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Evaluation of Pro-Vitamin A Maize (*Zea mays* L.) Hybrids for Grain Yield and Agronomic Performance Under Optimal Growing Conditions

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ABSTRACT

Background and Objective: The production and deployment of pro-vitamin A maize hybrid is crucial for combating vitamin A deficiency among consumers who rely predominantly on starchy foods with limited access to fruits and vegetables. The objectives of the study were to (i) Evaluate the performance of the newly developed pro-vitamin A maize hybrids under optimal growing conditions. **Materials and Methods:** Thirty-two newly developed pro-vitamin A maize hybrids and four commercial maize hybrids used as checks were evaluated under optimum growing conditions, using a 9×4 α-lattices design with three replicates at the Teaching and Research Farm of Ladoke Akintola University of Technology, Ogbomoso, Nigeria in 2023. Data were collected on grain yield and other agronomic traits. The least square means were calculated and separated using Fisher's Least Significant Difference (LSD) test at a 0.05 probability level. **Results:** The data were analyzed, and the results show that the maize hybrids' mean squares were significant ($p<0.01$) for most of the traits measured except anthesis-silking interval, plant height, ear height, and husk cover. The significant variations observed indicate the existence of variability useful for selection. Grain yield of the hybrids varied between 1451.9 (LY2213) and 4650.7 kg/ha (A1804-15) with a mean of 2884.6 kg/ha. The A1804-15 produced the highest grain yield (4650.7 kg/ha), followed closely by LY1409-61 (4628.6 kg/ha) and LY2201 (4274.9 kg/ha). Rank summation index identified the top five hybrids, viz. LY2214, LY2201, LY1914-14, A1804-15, and LY2202 with high grain yield potential and other desirable agronomic traits. **Conclusion:** These outstanding pro-vitamin A maize hybrids should be subjected to further testing in multi-locational yield trials over the years to confirm their stability and suitability for large-scale cultivation, before their release to farmers.

KEYWORDS

Grain yield, maize hybrid, pro-vitamin A, selection, variation

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops globally, serving as a staple food for millions of people, particularly in Sub-Saharan Africa[1]. However, maize is deficient in several essential nutrients, including pro-vitamin A (PVA), leading to malnutrition-related health issues, especially in regions where maize is a dietary staple. Bio-fortification, the process of increasing the nutritional content of crops

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through conventional breeding or biotechnology, offers a sustainable solution to address malnutrition[2]. Pro-vitamin A enriched maize hybrids have been developed to combat vitamin A deficiency (VAD), a significant public health concern in many developing countries. Vitamin A deficiency is a prevalent health challenge globally, particularly in low and middle-income countries where access to diverse diets is limited. According to the World Health Organization, VAD affects approximately 250 million preschool-age children worldwide, leading to increased susceptibility to infectious diseases, blindness, and even death[3]. In Sub-Saharan Africa (SSA), maize is consumed in diverse forms, but it lacks significant levels of PVA, contributing to the persistence of VAD in the region[4].

Vitamin A deficiency is aggravated by over-dependence on cereal-based diets, which supply little or no vitamin A to meet the minimum daily requirement of the body[5]. One of the reasons for VAD in Nigeria and other African countries stems from insufficient intake of vitamin A-rich foods. While animal-based foods offer ample vitamin A, their high cost renders them inaccessible to the majority of people[6,7]. It is thus necessary to consider crop-based approaches as a long-term solution to combat VAD. Enhancing the PVA content of staple food crops like maize has been considered an important approach with a good prospect of contributing to reductions in VAD[8,9] particularly among resource-poor dwellers of SSA.

Conventional breeding techniques used to develop PVA enriched maize hybrids are cost-effective and environmentally sustainable compared to other interventions, such as supplementation or fortification[4]. By integrating biofortified crops into existing agricultural systems, farmers can improve their livelihoods while contributing to better nutrition and health outcomes in their communities. In the past, agricultural research has focused on increased cereal production; recently, there has been a paradigm shift towards producing more nutrient-rich food crop varieties to reduce hidden hunger and widespread malnutrition. It is therefore imperative to develop maize varieties that are capable of supplying adequate quantities of PVA to consumers in countries such as Nigeria, where maize is a major staple crop.

