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Agronomic Performance of Provitamin A-Enriched Maize Hybrids Under Field Conditions in the Guinea Savanna of Nigeria

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ABSTRACT
Vitamin A deficiency (VAD) is a critical public health challenge in sub-Saharan Africa, where maize is a primary staple food. The development and deployment of provitamin A-enriched maize hybrids offer a sustainable strategy to combat this malnutrition. This study was conducted to evaluate the agronomic performance and grain yield potential of thirty-two provitamin A-enriched maize hybrids. The hybrids were assessed in a randomized complete block design with three replications across two environments (Ilorin and Ogbomosho, Nigeria) during the 2024 growing season. Data were collected on grain yield, days to anthesis and silking, plant and ear height, anthesis-silking interval, root and stalk lodging, and overall phenotypic appeal. A combined analysis of variance revealed highly significant differences ($p \leq 0.01$) among the hybrids, environments, and their interaction for most of the measured traits, indicating the presence of sufficient genetic variability and differential responses to environments. Grain yield ranged from 1.78 t/ha (M2414-13) to 4.44 t/ha (M2414-02). The three highest-yielding hybrids M2414-02, M2414-24, and M2414-11 significantly outperformed the local check by 46.53%, 46.20%, and 44.80%, respectively. These results underscore the potential of provitamin A-enriched maize hybrids to boost both food and nutritional security in the region. The outstanding hybrids identified in this study are recommended for further multi-location and on-farm trials to confirm their stability and superiority before nomination for registration and release.

Keywords: Maize hybrids, biofortification, evaluation, vitamin A deficiency

INTRODUCTION
Maize (*Zea mays* L.) is pivotal to global food security, especially in sub-Saharan Africa where it is a primary staple food for millions of people (Erenstein *et al.,* 2022). The crop has undergone domestication and though it originated from South Mexico, its genetic adaptability has allowed it to thrive across various agro-ecologies, earning it the title 'queen of cereals' due to its versatility and potential for high yield (Badu-Apraku *et al.,* 2018; Tripathi *and Misha,* 2020). In Nigeria, maize production is very important, with the country recognized as Africa's second-largest producer after South Africa, cultivating approximately 11 million metric tons annually, predominantly by subsistence farmers who form the backbone of the nation's agricultural system (FAOSTAT, 2021; Marechera *et al.,* 2022; PwC, 2024). The economic benefit of maize extends beyond food purposes to feed and industrial purposes (Sher *et al.,* 2017; Satyanarayana *et al.,* 2022).

In spite of the importance of maize, its production is constrained by biotic (diseases and pests) and abiotic stress (drought, low soil Nitrogen) factors. These stress factors severely reduce grain yield, especially during the flowering stage (Rathore *et al.,* 2016; Sheoran *et al.,* 2022). These constraints also threaten the livelihoods of resource-limited farmers who often lack optimal management strategies and also have limited access to the required inputs (Njeru *et al.,* 2023; Asfawa *et al.,* 2024; Singl *et al.,* 2025). Intensifying these productivity challenges is nutritional quality because conventional maize varieties are low in essential micronutrients. A population that consumes mainly maize as a dietary staple are therefore at a high risk of malnutrition caused by micronutrient deficiencies (Bouis *et al.,* 2017). Vitamin A deficiency (VAD) is one of the most prevalent disorders, affecting over 250 million preschool-aged children globally, its consequences include impaired vision, weakened immunity, and increased mortality (WHO, 2020). Biofortification, the process of breeding crops to enhance their nutritional status, presents a sustainable and “pocket-friendly” approach to address VAD.

The development and deployment of provitamin A-enriched maize varieties have been a major focus of international agricultural research to complement other interventions (Katola *et al.,* 2023; Menkir *et al.,* 2025). However, for these nutritious varieties to be adopted by farmers they must possess good agronomic characters and higher productivity indices compared to the existing cultivars they are meant to replace (Goredema-Matongera *et al.,* 2021; Kolawole *et al.,* 2022; Olayinka *et al.,* 2025). While significant investments have been made in the development of provitamin A-enriched maize germplasm, the successful adoption depends largely on identifying high-yielding and stable genotypes that have a high level of Vitamin A. The Nigerian Guinea savanna zone is a major maize-producing region, yet it faces prevalent VAD due to high maize consumption. There is a need to assess the newly developed provitamin A hybrids under local conditions to identify those suitable for cultivation in this environment. Assessing their performance across multiple locations is also essential to understand genotype-by-environment (G×E) interactions and to select hybrids with broad or specific adaptation. Therefore, this study was designed to evaluate the agronomic performance and grain yield of thirty-two provitamin A-enriched maize hybrids across two environments in the Guinea savanna zone of Nigeria and identify the highest-yielding and most stable provitamin A-enriched maize hybrid(s) with superior agronomic traits for advancement to on-farm trials.

