filled cobs, and 10 is dead leaf area and wholly filled crops. The length of cobs was also measured in cm, and the husk cover was recorded on a scale of 1–5, where 1 is husked tightly arranged and extended beyond the ear tip, and 5 is open tip cover.

Data analysis

Data obtained for quantitative characters were subjected to analysis of variance (ANOVA) using the Statistical Analysis Software version (2001). Stepwise regression analysis and sequential path diagrams were used to show the cause-and-effect relationships among traits in the present study. R Statistical software was used for the stepwise regression analyses to obtain information on the path coefficients and the causal relationships required for the path diagrams. Following the method proposed by Mohammadi et al. (2003), the predictor traits were organised into first, second, and third order, based on their contributions to the total variation in grain yield, with minimised multicollinearity (Badu-Apraku et al., 2014; Talabi et al., 2017). To perform the stepwise regression analysis, grain yield was regressed on measured traits to identify traits with significant contributions to the total variation in grain yield at $p \leq 0.05$, which were categorised as first-order traits. The first-order traits thereafter were each regressed on other traits that were not in the first-order category to identify traits with significant contributions to grain yield through the first-order traits. These traits were classified as second-order traits. The same procedure was repeated to identify third-order trait(s), and so on. The path coefficients were obtained from the standardised b values of the stepwise regression analysis (Badu-Apraku et al., 2014; Talabi et al., 2017).

The significance of the path coefficients was tested using the SEs at the 0.05 probability level, with only traits having significant path coefficients retained in each order. Factor analysis was carried out to determine the traits that majorly explained the variability in the grain yield of the 27 maize genotypes.

RESULTS

Exploratory factor analysis for determination of traits that mostly influenced grain yield

All of the 20 measured growth traits were assessed. The Eigenvalue criterion was used to select a number of components that best accounted for most of the variability in the grain yield. Factor analysis was initially modelled for each planting condition (well-watered and drought); however, the combined analysis was later used because the traits that emerged under the well-watered conditions emerged under the drought conditions, albeit, with different factor components loading scores. Given that the differences between the scores were marginal, the result of the combined factor analysis was used. Eigenvalues and scree plots were used to identify the number of component factors that would be retained. The commonly accepted of keeping only components with Eigenvalues larger than 1 was used to screen the emerging 27 components. Of the 27 components, four components with Eigenvalues 6.82, 2.72, 2.03, and 1.50 were retained – given the Eigenvalue-one criterion (Table 3; see Figure 1 for screen plot).

The first component explained 52% of the data variation, and grain yield loaded very highly (0.90) on the component. Grain yield was poorly loaded (less than 40%) on the other components; as a result, they were not used to screen the traits. Other traits that loaded highly onto the first component were: Number of leaves, plant height, Number of ears per plant, leaf width, leaf area, ear height, cob weight, whole cob, and plant aspect ratio. This implied that these variables had high levels of association with grain yield, and because all trait value loading scores were positive, an increase in any other said trait would increase the value of the component and consequently increase grain yield. Variable with component loadings less than 0.40 or 40% were not deemed influential and were screened out. Variables that had high loading scores on the first component also had high levels of commonalities – h2

Table 3. Exploratory factor analysis to determine traits that mostly influenced grain yield

