Article

Field Performance of Extra-Early Maturing Pro-Vitamin A Maize (*Zea mays* L.) Hybrids under Optimal Rainfed Conditions in the Derived Savanna Agroecology Zone

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ABSTRACT

Adopting extra-early maturing pro-vitamin A (PVA) maize hybrids, which can help combat malnutrition and enhance grain yield, is essential in areas with erratic rainfall patterns. This study was carried out to (i) evaluate the performance of extra-early maturing PVA maize hybrids under optimal growing conditions; (ii) identify superior hybrids in terms of high yield and adaptability. A total of 16 hybrids, including two commercial hybrids used as local checks, were evaluated for two years. The trials were laid out in a randomized complete block design (RCBD) with three replicates at the Teaching and Research (T&R) Farm of Ladoke Akintola University of Technology, Ogbomoso, Nigeria. Data were recorded on grain yield and other agronomic traits and analysed. Significant variations ($p < 0.001$) were observed among the hybrids for measured traits, indicating adequate genetic variability among the hybrids, which can be exploited for trait improvement and selection of superior hybrids. The years of evaluation contributed 70.9% to the total variation in grain yield, the hybrid accounted for 18.6% and the hybrid × year interaction, 10.5%. Grain yield (GY) of hybrids ranged from 2.25 t ha^{-1} (EEPVAH-38) to 4.22 t ha^{-1} (EEPVAH-48), with a mean of 3.51 t ha^{-1}. The outstanding PVA hybrid (EEPVAH-48) outyielded the best check by 19%. The results of the rank summation index and cultivar superiority index were found to be consistent, as both methods identified EEPVAH-48 (4.22 t ha^{-1}), followed closely by EEPVAH-40 (4.10 t ha^{-1}), as the highest yielding hybrids. These hybrids exhibited outstanding yield and adaptability, highlighting the need for extensive on-farm trials to confirm their superiority and potential for commercialization in the derived savanna agroecology zone.

KEYWORDS: adaptation; derived savanna agroecology; extra-early maturing PVA hybrid; grain yield; selection; variation

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INTRODUCTION

Maize (*Zea mays* L.) is a widely cultivated cereal crop that is predominantly used for food, feed, forage, and industrial purposes such as flours, ethanol, starch, oil, sugar, and syrup globally [1,2]. It is a versatile crop utilized in diverse ways and cultivated in the tropical as well as subtropical regions of the world. The annual worldwide production of maize is 785 million tonnes, with the United States of America, China, and Brazil being the largest producers, with grain yield ranging between 7 to 12 t ha^{-1}, accounting for approximately 72% of global production. In contrast, Africa produces about 7% of maize globally [3,4]. In Africa, Nigeria's maize grain yield has been oscillating between 1.7 and 2.0 t ha^{-1} since 2017, which is significantly lower than South Africa's 4.9 t ha^{-1} and Ethiopia's 4.2 t ha^{-1} [5]. The wide gap in production and abysmal grain yield recorded in diverse agroecologies is attributed to a combination of biotic (diseases, parasitic weeds, insect-pests) and abiotic (heat, frequent drought, prolonged dry spell, waterlogging, low soil fertility) constraints, as well as the predominant cultivation of open-pollinated varieties over hybrids.

The significance of maize in food and nutritional security and its adaptability necessitates continuous research efforts. Improved crop varieties significantly contribute to agricultural productivity [6]. The development of maize hybrids was described as the best alternative to enhance production and productivity [7,8]. The International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, has developed several biofortified (PVA) maize hybrids (single, three-way, and double-cross) that combine tolerance to multiple stresses with diverse maturity groups (late, intermediate, early, and extra-early). These hybrids address health issues related to vitamin A deficiency and are suitable for areas with marginal rainfall or short rainy seasons, enabling flexible planting dates and multiple plantings to mitigate drought stress during the grain-filling stage. Extra-early maturing PVA maize hybrids (maturing in 80–85 days) are particularly valuable for curbing hunger and enhancing food security amidst erratic rainfall patterns. Disseminating and adopting these hybrids in savanna agroecologies is vital for meeting the calorie and nutrient needs of consumers, especially in the context of climate change and geometric population growth. Therefore, evaluating these new genetic materials for grain yield and other desirable agronomic traits is crucial to ensure their adaptation to the environments where they will be cultivated [9,10].

The variability in temperature, evapotranspiration, solar radiation, and precipitation during the cropping season significantly influences the cultivation and production of staple crops [11,12]. The savanna agroecological zones in Nigeria have immense potential for maize production due to high solar radiation, low night temperatures, and low pests and diseases. However, the incessant variability in the duration, amount, and distribution of rainfall, mid-season drought, and poor soil water-holding capacity adversely affect maize productivity, posing a threat to food security and economic growth [13]. The Derived Savanna constitutes an east-west band between the Lowland Rain Forest and Guinea Savanna ecological zones, shares agro-climatic conditions with sufficient annual precipitation with the rainforest zone and abundant radiation with the Guinea savanna [2]. This area, with a mean annual rainfall of about 1300 mm and an average temperature of 32.5 °C, enjoys approximately 60% relative humidity and 8–10 h of daily sunshine, making it suitable for high maize productivity [14]. Despite experiencing a bimodal rainfall pattern, the abrupt cessation of rains during crop cycles is a challenge, leading to dry spells during critical growth stages such as flowering and grain filling [15]. Over the years, this variability in rainfall patterns has significantly impacted maize growth, development, and grain yield in this region [16].