MATERIALS AND METHOD

Description of Study Location

This experiment was conducted at two locations in South-West; University of Ilorin, Ilorin, Kwara State (8.53˚N and 4.54˚E) and at Ladoke Akintola University of Technology, Ogbomosho, Oyo State (8.14˚N and 4.25˚E) during the 2024 planting season.

Description of the Experimental

The thirty-two experimental materials used for the research were obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. The materials are Provitamin A enriched maize hybrids. The local check was obtained from the seed store. The list of the hybrids is presented in Table 1.

Experimental Design

Field trials at each site were implemented using a Randomized Complete Block Design (RCBD). Each trial comprised double-row plots measuring 5 m in length, with 75 cm inter-row spacing and 40 cm within-row spacing. To enhance data reliability, trials were replicated three times across the two locations. At planting, three seeds were sown per hole and subsequently thinned to two plants per hill at two weeks (WAP). The experiments were conducted under rain-fed condition in 2024

Agronomic Practices

Agronomic management practices (pre-emergence herbicide and fertilizer application in two doses) necessary for optimum crop performance were carried out to enhance crop performance. Weed control was done with the application of pre-emergence herbicides (3 g/L Metolachlor and 170 g/L Atrazine a.i). Supplementary weeding at 6 and 10 weeks after sowing (WAS) were carried out to keep the field clean of weeds. Fertilizer application was done at 3 WAS at the dosage rate of 180 kg/ha of NPK 20-10-10 and top-dressed with 60 kgN/ha of urea fertilizer (46% N) at 6 WAS. Harvesting and threshing of cobs on each plot were done manually at both locations.

Data Collection

The following data were collected on the field:

Days to pollen-shed: Days to pollen-shed was recorded as the number of days from planting to when 50% of the plants had shed pollen on each plot.

Days to silking: Days to silking was recorded as the number of days from planting to when 50% of the plants had emerged silks on each plot.

Plant height: The height of five (5) plants selected at random in a plot was measured as the distance (cm) from the base of the plant to the height of the first tassel branch.

Ear height: The ear placement of the same five (5) random plants selected at random in a plot was measured as the distance (cm) from the base of the plant to the node bearing the upper leaf ear.

Plant and ear aspects: Plant and ear aspects were rated on a scale of 1 to 5, where 1 = excellent in overall phenotypic appearance and 5 = poor in overall phenotypic appearance.

Moisture content (%): Moisture content was determined with the aid of a moisture meter at harvest.

Grain yield: Grain yield was measured in kilograms/plot (kg/plot), but later converted to tonnes per ha (t/ha) at 12% grain moisture using the formula below.

$$\text{Grain Yield} = \frac{\text{FWT}\ (100 - \text{MC}) \times 0.8 \times 10{,}000}{(100-12) \times 7.5}$$

Where: FWT = Field Weight (in kg plot^{-1}); MC = Moisture Content at harvest (%); 0.8 = shelling co-efficient; 7.5 = Area harvested plot^{-1} (m^2); 1 hectare = 10,000 m^2 and 12% = moisture content required in maize grain at storage.

Statistical Analysis

The data collected were subjected to analyses of variance (ANOVA) using SAS version 9.0 (SAS, 2009). Combined analyses of variance (ANOVA) were performed across locations to determine whether there is a significant difference between them. Means were separated using Least Significant Difference (LSD).

