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ASSESSMENT OF INTER-TRAIT RELATIONSHIP AND IDENTIFICATION OF KEY SELECTION TRAITS FOR DROUGHT TOLERANCE IN MAIZE (*ZEA MAYS* L.) INBRED LINES UNDER WATER-STRESS CONDITIONS

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ABSTRACT

Drought is a major constraint on crop production especially in maize. It significantly reduces productivity, affecting the livelihoods of millions and the overall economy. Malnutrition due to lack of essential nutrients like Vitamin A is another major challenge in many African countries. Breeding for pro-vitamin A drought-tolerant maize varieties is crucial to address these. Knowledge and understanding of interrelationships between grain yield and yield-related traits would ensure progress from selection in maize breeding programs through the use of appropriate selection indices. 107 pro-vitamin A maize inbred lines along with 3 testers were screened for drought tolerance in Samaru and Bagauda in 2020/2021 dry season to assess the relationship between grain yield and yield-related traits. The experiments were laid out in a 10 x 11 alpha lattice design and replicated two times using single-row plot of 5m long. Inbred lines with high tolerant index values were identified; SLMP-59 has the highest index value (18.06) with a low yield reduction percentage of 38.07% making it the best drought response. The inbred SLMP-3 turns out to be most drought susceptible with drought index value of -12.59 and yield reduction of 83.39% The negative genotypic association of days to pollen ($r_g = -0.80^{**}$) and days to silking ($r_g = -0.79^{**}$) and phenotypic association of days to pollen ($r_p = -0.97^{***}$) and days to silking ($r_p = -0.98^{***}$) with grain yield implies that these traits are not co-inherited together with grain yield and that short anthesis silking interval period would increase grain yield due to the synchronization of pollen shedding and silking emergence. Traits associated with ear aspect are the most reliable traits for indirect selection for grain yield improvement under drought condition.

Key Words: *index value, path–coefficient analysis, correlation, yield-related traits, Zea mays L.*

INTRODUCTION

Maize (*Zea mays* L.) is one of the most widely consumed cereal crops among both rural and urban populations in West Africa, serving as a vital source of food, income, and livelihood. Its production has expanded considerably across the savanna agro-ecological zones, largely due to favorable environmental conditions, including abundant solar radiation, reliable rainfall, cool night temperatures, and relatively low pest and disease pressure. Despite these advantages, sustainable maize production remains severely constrained by several biotic and abiotic stresses, notably *Striga hermonthica* infestation, recurrent drought episodes, and low soil nitrogen (N) (Badu-Apraku *et al*., 2003). It is therefore important to develop and make available maize varieties capable of overcoming the production challenges.

Drought is the single most important production constraint affecting maize production and productivity in the sub region. Edmeades *et al*. (1995) reported an estimated 15% annual maize yield loss from drought in the West African savannas and indicated that localized losses may be much higher in the marginal areas where the annual rainfall is below 500 mm and soils are sandy or shallow. Grain yield losses can even be greater if drought occur at the most drought-sensitive stages of crop growth, such as the flowering and grain filling (Denmead and Shaw, 1960; Ne Smith and Ritchie, 1992). Changes in climatic conditions resulting from global warming have further increased the occurrences of drought, even in the forest agro-ecology of West and Central Africa (Fakorede *et al*., 2003). Given the recurring incidence of drought across the savanna agro-ecologies of the sub-region, the development of drought-tolerant maize varieties should be a main focus of breeding programs aimed at improving productivity, resilience, and yield stability under drought conditions.

Understanding the relationships between grain yield and its associated agronomic traits is essential for developing effective breeding strategies, particularly under stress conditions where yield expression is influenced by multiple interacting factors. Such knowledge enables breeders to identify key traits that contribute directly or indirectly to grain yield, thereby facilitating more efficient selection. To elucidate these relationships, several statistical approaches have been employed, with correlation analysis and path coefficient analysis being among the most widely used tools in plant breeding. These methods provide valuable insights into the strength and direction of trait associations and help partition the direct and indirect effects of individual traits on grain yield. These methods have also been used to determine the causal relationship between grain yield and its contributing components, and to identify those components with significant effects on yield for potential use as selection criteria (Board *et al*., 1997; Moghaddam *et al*., 1998; Samonte *et al*., 1998). Several breeders have utilized path-coefficient analysis for examining the direct and indirect effects of various yield-related characters on grain yield in an array of crop plants, including rice (*Oryza sativa* L.) Samonte *et al*. (1998), maize (Badu-Apraku, *et al*., 2012, Italia, *et al*., 2022; Saleh, *et al*., 2022).

Grain yield generally exhibits low heritability under drought and other stress conditions, making direct selection for yield improvement less effective (Badu-Apraku *et al*., 2012). Consequently, plant breeders often rely on secondary traits that are strongly associated with grain yield to facilitate indirect selection under stress environments. Traits such as ears per plant, stay-green characteristics, and anthesis–silking interval have consistently shown strong associations with grain yield under drought stress and have therefore been widely adopted as reliable indicators of drought tolerance in maize (Lafitte and Edmeades, 1994; Bänziger and Lafitte, 1997).

