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Grain Yield and Stability of Early-Maturing Single-Cross Provitamin A (PVA) Maize Hybrids Under Artificial *Striga* Infestation

[1,2]Bolatito R. Aleji, [2]Baffour Badu-Apraku*[1]Andrew S. Gana, [1]Kehinde D. Tolorunse

1 Department of Crop Production, Federal University of Technology Minna, Niger State, 920101, Nigeria;
2 International Institute of Tropical Agriculture, IITA, PMB 5320 Oyo Road, Ibadan 200001, Nigeria
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Abstract: *The potential of maize yield in sub-Saharan Africa (SSA) is rarely maximized due to adverse effect of Striga hermonthica. One of the largest challenge to food security is present by Striga species in the region affecting the livelihood of over 300 million people. Striga is the most devastating and widely spread parasitic weed species to maize production. Therefore, early maturing pro vitamin A (PVA) maize hybrids with resistance to Striga have the potential to combat this devastating effect. Two hundred and six early maturing PVA hybrids and four commercial checks were evaluated in Mokwa, Niger State of Nigeria for two years under artificial Striga infestation and in optimal growing conditions. The performance of the early maturing PVA inbred lines was assessed and high yielding and stable PVA hybrids were identified under test environment. Genotype × environment interactions was significant for grain yield, with high repeatability (68%). Ear and plant aspects identified as primary contributors to grain yield while hybrid TZEIOR 21 x TZEI 25 was the highest yielding and stable hybrid under artificial Striga infested condition. This outstanding hybrid with resistance to Striga should be further tested extensively on-farm for potential release in Nigeria and other West African countries.*

Keywords: Genetic analysis, *PVA, Striga hermonthica; inbred lines; hybrid; genotype × environment interaction; yield*

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I. Introduction

Maize takes a remarkable place among cereals and its usefulness serves in human food, animal feeding and industry (Badu-Apraku *et al.,* 2010a). In all agro-ecologies maize is widely cultivated, however, the savannas of sub-Saharan Africa (SSA) provide more favourable environment for optimum production of maize. This is due to high incoming solar radiation, low night temperature and minimized pest and disease prevalence. Furthermore, the availability of early and extra-early maturing maize varieties has facilitated the expansion of maize production and its productivity into new boundaries beyond areas with annual rainfall below 500 mm or where the soils are shallow or sandy (Badu-Apraku *et al.,* 2013).

Despite high prospects of maize production, *Striga hermonthica* parasitism is a major production constraint of maize in SSA threatening the livelihood of over 300 million people, accounting for an estimated loss valued at $7 billion yearly (Badu-Apraku 2010b). Grain yield loss due to infestation by *Striga* could vary from 0 to 100% depending on the severity of the infestation, variety under cultivation, climatic conditions and fertility status of the soil. Farmers in the SSA have experienced complete crop failure under severe *Striga* infestation and have often been forced to abandon their farmlands (Badu-Apraku *et al.,* 2019). A study conducted by Badu-Apraku *et a*l. (2004) where the performance of cultivars with early maturity under *Striga* infestation and optimal (well-watered and *Striga*-free) conditions were examined, 42% yield reduction resulted from *Striga* infestation alone. A similar study conducted by Badu-Apraku *et al*. (2010) demonstrated yield reductions of 65% under *Striga* infestation. Therefore, it is important that maize breeding programs in the savannas of West and Central Africa (WCA) pay more attention to commercialization of maize varieties with resistance to *Striga* infestation.

Development of *Striga* resistant maize populations, and improvement of such populations through phenotypic recurrent selection has proven to be most effective approach of increasing grain yield, reducing *Striga* seed bank in the soil, while maintaining genetic variability within the population (Hallauer *et al.,* 2010, Menkir *et al*., 2012; Badu-Apraku, Fakorede *et al*., 2016; Yallou *et al*., 2016, Menkir and Meseka, 2019). Other strategies available for control of *Striga* include hand pulling, crop rotation, trap and catch crops, fertilizer use, fallow and seed treatments (Odhiambo and Ransom, 1994, 2000; Shaxson and Riches, 1998, Badu-Apraku 2007).