Maize breeders emphasize the interaction between genotype and environmental factors (location, year of planting, climate, soil type, technology level) due to genotype instability caused by environmental variations, leading to yield discrepancies [17,18]. Dry matter accumulation is also highly influenced by the environment [19]. Identifying stable and productive genotypes that perform well across various environments is essential. These superior genotypes can then be promoted for release to farmers. The objectives of this study are to: (i) evaluate the performance of extra-early maturing PVA maize hybrids under optimal growing conditions; and (ii) identify superior hybrids in terms of high yield and adaptability for cultivation in the derived Savanna agroecological zone of Nigeria.

MATERIALS AND METHODS

Planting Materials

The planting materials used for this study were 14 extra-early maturing PVA maize hybrids and two checks (as shown in Table 1), i.e., 16 hybrids in total. These materials were obtained from the Maize Improvement Programme of the IITA, Ibadan, Nigeria. The two checks used were a reference check from IITA and a commercial hybrid planted by farmers in the derived savanna agroecology.

Table 1. List of extra-early PVA maize hybrids used in the study and their sources.

Entry	Name	Grain Color	Source
1	EEPVAH-38	Orange	IITA
2	EEPVAH-39	Orange	IITA
3	EEPVAH-40	Orange	IITA
4	EEPVAH-41	Orange	IITA
5	EEPVAH-43	Orange	IITA
6	EEPVAH-45	Orange	IITA
7	EEPVAH-46	Orange	IITA
8	EEPVAH-47	Orange	IITA
9	EEPVAH-48	Orange	IITA
10	EEPVAH-49	Orange	IITA
11	EEPVAH-8	Orange	IITA
12	EEPVAH-52	Orange	IITA
13	EEPVAH-53	Yellow	IITA
14	EEPVAH-24	Orange	IITA
15	Reference check	Yellow	IITA
16	Local check	Yellow	Ogbomoso

EEPVAH = Extra-early Pro-Vitamin-A Hybrid; IITA = International Institute of Tropical Agriculture.

Description of the Experimental Site

The trial was carried out at the T&R Farm of Ladoke Akintola University of Technology (LAUTECH), Ogbomoso (8°10'N, 4°10'E, and altitude 341 m above sea level) in the derived savanna agroecology of Nigeria. The annual mean rainfall of the experimental site ranges between 1000 and 1200 mm, while the daily temperature is between 28–30 °C, and the soils are characterized as Alfisol, which are generally low in nitrogen. The rainfall distribution data for 2018 and 2019 (Figure 1) were obtained from the weather station situated at the Faculty of Agricultural Sciences, LAUTECH, Ogbomoso. The 16 maize hybrids were planted during the main cropping seasons under normal rainfed conditions in 2018 and 2019, respectively. Rainfall amount and distribution during the growing periods of both years showed that, in comparison to 2018, rainfall was not equally distributed throughout the flowering/grain filling periods of July and August 2019. The rainfall patterns were different in both cropping years, which resulted in varied performances for all agronomic traits measured.