In response to the complex nature of drought tolerance, maize breeding programs at the International Institute of Tropical Agriculture (IITA) and Institute for Agricultural Research (IAR)/Ahmadu Bello University Zaria (ABU), employ a selection index that integrates grain yield under both drought-stressed and well-watered conditions with key adaptive traits, including a shorter ASI, higher ears per plant, superior stay-green expression, and favorable plant and ear aspects (Menkir and Akintunde, 2001; Menkir *et al*., 2003; Badu-Apraku *et al*., 2004; Meseka *et al*., 2006; Oyekunle *et al*., 2015; Saminu *et al*., 2021). This multi-trait approach has substantially enhanced the efficiency of developing drought-tolerant maize germplasm.

Several studies have further identified the most informative secondary traits for indirect selection under drought. For early-maturing maize germplasm, ear aspect, ears per plant, ASI, and plant aspect were reported as the most reliable predictors of grain yield under drought stress (Badu-Apraku *et al*., 2011a). Similarly, in extra-early maize inbred lines, plant aspect together with plant and ear heights proved effective for simultaneous selection for grain yield under both drought and low-nitrogen conditions (Badu-Apraku *et al*., 2012). Moreover, the same study demonstrated that ear aspect, plant height, and ASI were consistently identified by both path coefficient analysis and genotype main effect plus genotype × environment interaction (GGE) biplot analysis as robust selection criteria for improving drought tolerance (Badu-Apraku *et al*., 2012).

In another study by Badu-Apraku *et al*. (2011b) involving extra-early inbreds, a low correlation was obtained between grain yield and the stay green characteristic under drought stress and in low-N environments. The contrasting results call for a thorough assessment of the interrelationships among traits with a view to confirming the most reliable traits for indirect selection for grain yield of early maize germplasm under stress and non-stress environments. Furthermore, there is a need to re-examine the IITA base index used for selection of drought tolerant early maize genotypes in WA to confirm the most reliable traits for computing the base index for selection for improved grain yield under drought. The objectives of the present study were to (i) asses relationship between grain yield and yield-related traits under drought and well-watered conditions, (ii) confirm the reliability of the traits with direct and indirect contribution to yield improvement under drought identified in previous studies.

MATERIALS AND METHODS

Genetic materials, Field evaluation and Experimental procedures

One hundred and seven (107) PVA maize inbred lines (sourced from IAR maize improvement unit), plus three known testers (LY1001-14 MALE, LY1001-14 MALE HYBRID and LY1001-21 MALE) (sourced from IITA) were used for this experiment. The inbred lines and the testers were evaluated under optimum water and managed drought stress at Samaru and Bagauda during the 2020/2021 dry season. The 110 genotypes were set up in a 10 × 11 lattice design with two replications. Each genotype was laid in a single-row plot of 5.00m long with a row spacing of 0.75 m and intra-row spacing of 0.5 m. Three seeds were planted per hill and the seedlings were later thinned to two per hill 2 weeks after emergence to give a plant population density of about 53,333 plants ha^{-1}. A compound fertilizer (NPK 15:15:15) was applied at the rate of 60 kg N ha^{-1}, 60 kg P ha^{-1} and 60 kg K ha^{-1} two weeks after planting. An additional 60 kg N ha^{-1} Urea was top-dressed two weeks later in the drought experiment and 4 weeks later in the optimum water experiment. The experiments were kept weed-free by the application of paraquat, a contact herbicide just after planting. Subsequently, manual weeding was carried out two weeks after planting and two weeks later to keep the trials field weed-free. The managed drought stress was achieved through surface irrigation system. These provide water twice a week up to 35 days after planting. Thereafter, the irrigation water was withdrawn in the drought experiment, so that the maize plants rely on stored water in the soil for growth and development until maturity. On the other hand, the experiment under optimum water condition continued to receive irrigation until physiological maturity. Except for the water treatment, all management practices remain the same for both the optimum water and drought experiments in all locations (Saminu *et al.,* 2021).

