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INTERCHARACTER RELATIONSHIPS AND TRAIT PROFILES IN PVA MAIZE (*Zea mays L.*)

***[1]R. O. OLAYIWOLA, [1]K. M. JOLAOSHO, [2]O. A. OYETUNDE, [3]O. A. OGUNTADE, [1]A.A. OLAYIWOLA AND [4]O.J. ARIYO**

[1]Department of Crop Production, College of Agricultural Sciences, Olabisi Onabanjo University, Ago-Iwoye, Nigeria.
[2]Department of Horticulture and Landscape Management, College of Agriculture, Lagos State University of Science and Technology, Ikorodu, Nigeria
[3]Department of Agronomy, University of Ibadan, Nigeria
[4]Department of Plant Breeding and Seed Technology, Federal University of Agriculture Abeokuta, Nigeria
***Corresponding Author**: ollyrichie@gmail.com **Tel**:

ABSTRACT

Understanding the intercharacter relationships between grain yield and related traits is crucial in developing selection index for yield improvement of crops. Forty-five PVA maize genotypes were evaluated in Nigeria to examine interrelationships among agronomic characters of PVA maize genotypes and identify trait(s) that significantly contribute to grain yield. The field experiment was laid out in a randomized incomplete block design (RIBD) replicated three times. Observations were made on grain yield and other agronomic traits. There was significant ($p \leq 0.05, 0.01$) genotypic effect for most of the measured traits. Grain yield was significantly correlated with plant height, ear height, husk cover, plant aspect and ear aspect. However, these characters were correlated inter se. Ear aspect highly influenced associations with grain yield and should therefore be weighted accordingly in the selection index. The Genotype × yield-trait (GYT) biplot identified genotypes LY1409-61, A1804-15, and LY1913-23 as having superior trait profiles and could be useful in future breeding strategies.

Keywords: grain yield, path analysis, selection index, trait profiles

INTRODUCTION

Maize (Zea mays L.) is well adapted to several agroecologies in Africa where it is considered strategic to achieving food security (Kogbe and Adediran, 2003; Rovere et al., 2014). However, the precusors of vitamin A are completely lacking in maize. Therefore, overdependence on maize as source of nutrients could lead to deficiency in vitamin A (Menkir et al., 2008). Pfeiffer and McClafferty (2007) suggested the need to develop pro-vitamin A (PVA Maize) biofortified maize cultivars to alleviate vitamin A deficiency in the region. HarvestPlus then included maize among the six crops that were selected for biofortification to mitigate vitamin A deficiency in Africa (Tanumihardjo, 2008). This led to development of PVA maize populations from which inbred lines were developed for the production of hybrids (Dhliwayo et al., 2014; Menkir et al., 2014; Halilu et al., 2016; Gebremeskel et al., 2018). However, genotypes with high provitamin A content are low yielding (Menkir et al., 2014). Maqbool et al. (2018) and Mengesha et al. (2019) opined that high grain yield potential was central to the success and acceptability of PVA maize genotypes among farmers. The need to develop high-yielding PVA genotypes becomes imperative.

Grain yield is a complex character resulting from the interplay among several less complex but related characters. Also, it is under polygenic control and highly influenced by the environment. Therefore, in maize breeding programs, direct selection for grain yield is mostly less efficient and not usually recommended. Simultaneous selection of yield-related traits has been suggested and widely used in breeding programs to identify superior genotypes (Muhammad et al., 2003; Bello et al., 2010). Thus, adequate information on the relationship between grain yield and related traits is crucial for the development of an efficient selection index. Though plant breeders have employed correlation analysis to understand associations between plant characters (Rambabu et al., 2019), results from such analysis are interpreted with caution because correlation does not account for causation (Anderson and Finn, 2012). If the association involves more than two characters that are significantly correlated, the analysis becomes unreliable because there could be interdependence and collinearity effect (Fakorede and Opeke, 1985; Garcia del Moral et al., 2013).Path analysis (Wright, 1921) accounts for cause-and-effect relation among correlated characters by decomposing correlation into direct and indirect effects (Almeida et al., 2018). Information obtained from path analysis is then used to allot appropriate weights to characters in the development of a more efficient selection index to identify superior candidates.