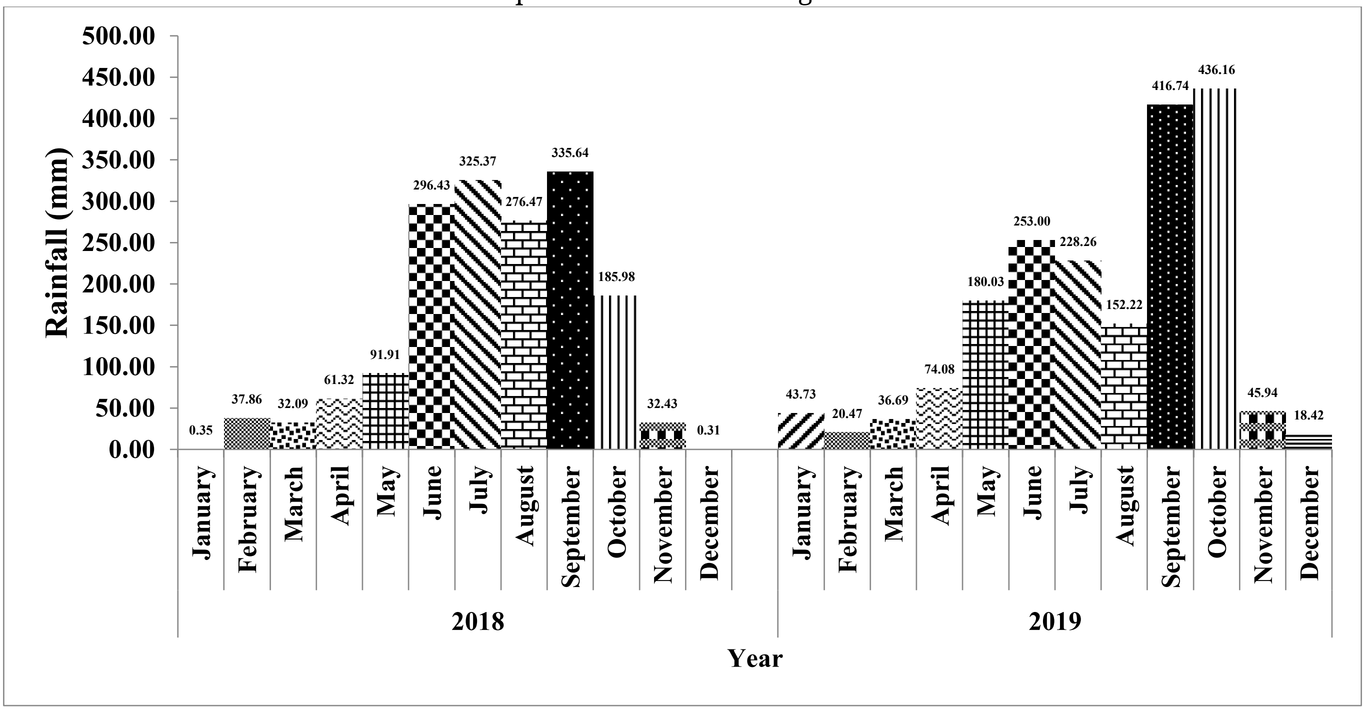

Figure 1. Monthly rainfall distribution pattern at Ogbomoso in 2018 and 2019.

Layout and Field Evaluation

The experiment was laid out in a RCBD with three replications. A plot was two rows of 5 m length with a spacing of 0.50 m within rows and 0.75 m between rows. Three seeds were planted per hill, but later thinned to two per hill at the three-leaf stage of development after sowing. A maximum of 22 plants per plot was obtained to attain the optimum population density of 53,333 plants ha^{-1}. Weeds were controlled with a mixture of Gramoxone (which contained paraquat as an active ingredient) and Primextra (which contained atrazine and metolachlor as active ingredients) applied as pre- and post-emergence herbicides at the rate of

5.0 litres ha^{-1} at sowing. Weeds were also controlled by hand weeding as necessary after the crop had established. NPK 15-15-15 fertilizer was applied at the rate of 60 kg ha^{-1} N, 60 kg ha^{-1} of P_2O_5, and 60 kg ha^{-1} of K_2O at the time of sowing. Urea (45% N) was applied 4 weeks after sowing as top-dressing at the rate of 60 kg ha^{-1} N to achieve the 120 kg ha^{-1} N recommended for maize production in the zone.

Data Collection

Data were recorded on the number of days to 50% anthesis (DA) and silking (DS) as the number of days from planting to when 50% of the plants had extruded tassels, shed pollen, and emerged silks, respectively. Anthesis-silking interval (ASI) was calculated as the difference between the number of days to 50% silking and anthesis. Plant (PH) and ear (EH) heights were measured as the distance from the base of the plant to the height of the first tassel branch and the node bearing the upper ear, respectively. Both variables were recorded as an average of 20 competitive plants per plot using a meter rule (cm). Husk cover (HC) was rated on a scale of 1 to 5, where 1 = husk tightly arranged and extended beyond the ear tip, and 5 = ear tips exposed. Plant aspect (PASP) was based on overall plant phenotypic appeal (plant and ear heights, uniformity of plants, cob size, lodging, disease, and insect damage) and was recorded on a scale of 1 to 5, where 1 = excellent plant type and 5 = poor plant type. Ear aspect (EASP) was scored on a 1 to 5 scale, where 1 = clean, uniform, large, and well-filled ears, and 5 = rotten, poorly filled, and small ears, and partially or poorly filled ears. The number of ears per plant was computed by dividing the total number of ears harvested per plot by the number of plants in a plot. GY was computed from the ear weight and converted to kg ha^{-1}. A shelling percentage of 80% was assumed for all hybrids, and the grain yield was adjusted to 15% moisture using the following formula:

$$\text{Grain yield (kg ha}^{-1}) = \text{ear weight (kg plot}^{-1}) \times \frac{100 - \text{MC}}{85} \times \frac{10{,}000}{\text{plot area (m}^2)} \times 0.80 \quad (1)$$

Where MC = grain moisture at harvest.