Data collection

Days to pollen (DP) and silking (DS) were recorded as the number of days from planting to when 50% of the plants in a row had shed pollen and had emerged silks. Anthesis-silking interval (ASI) was computed as the interval in days between silking and anthesis. Plant (PHT) and ear (EHT) heights were measured as the distance from the base of the plant to the height of the first tassel branch and the node bearing the upper ear. Plant aspect (PASP) was based on overall plant type (plant and ear heights, uniformity of plants, cob size, disease and insect damage and lodging) on a scale of 1 to5 where 1 = excellent plant type and 5 = poor plant type. Ear aspect (EAS) was based on freedom from disease and insect damage, ear size, uniformity of ears and was recorded on a scale of 1 to 5, where1 = clean, uniform, large, and well-filled ears and5 = rotten, variable, small, and partially or poorly filled ears. In addition, leaf senescence (LDC) scores were recorded for the drought-stressed plots at 70days after planting on a scale of 1 to 10, where 1 =0–10% dead leaves and 10 = 90-100% dead leaves. The number of ears per plant (EPP) was computed as the proportion of the total number of ears at harvest divided by the number of plants at harvest. Under drought environment, all ears harvested from each plot were shelled to determine percentage grain moisture and grain weight using a moisture meter and a weighing scale, respectively. Grain yield, adjusted to 15% moisture, was computed from the shelled grain weight. On the other hand, under well-watered environment, harvested ears from each plot were weighed and representative samples of ears shelled to determine percent grain moisture. Grain yield adjusted to 150 g kg^{-1} moisture, was computed from ear weight and grain moisture assuming a shelling percentage of 80% (800g grain kg^{-1} ear weight). Grain weight was converted to grain yield (kg) per hectare using the following equation:

$$GY = GWT \times \left(\frac{100 - m}{85}\right) \times \frac{10{,}000}{A}$$

Where, GY = grain yield in kg/ha, GWT = grain yield at harvest moisture content per plot, m = grain moisture content at harvest, and A = plot area, 10,000 = total land area (m^2) of a hectare.

Data analysis

Combined analysis of variance (ANOVA) across environments was conducted separately for data collected under drought stress and well-watered environments with PROC GLM in SAS using a random statement with the TEST option (SAS Institute, 2011). In the combined ANOVA, environment and inbreds were considered as random effects. Thus, a random model was used in the analysis. Since the traits were measured in different units, the mean values for each entry were standardized using standard deviation method (scale = 1) (Yan and Tinker, 2005). The PROC CORR procedure of SAS (SAS Institute, 2011) was also used to compute the correlation coefficients.

RESULTS

Screening of PVA Maize Inbred Lines for Drought Tolerance

The combined analysis of variance (ANOVA) for all quantitative traits studied are presented in Table 1. The ANOVA revealed highly significant differences ($p < 0.01$) among genotypes for all the traits studied. However, environment and genotype × environment interaction were not significance.

The results from the combined analysis of variance revealed significant ($p < 0.01$) variability for grain yield under both research conditions and across research environments and highly significant ($p < 0.01$) anthesis-silking interval under drought across environments (Table 1). SLMP-59 has the highest index value (18.06) with a low yield reduction percentage of 38.07% making it the inbred line with the best drought response, followed by SLMP-76 with index value of 15.09 and yield reduction of 40%, followed by SLMP-18 with index value of 14.08 and yield reduction of 26.9%. Inbred line SLMP-3 turns out to be most drought susceptible genotype with drought index value of -12.59 and yield reduction of 83.39% followed by SLMP-63 with drought index value of -11.36 and yield reduction of 79.74%. The result also showed that drought tolerant inbred lines had positive index values and hence shorter anthesis-silking interval while drought susceptible inbred lines had negative index value and hence longer anthesis-silking interval (Table 2)

Inter-trait Relationships among the PVA Maize Hybrids

The genotypic correlation coefficients among measured traits indicated that grain yield had significant positive correlation with plant height ($r_g = 0.71^*$) ear height ($r_g = 0.73^*$), stem lodging ($r_g = 0.63^*$) and the number of ears per plant ($r_g = 0.75^{**}$) under drought. In contrast, grain yield had significant and negative correlation with days to pollen ($r_g = -0.80^{**}$), days to silking ($r_g = -0.79^{**}$), anthesis silking interval ($r_g = -0.77^{**}$), leaf death score ($r_g = -0.80^{**}$) and ear aspect ($r_g = -0.81^{**}$). Additionally, ear aspect had significant and positive correlation with days to pollen (r_g = 0.99***), days to silking (r_g = 0.99***), anthesis silking interval (r_g = 0.99***) and leaf death score (r_g = 1.00***), but significant and negative correlation with grain yield (r_g = -0.81**), plant height (r_g = -0.97***) and ear height (r_g = -0.95***). Number of ears per plant also has significant and positive correlation with grain yield (r_g = 0.75**), plant height (r_g = 0.96***) and ear height (r_g = 0.92***), but negative correlation with days to pollen (r_g = -0.99***), days to silking (r_g = -0.99***), anthesis silking interval (r_g = -0.99***), leaf death score (r_g = -0.98***) and ear aspect (r_g = -0.96***) (Figure 1).