The derived Guinea Savanna in Southwestern Nigeria is characterized by a semi-arid climate and poor soil fertility, posing challenges to agricultural productivity and food security[10,11]. To improve maize productivity across diverse agro-ecologies, the development and deployment of maize hybrids adapted to a specific production environment should be promoted. Maize cultivation is prevalent in the derived Guinea Savanna agro-ecology zone, making it an ideal location to evaluate the performance of newly developed PVA-enriched maize hybrids under conditions representative of smallholder farming systems in Nigeria. Therefore, the objectives of this study were to (i) Evaluate the performance of the newly developed PVA maize hybrids under optimal growing conditions and (ii) Identify superior PVA maize hybrids with potential high grain yield and other desirable agronomic traits.

MATERIALS AND METHODS

Study area: The field experiment was carried out at the Teaching and Research (T&R) farm of Ladoke Akintola University of Technology, Ogbomoso, Nigeria (8°10'N, 4°10'E, and altitude 341 m above sea level). This location experiences a bi-modal rainfall, with a major season stretching from May through July and a minor season from August to November. The annual mean rainfall and daily temperature of the experimental site are 1000-1200 mm and 28-30°C, respectively. Soils of the site are generally low in nitrogen and have been classified as Alfisol[12].

Genetic materials: Thirty-two newly developed PVA-enriched maize hybrids developed by the Maize Improvement Programme (MIP) of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, and four commercial maize hybrids used as checks were evaluated in this study (Table 1).

Table 1: Pro-vitamin A enriched maize hybrid and checks evaluated in the study

Entry	Hybrid	Origin	Entry	Hybrid	Origin
1	LY1507-7	IITA	19	A2125-6	IITA
2	LY1501-5	IITA	20	LY2201	IITA
3	LY1501-6	IITA	21	LY2202	IITA
4	LY1409-61	IITA	22	LY2204	IITA
5	A1804-15	IITA	23	LY2205	IITA
6	LY1913-16	IITA	24	LY2207	IITA
7	LY20001-1	IITA	25	LY2209	IITA
8	LY20001-8	IITA	26	LY2210	IITA
9	LY20001-13	IITA	27	LY2212	IITA
10	A2101-21	IITA	28	LY2213	IITA
11	A2125-13	IITA	29	LY2214	IITA
12	A2125-14	IITA	30	LY2215	IITA
13	A2126-8	IITA	31	LY2216	IITA
14	A2126-11	IITA	32	LY1001-23	IITA
				CHECKS	
15	A2126-32	IITA	33	Ife Hybrid-3	IITA
16	LY1914-14	IITA	34	ZMS608Y	ZAMSEED
17	LY20001-2	IITA	35	Ife hybrid-4	IITA
18	A2101-6	IITA	36	Dominant yellow hybrid	Dominant yellow

IITA: International Institute of Tropical Agriculture

Experimental layout, design, and cultural practices: The experimental field was carefully prepared by ploughing twice and harrowing two weeks after using a tractor, before the field layout and planting were done. Ploughing and harrowing were carried out to manage weeds, provide good soil aeration, promote healthy root penetration, enhance seed germination, and seedling emergence.

The evaluated maize hybrids were planted in June, 2023 under normal rain-fed conditions, which falls within the main cropping season. The experiment evaluated 32 newly developed PVA maize hybrids and 4 local checks laid out in a 9×4 α-lattice design[13] with three replications. Each plot was a single row measuring 5 m long, spaced at 0.75 m between rows and with 0.50 m spacing between plants within a row (11 hills with two plant stands per row). Two guard rows were planted on each range at both sides of the experimental field to protect the main evaluated maize hybrids. Three seeds were sown per hole, and seedlings were thinned at the three-leaf stage development to two plants per stand (two weeks after sowing) to obtain a plant population density of 53,333 plants per hectare.