Table 1: List of the 32 Genetic Materials Used in the Study

S/N	Hybrids	Source	S/N	Hybrids	Source
1	M2414-15	IITA	17	M2414-21	IITA
2	M2414-19	IITA	18	M2414-03	IITA
3	Ife Hybrids-3	IITA	19	M2414-18	IITA
4	M2414-23	IITA	20	M2414-11	IITA
5	LY1001-23	IITA	21	M2414-10	IITA
6	M2414-27	IITA	22	M2414-17	IITA
7	M2414-13	IITA	23	M2414-22	IITA
8	ObaSuper 2	Seed store	24	M2414-14	IITA
9	M2414-01	IITA	25	M2414-07	IITA
10	M2414-04	IITA	26	M2414-26	IITA
11	M2414-12	IITA	27	Ife Hybrid-4	IITA
12	M2414-08	IITA	28	M2414-16	IITA
13	M2414-06	IITA	29	M2414-09	IITA
14	M2414-24	IITA	30	M2414-25	IITA
15	M2414-02	IITA	31	M2414-05	IITA
16	M2414-20	IITA	32	M2414-28	IITA

RESULTS AND DISCUSSION

Combined Analysis of Variance for Grain Yield and Agronomic Traits

A combined analysis of variance (ANOVA) was done to evaluate the agronomic performance of 32 maize hybrids across two test environments. The results (table 2) showed highly significant ($\rho \leq 0.01$) differences among the hybrids for all agronomic traits assessed, including grain yield (GY), days to pollen-shed (DP), days to silking (DS), anthesis-silking interval (ASI), plant height (PH), ear height (EH), root lodging (RL), stem lodging (SL), plant aspect (PA), and ear aspect (EA). These observed significant differences underscore the considerable effect of both genetic composition and environment on the expression of all traits. The observed genetic variation among the hybrids is consistent with findings from Kolawole et al. (2021) and Menkir et al. (2021), who emphasized that genetic diversity is requisite for the selection of hybrids with superior performance and broad adaptation.

The ANOVA further indicated that replications within environments were a significant source of variation ($p \leq 0.05$ or $p \leq 0.01$) for several traits, namely GY, DP, DS, RL, SL, and PA. This implied that micro-environmental variations, such as those in soil fertility, drainage, or sun exposure across blocks, influenced the expression of the traits. The presence of significant replication effects confirmed that the experimental locations were not entirely uniform. This practice enhanced the reliability and precision of hybrid comparisons, which aligned with the approaches of

Kolawole *et al*. (2021) and Adebayo, 2023), who employed replicated multi-environment trials to partition environmental and genetic effects effectively.

The main effect of environment was highly significant ($p \leq 0.01$) for GY, DS, ASI, PH, and EH, and significant ($p \leq 0.05$) for DP and EA. This strong environmental influence indicated that hybrid performance was markedly affected by conditions that are location-specific, including variations in rainfall distribution, temperature, and soil type. This observation corroborates the work of Bankole *et al.,* 2023 and Akintunde 2024, who highlighted the critical role of rainfall distribution, particularly during flowering and grain-filling stages, in determining maize yield outcomes across different locations in Nigeria.

Furthermore, the hybrids-by-environment (H× E) interaction effects were highly significant ($p \leq 0.01$) for GY, ASI, and PH. This significant crossover H×E interaction revealed that the relative performance of hybrids was not consistent across the two environments; some genotypes performed well in one location but exhibited reduced performance in the other. The significant H×E interaction underscores the necessity for location-specific adaptation trials to identify hybrids with specific adaptation to target environments.

Mean Performance of Thirty-Two Selected Maize Hybrids

The mean performance evaluation of the 32 hybrids revealed substantial variation for all measured traits (Table 3). Seventeen hybrids recorded grain yields that exceeded the grand mean of 3.44 t/ha, and 24 hybrids outperformed the local checks. The three highest-yielding hybrids M2414-02, M2414-24, and M2414-11 exhibited a combination of desirable agronomic characteristics, including short ASI, moderate plant and ear height, and favourable plant and ear aspect scores. These traits are associated with enhanced stress tolerance, efficient photosynthesis, and overall plant stability. Conversely, the lowest-yielding hybrids were M2414-13 (1.78 t/ha), M2414-27 (2.24 t/ha), M2414-22 (2.36 t/ha), and M2414-28 (2.36 t/ha).