The phenotypic correlation indicated that grain yield had significant positive correlation with plant height (r_p = 0.93***), ear height (r_p = 0.89***) and the number of ears per plant (r_p = -0.95***) but significant negative correlation with days to anthesis (r_p = -0.97***), days to silking (r_p = -0.98***), anthesis silking interval (r_p = -0.98***), leaf death score (r_p = -0.99***) and ear aspect (r_p = -0.99***). Ear aspect also had significant and positive correlation with leaf death score (r_p = 1.00***), anthesis silking interval (r_p = 0.97***), days to silking (r_p = 0.98***) and days to anthesis (r_p = 0.97***), but negative correlation with ear height (r_p = -0.92***), plant height (r_p = -0.95***) and grain yield (r_p = -0.99***). Similarly, number of ears per plant had significant positive correlation with ear height (r_p = 0.82**), plant height (r_p = 0.87***) and grain yield (r_p = 0.95***), but significant negative correlation with ear aspect (r_p = -0.93***), leaf death score (r_p = -0.93***), anthesis silking interval (r_p = -0.95***), days to silking (r_p = -0.94***) and days to anthesis (r_p = -0.93***) (Figure 2).

The structural equation modelling was used to investigate the relationships among grain yield, leaf death score, and the measured agronomic traits of the pro-vitamin A maize inbred lines. The model partitioned the observed variables into two constructs, namely Leaf Death Score and ear aspect, and estimated their relationships with grain yield.

The structural model indicated that the ear aspect construct exhibited a significant direct effect with grain yield (path coefficient = 1.00) than the leaf death score (path coefficient = 0.50), suggesting that the group of traits represented by ear aspect contributed more strongly to variation in grain yield than those associated with leaf death score (Figure 3).

Leaf death score was characterized by both positive and negative factor effects among the measured traits. Significant positive direct effects were observed for stem lodging (0.19), root lodging (0.21), ear height (0.26), anthesis-silking interval (0.29), and days to pollen (0.07). Whereas, husk cover (-0.06), plant height (-0.42), and days to silking (-0.54) exhibited negative effect. Among these variables, days to silking and plant height showed the strongest negative associations with the leaf death score effect, whereas anthesis-silking interval and ear height displayed the highest positive contributions (Figure 3).

Ear aspect exhibited high positive effect across all observed variables. Plant height recorded the highest effect (1.09), followed by husk cover (1.02), days to pollen (1.00), days to silking (0.99), anthesis-silking interval (0.95), stem lodging (0.90), ear height (0.88), and root lodging (0.69). These results indicate that these agronomic traits collectively explained a substantial proportion of the variation represented by the EAS construct (Figure 3).

Overall, the structural equation modelling results suggest that variation in flowering characteristics, plant architecture, and related agronomic traits contributed more strongly to grain yield than variation associated with leaf senescence alone.

Table 1. Mean squares of ANOVA for grain yield and other agronomic traits of the 110 inbred lines evaluated at Samaru and Bagauda during the 2020/2021 growing season

Source	**Df**	**Grain Yield**	**Days to Anthesis**	**Days to Silking**	**ASI**	**Plant Height**	**Ear Ht**	**Leaf Death Score**	**Husk Cover**	**Plant Aspect**	**Ear Aspect**
Env	1	8207	0.00	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
Rep (Env)	2	127925	11.62**	7.04**	0.56	4.64	1050**	5.25**	0.76**	0.03	0.05
Block (Rep×Env)	40	85908	2.24**	2.29*	0.70	291	146	1.11	0.27*	0.22	0.20
Gen	109	192152**	1.92**	4.3**	3.07**	719**	389**	3.19**	0.45**	0.76**	0.75**
Gen x Env	109	1278	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residuals	178	90384	1.26	1.48	0.79	256	135	1.14	0.18	0.23	0.25
Heritability		0.55	0.75	0.83	0.76	0.77	0.75	0.74	0.80	0.79	0.66
$LSD_{.05}$		0.96	1.23	0.92	16.00	11.87	1.06	0.43	0.49	0.50	0.59
CV%		1.40	1.38	11.60	13.06	21.38	14.72	20.86	13.74	14.39	53.71

*- significant, **- highly significant

Table 2. Grain Yield of contrasting maize inbred lines under moisture stress and optimum conditions at Samaru and Bagauda.