Data Analysis

All collected data were entered in Microsoft Excel 2010 and analyzed by using the Statistical Analysis System (SAS) software package version 9.4 [20]. The data were subjected to analysis of variance (ANOVA) as described by Gomez and Gomez [21] for RCBD experiments using the procedure of General Linear Model (PROC GLM) in SAS for the separation of the variance components [22]. First, ANOVA was performed for each year of evaluation separately, to test the homogeneity of the mean squared error using Bartlett's test. After validating the homogeneity, the combined ANOVA for all traits measured across years was performed to determine hybrid × year interactions. In the combined ANOVA, replications, years, and hybrid × year interaction were considered as random effects, while the hybrids were considered fixed effects. The linear additive model used for the combined analysis over the years was:

$$Y_{ijk} = \mu + Y_i + R(Y)_{ij} + G_k + GY_{ik} + \varepsilon_{ijk} \quad (2)$$

Where Y_{ijk} = the observation made in the j-th replication of the i-th year on the k-th genotype; μ = overall means; y_i = the effect of the i-th year; $R(Y)_{ij}$ = the effect of the j-th replication within the i-th year; G_k = the effect of the k-th genotype; GY_{ik} = effect of the interaction of the k-th genotype with the i-th year; ε_{ijk} = components of error effect due to sampling among the genotypes in the years (random error).

Least-squares means for each trait were computed, and when the effects of the hybrid were found significant for traits measured, the means were further separated using Fisher's least significant difference (LSD) test at a 0.05 probability level. Rank Summation Index (RSI) [2,23] and Cultivar Superiority Index (CSI) [24,25] were used to assess the superiority of the hybrids. The RSI was constructed by ranking four traits associated with grain yield, which showed a significant difference from ANOVA. These traits were ranked for each hybrid in order of preference. For grain yield, the higher the values, the better, while for anthesis-silking interval (days), plant aspect and ear aspect scores (1–5), the lower the values, the better. The ranks for each hybrid for the four traits were then summed up to obtain an index as:

$$RSI_1 = \Sigma a_1 + b_1 + \cdots + n_1 \quad (3)$$

Where a_1 = rank of mean of trait "a" of hybrid 1; b_1 = rank of mean of trait "b" of hybrid 1; n_1 = rank of mean of trait "n" of hybrid 1.

The CSI measures the behavior of genotypes where genotype × year interactions are significant [24]. The superiority index (P_i) helps to identify a promising and stable genotype. Thus, the genotype with the lowest P_i value is considered most productive, stable, and adapted in each of the evaluation years (environment). The superiority index characterizes genotypes with a single trait (grain yield) and was computed using the following formula:

$$P_i = \sum_{j=i}^{n} \frac{(X_{ij} - M_j)^2}{2n} \quad (4)$$

Where P_i = superiority index of *i*-th hybrid (the distance mean square between the hybrid's yield response and the maximum hybrid yield response averaged over all years of evaluation; X_{ij} = yield of the *i*-th hybrid in the *j*-th year; M_j = maximum yield among all the hybrids in the *j*-th year; and *n* = years of evaluation/number of environments.

RESULTS

Analysis of Variance for Grain Yield and Other Agronomic Traits

Mean square estimates from ANOVA for each year of evaluation (data not shown) revealed that hybrid effects were highly significant ($p < 0.001$) for grain yield and other agronomic traits. The combined ANOVA for grain yield and other agronomic traits on 16 maize hybrids in two years revealed that years, hybrids, and hybrid × year interaction significantly affect most of the traits measured (Table 2). As a factor, hybrids showed significant ($p < 0.001$) mean squares for all traits measured except for husk cover rating. Also, years of evaluation revealed highly significant ($p < 0.001$) mean squares for all measured traits, except number of days to silking and anthesis-silking interval. There were significant ($p < 0.001$) hybrid × year interaction effects for grain yield, plant height, number of days to anthesis and silking, plant and ear aspects. Moreover, the expression of the hybrids for anthesis-silking interval, ear height, and husk cover was consistent and not affected by the hybrid × year interaction. The years of evaluation contributed 70.88% of the total variation in grain yield, the hybrids accounted for about 18.59% and the hybrid × year interaction accounted for about 10.53%. The high coefficients of determination (R^2) values ranging from 51 to 95% depict that the variation explained by the statistical model was high. Coefficients of variability (CV) were ≤ 20% (reasonable) for most of the traits measured, except for anthesis-silking interval and husk cover, indicating high precision in experimentation and reliability of the statistical model used.

Table 2. Mean squares from the analysis of variance for grain yield and other agronomic traits of extra-early PVA maize hybrids.

Source	df	Anthesis (Days)	Silking (Days)	Anthesis-Silking Interval (Days)	Plant Height (cm)	Ear Height (cm)	Husk Cover (1–5)	Plant Aspect (1–5)	Ear Aspect (1–5)	GY (kg ha^{-1})	% Total Contribution
Year (Y)	1	16.67 **	6.00	2.67	100,556.76 ***	21,093.01 ***	14.65 ***	1.63 ***	8.46 ***	111,147,969 ***	70.88
Replication (Y)	4	5.29	5.86	4.55	474.85 ***	142.14	0.96 *	0.10	0.08	360,434.80	-
Hybrid	15	9.78 ***	11.98 ***	4.62 *	666.64 ***	298.86 ***	0.53	0.42 ***	0.78 ***	1,942,983.00 ***	18.57
Hybrid × Y	15	7.51 ***	7.09 *	3.80	213.16 *	101.69	0.49	0.29 *	0.96 ***	1,101,021.80 **	10.53
Error	60	2.47	3.31	2.37	108.01	58.61	0.36	0.14	0.12	491,826.90	-
CV (%)	-	3.02	3.24	37.93	6.39	10.54	24.93	15.12	13.36	20.23	-
R^2 (%)	-	67	61	51	95	89	61	61	83	84	-