The ASI, a critical indicator of stress tolerance, varied among hybrids. Hybrids such as M2414-23 and M2414-27 displayed short ASI values, which demonstrated their potential for better performance under drought conditions. This finding is consistent with Menkir et al. (2021), who identified a short interval between anthesis and silking as a key trait for ensuring successful pollination and grain set under water-deficit conditions.

The average plant height across hybrids was 151.48 cm. Hybrid M2414-06 was the tallest (167.80 cm), while M2414-15 was the shortest (126.22 cm). Mean ear height was 62.78 cm, with hybrid M2414-10 exhibiting the highest ear placement (86.79 cm) and M2414-15 the lowest (52.25 cm). Notably, the most productive hybrids generally maintained moderate plant heights, a characteristic that reduces lodging risk and optimizes light interception for canopy photosynthesis.

Top-performing hybrids received plant and ear aspect scores below 2.5, reflecting desirable plant architecture and well-filled, uniform ears. This association between good phenotypic scores and high yield aligned with Kolawole and Olayinka (2022), supporting the utility of visual selection indices in maize breeding programs. Lodging scores were generally low, particularly for elite hybrids like M2414-24 and M2414-02, indicating their potential for field resilience. Additionally, husk cover was predominantly tight across hybrids, an important for protecting grain from pest damage and moisture, thereby preserving grain quality and harvest efficiency.

Significant differences observed indicate the impact of the genetic factors and environmental conditions on the expression of traits across the test environments. This confirms considerable genetic variability among the hybrids and exclusivity of agThe significant differences among genotypes confirmed the influence of genetic diversity that can be utilized to improve g. Also, the strong environmental effect and significant genotype by environment interaction showed the effect of location-specific condition on hybrid performance, emphasizing the need for location-specific adaptation studies.

Table 2: Mean squares from combined ANOVA of grain yield and agronomic characters of thirty-two provitamin A maize hybrids evaluated across environments

Source of Variation	df	GY	DP	DS	ASI	PH	EH	RL	SL	PA	EA
Environment(Env)	1	22.07**	1175.13**	77.52**	649.01**	18616.5**	8270.06**	114.86**	138.38**	15.19**	19.22**
Replicate(Env)	4	2.69**	11.78*	5.73*	2.14	45.22	52.34	0.19*	0.51**	1.48**	0.23
Hybrids	31	2.59**	7.55*	17.00**	6.86**	358.28**	202.25**	0.08	0.14	0.18	0.56*
Env*Hybrids	31	1.31**	2.76	3.77	2.95*	132.43*	71.86	0.10	0.20*	0.19	0.26
Error	82	0.69	4.78	4.83	2.94	72.36	82.50	0.08	0.10	0.16	0.23

*, ** significantly different at 0.05 and 0.01 levels of probability respectively.

N.B: df: Degree of freedom, GY: Grain yield, DP: Days to pollen shed. DS: Days to silking, ASI: Anthesis-silking interval, PH: Plant height, EH: Ear height, RL: Root lodging, SL: Stem lodging, PA: Plant aspect, EA: Ear aspect

Table 3: Mean performance for grain yield and agronomic characters of 32 Provitamin A maize hybrids evaluated across two environments