	Inbred	Pedigree	Drought Response	Grain Yield (t/ha)		ASI under Drought	Yield Reduction (%)	Base Index	Grain Colour
				DS	WW				
20 Best Performing									
1	SLMP-59	TZE-Y 7-11-2-2-2-3-3	T	1.23	1.99	4.00	38.07	18.06	Orange
2	SLMP-76	SAMMAZ 39 6-10-2-2-2-1-3	T	1.05	1.75	4.00	40.03	15.09	Orange
3	SLMP-18	SAMMAZ 39 7-10-2-1-1-1-3	T	1.10	1.50	3.50	26.90	14.08	Orange
4	SLMP-65	SAMMAZ 39 7-10-2-3-2-1-2	T	1.26	1.97	4.50	35.99	13.20	Orange
5	SLMP-96	SAMMAZ 38 6-10-2-2-2-1-4	T	0.92	1.55	5.00	41.01	11.22	Orange
6	SLMP-90	SAMMAZ 39 6-10-2-2-2-2-2	T	0.87	1.23	4.00	29.71	11.02	Orange
7	SLMP-21	SAMMAZ 28 7-5-2-2-2-2-2	T	0.76	1.15	4.50	33.51	9.71	Orange
8	SLMP-5	SAMMAZ 38 7-10-2-2-2-2	T	0.76	1.27	4.67	39.97	8.34	Orange
9	SLMP-83	SAMMAZ 40 6-11-2-2-2-2-1	T	0.77	1.19	5.00	35.08	8.18	Orange
10	SLMP-37	SAMMAZ 40 7-11-2-2-2-1-3	T	0.94	1.44	4.50	34.74	8.06	Orange
11	SLMP-99	SAMMAZ 40 6-11-2-2-2-1-3	T	0.77	1.69	5.00	54.45	7.92	Orange
12	SLMP-46	SAMMAZ 13 7-2-2-2-2-2-3	T	0.92	2.08	4.00	55.93	7.91	Orange
13	SLMP-80	SAMMAZ 38 6-10-2-2-2-1-1	T	0.81	1.57	4.50	48.74	7.89	Orange
14	SLMP-60	SAMMAZ 39 7-10-2-2-1-3	T	0.53	0.93	4.50	42.75	7.82	Orange
15	SLMP-30	SAMMAZ 40 7-11-2-2-2-2-2	T	0.76	1.25	5.00	39.36	6.66	Orange
16	SLMP-6	SAMMAZ 38 7-10-2-2-2-2	T	0.93	1.74	4.00	46.26	5.80	Orange
17	SLMP-53	TZE-Y 7-11-2-1-2-1-2	T	0.70	1.07	5.00	34.49	5.74	Orange
18	SLMP-27	SAMMAZ 39 7-10-2-1-2-2-3	T	0.76	1.21	6.00	36.96	5.54	Orange
19	SLMP-72	SAMMAZ 39 6-10-2-2-2-2-4	T	0.76	1.19	5.50	36.41	5.52	Orange
20	SLMP-71	SAMMAZ 38 7-11-2-1-2-2=1	T	0.67	1.26	5.00	47.03	5.31	Orange
10 Worst Performing									
101	SLMP-103	SAMMAZ 40 6-11-2-2-3-2-3	S	0.21	0.94	6.50	77.34	-7.32	Orange
102	SLMP-12	SAMMAZ 39 7-10-2-1-2-2-1-3	S	0.16	0.97	7.00	83.31	-7.66	Orange
103	SLMP-84	SAMMAZ 38 6-10-2-2-2-2-1	S	0.22	0.78	6.00	71.40	-7.67	Orange
104	SLMP-4	SAMMAZ 39 7-10-2-2-2-2	S	0.27	0.65	6.50	58.29	-7.84	Orange
105	SLMP-50	SAMMAZ 39 7-10-2-2-2-2-4	S	0.27	0.83	7.50	67.51	-8.58	Orange
106	SLMP-75	SAMMAZ 39 6-10-2-2-2-1-1	S	0.16	0.77	7.00	78.65	-8.73	Orange
107	SLMP-69	SAMMAZ 39 6-10-2-2-2-1-4	S	0.22	0.93	6.50	76.76	-8.73	Orange
108	SLMP-19	SAMMAZ 28 7-3-2-2-1-2	S	0.22	1.05	7.50	79.36	-8.86	Orange
109	SLMP-63	SAMMAZ 39 6-10-2-3-2-1-2	S	0.16	0.77	7.00	79.74	-11.36	Orange
110	SLMP-3	SAMMAZ 39 7-10-2-2-2-2	S	0.11	0.68	7.50	83.39	-12.59	Orange
	Mean			0.52	1.15	6.19			
	SE			88.63	163.14	0.52			
	Genotype Significance			*	**	*			