Since the decision on genotype superiority is often based on multiple traits, a desirable cultivar must show appreciable levels for key traits. However, unfavourable association among targeted traits may hinder superiority judgment in plant breeding programs (Akin-Idowu, 2016). The genotype x yield-trait (GYT) biplot analysis was thus proposed by Yan and Fregeau-Reid (2018) as a means to resolve the challenges that are usually associated with simultaneous evaluation of several genotypes for multiple traits. The procedure offers a unique way to rank and visualize genotypes (Gs) based on their value for yield (Y) in combination with other traits (T), rather than their performance for individual traits and thus provide information on total worth of the genotype. The GYT biplot has been used to profile genotypes of crops including barley (Karahan and Akgün, 2019) and wheat (Kendal, 2019).

The focus of this study was to examine interrelationships among agronomic characters of PVA maize genotypes and identify trait(s) that significantly contributed to grain yield and superior genotypes based on their trait profiles.

MATERIALS AND METHODS

Planting materials and source

Forty-five PVA maize genotypes were obtained from the International Institute of Tropical Agriculture (IITA) Ibadan, Nigeria.

Experimental site and field establishment

A field experiment was conducted at the Teaching and Research Farm of Olabisi Onabanjo University, Ayetoro (Lat.7°12´N and Long.3°3´E), Ogun State, Nigeria.

The land was prepared mechanically using plough and harrow. The field was laid out in a 9 x 5 Randomized Incomplete Block Design (RIBD) replicated thrice. Thus, nine genotypes were contained in each of the five blocks. Two seeds of each genotype were sown on a 3-m long single-row plot. The rows were 0.75 m apart and intra-row spacing was 0.25 m. The plants were later thinned to one plant per stand to give a population of 53,333 plants per hectare. All recommended agronomic best practices were followed as required.

Data collection and analysis

Observations were made on days to anthesis, days to silking, plant aspect, plant height (cm), ear height (cm), husk cover, ear aspect and ear weight (kg). Anthesis-silking interval (ASI) was taken as the difference between days to anthesis and days to silking. Grain yield was estimated from ear weight and the estimate was adjusted to 15 % moisture content.

The data collected were subjected to analysis of variance (ANOVA) and correlation analysis. Husk cover, ear aspect and plant aspect ratings were log-transformed prior to analysis. Path analysis was used to partition significant correlations with grain yield into direct and indirect effects. All analyses were done using the SAS 9.3 version (SAS Institute, 2014).The GYT biplot analysis was performed on the data to elucidate the pattern of trait variation among genotypes and to visualize the trait profiles of selected genotypes. The procedure for obtaining the YT values is described in Oyetunde et al. (2021) and Yan and Fregeau-Reid (2018). Briefly, the values of yield and other traits for each genotype were multiplied. However, for plant and ear aspects where lower values were desirable, the yield values were divided by the values of plant and ear aspect to obtain YT estimates. Thus, larger YT values correspond to 'better' or more desirable genotypes. The obtained YT estimates were then standardized to obtain the YT matrix used for the GYT biplot analysis. The genotypes were ranked for superiority according to the arithmetic mean of their standardized values. Fifteen accessions comprising the 10 highest ranked and five lowest ranked genotypes were selected for the GYT biplot analysis. The biplot analysis was performed via the GGEBiplotGUI package in R.

RESULTS AND DISCUSSION

Mean squares obtained from the analysis of variance showed significant ($p \leq 0.05$, 0.01) genotypic effect for most of the traits including grain yield (Table 1). 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.