Hybrids	Grain Yield (kg/ha)	Days to Pollen Shed	Days to Silking	Anthesis Silking Interval (days)	Plant Height (cm)	Ear Height (cm)	Root Lodging(1-5)	Stem Lodging (1-5)	Husk Cover (1-5)	Plant Aspect (1-5)	Ear Per Plant (no)	Ear Aspect (1-5)
M2414-15	2.48	56	59	3	126.22	52.25	0.79	0.56	2.42	2.33	1.13	2.20
M2414-19	2.56	58	62	4	156.70	69.60	0.84	0.76	1.69	2.05	1.45	1.35
Ife Hybrids-3	3.59	58	63	5	158.33	65.05	0.71	0.84	1.85	2.07	1.17	1.68
M2414-23	3.30	61	64	2	157.23	65.68	0.82	1.00	1.89	2.27	0.79	1.67
LY1001-23	3.50	58	62	4	161.49	70.90	0.88	0.96	2.34	2.35	1.15	2.08
M2414-27	2.24	56	58	2	153.46	58.42	0.94	1.07	2.35	2.79	1.60	1.96
M2414-13	1.78	57	58	2	157.29	59.08	1.12	1.21	2.22	2.27	1.87	2.24
Oba Super 2(LC)	3.03	57	62	5	145.12	59.97	0.82	0.66	1.89	2.58	1.06	1.74
M2414-01	3.83	58	61	3	150.18	65.57	0.76	0.90	2.07	2.08	1.29	2.48
M2414-04	3.26	59	63	4	156.65	60.07	0.75	0.85	1.97	2.22	1.04	1.92
M2414-12	3.35	59	64	5	159.31	64.04	0.88	1.05	2.41	2.35	1.07	2.35
M2414-08	4.28	59	64	5	160.95	62.32	0.72	0.56	2.13	2.20	1.31	1.54
M2414-06	3.75	58	64	6	167.80	64.25	0.76	0.83	2.06	2.27	1.28	1.38
M2414-24	4.43	59	62	3	152.90	65.45	0.72	0.87	1.96	2.32	1.37	1.43
M2414-02	4.44	59	62	3	149.58	54.87	0.94	1.13	1.88	2.24	1.15	1.46
M2414-20	4.32	57	61	4	153.23	63.48	0.34	0.55	1.80	1.89	1.30	1.61
M2414-21	4.17	56	60	4	150.58	61.27	0.62	0.71	1.99	2.18	1.27	1.65
M2414-03	4.03	59	62	3	145.14	55.49	0.77	0.91	2.32	2.20	1.83	1.49
M2414-18	3.11	59	62	3	152.22	68.06	0.74	0.75	1.78	2.29	1.02	1.44
M2414-11	4.39	58	61	3	159.39	69.91	0.83	0.94	2.18	2.56	1.24	1.54
M2414-10	4.02	58	61	4	153.82	86.79	1.02	1.16	2.10	2.23	1.17	1.78
M2414-17	2.52	59	65	7	137.24	59.64	0.76	0.76	2.18	2.54	1.12	1.74
M2414-22	2.36	60	66	6	144.15	57.24	0.66	1.03	2.55	2.76	1.33	2.24
M2414-14	3.34	56	59	2	152.36	65.94	0.87	1.02	2.11	2.04	1.33	2.19
M2414-07	3.82	58	60	3	150.59	63.62	0.68	0.73	2.00	2.10	1.21	2.05

M2414-26	3.75	56	59	3	153.43	49.56	0.74	0.99	1.86	2.36	1.07	2.04
Ife Hybrid-4	3.99	59	62	4	165.61	60.37	0.78	0.97	2.27	2.48	1.07	2.01
M2414-16	3.10	57	61	3	145.12	59.81	0.82	0.81	2.51	2.44	1.16	2.52
M2414-09	3.68	57	61	4	151.02	71.61	0.91	1.29	2.23	2.32	0.94	2.39
M2414-25	3.83	57	61	5	144.82	62.91	0.71	0.88	2.05	2.34	1.05	2.34
M2414-05	3.41	57	63	6	139.20	62.95	0.84	0.74	2.10	2.25	1.22	2.08
M2414-28	2.36	56	60	4	136.27	52.91	0.89	1.03	2.10	2.32	1.26	1.88
MEAN	3.44	58	61	3.89	151.48	62.78	0.79	0.89	2.10	2.30	1.23	1.89
LSD	0.95	2.51	2.52	1.97	9.75	10.43	0.31	0.38	0.37	0.46	0.26	0.55
CV (%)	24.09	3.78	3.57	44.03	5.62	14.46	34.23	37.01	15.45	17.56	18.58	25.48

LSD: Least significant difference; CV: Coefficient of variation

CONCLUSION

This study confirmed that both genetic factors and environment significantly influence the performance of provitamin A-enriched maize hybrids. The identification of high-yielding hybrids like M2414-02, M2414-24, and M2414-11 that combined superior yield with desirable agronomic traits demonstrated the effectiveness of breeding strategies. With 24 hybrids outperforming the local check, the research underscored the potential of multi-environmental testing to identify resilient, nutritionally enhanced varieties. These results will facilitate the identification and release of maize hybrids with the capacity to tolerate environmental stresses while also combating micronutrient deficiencies, thereby fostering sustainable agriculture and enhancing the nutritional status of the resource-limited farming communities.

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