T- tolerant, S- susceptible, *- significant, **- highly significant

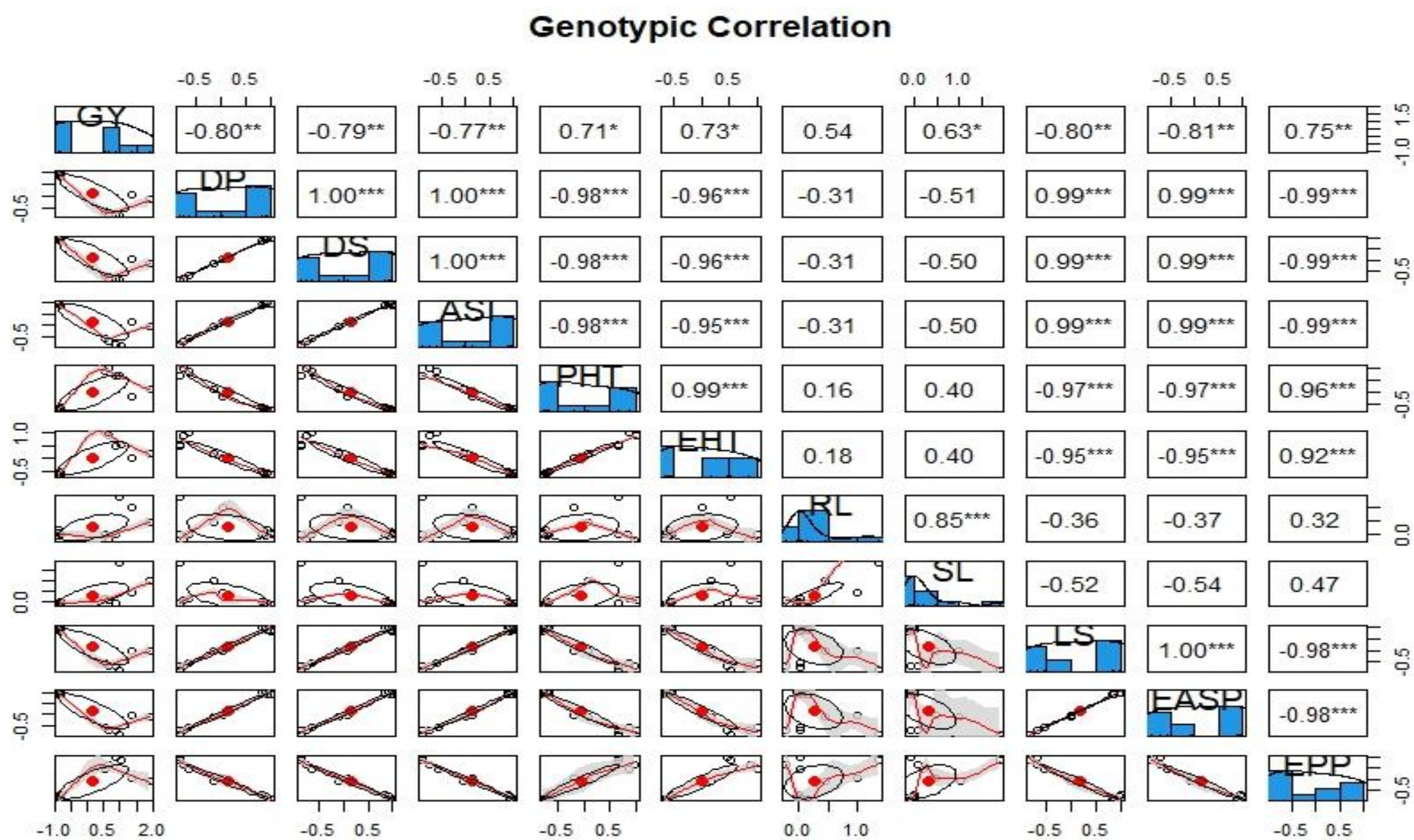

Figure 1. Genotypic correlations for yield and other traits of the 247 hybrids evaluated under drought and optimum conditions at Samaru and Bagauda in 2021/2022 and 2022/2023 in Nigeria