Fertilizer was applied at a total rate of 120 kg N, 60 kg P_2O_5, and 60 kg K_2O per hectare using NPK 20:10:10 and urea. The N was applied in two split doses at planting and 4 weeks after sowing (WAS) while the P and K were applied basally at planting. A mixture of atrazine and gramoxone was applied as pre- and post-emergence herbicides at the rate of 5 L/ha to control weeds at sowing. Subsequently, weeds were controlled manually (using a hoe) as necessary after the crop had established. Infestation of fall armyworms (*Spodoptera frugiperda*) was controlled at a two-weeks interval with the application of Caterpillar Force®, containing Emamectin Benzoate 5% water-dispersible granules as the active ingredient at the rate of 10 g/15 L. In October, 2023, the maize hybrids were harvested by hand after reaching physiological maturity, when the stalks have dried and the moisture of the grain is low (<25%).

Data collection: Data were recorded on plot basis for the number of days to 50% anthesis and silking estimated as the number of days from planting to the day when 50% of the plants in a plot had started shedding pollen grains (from the male reproductive organ called anther) and had extruded silks (from the female reproductive flower). The anthesis-silking interval was then computed by deducting the number of days to anthesis from the number of days to silking. Plant aspect was rated per plot after anthesis on a scale of 1-9, where, 1 = Vigorous and appealing plants without lodging, leaf defoliation, nor disease symptoms, and the first ear attached in the middle of the plant; and 9 = Lodged, diseased and defoliated plants with the first ear being closer to the soil surface or the tassel. Likewise, ear aspect was rated per plot based on the neatness and filling of grains on the cobs on a scale of 1-9, where 1 = Clean, large cobs, uniform ears, and fully filled grains, and 9 = Ears with scanty and damaged grains. Plant and ear height were measured with the aid of a meter rule as the distance from the base of the plant to the height of the first tassel branch and the node bearing the uppermost ear (in prolific hybrids), respectively, for an average of 6 plants per plot. Percentage root and stalk lodging were determined as the proportion of plants per plot that fell from the root or with stalk bending more than 45° from the vertical position and those with broken stalk below the topmost ear, respectively. Husk cover was scored on a scale of 1-5; where 1 = Very tight husk extending beyond the tip, and 5 = Exposed ear tip. The total number of plants and ears was counted in each plot at the time of harvest. The number of ears per plant was estimated as the ratio of the number of harvested ears per plot to the number of plants at harvest in a plot. Grain moisture content was measured using a digital grain moisture content tester. Grain yield was computed from the ear weight and converted to kg/ha. A shelling percentage of 80% was assumed for all hybrids, and the grain yield was adjusted to 15% moisture using the following formula:

$$\text{Grain yield (kg/ha)} = \text{Ear weight (kg/plot)} \times \frac{100 - \text{MC}}{85} \times \frac{10{,}000}{\text{Plot area (m}^2\text{)}} \times 0.80$$

Where:
MC = Moisture content at harvest

Statistical analysis: The data from the field experiment were entered in Microsoft Excel 2019 and subjected to Analysis of Variance (ANOVA) using the General Linear Model (GLM) procedure of Statistical Analysis System (SAS) version 9.4[14] to enable separation of the variance components[15]. In the linear model, the least square means were calculated and separated using Fisher's Least Significant Difference (LSD) test at a 0.05 probability level.

The linear model was:

$$y_{ij} = \mu + b_j + \alpha_i + \varepsilon_{ij}$$

where, y_{ij} is the observed value of the response variable obtained from i-th hybrid in j-th block, μ is the overall mean, b_j is the effect of j-th block, α_i is the effect of i-th hybrid, and ε_{ij} is the error associated with y_{ij}.