Genetic Materials: The genetic material used in this study comprised of 50 early maturing (90–95 days to physiological maturity) maize inbred lines with varying reactions to *Striga* infestation. Development of the PVA-QPM inbred lines was initiated in 2007 by crossing a drought and *Striga* resistant early QPM variety, TZE-Y-Pop-DT-STR-QPM with an intermediate maturing (105-110 days to physiological maturity), high PVA maize [Syn-KU1409/DES/1409-(OR2)] from the IITA-MIP to introgress genes for high β-carotene into the QPM variety. This was followed by a cycle of backcrossing to the recurrent parent to recover earliness. In 2008, the BC_1F_2 lines with deep orange colour (for PVA) and/or appropriate endosperm modifications were selected and advanced to the F_2 and the F_3 generations. In 2009, the F_3 lines were selected based on their reactions to *Striga* and drought, then recombined to reconstitute the early PVA-QPM variety, 2009 TZE-OR2-DT-STR-QPM. Subsequent evaluations of this variety for *Striga* resistance and drought tolerance in 2010 showed superior performance. S_1 lines from the PVA-QPM variety 2009-TZE -OR2 DT-STR QPM were advanced through inbreeding to the S_6 generation from 2011 to 2014.

Table 1. Description of 50 early maturing PVA maize inbred lines used in line × tester mating design to generate 206 single-cross hybrids

S/NO	Inbred designation	Pedigree
1	TZEIOR 7	2009 TZE OR1 DT STR S_6 inb 9 -1/2-2/3-1/2-1/3-1/1
2	TZEIOR 9	2009 TZE OR1 DT STR S_6 inb 10-1/1-1/2-1/1-1/3-1/1
3	TZEIOR 10	2009 TZE OR1 DT STR S_6 inb 10-1/1-1/2-1/2-1/3-1/1
4	TZEIOR 12	2009 TZE OR1 DT STR S_6 inb 10-1/1-2/2-2/3-1/3-1/1
5	TZEIOR 13	2009 TZE OR1 DT STR S6 inb 10-1/1-2/2-3/3-1/2-1/1
6	TZEIOR 16	2009 TZE OR1 DT STR S_6 inb 12-1/2-1/1-1/3-1/3-1/1
7	TZEIOR 17	2009 TZE OR1 DT STR S_6 inb 12-1/2-1/1-2/3-1/4-1/1
8	TZEIOR 18	2009 TZE OR1 DT STR S_6 inb 12-1/2-1/1-3/3-1/4-1/1
9	TZEIOR 20	2009 TZE OR1 DT STR S_6 inb 12-2/2-1/2-2/2-1/2-1/1
10	TZEIOR 21	2009 TZE OR1 DT STR S_6 inb 12-2/2-2/2-1/3-1/3-1/1
11	TZEIOR 23	2009 TZE OR1 DT STR S_6 inb 12-2/2-2/2-2/3-1/4-1/1
12	TZEIOR 25	2009 TZE OR1 DT STR S_6 inb 19-1/1-2/2-1/2-3/4-1/1
13	TZEIOR 27	2009 TZE OR1 DT STR S_6 inb 19-1/1-2/2-2/2-1/4-1/1
14	TZEIOR 30	2009 TZE OR1 DT STR S_6 inb 19-1/1-2/2-2/2-4/4-1/1
15	TZEIOR 33	2009 TZE OR1 DT STR S_6 inb 22-2/2-1/2-2/4-1/3-1/1
16	TZEIOR 34	2009 TZE OR1 DT STR S_6 inb 22-2/2-1/2-2/4-2/3-1/1
17	TZEIOR 35	2009 TZE OR1 DT STR S_6 inb 22-2/2-1/2-2/4-3/3-1/1
18	TZEIOR 42	2009 TZE OR1 DT STR S_6 inb 22-2/2-2/2-2/3-1/3-1/1
19	TZEIOR 43	2009 TZE OR1 DT STR S_6 inb 22-2/2-2/2-2/3-2/3-1/1
20	TZEIOR 44	2009 TZE OR1 DT STR S_6 inb 22-2/2-2/2-2/3-3/3-1/1
21	TZEIOR 45	2009 TZE OR1 DT STR S_6 inb 22-2/2-2/2-3/3-1/3-1/1
22	TZEIOR 46	2009 TZE OR1 DT STR S_6 inb 22-2/2-2/2-3/3-3/3-1/1
23	TZEIOR 58	2009 TZE OR1 DT STR S_6 inb 38-2/3-1/3-2/3-1/3-1/1
24	TZEIOR 59	2009 TZE OR1 DT STR S_6 inb 38-2/3-1/3-2/3-2/3-1/1
25	TZEIOR 62	2009 TZE OR1 DT STR S_6 inb 38-2/3-1/3-3/3-1/4-1/1
26	TZEIOR 69	2009 TZE OR1 DT STR S_6 inb 38-2/3-3/3-1/4-2/3-1/1
27	TZEIOR 75	2009 TZE OR1 DT STR S_6 inb 38-2/3-3/3-3/4-2/4-1/1
28	TZEIOR 76	2009 TZE OR1 DT STR S_6 inb 38-2/3-3/3-3/4-3/4-1/1
29	TZEIOR 83	2009 TZE OR1 DT STR S_6 inb 38-3/3-1/3-2/3-1/2-1/1
30	TZEIOR 90	2009 TZE OR1 DT STR S_6 inb 38-3/3-3/3-2/2-1/2-1/1
31	TZEIOR 102	2009 TZE OR1 DT STR S_6 inb 56-1/3-3/3-4/4-1/4-1/1
32	TZEIOR 116	2009 TZE OR1 DT STR S_6 inb 77-1/3-1/2-2/3-1/3-1/1
33	TZEIOR 119	2009 TZE OR1 DT STR S_6 inb 77-2/3-1/2-2/3-1/4-1/1
34	TZEIOR 120	2009 TZE OR1 DT STR S_6 inb 77-2/3-1/2-3/3-1/4-1/1
35	TZEIOR 126	2009 TZE OR1 DT STR S_6 inb 77-3/3-2/2-1/2-1/4-1/1
36	TZEIOR 127	2009 TZE OR1 DT STR S_6 inb 77-3/3-2/2-2/2-1/3-1/1
37	TZEIOR 163	(TZEI 17 X TZEI 11) S_6 inb 55-1/4-4/4-1/3-4/4-1/1
38	TZEIOR 172	(TZEI 17 X TZEI 11) S6 inb 55-1/4-4/4-2/3-3/3-1/1-1/1
39	TZEIOR 175	(TZEI 17 X TZEI 11) S6 inb 84-2/3-1/4-3/3-3/3-1/1-1/1
40	TZEIOR 183	(ENT 8 × TZEI 158) S6 Inb. 14-2/3-2/2-1/2-1/2-1/1