	PC1	PC2	PC3	PC4	h2	u2	Communality
Number of leaves	**0.78**	0.12	-0.16	0.02	0.65	0.35	1.1
Plant height	**0.82**	0.22	-0.01	0.04	0.72	0.28	1.1
No of ears per plant	**0.91**	-0.01	-0.01	0.12	0.84	0.16	1.0
Leaf length	0.16	-0.08	**0.66**	-0.15	0.50	0.50	1.3
Leaf width	**0.83**	0.11	-0.09	-0.05	0.72	0.28	1.1
Leaf area	**0.85**	-0.02	0.09	-0.08	0.73	0.27	1.0
Ear height	**0.68**	-0.13	0.04	**0.48**	0.71	0.29	1.9
RU	-0.01	**0.77**	0.20	0.28	0.72	0.28	1.4
BL	0.13	**0.84**	-0.08	0.09	0.74	0.26	1.1
Cob weight	**0.82**	-0.11	0.05	-0.21	0.74	0.26	1.2
Husk cover	-0.09	**-0.58**	**0.65**	0.17	0.79	0.21	2.2
Whole Cob	**0.45**	-0.27	0.06	**-0.54**	0.56	0.44	2.5
CL	0.12	-0.33	0.21	0.38	0.31	0.69	2.8
LD	0.06	**0.66**	0.17	-0.22	0.51	0.49	1.4
Ear aspect ratio	-0.19	0.09	-0.08	-0.26	0.12	0.88	2.3
Plant aspect ratio	**0.43**	**0.47**	0.13	-0.17	0.45	0.55	2.4
Days to Silking	-0.19	0.06	-0.06	**0.68**	0.51	0.49	1.2
Days to Anthesis	0.15	-0.22	**-0.74**	-0.07	0.63	0.37	1.3
Asynchrony index	-0.12	0.20	**0.64**	0.10	0.47	0.53	1.3
Grain yield	**0.90**	0.06	-0.02	-0.08	0.82	0.18	1.0
Eigen values	6.82	2.72	2.03	1.50			
Proportion of variance explained (%)	52.00	18.00	14.00	10.00			
Cumulative proportion of variance explained (%)	52.00	70.00	84.00	94.00			

PC: Principal component: h2: common variance; u2: unique variance. RU: Rust; BL: Blight; CL: Cob Length; LD: Leaf Death

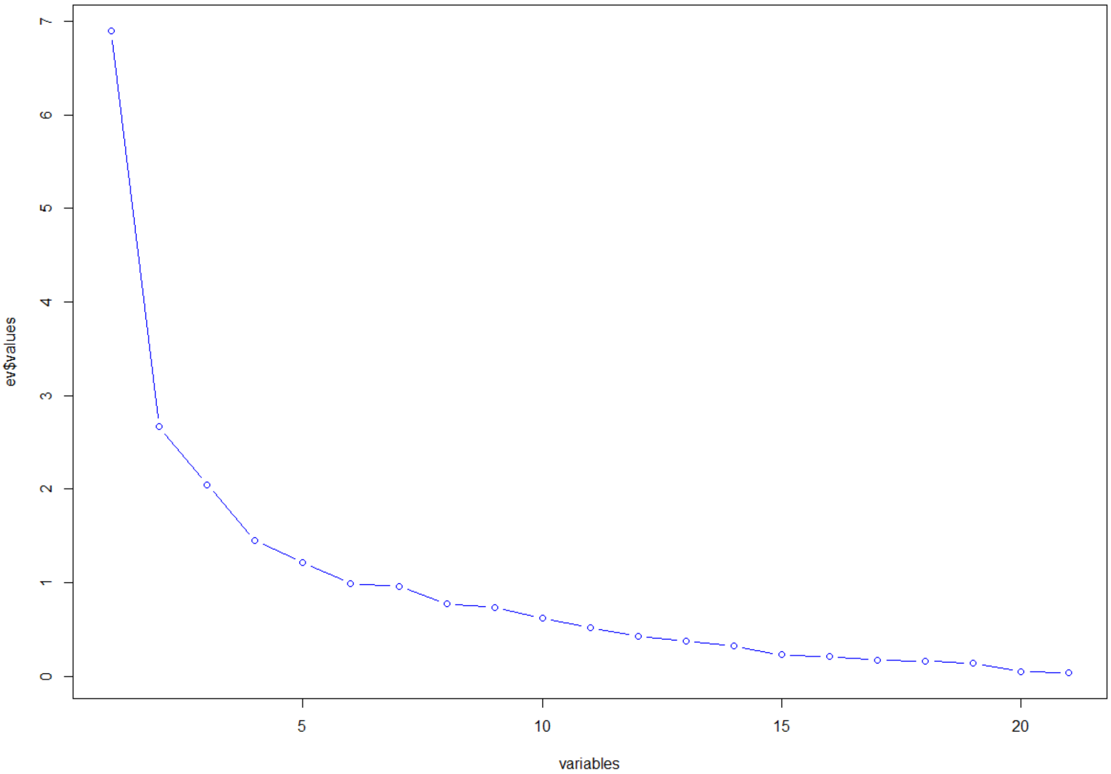

Figure 1. Screen plot showing the selection of component factors based on Eigen values

(i.e. the extent to which the factor components can explain the variable), and low levels of uniqueness – u2 (i.e. the extent to which the variable cannot be explained by the factors). This implies that the levels of association between the traits are very high.