Coefficients of variation (CV) and determination (R^2) were used to measure the reliability of the statistical model of ANOVA. To examine the proportion of the total variance of a trait that is due to genetic differences among the hybrids, repeatability was computed. The GLM procedure of SAS was used to estimate the variances, and repeatability of the traits was computed as the ratio of genotypic variance to phenotypic variance to determine the precision of the experiment. The descriptive statistics parameters of the PVA maize hybrids were also computed. The rank summation index (RSI) of Mulumba and Mock[16] was used to rank the performance of hybrids. The maize hybrids were ranked for each selected trait, and the ranks for each trait were summed up to obtain an index for each hybrid. The best hybrid would have the least RSI value, whereas the worst one would have the highest RSI value[17].

RESULTS

Analysis of variance revealed highly significant mean squares ($p<0.001$) for grain yield, number of days to anthesis, plant and ear aspects (Table 2). Also, the mean squares for the number of days to silking and number of ears per plant were significant ($p<0.05$). There were no significant differences among the hybrids for anthesis-silking interval, husk cover, plant and ear heights. Furthermore, the block effect was

Table 2: Mean squares of grain yield and other agronomic traits of pro-vitamin A enriched maize hybrids evaluated at LAUTECH T&R farm Ogbomoso

Source of variation	df	Days to anthesis	Days to silking	Anthesis-silking interval (days)	Plant height (cm)	Ear height (cm)	Husk cover (1-5)	Plant aspect (1-9)	Ear aspect (1-9)	Number of ears per plant	Grain yield (kg/ha)
Replication (Rep)	2	10.26**	9.03**	0.12	172.96	27.19	1.51	2.01**	3.06*	0.03	815658.7
Block (Rep)	24	3.47*	7.38***	4.65**	164.91	100.84	0.83	1.13***	1.39	0.02	2060591.48***
Hybrid	35	3.76**	2.87*	2.18	225.03	76.08	0.70	1.19***	1.85**	0.03*	1793259.80**
Error	46	1.73	1.45	1.86	202.08	73.23	0.53	0.41	0.89	0.02	720448.20
R^2		0.76	0.84	0.70	0.60	0.68	0.65	0.82	0.75	0.69	0.82
CV (%)		2.19	1.96	90.33	9.24	12.62	22.53	17.39	29.18	14.54	29.42
Repeatability		0.64	0.67	0.90	0.93	0.98	0.84	0.56	0.66	0.71	0.60

*,**,***Significant at 0.05, 0.01 and 0.001 probability levels, respectively, R^2: Coefficient of determination, CV: Coefficient of variation, df: Degree of freedom. Husk cover (1-5): Where 1 = Very tight husk extending beyond the tip, and 5 = Exposed ear tip. Plant aspect (1-9): Where 1 = Excellent overall phenotypic appeal and 5 = Poor overall phenotypic appeal. Ear aspect (1-9): Where 1 = Clean, uniform, large, and well-filled ears and 9 = Rotten, variable, small and partially filled ears

Table 3: Mean performance of PVA maize hybrids and checks for grain yield and other agronomic traits