Days to anthesis showed highly significant and positive correlations with days to silking- 0.71** and plant aspect- 0.34** (Table 2). It also showed significant and negative correlations with anthesis-silking interval (-0.22*) and ear height (-0.32**). Days to silking had highly significant and positive correlations with anthesis-silking interval (0.28**) and plant aspect (0.20*) -Table 2.These associations underscored the linkage between earliness and architecture of the plants (Begum et al., 2013; Adeniji et al., 2020). It gives opportunity to drive these plant attributes in the

Table 1: Mean squares from the analysis of variance of forty-five PVA maize genotypes.

Source	Df	Days to anthesis	Days to silking	Anthesis-silking interval	Plant height	Ear height	Husk cover	Plant aspect	Ear aspect	Grain yield
Rep	2	24.10 **	19.48 **	46.25 ns	630.20 *	294.40 **	0.42 ns	12.81 **	2.29 ns	2689664.7 ns
BLK/ Rep	12	3.97 *	1.30 ns	31.52 ns	113.35 ns	98.39 **	0.21 ns	1.93 **	2.63 ns	2899354 Ns
Genotype	44	2.42 ns	2.65 *	28.57 ns	255.76 **	63.82 *	0.30 *	1.08 ns	2.13 ns	3524019 *
Error	76	1.82	1.48	31.49	136.7	36.51	0.19	0.71	1.45	2207201

** Significant at p ≤0.01
*Significant at p ≤0.05, ns: not significant

Table 2: Phenotypic correlations among nine agronomic characters of forty-five PVA maize genotypes.

	Days to silking	Anthesis-silking interval	Plant height	Ear Height	Husk Cover	Plant Aspect	Grain yield	Ear Aspect
Days to anthesis	0.71**	-0.22*	-0.13ns	-0.32**	-0.02ns	0.34**	-0.11ns	0.06ns
Days to silking		0.28**	0.04ns	-0.19*	0.01ns	0.20*	0.01ns	-0.09ns
Anthesis-silking interval			-0.07ns	-0.08ns	0.05ns	-0.09ns	0.02ns	-0.00ns
Plant height				0.64**	-0.15ns	-0.43**	0.28**	-0.28**
Ear height					-0.05ns	-0.52**	0.21*	-0.28**
Husk Cover						0.28**	-0.18*	0.15ns
Plant Aspect							-0.34**	0.31**
Grain yield								-0.62**

** Significant at p ≤0.01
*Significant at p ≤0.05, ns: not significant

desired direction. For instance, early maturing genotypes with good seed set and physical appeal could be targeted. Ear height showed significant and negative correlation with days to silking (-0.19*) -Table 2. Plant height had significant and positive correlations with ear height (0.64**) and grain yield (0.28**). Plant height showed negative and significant correlations with plant aspect (-0.43**) and ear aspect (-0.28**) -Table 2.The associations between plant height, plant and 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. Ear height showed significant positive correlation with grain yield (0.21*). It showed significant negative correlations with plant aspect (-0.52**) and ear aspect (-0.28**) -Table 2. Husk cover showed significant positive correlation with plant aspect (0.28**) but had significantly negative correlation with grain yield (-0.18*). Plant aspect was found to display highly significant positive correlation with ear aspect (0.31**) but had significantly negative correlation with grain yield (-0.34**). Grain yield had negative and significant correlation with ear aspect (-0.62**) -Table 2. The positive association between plant and ear aspects implies that selecting plants with good architecture could translate to quality cobs. The two 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 and ear aspects while plants with high values are preferred for grain yield. It is noteworthy that most of the measured traits showed correlation inter se and thus implied that decision on selection index could not be accurately guided by correlation coefficients alone (Rodriguez et al., 2017; Ajala et al., 2018). The significant correlations between grain yield and four other traits were decomposed into direct and indirect effects using path analysis (Table 3). Plant height had the highest positive direct effect on grain yield (0.12) and thus confirmed the strong linkage between the two traits. The highest negative direct effect was associated with ear aspect (-0.56) followed by plant aspect (-0.16) -Table 3. This implied that ear aspect, plant height and plant aspect chiefly accounted for the variation in grain yield and thus suggestive of the importance of these traits in the improvement of grain yield. Plant height and ear height had the joint highest positive indirect effects (0.16) on grain yield through ear aspect (Table 3) which further revealed the influence of ear aspect on the interactions with grain yield. The second highest negative indirect effect (-0.17) that was associated with plant aspect was exerted on grain yield through ear aspect (Table 3). These relationships offer possibility of developing high-yielding PVA maize genotypes with good physical appeal and ear quality. Ear aspect had the largest influence on grain yield and could be weighted as such to increase the efficiency of the index.