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41	TZEIOR 185	(ENT 8 × TZEI 158) S6 Inb. 25-1/3-1/1-1/1-1/1-1/1
42	TZEIOR 187	(ENT 8 × TZEI 158) S6 Inb. 45-2/2-1/2-2/3-1/1-1/1
43	TZEIOR 191	(ENT 8 × TZEI 158) S6 Inb. 47-2/2-1/1-2/2-1/1-1/1
44	TZEIOR 194	(ENT 8 × TZEI 158) S6 Inb. 51-2/2-1/2-2/4-3/3-1/1
45	TZEIOR 198	(ENT 8 × TZEI 158) S6 Inb. 57-1/2-1/2-4/4-2/2-1/1
46	TZEIOR 199	(ENT 8 × TZEI 158) S6 Inb. 59-1/1-1/2-1/3-1/1-1/1
47	TZEIOR 200	(ENT 8 × TZEI 158) S6 Inb. 59-1/1-1/2-2/3-1/1-1/1
48	TZEIOR 201	(ENT 8 × TZEI 158) S6 Inb. 60-1/2-1/2-2/2-2/2-1/1
49	TZEIOR 202	2009 TZE OR2 DT STR QPM S_6 inb 31-1/2-4/4-1/2-1/1-1-1
50	TZEIOR 203	2009 TZE OR2 DT STR QPM S_6 inb 62-2/2-2/2-1/2-1/2-1/1