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively. R^2 = coefficient of determination; CV = coefficient of variation; Bartlett test of homogeneity of variances: Anthesis (p = 0.0533), Anthesis-silking interval (p = 0.1927), Plant height (p = 0.3425), Ear height (p = 0.2662), Husk cover (p = 0.0709), Field weight (p = 0.7964), Ear aspect (p = 0.3279)

Mean Performance of Extra-Early Maturing PVA Maize Hybrids

The mean performance of the hybrids showed that the hybrids had lower scores for husk cover, plant, and ear aspects, with corresponding higher grain yield, plant, and ear heights in 2018. However, the flowering traits remained relatively unaffected by the differences in the growing conditions in the two years of evaluation (Table 3). In 2018, the mean grain yield of the hybrids was 4572 kg ha^{-1}, with the highest yielding hybrid

(EEPVAH-53) producing a grain yield of 5668 kg ha^{-1} while the lowest yielding hybrid (EEPVAH-38) produced a grain yield of 2403 kg ha^{-1}. In 2019, the mean grain yield of the hybrids was 2450 kg ha^{-1}, with the highest yielding hybrid (EEPVAH-40) producing a grain yield of 3212 kg ha^{-1} while the lowest yielding hybrid (EEPVAH-8) produced a grain yield of 1497 kg ha^{-1}. In each year, the highest yielding hybrid out-yielded the IITA reference check, by 24–53% The highest yielding hybrids in 2018 and 2019 were 23 and 38% above the check's mean (the reference check from IITA and local check from Ogbomoso), respectively. There was no significant yield advantage between the local check and the IITA reference check in 2018, whereas, in 2019, the local check significantly ($p < 0.05$) outyielded the IITA reference check.

Table 3. Interactive effects of Hybrid × Year on grain yield and other agronomic traits of the evaluated extra-early PVA maize hybrids.

	2018									2019								
Hybrid	**DA**	**DS**	**ASI**	**PH**	**EH**	**HC**	**PASP**	**EASP**	**GY**	**DA**	**DS**	**ASI**	**PH**	**EH**	**HC**	**PASP**	**EASP**	**GY**
EEPVAH-38	52	58	6	179	73	3	3	3	2403	52	55	3	119	57	3	3	4	2089
EEPVAH-39	50	56	7	194	88	2	2	2	4867	52	55	3	154	77	2	2	2	2744
EEPVAH-40	53	56	4	207	97	3	2	2	4990	50	55	4	136	56	2	2	3	3212
EEPVAH-41	52	55	3	200	92	2	3	2	5052	52	55	3	119	47	3	2	3	2432
EEPVAH-43	51	54	3	218	100	3	3	3	5113	53	57	4	156	67	2	3	2	2495
EEPVAH-45	52	55	3	197	81	2	3	2	4620	52	56	5	127	59	3	2	2	2495
EEPVAH-46	51	55	4	202	93	2	3	3	4066	53	58	5	136	62	3	2	3	2806
EEPVAH-47	51	58	6	191	81	2	2	2	3142	52	57	5	133	55	2	3	4	2214
EEPVAH-48	51	56	5	202	84	2	2	2	5606	52	56	4	117	49	3	2	3	2838
EEPVAH-49	54	58	3	210	103	2	2	2	3943	56	58	2	138	70	3	3	2	2557
EEPVAH-8	51	53	3	181	83	2	2	2	5052	52	54	2	119	51	3	3	4	1497
EEPVAH-52	52	56	5	183	86	2	2	3	5421	53	57	4	134	60	3	3	2	2495
EEPVAH-53	50	55	5	189	85	2	2	2	5668	53	56	3	111	54	3	2	3	2682
EEPVAH-24	52	55	3	187	78	2	3	3	4066	52	56	4	116	50	3	3	2	1746
Mean	52	56	4	196	87	2	2	2	4572	52	56	4	130	58	3	3	3	2450
Minimum	50	53	3	179	73	2	2	2	2403	50	54	2	111	47	2	2	2	1497
Maximum	54	58	7	218	103	3	3	3	5668	56	58	5	156	77	3	3	4	3212
Range	5	5	4	39	30	1	1	1	3265	6	4	3	45	30	1	1	2	1715
LSD (0.05)	3	4	3	19	14	1	0	0	1457	2	2	2	20	11	1	1	1	783
S.E (±)	1	1	1	7	5	0	0	0	504	1	1	1	4	2	0	0	0	271
Reference check	53	56	3	195	86	2	2	2	4312	48	54	6	140	60	3	3	4	1497
Local check	52	57	5	184	89	2	3	3	4374	58	63	5	132	55	3	3	2	2463