The superiority index for each genotype is the mean of each genotype × yield-trait combination estimates (Table 4). The index ranged from 1.821 for LY1901-61 to -1.097 for LY1901-25 (Table 4). The polygon view of the GYT biplot (Fig. 1) displays the trait profiles of the maize genotypes. The lowest-ranking genotypes; LY1901-16, LY1901-17, LY1901-17, A1702-28 and LY1901-22 belonged to sector 1 with genotype LY1901-22 as the vertex genotype, and clearly located away from the high-ranked genotypes, reflecting the differential superiority indices (Fig 1). This sector was not associated with any of the yield-trait combinations measured in this study suggesting the need to include more traits to determine the trait profiles of the genotypes. The highest-ranked genotypes were further delineated into sectors 2 and 3 (Fig. 1). Sector 2 had genotype LY1409-61 at the vertex and contained genotypes LY1501-5 and LY1901-14 as sector genotypes (Fig 1).

Table 3: Partitioning of the significant phenotypic correlations into direct (on diagonal, bold) and indirect (off-diagonal) effects of the corresponding traits on grain yield.

	Plant Height	**Ear Height**	**Husk Cover**	**Plant Aspect**	**Ear Aspect**	**Correlation coefficient with Grain yield**
Plant height	**0.12**	-0.07	0.01	0.07	0.16	0.29
Ear height	0.07	**-0.11**	0.00	0.08	0.16	0.20
Husk cover	-0.02	0.01	**-0.04**	-0.05	-0.08	-0.18
Plant aspect	-0.05	0.06	-0.01	**-0.16**	-0.17	-0.33
Ear aspect	-0.03	0.03	-0.01	-0.05	**-0.56**	-0.62

Table 4: Matrix of genotype × yield-trait combination estimates and superiority indices of 45 PVA maize genotypes

Genotype	Label on Biplot	Y*Da	Y*Dy	Y*As	Y*Ph	Y*Eh	Y*Hu	Y*Pa	Y*Ea	Superiority index
LY1409-61	1	1.473	1.609	1.438	2.108	1.038	1.718	1.848	3.338	1.821
A1804-15	2	1.942	1.908	0.312	1.634	1.749	2.032	1.51	1.402	1.561
LY1501-1	3	1.547	1.57	0.625	1.268	2.038	1.112	1.49	1.671	1.415
LY1913-23	4	1.507	1.429	-0.198	0.857	1.506	1.548	2.184	1.035	1.234
LY1001-18	5	1.618	1.611	0.468	1.1	1.906	1.171	0.564	1.187	1.203
LY1501-8	6	1.156	1.198	0.637	1.693	1.072	1.309	1.152	0.598	1.102
LY1901-23	7	1.311	1.21	-0.454	1.163	1.116	1.435	1.57	1.455	1.101
LY1501-5	8	0.922	0.97	0.546	1.281	1.148	1.113	0.974	0.922	0.984
LY1901-14	9	1.085	1.079	0.277	0.82	0.684	1.242	1.38	1.285	0.982
LY1913-3	10	1.034	1.058	0.441	1.193	0.961	0.225	0.842	0.551	0.788
A1312-12	Not Selected	0.914	0.886	-0.014	0.905	0.754	1.015	0.651	0.842	0.744
A1706-2	Not Selected	-0.956	-0.966	-0.571	-0.777	-1.263	-0.976	-0.693	-0.746	-0.869
A1736-12	Not Selected	-0.744	-0.742	-0.373	-0.541	-0.863	-0.769	-0.477	-0.814	-0.665
A1736-13	Not Selected	-0.169	-0.219	-0.542	-0.236	-0.135	0.097	-0.326	-0.814	-0.293
A1736-6	Not Selected	-0.392	-0.354	0.009	-0.173	-0.32	-0.054	-0.254	-0.551	-0.261
A1802-12	Not Selected	-0.928	-0.892	-0.169	-0.711	-1.147	-0.943	-0.659	-0.651	-0.762
A1802-4	Not Selected	0.448	0.382	-0.44	0.161	0.604	0.525	0.439	0.443	0.32
A1804-14	Not Selected	-0.066	-0.069	-0.135	-0.386	0.006	-0.585	-0.287	-0.119	-0.205