Hybrid	Days to anthesis	Days to silking	Anthesis-silking interval (days)	Plant height (cm)	Ear height (cm)	Husk cover (1-5)	Plant aspect (1-9)	Ear aspect (1-9)	Number of ears per plant	Grain yield (kg/ha)
LY1501-7	60.9	62.3	1.4	155.7	68.3	2.8	4.0	2.2	1.0	3343.4
LY1501-5	60.7	64.2	3.5	151.2	67.7	3.2	4.0	3.1	0.8	2406.8
LY1501-6	59.9	62.5	2.6	163.8	67.0	2.7	3.8	2.7	0.9	3106.2
LY1409-61	59.4	61.4	2.0	152.7	64.6	2.9	4.2	2.2	1.1	4628.6
A1804-15	60.6	61.2	0.6	151.1	69.2	3.8	2.8	2.6	1.1	4650.7
LY20001-1	59.6	61.3	1.7	154.9	72.6	3.2	4.0	2.6	0.8	3809.3
LY20001-2	58.6	60.1	1.5	152.2	66.9	3.5	3.2	2.3	1.0	2519.3
LY2202	60.4	60.5	0.2	150.0	67.2	3.3	3.5	2.3	1.1	3311.4
LY20001-8	58.2	59.7	1.4	162.5	61.8	2.2	3.8	3.1	0.8	2997.0
A2101-21	60.3	61.7	1.4	160.9	68.7	2.7	4.0	2.9	0.8	4105.9
A2125-13	60.6	62.3	1.6	156.9	71.0	3.4	4.5	5.9	1.0	1738.5
A2125-14	61.3	61.0	-0.3	126.6	48.4	3.5	4.4	3.8	0.9	1751.6
A2126-8	59.7	62.5	2.8	165.4	71.9	3.8	4.3	3.7	0.8	1911.7
A2126-11	59.0	62.5	3.5	135.2	57.8	2.8	4.5	4.2	0.8	1515.4
A2126-32	58.0	59.7	1.7	142.8	67.1	3.2	2.7	3.3	0.9	2490.2
LY20001-13	57.5	59.5	1.9	155.4	67.3	2.5	2.7	2.9	0.9	2014.9
LY2201	59.0	60.4	1.4	158.2	77.4	2.9	2.5	2.4	1.0	4274.9
A2101-6	59.4	61.4	2.0	156.0	71.1	3.2	3.9	3.7	0.8	2964.7
A2125-6	58.8	60.1	1.3	156.4	62.9	4.3	3.3	2.8	0.9	2425.1
LY2204	60.4	62.4	1.9	158.1	68.4	2.5	3.6	3.8	0.9	3341.9
LY2205	59.0	61.9	2.9	148.1	68.6	2.2	3.1	2.9	1.2	3875.7
LY2207	61.9	64.0	2.1	150.7	65.8	3.1	4.7	3.2	0.9	2398.8
LY2209	59.9	60.7	0.8	160.6	71.2	3.6	3.9	2.3	0.9	3134.5
LY2210	60.0	61.9	1.8	147.7	70.4	2.9	4.0	3.3	1.0	3738.6
LY2212	60.4	62.2	1.8	152.3	64.2	3.2	4.0	3.3	1.0	2398.7
LY2213	62.1	62.3	0.2	143.7	64.6	3.5	4.8	4.5	0.8	1451.9
LY2214	60.2	60.9	0.7	158.1	63.9	3.2	1.6	2.1	1.0	4212.3
LY2215	62.7	62.7	0.0	158.9	71.2	2.9	3.5	2.8	0.7	2808.9
LY2216	60.3	62.5	2.2	157.3	76.2	3.4	3.4	3.5	1.0	2216.6
LY1914-14	59.5	61.2	1.7	149.9	72.2	3.6	2.6	2.1	1.1	4243.2
LY1913-16	61.5	62.8	1.3	132.0	59.4	3.5	4.2	4.8	0.6	1541.1
LY1001-23	63.0	61.8	-1.2	162.0	70.0	4.0	3.3	2.8	0.9	4162.3
Ife Hybrid-3	59.6	60.0	0.5	157.4	76.3	3.4	3.1	3.6	0.7	1781.0
ZMS608 Y	60.9	62.0	1.1	174.1	69.2	4.3	4.5	5.5	0.7	2471.6
Ife Hybrid-4	60.1	61.7	1.6	174.4	76.7	4.7	4.1	2.9	0.7	2451.4
Dominant yellow hybrid	59.2	61.8	2.7	144.8	64.0	2.3	4.3	4.6	0.7	1652.9
Mean	60.1	61.6	1.5	153.8	67.8	3.2	3.7	3.2	0.9	2884.6
Standard Error (±)	0.9	0.8	0.9	9.7	5.9	0.5	0.4	0.7	0.1	581.2
LSD (0.05)	2.2	2.0	2.2	23.4	14.1	1.2	1.1	1.6	0.2	1395.0