Variability of the grain yield and selected yield-related traits among 27 drought-tolerant maize genotypes under well-watered and drought conditions

The variability analysis of the selected growth traits under well-watered and drought conditions is presented in Tables 4 and 5. In all the measured traits, the value of the genotypic variance was higher than the value of the environmental variance. This resulted in very high phenotypic variance (genotypic + environmental variance) for all the measured traits. Most of the traits were very heritable, with heritability values (broad sense) ranging from 0.76–0.98 under well-watered conditions and 0.66–0.99 under drought conditions. The number of ears per plant had the highest genetic advancement as a percentage of the mean value (68.25 % and 67.83 % under well-watered and drought conditions, respectively).

There were variations between the mean values of the traits under well-watered and drought conditions. Traits values were higher under the well-watered conditions than in the drought conditions. The number of leaves produced by the plants had mean values ± SEM of 31.61 ± 0.72 and 21.81 ± 0.71 under well-watered and drought conditions. The plants were also taller and produced more ears per plant under the well-watered condition than in the drought condition (177.95 ± 4.62 and 123.32 ± 4.02 for plant height and 4.58 ± 0.13 and 3.22 ± 0.12 for the number of ears per plant under well-watered and drought conditions, respectively). Traits values for leaf width were 11.39 ± 0.28 and 7.84 ± 0.23 under well-watered and drought conditions, while mean leaf area values recorded under the well-watered and drought conditions were 727.61 ± 16.79 and 501.31 ± 16.58, respectively.

There were also variations in the ear height and cob weight values under the well-watered and drought conditions. Under the well-watered condition, the ear height and cob weight values were 90.46 ± 1.73 and 62.87 ± 2.30, respectively, while under drought conditions, trait values were 10.98 ± 0.27 and 7.58 ± 0.24, respectively. Mean whole cob values were 0.40 ± 0.04 and 0.28±0.05, while mean plant aspect ratio values were 3.42 ± 0.09 and 2.39 ± 0.07 under well-watered and drought conditions, respectively. There were also

Table 4. Variability of the grain yield and selected yield-related traits among 27 drought-tolerant maize genotypes under well-watered and drought conditions

Condition		NOL	PH	NOEPP	LW	LA
Well-Watered condition	Maximum	46.37	255.08	7.99	14.31	926.05
	Minimum	20.23	106.1	2.11	9.77	557.39
	Grand Mean	31.61	177.95	4.58	11.39	727.61
	Standard Error of Mean	0.72	4.62	0.13	0.28	16.79
	Co-efficient of Determination (5 %)	2.05	13.07	0.37	0.79	47.6
	Co-efficient of Determination (1 %)	2.73	17.41	0.49	1.06	63.39
	Environmental Variance	1.57	63.77	0.05	0.23	845.4
	Genotypic Variance	50.55	1562.02	2.35	0.73	6621.84
	Phenotypic Variance	52.12	1625.77	2.40	0.97	7467.24
	Environmental co-efficient of variance	3.97	4.49	4.87	4.26	4.00
	Genotypic co-efficient of variance	22.49	22.21	33.48	7.5	11.18
	Phenotypic co-efficient of variance	22.84	22.66	33.83	8.63	11.88
	Heritability (Broad sense)	0.97	0.96	0.98	0.76	0.89
	Genetic advance	14.42	79.8	3.13	1.53	157.86
	Genetic advance (% of Mean)	45.63	44.85	68.25	13.45	21.7
Drought	Maximum	32.88	179.93	5.56	9.87	655.88
	Minimum	14.34	76.09	1.45	6.44	391.32
	Grand Mean	21.81	123.32	3.22	7.84	501.31
	Standard Error of Mean	0.71	4.02	0.12	0.23	16.58
	Co-efficient of Determination (5 %)	2.02	11.40	0.34	0.66	47
	Co-efficient of Determination (1 %)	2.69	15.18	0.45	0.88	62.6
	Environmental Variance	1.52	48.50	0.04	0.16	824.55
	Genotypic Variance	22.18	721.41	1.17	0.35	2464.02
	Phenotypic Variance	23.71	769.91	1.22	0.51	3288.57
	Environmental co-efficient of variance	5.66	5.60	6.47	5.16	5.73
	Genotypic co-efficient of variance	21.59	21.61	33.53	7.54	9.9
	Phenotypic co-efficient of variance	22.32	22.32	34.15	9.14	11.44
	Heritability (Broad sense)	0.94	0.94	0.96	0.68	0.75
	Genetic advance	9.38	53.56	2.19	1.01	88.51
	Genetic advance (% of Mean)	43.02	43.08	67.83	12.82	17.66