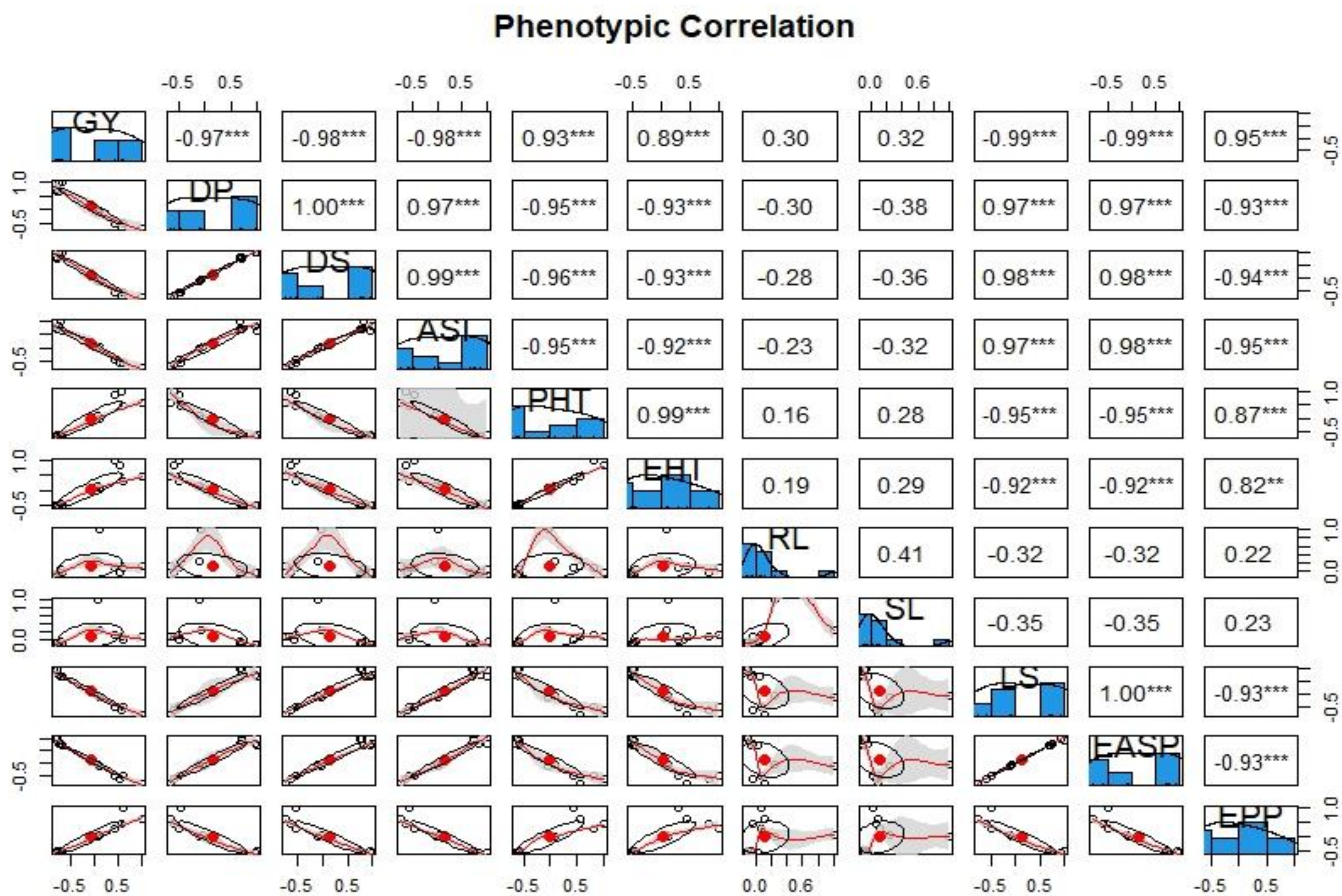

Figure 2. Phenotypic correlations for yield and other traits of the 247 hybrids evaluated under drought and optimum conditions at Samaru and Bagauda in 2021/2022 and 2022/2023 in Nigeria

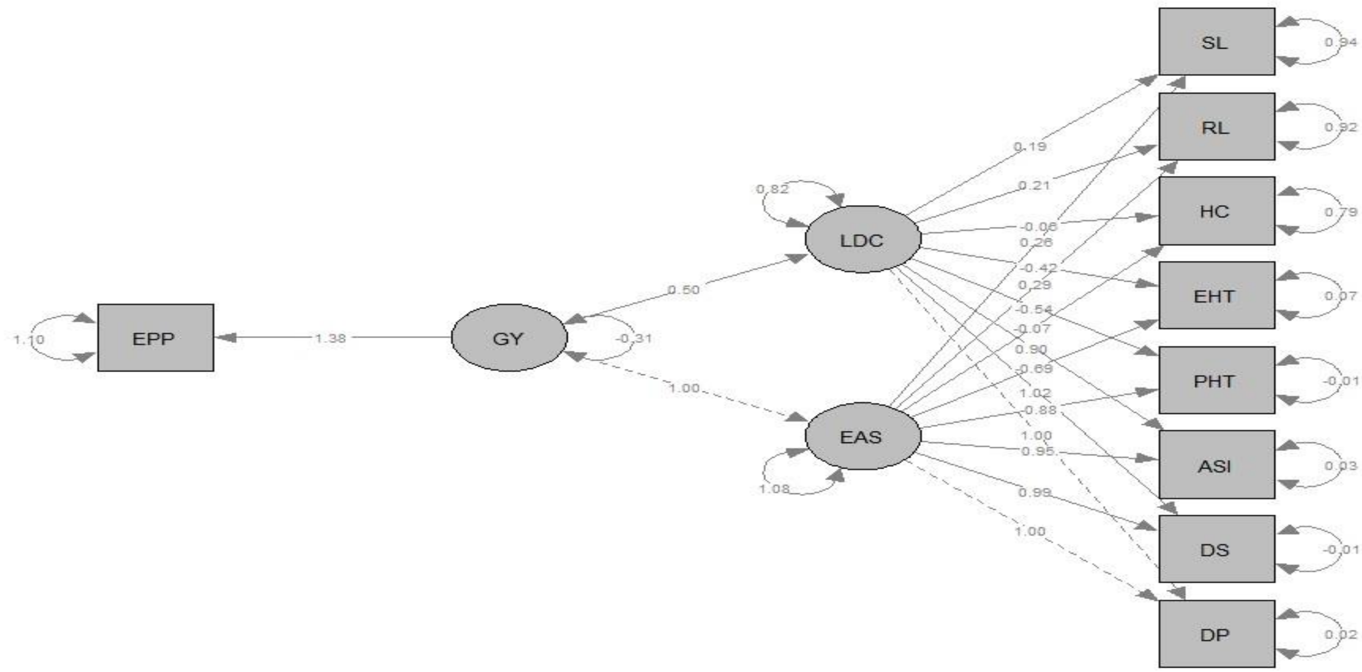

Figure 3. Path analysis model diagram showing causal relationships of measured traits of pro-vitamin A maize lines of IAR evaluated under drought stress at Samaru and Bagauda during the 2021/2022 and 2022/2023 dry seasons in Nigeria.