A1804-66	Not Selected	0.287	0.341	0.461	0.634	-0.213	0.539	0.689	-0.069	0.334
A1804-67	Not Selected	-0.276	-0.262	-0.106	-0.403	0.185	-0.066	-0.452	-0.273	-0.207
IfeHybrid-3	Not Selected	0.023	-0.013	-0.402	-0.427	0.341	0.182	-0.648	0.003	-0.117
IfeHybrid-4	Not Selected	-0.433	-0.433	-0.277	-0.117	-0.951	-0.228	-0.245	-0.168	-0.357
LY1001-23	Not Selected	-0.906	-0.873	-0.153	-0.857	-0.586	-0.916	-0.905	-0.918	-0.764
LY1409-14	Not Selected	0.053	0.082	5.777	0.33	-0.378	0.21	-0.238	0.188	0.753
LY1409-21	Not Selected	-0.023	-0.007	0	-0.094	0.521	0.188	-0.507	-0.178	-0.013
LY1501-6	Not Selected	0.364	0.324	-0.307	0.283	0.494	0.523	-0.145	0.054	0.199
LY1501-7	Not Selected	0.245	0.243	-0.05	0.459	-0.165	-0.024	0.109	-0.049	0.096
LY1501-9	Not Selected	0.667	0.666	0.114	1.126	0.085	0.808	1.754	0.904	0.766
LY1901-11	Not Selected	-0.949	-0.908	-0.13	-1.042	-0.881	-0.607	-0.87	-0.814	-0.775
LY1901-13	Not Selected	-0.638	-0.642	-0.355	-0.683	-0.874	-1.017	-0.738	-0.609	-0.695
LY1901-15	Not Selected	-0.71	-0.708	-0.36	-0.688	-0.461	-1.328	-1.051	-0.889	-0.774
LY1901-18	Not Selected	0.54	0.499	-0.26	0.381	0.669	0.689	0.588	0.386	0.436
LY1901-19	Not Selected	-1.399	-1.388	-0.54	-1.277	-1.466	-1.101	-1.14	-1.194	-1.188
LY1901-20	Not Selected	-1.116	-1.148	-0.776	-1.185	-1.143	-1.355	-1.248	-1.105	-1.135
LY1901-21	Not Selected	-0.256	-0.317	-0.706	-0.244	-0.031	0.047	-0.491	-0.489	-0.311
LY1901-24	Not Selected	0.42	0.44	0.193	0.588	0.445	0.215	0.341	0.545	0.398
LY1901-25	Not Selected	-1.012	-1.049	-0.751	-0.985	-0.828	-0.786	-1.097	-0.93	-0.93
LY1913-16	Not Selected	0.408	0.437	0.258	0.569	-0.097	0.075	0.639	0.622	0.364
LY1914-14	Not Selected	-0.21	-0.145	-0.06	-0.153	0.208	-0.312	-0.171	0.232	-0.076
ObaSuper2	Not Selected	0.868	0.866	0.169	0.378	1.215	0.48	0.337	0.202	0.564
LY1901-16	11	-1.444	-1.443	-0.632	-1.518	-1.178	-1.171	-1.307	-1.43	-1.265
LY1901-17	12	-1.527	-1.526	-0.662	-1.625	-1.453	-1.621	-0.899	-1.173	-1.311
LY1901-12	13	-1.476	-1.491	-0.775	-1.605	-1.246	-1.664	-1.186	-1.171	-1.327
A1702-28	14	-1.496	-1.504	-0.742	-1.57	-1.398	-1.252	-1.495	-1.286	-1.343
LY1901-22	15	-1.703	-1.709	-0.785	-1.633	-1.668	-1.722	-1.534	-1.424	-1.522