Experimental Design and Field Layout

The two hundred and ten early maturing PVA testcrosses (involving 200 line × tester crosses, six single-cross hybrids derived from intermating the 4 testers plus the four commercial checks) arranged in a 14 x 15 randomized incomplete block design with two replicates were evaluated at Mokwa (9^{o}18’N and 5^{o}04’E, 457 m asl, 1,100 mm annual rainfall and ferrisol plinthustalf soil type) in Nigeria were evaluated under artificial *Striga* infestation during the 2019 and 2020 growing seasons. The experimental unit in the trial were single-row plots, 3 m long, with a spacing of 0.75 m between two adjacent rows and 0.40 m between plants within rows. Three seeds were sown per planting hole and the emerged seedlings was thinned to two per stand at 2 weeks after emergence, resulting in a final plant population density of about 66,667 plants ha^{-1}. About 2 weeks before planting, ethylene gas was injected into the soil to stimulate suicidal germination of existing *Striga* seeds in the soil. Each hill was inoculated with *Striga* seeds by mixing the *Striga* seeds with finely sieved sand in a ratio of 1:99 by weight at the time of application following the procedure described by Kim (1991) and Kim and Winslow (1991). Each hill was inoculated with about 5,000 germinable *Striga* seeds. Fertilizer was applied at a rate of 30 kg ha^{-1} N, 30 kg ha^{-1} P, and 30 kg ha^{-1} K as 15–15–15 NPK. With the exception of *Striga* plants all weed were removed manually. In the second set of trials, the 210 early maturing PVA hybrids were evaluated at Mokwa in 2019 and 2020 growing seasons under optimal growing conditions (*Striga* free), where water and nitrogen were not limiting factors. Fertilizer was applied at the rate of 30 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} at 2 weeks after planting (WAP) and an additional 60 kg N ha^{-1} at 4 WAP using urea. The trials were kept weed free through the application of atrazine and gramozone as pre and post emergence herbicides. About 2 weeks before planting, ethylene gas was injected into the soil to stimulate suicidal germination of existing *Striga* seeds in the soil.

Data Collection

Agronomic and flowering traits were collected in both artificial *Striga* infested and *Striga* free conditions. Data were recorded for days to 50% anthesis and silking (DA and DS, respectively), anthesis-silking interval (ASI), plant and ear heights (PLHT and EHT, respectively), root and stalk lodging (RL and SL), plant and ear aspects (PASP and EASP) and number of ears per plant (EPP). Grain yield (kg ha^{-1}) for the optimal and *Striga* experiments, were estimated from field weight of ears per plot, assuming a shelling percentage of 80, adjusted to moisture content of 15%. Moisture content at harvest was recorded for representative shelled kernels per plot in all experiments using a moisture meter. The data recorded for *Striga* trials were basically the same as those assayed under optimal experiment except that plant aspect was not scored. In addition, *Striga* damage were scored at 8 and 10 WAP (SDR1 and SDR2) while the number of emerged *Striga* plants were counted at 8 and 10 WAP (ESP1 and ESP2) only in the *Striga*-infested plots. *Striga* damage was scored per plot on a scale of 1 to 9 where; 1 = no damage, an indication of normal plant growth and high resistance, and 9 = total collapse or death of the maize plant, which means highly susceptible.

***Statistical Analysis*:** *Striga* damage ratings at 8 and 10 WAP and *Striga* emergence counts at 8 and 10 WAP were log-transformed to achieve variance homogeneity (Badu-Apraku *et al.,* 2010) prior to statistical analyses using [log (counts + 1)], while square root transformation was carried out on data in percentages before subjecting them to analysis of variance (ANOVA). Data on grain yield and other agronomic traits were subjected to combined ANOVA for each environment using PROC GLM in Statistical Analysis System (SAS) version 9.3 (SAS Inc. 2011). Analysis of variance were performed on the adjusted means of the individual traits under combined drought and heat stress and optimal growing conditions and thereafter combined across environments. Subsequently, combined ANOVA was performed across the seven test environments. In the ANOVA for each and across environments, the environments, replications within environments, and incomplete blocks within replications × environment interaction were considered as random factors whereas the entries (inbreds) were regarded as a fixed factor (Suwarno *et al.,*2014). The statistical model corresponding to the experimental layout was:

$$y_{klmi}= \mu_i+ E_{ki}+ R(E)_{kli}+G_{mi}+GE_{kmi}+\epsilon_{klmi}$$

where y_{klmi} is the observed measurement of trait i with mean effect μ_i. E_{ki} is the effect of environment k on trait i, $R(E)_{kli}$ is the effect of replication l within environment k on trait i, G_{mi} is the effect of genotype m on trait i, GE_{kmi} is the effect of the interaction between genotypes m and environment k on trait i, and ϵ_{klmi} is the experimental error effect associated with genotype m and replication l within environment k on trait i. The entry means were adjusted for block effects, according to the lattice design (Cochran and Cox, 1960) and means were separated using the standard error (S.E). The least significant difference (LSD) was used for separation of means among the hybrids under each environmental condition. The variances for general and specific combining abilities were tested against their respective error variances (Singh and Chaudhary, 1977). The GCA and SCA effects were estimated and GCA of multiple traits (HGCAMT) was used to classify the inbred lines into heterotic groups as proposed by Badu-Apraku *et al*. (2013).

II. Results:

The combined ANOVA across the two *Striga* environments (2019 and 2020) showed highly significant ($P< 0.05$ or $P< 0.01$) differences among environments (E) and entries (inbred lines) for measured traits (Table 1). Broad sense heritability (H^2) estimates based on plot mean basis ranged from 42% for ear height (EHT) to 64% for ears per plant (EPP), while the estimate for grain yield was 68%. The H^2 for ASI could not be determined because of the negative genotypic variance. The results revealed moderately high to high heritability estimates for traits measured under *Striga* infestation. **Table 2:** The combined ANOVA across three optimal environments showed significant ($P< 0.05$ or $P< 0.01$) variations among environment, entry (genotype) and genotype x environment mean squares for all measured traits except Genotype x Environment Interaction (GEI) effects for ears per plant (EPP). Heritability (H^2) estimates ranged from 58% for ears per plant (EPP) to 80 % for ear aspect (EASP), grain yield had very high estimates of 85% and EPP 80% under optimal environments.

Table 1. Mean squares and heritability estimates of 256 early maturing PVA, PVA-QPM maize inbred lines evaluated under *Striga* infested condition at Mokwa during the 2019 and 2020 growing seasons

Source	DF	GY (t ha^{-1})	DA	DS	ASI	PLHT	EHT	*Striga* damage rating		*Striga* emergence count		EASP	EPP
								8WAP	10WAP	8WAP	10WAP		
ENV	1	600443359.30**	8841.87**	831.96**	868.41**	362441.60**	6015.94**	1681.00**	83.27*	0.19**	1.01**	243.91**	40.14**
Entry	255	1067995.40**	483.41**	533.29**	3.32*	1684.91**	599.67**	3.51**	6.44**	0.24**	0.25**	6.67**	0.12
Rep (ENV)	2	76139849.20**	54.24**	58.23**	10.34**	2580.10**	1223.76*	12.10**	12.10**	0.10**	0.31**	49.93**	1.37*
BLK (ENV*Rep)	60	798245.20**	11.95**	14.09**	3.12**	677.04**	264.83**	1.30**	2.12**	0.12*	0.10**	5.60**	0.13*
Entry*ENV	255	726600.50**	457.45**	501.42**	3.54	1577.01**	586.37**	3.22**	5.39*	0.20**	0.21**	6.53**	0.09**
Error	450	427852.00	3.30	4.79	1.55	264.30	130.41	0.33	0.97	0.06	0.04	1.25	0.05
Heritability	-	**68**	**50**	**58**	-	**56**	**42**	**51**	**48**	**51**	**48**	**69**	**64**

*, ** = Significant. at 0.05 and 0.01 probability. levels, respectively; Env = environment; Rep=replication; GY = Grain yield; DA.= days to 50 % anthesis; DS. = days to 50 % silking; ASI. = anthesis-silking interval; PLHT = plant height; EHT = ear height; EASP. = ear plant aspect; EPP. =ears per plant.

Table 2. Mean squares and heritability of grain yield and other agronomic traits of 256 PVA, PVA-QPM maize inbred lines evaluated under optimal growing environments at Mokwa 2019 and 2020 growing seasons.