significant ($p<0.01$) for grain yield, plant aspect, anthesis-silking interval, number of days to anthesis, and silking. This is an indication of the heterogeneity of soil on the experimental field. The coefficient of determination (R^2) values were very high for all traits measured, ranging from 0.60 (plant height) to 0.84 (number of days to silking). Similarly, high values (0.56-0.98) were obtained for repeatability estimates of all the traits measured. Coefficient of variation (CV) was low (<20%) for the number of days to anthesis and silking, plant and ear heights, plant aspect scores, as well as the number of ears per plant, but high for the anthesis-silking interval. The highest yielding PVA maize hybrid had a mean grain yield of 4650.7 kg/ha (A1804-15) followed closely by LY1409-61 (4628.6 kg/ha) (Table 3).

Table 4: Descriptive statistics based on grain yield and other agronomic traits of PVA maize hybrids and checks evaluated at LAUTECH T&R farm Ogbomoso

	Hybrid				Check			
Traits	Mean	Minimum	Maximum	Range	Mean	Minimum	Maximum	Range
Days to anthesis (days)	60.09±0.23	57.54	62.96	5.42	59.93±0.38	59.17	60.90	1.74
Days to silking (days)	61.61±0.21	59.46	64.19	4.73	61.40±0.45	60.05	62.00	1.95
Anthesis-silking Interval (days)	1.51±0.18	-1.15	3.52	4.67	1.46±0.46	0.49	2.67	2.18
Plant height (cm)	152.73±1.58	126.56	165.42	38.87	162.68±7.15	144.84	174.38	29.55
Ear height (cm)	67.35±0.97	48.44	77.37	28.92	71.53±3.05	63.97	76.69	12.71
Husk cover (1-5)	3.18±0.09	2.18	4.27	2.09	3.66±0.53	2.29	4.69	2.40
Plant aspect (1-9)	3.65±0.13	1.60	4.80	3.21	4.00±0.33	3.06	4.55	1.49
Ear aspect (1-9)	3.13±0.15	2.13	5.93	3.80	4.14±0.58	2.86	5.52	2.66
Number of ears/plants	0.92±0.02	0.61	1.18	0.57	0.72±0.01	0.68	0.75	0.07
Grain yield (kg/ha)	2984.06±172.43	1451.87	4650.67	3198.80	2089.23±216.56	1652.90	2471.59	818.68

Table 5: Top and bottom five PVA maize hybrid based on grain yield, flowering trait and phenotypic appeal of the plant

Hybrid	Days to silking	Plant aspect (1-9)	Ear aspect (1-9)	Grain yield (kg/ha)	Yield increase over the best check (%)	Rank Summation index
Top 5						
LY2214	60.9	1.6	2.1	4212.3	70.4	18
LY2201	60.4	2.5	2.4	4274.9	73.0	20
LY1914-14	61.2	2.6	2.1	4243.2	71.7	20
A1804-15	61.2	2.8	2.6	4650.7	88.2	30
LY2202	60.4	3.5	2.3	3311.4	34.0	40
Mean of top 5	60.8	2.6	2.3	4138.5		
Grand mean	61.6	3.7	3.2	2884.6		
Selection differential (%)	-1.3	-30.3	-27.9	43.5		
Bottom 5						
LY2207	64.0	4.7	3.2	2398.8	-2.9	116
A2125-13	62.3	4.5	5.9	1738.5	-29.7	125
LY1913-16	62.8	4.2	4.8	1541.1	-37.6	129
A2126-11	62.5	4.5	4.2	1515.4	-38.7	130
LY2213	62.3	4.8	4.5	1451.9	-41.3	130
Mean of top 5	62.8	4.5	4.5	1729.1		
Grand mean	61.6	3.7	3.2	2884.6		
Selection differential (%)	1.9	22.8	41.5	-40.1		