Y*Da, Y*Ds, Y*As, Y*Ph, Y*Eh, Y*Hu, Y*Pa, Y*Ea are Yield combination with days to anthesis, days to silking, anthesis-silking interval, plant height, ear height, husk cover, plant aspect, and ear aspect respectively

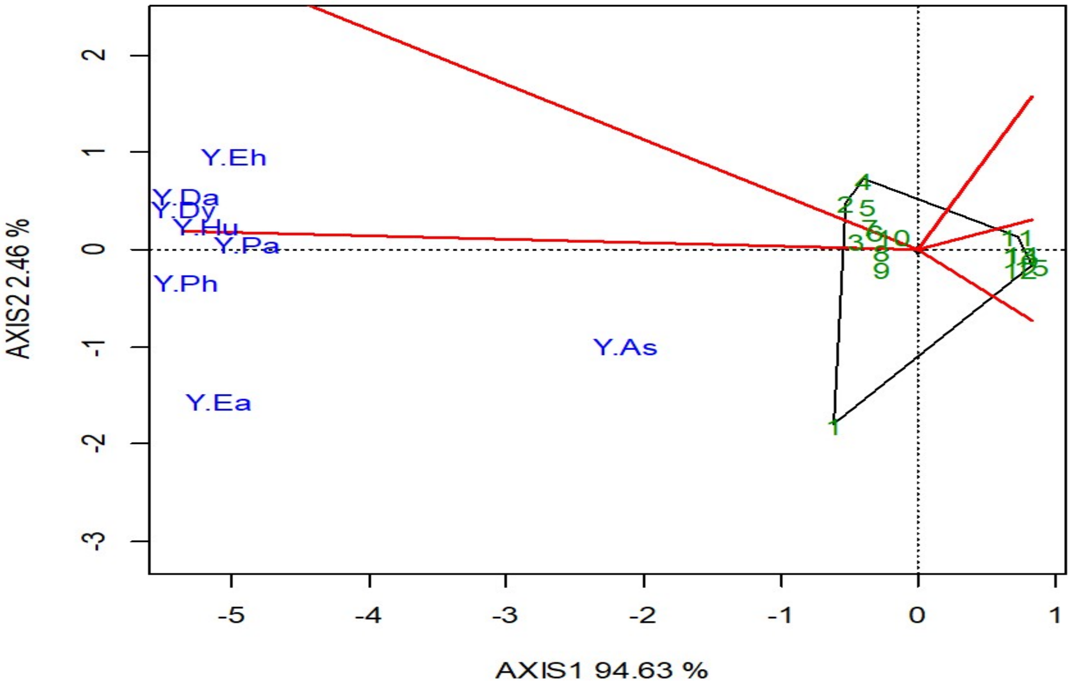

Fig. 1: Genotype × yield-trait biplot of selected seven highest- and 3 lowest-ranked maize genotypes (genotype and trait combinations named in Table 4).

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