SOURCE	DF	YIELD	DA	DS	ASI	PASP	EASP	EPP	PLHT	EHT
Env	1	396743.70**	11.04**	32.19**	638.80**	194.84**	98.79**	0.03**	42147.27**	7538.62*
Entry	255	1620201.60**	10.31**	13.13**	0.72**	2.31**	3.10**	0.11**	367.28**	135.14**
Rep (Env)	2	2799843.50**	860.59**	1148.64**	0.77**	19.65**	10.85**	0.64**	4168.83**	2431.98**
BLK (Env*Rep)	60	846949.30**	11.52**	15.81**	0.50*	1.27**	2.11**	0.10**	328.77*	202.51**
Entry*Env	244	771149.20*	4.86**	6.13**	0.93**	1.56**	2.17**	0.12	260.30**	100.87**
Error	437	481999.80	4.01	4.94	0.59	0.85	1.80	0.09	91.81	67.63
Heritability	-	**85**	**67**	**72**	**74**	**74**	**80**	**58**	**65**	**74**

*, ** = Significant at 0.05 and 0.01 probability levels, respectively; Env = environment; Rep = replication; DA = days to 50 % anthesis; DS = days to 50 % silking; ASI = anthesis-silking interval; PLHT = plant height; EHT = ear height; PASP = plant aspect; EASP = ear plant aspect; EPP = ears per plant

Interrelationship Among Traits

Figure 1, step-wise regression and sequential path analyses were used to investigate the cause-and-effect relationships between grain yield and other agronomic traits assayed under the research conditions. Husk cover, ears per plant and stalk lodging were third order traits with relatively weak positive indirect contributions to grain yield through ear rot, root lodging and days to anthesis. Plant and ear aspects, *Striga* rating 1 and *Striga* count 2 constituted the traits which directly contributed to grain yield, accounting for 95 % of the overall variation in grain yield under *Striga* infestation. Plant aspect (-0.916) recorded the highest negative direct contribution to grain yield, followed by days to *Striga* rating 2 (-0.121) and ear aspect (-0.052) while *Striga* count 1 (0.102) had significant positive direct contributions to grain yield. There were six traits in the second order of which days to 50 % silking made the highest positive (0.769) indirect contribution to grain yield followed by plant height (0.700). days to 50 % silking and anthesis silking interval positively and indirectly contributed to grain yield through ear aspect and days to 50 % anthesis respectively. Although, ears per plant was among the three third order traits under *Striga* infestation, it significantly contributed to grain yield through five out of the six second order traits.

Stability Analysis of Hybrid Performance under Striga Infestation and Optimal Environments

Significant differences observed for genotype, environments and genotype x environment interaction (GEI) for grain yield under *Striga* infestation and optimal environments in this study, necessitated the use of the GGE biplot procedure to decompose the GEI and investigate stability of the hybrids based on grain yied across test environments. The GGE biplot analysis for grain yield of the best 15 and worst 10 hybrids with four checks across 5 environments revealed that the axis 1 which is called the principal component axis 1 (PC1) explained 57.6 % of total variation and axis 2 called principal component axis 2 (PC2) explained 20.9 % of the total variation in grain yield across the environments with both PC1 and PC2 explaining 78.5 % of the total variation in grain yield.