NOL: Number of leaves; PH: Plant height (m); NOEPP: Number of ears per plant: LW: Leaf width(m): LA: Leaf area (m^2)

significant variations between the grain yield values obtained under the well-watered (3.44 ± 0.07) and drought (2.39 ± 0.08) conditions.

DISCUSSION

Screening for yield and yield-related traits

In order to increase the ability to statistically identify high-performing genotypes under contrasting environments and increase precision, the maize traits were screened using factor analysis so that the traits that best account for the variability in grain yield could emerge. Factor analysis has been used by several researchers to dissect the traits correlation in different crop plants (Burgueño et al., 2011) and was employed at the early stages of analysis to allow for a keen focus on just the traits that quantified grain yield.

Factor analysis separates genetic effects into common and specific components, increases the accuracy of genotypic selection in plant breeding multi-environment trials, produces a lower standard error of the BLUPs, and substantially reduces the computational requirements of mixed model analyses compared to standard multivariate models (Crossa et al., 2006). Ten traits emerged from the analysis and were the traits (number of leaves, plant height, no of ears per plant, leaf width, leaf area, ear height, cob weight, whole cob, and plant aspect ratio) linked to grain yield under the first component which served as the screening component. These traits could be used as a selection index for the genetic improvement of maize. Traits selection was made under a combined analysis of the well-watered and drought conditions, and the positive loadings of the selected traits imply that they

Table 5. Variability of the grain yield and selected yield-related traits among 27 drought-tolerant maize genotypes under well-watered and drought conditions

Condition		EH	CW	WC	PASP	GRY
Well-Watered condition	Maximum	114.76	16.34	6.91	4.35	5.82
	Minimum	71.81	7.76	0.11	2.29	2.48
	Grand Mean	90.46	10.98	0.40	3.42	3.44
	Standard Error of Mean	1.73	0.27	0.04	0.09	0.07
	Co-efficient of Determination (5 %)	4.92	0.76	0.10	0.24	0.21
	Co-efficient of Determination (1 %)	6.55	1.02	0.14	0.32	0.27
	Environmental Variance	9.02	0.22	0.004	0.02	0.02
	Genotypic Variance	75.01	2.55	1.44	0.2	0.78
	Phenotypic Variance	84.03	2.77	1.45	0.23	0.8
	Environmental co-efficient of variance	3.32	4.24	15.83	4.33	3.65
	Genotypic co-efficient of variance	9.57	14.54	2.46	13.2	25.71
	Phenotypic co-efficient of variance	1013	15.15	2.88	13.9	25.96
	Heritability (Broad sense)	0.89	0.92	0.98	0.90	0.98
	Genetic advance	16.86	3.16	2.47	0.88	1.81
	Genetic advance (% of Mean)	18.63	28.76	6.95	25.84	52.43
Drought	Maximum	82.18	10.51	4.92	3.16	4.05
	Minimum	42.27	5.36	0.07	1.76	1.63
	Grand Mean	62.87	7.58	0.28	2.39	2.39
	Standard Error of Mean	2.30	0.24	0.05	0.07	0.08
	Co-efficient of Determination (5 %)	6.53	0.69	0.14	0.19	0.23
	Co-efficient of Determination (1 %)	8.70	0.92	0.19	0.26	0.31
	Environmental Variance	15.94	0.18	0.007	0.01	0.02
	Genotypic Variance	30.6	1.26	0.65	0.11	0.37
	Phenotypic Variance	46.54	1.43	0.66	0.12	0.4
	Environmental co-efficient of variance	6.35	5.57	31.04	4.93	5.9
	Genotypic co-efficient of variance	8.80	14.78	2.01	13.63	25.63
	Phenotypic co-efficient of variance	10.85	15.79	2.64	14.49	26.29
	Heritability (Broad sense)	0.66	0.88	0.99	0.88	0.95
	Genetic advance	9.24	2.16	1.66	0.63	1.23
	Genetic advance (% of Mean)	14.7	28.49	6.25	26.4	51.45

EH: Ear height (m); CW: Cob weight (kg); WC: Whole cob; PASP: Plant aspect ratio; GRY: Grain yield (Tonnage)

are the traits that can be best used for improvements in grain yield. Overall, the consistent identification of traits under contrasting environments confirmed their reliability for selection to improve grain yield across diverse environments.