There were no significant ($p<0.05$) differences for grain yield among the commercial hybrids (ZMS608Y, Ife Hybrid-3, Ife Hybrid-4, and Dominant yellow hybrid) used as checks (Table 3). A total of 17 (53%) of the 32 newly developed PVA maize hybrids produced grain yields that were above the trial mean grain yield of 2884.6 kg/ha. The highest yielding check (ZMS608Y) had a mean grain yield of 2471.6 kg/ha, followed closely by Ife Hybrid-4 (2451.4 kg/ha), and 8 (25%) of the PVA maize hybrids evaluated were statistically ($p<0.05$) different in yield from ZMS608Y. Comparison of the PVA maize hybrid and checks revealed that the highest yielding hybrid (A1804-15) had an 88% yield advantage over the best check (ZMS608Y). Moreover, the evaluated hybrids shed pollens between 58 and 63 days while they had silks between 59 and 64 days, and the average anthesis-silking interval was 2 days (Table 4). The hybrids were generally tall with an average plant height of 153.8 cm and ear height of 67.4 cm. In addition, the hybrids had good ratings (<4) for the breeder traits (husk cover, plant, and ear aspects).

Rank summation index values for the newly developed PVA maize hybrids evaluated in this study varied between 28 and 130 (Table 5). The top five hybrids, viz: LY2214, LY2201, LY1914-14, A1804-15 and LY2202, were not significantly ($p<0.05$) different from each other. The PVA maize hybrid with the lowest RSI (LY2214) had plant and ear aspect ratings of 1.6 and 2.1, respectively, with a grain yield of 4212.3 kg/ha. On the other hand, the hybrid with the highest RSI (LY2213) had a rating of 4.8 (plant aspect) and 4.5 (ear aspect) with a grain yield of 1451.9 kg/ha.

DISCUSSION

Identifying high-yielding and nutritious maize hybrids, tailored to a specific agro-ecological zone, is a top priority in breeding. Conducting this assessment is crucial before the release of maize hybrids. The mean squares for grain yield, flowering traits, plant, and ear aspects showed that replication and block within replication effects were highly significant. This implies that blocking using the α-lattice design was effective in a field study for analyzing phenological and morphological traits in agreement with the report of Akinwale *et al.*[18]. The significant hybrid mean squares observed for most traits measured were indicative of the existence of high genetic variability, which can be exploited through selection. This result was in agreement with findings by Kolawole and Olayinka[17] and Menkir *et al.*[19], who reported significant variation for grain yield and other traits of biofortified maize hybrids. The lack of significant differences for anthesis-silking interval, husk cover, plant and ear heights could be attributed to large mean error variance for these traits[20]. The variations found among the maize hybrids were due to the diverse genetic backgrounds from which they were developed. To ascertain the stability of these hybrids, it is necessary to carry out multi-environment field trials across several years for accurate selection of PVA maize hybrids that are high-yielding with specific adaptation.

According to Resende *et al.*[21] values of repeatability equal to or less than 0.30 are considered low, values between 0.30 and 0.60 fall into the median class, and values above 0.60 are considered high. In this study, ear height showed the highest repeatability magnitude with a value of 0.98, and plant aspect had the lowest (0.56) value, which implies that PVA maize hybrids evaluated have higher possibilities to repeat their present performance if proper management is ensured in the future. In addition, high repeatability values for most traits measured indicated that the differences in the traits performance of maize hybrids were mainly due to genetic factors and the effects of the test environment were relatively little. The high value of R^2 observed in this study explains the total variability that was captured by the statistical model and the reliability of the statistical analysis. Conversely, the low CVs estimates for all agronomic traits measured except anthesis-silking interval show high precision in the experimentation, data collection procedure, and the reliability of the statistical model. The high CV (90.3%) for anthesis-silking interval may be attributed to the fact that it was mathematically derived. According to Vah *et al.*[22] the CVs for secondary traits are usually higher than the traits measured directly.