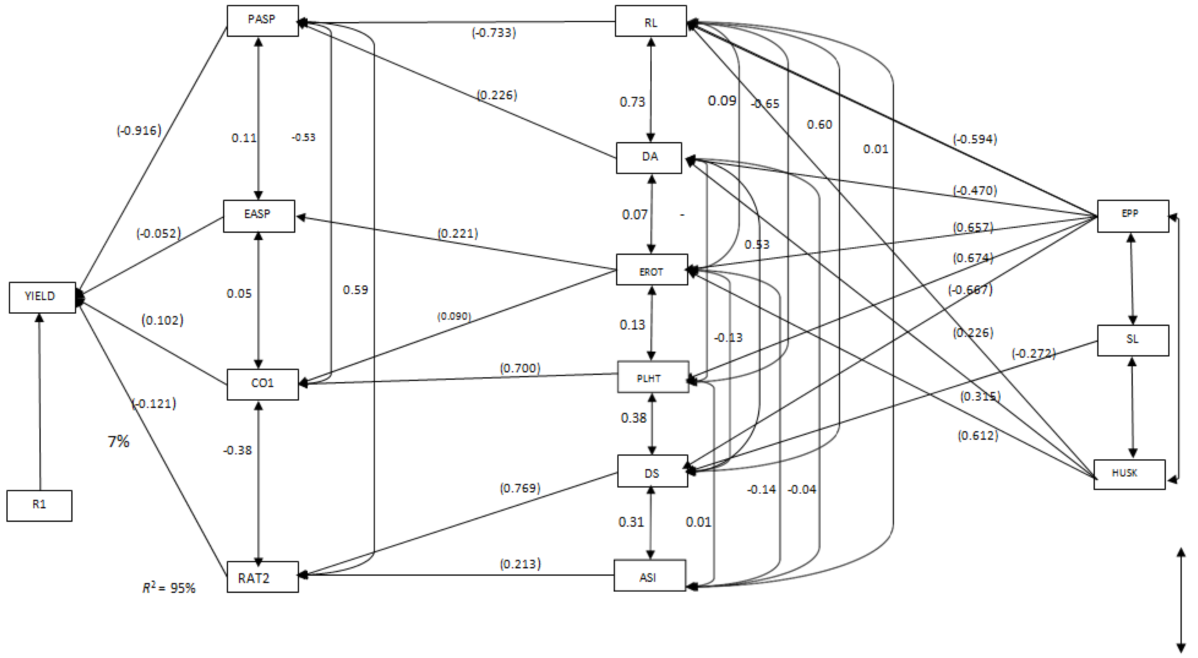

Figure 1: Path analysis model diagram showing causal relationships of measured traits of early maturing provitamin A maize hybrids evaluated under *Striga* infestation in the 2019 and 2020 growing seasons at Mokwa in Nigeria. Bold value is the residual effect; values in parenthesis are direct path coefficients while other values are correlation coefficients. R^2= co-efficient of determination; R1= residual effects; YIELD= grain yield; EASP= ear aspect; PASP= plant aspect; EHT= ear height; DA= days to 50% anthesis; RL= root lodging; EROT= ear rot; PLHT= plant height; DS= days to 50 % silking; ASI= anthesis–silking interval; EPP= ears per plant; SL= stalk lodging; RAT2= *Striga* rating 2; CO1= *Striga* count 1

III. Discussion:

This study addressed the development of maize hybrids with potential to alleviate the nutritional problems under one of the most important biotic (*Striga hermonthica)* constraints to increased maize production and productivity in WCA. The highly significant differences seen for grain yield as well as other measured agronomic traits of early maturing PVA hybrids under research conditions shows that substantial genetic variability existed among early maturing PVA hybrids studied and progress could be made from selection for important agronomic traits under the stress environments as well as non-stress environment. Bhatnagar, Betran, and Rooney (2004), Langa (2005), Tilahun *et al*. (2017), Solomon (2020) also reported significant differences for grain yield and other traits of QPM lines studied in hybrid combinations.

The significant environment mean square observed for grain yield and other measured traits under *Striga*-infested and optimal conditions in this study indicated that the environments showed uniqueness in discriminating among the early maturing PVA genotypes under research conditions. The environment significant effects observed for grain yield and most other agronomic traits measured under *Striga*-infested and optimal growing environments suggested that there were differential responses in the environments which could be of great help in selection under the research conditions, this could be attributed to the varying environmental factors such as soil fertility, amount of incoming solar radiation, temperature, soil type, rainfall pattern, pest and disease prevalence (Badu-Apraku and Lum 2007; Badu-Apraku *et al* 2010; Badu-Apraku 2019; Okunlola 2022).

IV. Conclusion:

The stability analysis revealed TZEIOR 21 x TZEI 25 as the highest yielding and most stable hybrid under *Striga*-infested and optimum environments. This outstanding hybrid with tolerance to *Striga* should be further tested extensively on-farm for potential release in Nigeria and other West African countries. The hybrid will be useful in areas where *Striga* is a constraint to production and for improving nutrition and maize yields

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