DISCUSSION

Genetic diversity forms the foundation of sustainable hybrid breeding for long-term genetic improvement strategies. It is particularly important that the genetic variability that exists among inbred lines could facilitate the development of productive hybrids, which are usually a product of crosses involving inbred lines from opposing heterotic groups (Tanksley & McCouch, 1997; Xu *et al*., 2017). The variability observed from the ANOVA for grain yield and all other quantitative traits indicated that adequate genetic diversity existed among the breeding materials studied. This finding is consistent with many other authors (Sharma *et al*., 2018; Zhang *et al*., 2021).

Information on inter-trait relationships between grain yield and other agronomic traits will enhance the efficiency of breeding programs using appropriate traits as selection criteria under drought stress condition (Banziger and Lafitte, 1997).

Mean squares obtained from the analysis of variance showed the presence of significant genotypic and phenotypic correlation for most of the traits including grain yield, this is an indication of the presence of genetic variability among the genotypes and offers hope for the improvement of the affected traits through selection. The positive significant genotypic and phenotypic correlation observed for grain yield and other agronomic traits such as plant height, ear height, stem lodging as well as the number of ears per plant are in accordance with the findings of Pavan *et al.,* (2011), Kumar *et al.,* (2014), Hailegebrial *et al.,* (2015), and Pandey *et al.,* (2017). However, the findings were in contrast to the findings of Zorana *et al.,* (2011) and Silva *et al.,* (2016) who reported negative correlation for grain yield with plant and ear height. Tall plants with higher ear placement increase grain yield due to high number of leaves possessed and stem reserve mobilization which is in agreement with the findings of Zeeshan *et al.,* (2013) and Al-Tabbal and Al-Fraihat (2012). Positive genotypic correlations for these traits imply the presence of moderate inherent relationship, thereby discloses the improvement of maize grain yield was linked with the selection for these traits. The associations between plant height, ear aspects as well as grain yield are desirable because the traits are vital components of selection index for grain yield. Ajala *et al*. (2018) and Adeniji *et al*. (2020) reported similar findings. However, there is need for caution in exploring the association between plant height and grain yield. This is because plants that are too tall could be susceptible to lodging and/or breakage and thus lead to yield reduction. The positive association between ear aspects implies that selecting plants with good ear aspect could translate to quality cobs. The traits had negative associations with grain yield and this is beneficial to the progress of any maize breeding program. Lower ratings are normally desired for plant ear aspects while plants with high values are preferred for grain yield. The negative genotypic and phenotypic association of days to flowering with grain yield implies that these traits are not co-inherited together with grain yield and that short anthesis silking interval period would increase grain yield due to the synchronization of pollen shedding and silking emergence. The highly significant positive genotypic and phenotypic correlation observed between days to anthesis and days to silking corroborate the findings of Nataraj *et al.,* (2014) and Hussain *et al.,* (2016). This infers jointly improvement of these traits could be possible due to positive genotypic correlation.

Path coefficient analysis is a valuable statistical tool for quantifying the relative contributions of different agronomic traits to grain yield by partitioning their relationships into direct and indirect effects (Dewey and Lu, 1959; Wright, 2020). It provides a cause-and-effect framework that distinguishes the direct influence of individual traits from their indirect effects mediated through other traits, thereby revealing the relative importance of each trait in determining final grain yield. Under drought conditions, leaf death score and ear aspect emerged as first-order traits with significant direct effects on grain yield in the pro-vitamin A maize inbred lines, indicating that they are major determinants of grain yield under moisture stress. These findings confirm the importance of leaf death score and ear aspect as key secondary traits associated with drought tolerance, consistent with previous reports (Badu-Apraku *et al*., 2011a, 2013; Talabi *et al*., 2017). Furthermore, the results suggest that incorporating these secondary traits alongside grain yield in a selection index would improve selection efficiency and genetic gain under drought conditions compared with selection based solely on grain yield (Bänziger *et al*., 2000; Badu-Apraku *et al*., 2013). Therefore, it may be concluded that there was effective direct selection for these traits.

CONCLUSION

There was sufficient genetic variability among newly developed pro-vitamin A maize inbred lines with identification of drought tolerant lines (SLMP-59, SLMP-76, SLMP-18, SLMP-65, SLMP-96 and SLMP-90) with good drought tolerance indices, and the significant association between grain yield and other traits could serve as secondary traits in selecting for improvement of grain yield under drought. Since the results of the present study revealed that leaf death score and ear aspects were the most reliable traits under drought condition, improvement of grain yield under well-watered conditions would indirectly result in improved grain yield in drought environments.

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