DA = Anthesis; DS = Silking; ASI = Anthesis-silking interval; PH = Plant height; EA = Ear height; HC = Husk cover; PASP = Plant aspect; EASP = Ear aspect; GY = Grain yield

In 2018, a comparison of the mean performances of the evaluated hybrids against the mean of the two checks for various agronomic traits revealed the following: 64% of the hybrids had a shorter number of days to anthesis, taller plants, and higher grain yield. Approximately half of the hybrids exhibited earlier silk emergence, while 36% demonstrated superior values for ear height and lower scores for plant and ear aspect. About 20% of the hybrids had lower values for the anthesis-silking interval and husk cover scores. However, only one hybrid (EEPVAH-39) showed a significant difference ($p < 0.05$) from the checks for plant and ear aspect scores.

Similarly, in the second year of evaluation (2019), the hybrids demonstrated the following performance compared to the mean performance of the checks: 93–100% of the hybrids flowered earlier, 79%

had better husk cover and plant aspect scores. Half of the hybrids showed better ear aspect scores, while 38% exhibited higher plant and ear heights. Additionally, some of the elite 14 PVA maize hybrids evaluated showed a significant difference ($p < 0.05$) from the two checks in the following traits: grain yield, number of days to silking, anthesis-silking interval, plant and ear heights, plant and ear aspects.

Across the two years of evaluation, the mean grain yield of hybrids ranged from 2246 kg ha^{-1} (EEPVAH-38) to 4222 kg ha^{-1} (EEPVAH-48), with a mean of 3511 kg ha^{-1} (Table 4). The hybrids attained anthesis earlier than silking, with a mean of 52 and 56 days, respectively. Most of the hybrids exhibited anthesis-silking interval ranging from 3 to 4 days, with a mean of 4 days. The hybrids had good plant and ear aspects, with a mean of 2.4 and 2.6, respectively. The husk cover score was between 1.8 and 2.9, with a mean of 2.4. The top-performing hybrid (EEPVAH-48) had 25% higher grain yield than the average grain yield of the checks, which was 3162 kg ha^{-1}, but outyielded the best check by 19%.

Table 4. Means performance of the evaluated extra-early PVA maize hybrids across years.

Hybrid	Anthesis (Days)	Silking (Days)	Anthesis-Silking Interval (Days)	Plant Height (cm)	Ear Height (cm)	Husk Cover (1–5)	Plant Aspect (1–5)	Ear Aspect (1–5)	GY (kg ha^{-1})
EEPVAH-38	52.17	56.50	4.33	148.50	68.86	2.92	2.92	3.33	2245.89
EEPVAH-39	50.67	55.67	5.00	173.83	83.17	1.75	2.08	1.83	3805.40
EEPVAH-40	51.50	55.50	4.00	171.17	76.50	2.25	2.33	2.67	4100.87
EEPVAH-41	52.17	54.83	2.67	160.17	69.67	2.42	2.42	2.58	3741.89
EEPVAH-43	52.00	55.33	3.33	187.00	83.50	2.42	2.75	2.25	3803.87
EEPVAH-45	51.67	55.67	4.00	162.00	66.50	2.42	2.25	2.25	3557.46
EEPVAH-46	52.00	56.67	4.67	168.00	77.67	2.58	2.42	2.58	3436.15
EEPVAH-47	51.83	57.50	5.67	161.83	68.50	1.83	2.50	3.00	2677.88
EEPVAH-48	51.50	56.00	4.50	159.50	66.83	2.33	1.92	2.50	4221.79
EEPVAH-49	55.17	58.00	2.83	173.67	86.67	2.50	2.33	2.33	3249.82
EEPVAH-8	51.33	53.83	2.50	150.00	67.00	2.75	2.50	2.92	3274.15
EEPVAH-52	52.33	56.67	4.33	158.67	72.83	2.50	2.75	2.42	3957.88
EEPVAH-53	51.50	55.67	4.17	150.17	69.50	2.58	2.08	2.75	4174.64
EEPVAH-24	52.00	55.67	3.67	151.50	63.67	2.17	2.58	2.25	2906.05
Mean	51.99	55.96	3.98	162.55	72.61	2.39	2.42	2.55	3510.98
Minimum	50.67	53.83	2.50	148.50	63.67	1.75	1.92	1.83	2245.89
Maximum	55.17	58.00	5.67	187.00	86.67	2.92	2.92	3.33	4221.79
Range	4.50	4.17	3.17	38.50	23.00	1.17	1.00	1.50	1975.90
LSD (0.05)	1.81	2.10	1.78	12.00	8.84	0.69	0.42	0.39	809.92
S.E (±)	0.64	0.74	0.63	2.64	1.76	0.24	0.15	0.14	286.31
Reference check	50.50	55.00	4.50	167.00	73.17	2.50	2.50	2.83	2904.53
Local check	55.00	59.83	4.83	157.33	71.83	2.50	2.58	2.42	3418.66
Superiority of hybrids over checks (%)	−1.47	−2.60	−17.37	0.23	0.15	−4.74	−5.17	−3.04	9.95
Superiority of the best hybrid over checks (%)	−4.10	−6.66	−86.67	13.28	16.35	−42.86	−32.38	−43.44	25.11