The association of grain yield with plant height and the number of leaves has been well reported in the literature when maize lines are screened for high-yield performance (see Adu et al., 2016; Badu-Apraku et al., 2018). It is possible that by increasing plant height and the number of leaves, the plants would be tall enough for sunlight capture and produce more leaves to improve the incidence of sunlight capture for photo-assimilate production, resulting in the accumulation of more biomass for high nutrient storage in plant storage sinks such that higher grain yields can be produced. Mwadzingeni et al. (2016) also reported similar findings for some screened maize lines and gave similar reasons as in this study for the relationship between the number of leaves, plant height, and grain yield. An expected association between grain yield, the number of ears per plant, and cob weight was observed in this study. This finding was expected because the production of a higher number of maize ears and heavier cobs has been reported to raise the potential that grain yield would be higher (Adu et al., 2016). Similar findings have been reported in a previous study (Mogesse et al., 2020). The screening of traits using factor analysis also revealed that the cob weight and the number of ears are highly correlated with grain yield. Also, Meseka et al. (2006) have reported that during the selection process, the plant aspect ratio is one of the traits that can be used to effectively model grain yield, especially when working with drought-resistant maize lines.

Variability of the grain yield and selected yield-related traits of 27 drought-tolerant maize genotypes under well-watered and drought conditions

These results revealed that – for all the measured traits – there was higher genotypic variance than phenotypic variance values under the well-watered and drought conditions. This suggested that the cultivars were genetically distinct in expressing these traits, which should facilitate the identification and selection of superior cultivars under the conditions (i.e., well-watered and drought environments). The observed differences in environmental variance recorded for the traits under the different conditions revealed that the environments were unique in discriminating among the accessions under well-watered and drought environments. These findings corroborate the results reported by Badu-Apraku and Fakorede (2013), who compared 50 early-maturing maize cultivars developed during three breeding eras under drought stress and optimal environments. Overall, the genotypic and phenotypic variation indicates the existence of high levels of heterogeneity among the maize genotypes, and judging the maize genotypes based on the classification system outlined by Mazid et al. (2013), the maize traits could be adjudged to have intermediate to high genotypic co-efficient of variation and low phenotypic coefficient of variation. In essence, the traits' considerable expression was determined by gene action and not by the environment.

The high genotypic variance coefficient is an indication that the development of the traits would be easier (Khan et al., 2020). Also, given the relatively high recorded heritability values, the traits are deemed very heritable and controlled by the additive gene action. The environmental effects placed very slight constraints on trait expression (Khan et al., 2020; Mazid et al., 2013; Usman et al., 2014). This implies that a significant proportion of the trait plasticity observed in this study was controlled by the genetic component of the plants, with the environment having very minimal influence on how they are expressed; as such, very powerful selection can be attained given that the additive gene effects are much stronger than the environmental effects (Usman et al., 2014).

This study also shows reliable genetic progress for the traits over time with fairly consistent results under well-watered and drought conditions. The number of ears per plant and grain yield traits' has higher levels of genetic progress than the other traits implying that direct improvement of the traits would be relatively easier (Usman et al., 2014). This study also showed that very slight variations existed in the genetic advancement of the traits under the well-watered and drought condition, giving further credence to the fact that the maize lines were developed for drought conditions.

Overall, the variability analysis results show that improvement of grain yield and yield-related traits is possible through direct genotypic selection, given the heritability of the traits and genetic advances.

CONCLUSION

In conclusion, this study summarises the variability that exists amongst drought-tolerant maize genotypes; the study reveals that the number of ears per plant has a direct relationship with grain yield, which indicates that when breeding for grain yield, targeting the number of ears per plant traits can make grain yield to increase.

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CONFLICT OF INTEREST

The authors declared no conflicts of interest with respect to the research, authorship, and publication of this article.

ETHICAL COMPLIANCE

The authors have followed ethical standards in conducting the research and preparing the manuscript.

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