The average anthesis-silking interval of 2 days observed in this study implies that the plants physiological stress did not occur during the planting period. This is an indication of good nicking, which probably explains the improvement in grain yield. The newly developed PVA maize hybrids had considerable performance for grain yield in the derived Guinea Savanna agro-ecological zone, where the mean grain yields have rarely gone above 2000 kg/ha[10]. The average yield of 2984.1 kg/ha obtained in this study is significantly higher than the recorded yield in the area. This mean yield was, however, lower than that reported by Kolawole and Olayinka[17] in a similar study conducted in the same zone, as well as those of Menkir *et al.*[19] conducted in an entirely different agro-ecological zone. The differences observed between these studies can be attributed to differences in the genetic constituent of the planting materials, the climatic and edaphic features of the environments.

One method of evaluating the potential of newly developed maize hybrids is to compare their performance with the hybrids currently marketed as commercial hybrids. In comparison with the check hybrids, the PVA hybrids were at par for all agronomic traits measured except for plant aspect and grain yield. Twenty-five percent of all the newly developed PVA maize hybrids yielded significantly higher than the best check (ZMS608 Y) with a mean grain yield of 2471.6 kg/ha. The grain yield advantage of the PVA maize hybrid could be due to the higher kernel number per ear and bigger cobs[22]. Abera *et al.*[23] identified superior hybrids based on grain yield in maize. However, due to the quantitative nature of grain yield, it is critical to ensure that there is alignment between grain yield and other farmers' desirable agronomic traits. Plant and ear aspect is a measure of the overall phenotypic appeal of the maize plant, which depicts clean, uniform, large, and well-filled ears. These traits determine acceptability under a farmer's condition. The lower ratings for these traits signify resistance to foliar diseases and improved phenotypic performance. It is therefore not surprising to observe that hybrids with higher grain yields were those that had lower ratings for these traits. Rank summation index revealed that LY2214 ranked top among the newly developed PVA maize hybrids, followed closely by LY2201 and LY1914-14 in that order. The top five PVA hybrids in this study significantly out-yielded all the check varieties tested, with a yield increase between 34-88% more than the highest yielding commercial hybrid, revealing their potential adaptation to the derived Guinea Savanna Agro-Ecological Zone.

CONCLUSION

Newly developed maize hybrids are routinely evaluated in a specific agro-ecological zone for adaptation, yield potential, disease reactions, and identification of hybrids that can replace existing cultivars. The acceptability of biofortified hybrids by farmers will depend on high yield potential and other desirable agronomic traits. The newly developed PVA hybrids evaluated in this study possess genetic variability for grain yield and other agronomic traits of interest. The notable variations observed among the PVA maize hybrids were attributed to grain yield, number of ears per plant, number of days to anthesis and silking, as well as plant and ear aspects. Hybrids viz., LY2214, LY2201, LY1914-14, A1804-15, and LY2202 flowered early, had higher grain yield, and lower ratings for plant and ear aspect. These top 5 hybrids identified by rank summation index had a 34-88% yield advantage over the highest yielding check (ZMS608 Y). Thus, these PVA maize hybrids can be subjected to on-farm trials across the derived Guinea Savanna Zone of Nigeria before considering their release for cultivation in farmers' fields.

SIGNIFICANCE STATEMENT

This study aimed to evaluate new pro-vitamin A maize hybrids to help combat vitamin A deficiency in populations relying heavily on starchy foods with limited access to fruits and vegetables. Thirty-two hybrids were tested under optimal conditions to identify those with high grain yield and desirable traits. Significant differences were found among the hybrids, showing potential for improvement through selection. The top-performing hybrids yielded up to 4,650.7 kg/ha and showed strong agronomic potential. These findings are important for developing maize varieties that can improve both nutrition and food security. Further multi-location testing is recommended to confirm their performance and support their release to farmers.

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