Identification of the Best Five Extra-Early Maturing PVA Maize Hybrids

None of the hybrids demonstrated a consistent trend in productivity as the ranks changed with the year of evaluation. The top five (EEPVAH-48, EEPVAH-8, EEPVAH-41, EEPVAH-53, EEPVAH-39) outstanding hybrids in 2018 were superior for grain yield, which ranged from 4867 to 5668 kg ha^{-1} with 11 to 23% yield increase over the checks (Table 5). Likewise, the top five (EEPVAH-39, EEPVAH-49, EEPVAH-48, EEPVAH-40, EEPVAH-45) hybrids in 2019 were superior for grain yield, which ranged from 2495 to 3212 kg ha^{-1} with 21 to 38% yield increase over the checks. Furthermore, across the years, results of the RSI showed that the five outstanding hybrids selected had 11 to 25% yield increase over the checks. The efficiency of RSI was further highlighted by identifying EEPVAH-48 (4222 kg ha^{-1}) and EEPVAH-39 (3805 kg ha^{-1}), which were selected independently in the years 2018 and 2019 as outstanding. Incidentally, EEPVAH-39 also had the shortest number of days to anthesis and a lower score for husk cover.

Table 5. GY and selected agronomic traits of the best five hybrids based on the rank summation index.

Rank	Hybrid	Anthesis-Silking Interval (Days)	Plant Aspect (1–5)	Ear Aspect (1–5)	GY (kg ha^{-1})	RSI	Yield Increase over Checks (%)
Top 5			2018				
1	EEPVAH-48	5	2	2	5606	18	23
2	EEPVAH-8	3	2	2	5052	18	14
3	EEPVAH-41	3	3	2	5052	19	14
4	EEPVAH-53	5	2	2	5668	22	23
5	EEPVAH-39	7	2	2	4867	24	11
Bottom 5							
1	EEPVAH-49	3	2	2	3943	29	
2	EEPVAH-46	4	3	3	4066	41	
3	EEPVAH-47	6	2	2	3142	41	
4	EEPVAH-24	3	3	3	4066	43	
5	EEPVAH-38	6	3	3	2403	54	
Top 5			2019				
1	EEPVAH-39	3	2	2	2744	14	28
2	EEPVAH-49	2	3	2	2557	21	23
3	EEPVAH-48	4	2	3	2838	22	30
4	EEPVAH-40	4	2	3	3212	25	38
5	EEPVAH-45	5	2	2	2495	25	21
Bottom 5							
1	EEPVAH-24	4	3	2	1746	37	
2	EEPVAH-52	4	3	2	2495	38	
3	EEPVAH-8	2	3	4	1497	40	
4	EEPVAH-38	3	3	4	2089	41	
5	EEPVAH-47	5	3	4	2214	45	
Top 5			COMBINED				
1	EEPVAH-48	5	2	3	4222	20	25
2	EEPVAH-39	5	2	2	3805	21	17
3	EEPVAH-45	4	2	2	3557	22	11
4	EEPVAH-40	4	2	3	4101	24	23
5	EEPVAH-41	3	2	3	3742	24	16
Bottom 5							
1	EEPVAH-8	3	3	3	3274	33	
2	EEPVAH-52	4	3	2	3958	33	
3	EEPVAH-46	5	2	3	3436	38	

4	EEPVAH-47	6	3	3	2678	49
5	EEPVAH-38	4	3	3	2246	51

Cultivar Superiority Index

The hybrids exhibited differences in their superiority index, which ranged from 0.04 (EEPVAH-48) to 2.98 (EEPVAH-38). EEPVAH-48 exhibited the highest mean grain yield, and was regarded as the most superior, followed by EEPVAH-53, EEPVAH-40, EEPVAH-52 and EEPVAH-43 as the top five (Table 6). These hybrids had more than 5000 kg ha^{-1} grain yields in 2018 and also performed better in 2019. The percentage similarity between the hybrids selected as the best five by RSI and CSI was 40%. It is noteworthy that two hybrids, EEPVA-48 (4222 kg ha^{-1}) and EEPVA-40 (4101 kg ha^{-1}) were distinct as they cut across both selection indices as superior for grain yield and other agronomic traits (Table 7). In a similar ranking, EEPVAH-47 and EEPVAH-38 were among the bottom five hybrids identified by both selection indices.

Table 6. CSI of extra-early maturing PVA maize hybrid across years of evaluation.

		GY (kg ha^{-1})			
Rank	**Hybrid**	**Year 2018**	**Year 2019**	**Mean**	**CSI (P_i)**
1	EEPVAH-48	5605.99	2837.60	4221.79	0.04
2	EEPVAH-53	5667.59	2681.69	4174.64	0.07
3	EEPVAH-40	4989.95	3211.79	4100.87	0.12
4	EEPVAH-52	5421.18	2494.59	3957.88	0.14
5	EEPVAH-43	5113.16	2494.59	3803.87	0.21
6	EEPVAH-39	4866.74	2744.05	3805.40	0.22
7	EEPVAH-41	5051.55	2432.23	3741.89	0.25
8	EEPVAH-45	4620.32	2494.59	3557.46	0.40
9	Local check	4373.90	2463.41	3418.66	0.56
10	EEPVAH-46	4065.88	2806.42	3436.15	0.68
11	EEPVAH-8	5051.55	1496.76	3274.15	0.83
12	EEPVAH-49	3942.67	2556.96	3249.82	0.85
13	EEPVAH-24	4065.88	1746.22	2906.05	1.18
14	Reference check	4312.30	1496.76	2904.53	1.19
15	EEPVAH-47	3141.82	2213.95	2677.88	1.85
16	EEPVAH-38	2402.57	2089.22	2245.89	2.98

Table 7. Stable extra-early PVA maize hybrids based on RSI and CSI.

Rank	**Hybrid Selected**	**Anthesis-Silking Interval (Days)**	**Plant Aspect (1–5)**	**Ear Aspect (1–5)**	**GY (kg ha^{-1})**
	RSI				
1	EEPVAH-48	5	1.9	2.5	4221.8
2	EEPVAH-39	5	2.1	1.8	3805.4
3	EEPVAH-45	4	2.3	2.3	3557.5
4	EEPVAH-40	4	2.3	2.7	4100.9
5	EEPVAH-41	3	2.4	2.6	3741.9
	Mean	4	2.2	2.4	3885.5
	Superiority of top 5 hybrids over checks (%)	−15.7	−15.5	−10.9	18.6
	Superiority of hybrid, which ranked first over checks (%)	−3.7	−32.6	−5.0	25.1
	CSI				
1	EEPVAH-48	5	1.9	2.5	4221.8
2	EEPVAH-53	4	2.1	2.8	4174.6
3	EEPVAH-40	4	2.3	2.7	4100.9
4	EEPVAH-52	4	2.8	2.4	3957.9
5	EEPVAH-43	3	2.8	2.3	3803.9
	Mean	4	2.4	2.5	4051.8
	Superiority of top 5 hybrids over checks (%)	−14.8	−7.4	−4.3	22.0

	Superiority of hybrid, which ranked first over checks (%)	−3.7	−32.6	−5.0	25.1
	RSI and CSI				
1	EEPVAH-48	5	1.9	2.5	4221.8
2	EEPVAH-40	4	2.3	2.7	4100.9
	Mean	4	2.1	2.6	4161.3
	Superiority of top 5 hybrids over checks (%)	−9.8	−19.6	−1.6	24.0
	Superiority of hybrid, which ranked first over checks (%)	−3.7	−32.6	−5.0	25.1

The regression of grain yield on other agronomic traits measured (Table 8) revealed that the overall phenotypic appeal (plant and ear aspects) of the hybrids contributed significantly ($p < 0.01$; $p < 0.05$) to grain yield. There were negative relationships between grain yield and all traits measured except plant and ear heights. For every unit increase in plant and ear aspects scores, grain yield decreases significantly by 1266 kg ha^{-1} and 799 kg ha^{-1}, respectively. Approximately 35% and 26% of the variation in grain yield was explained by the variation in plant and ear aspects, respectively. Other traits had negligible contributions to grain yield.

Table 8. Contributions of agronomic traits (X) measured to response in grain yield (Y) of extra-early PVA maize hybrids based on linear regression.

Trait	Intercept (α)	Slope (β)	Standard Error	R^2
Days to anthesis (days)	6137.13	−51.26	585.12	0.01
Days to Silking (days)	7554.89	−72.80	579.33	0.03
ASI (days)	3793.48	−80.29	584.50	0.02
Plant height (cm)	986.11	15.27	565.08	0.08
Ear height (cm)	2184.31	17.61	575.73	0.04
Husk cover (1–5)	4172.14	−293.53	582.06	0.02
PASP (1–5)	6545.21	−1265.65 **	474.79	0.35
EASP (1–5)	5511.23	−799.38 *	507.68	0.26

*, ** = Significant at 0.05 and 0.01 probability levels, respectively; R^2 = Coefficient of determination

DISCUSSION

The contribution of years of evaluation to the total variation in grain yield was more than three times that of hybrids and six times that of hybrid × year interaction. The large proportion of total variation caused by the year of evaluation further highlights its effect on grain yield and the need for evaluation of these hybrids in multiple environments across years before recommending them for specific production areas [26]. The existence of variability among the hybrids for grain yield and other agronomic traits as a result of their different genetic backgrounds could be exploited during selection for those traits and also facilitate the identification of promising hybrids with desired attributes [27]. The non-significant hybrid × year interactions for anthesis-silking interval, ear height, and husk cover implied that they responded similarly in the two years of evaluation. The highly significant hybrid × year interactions for grain yield, number of days to anthesis and silking, plant height, plant and ear aspects ratings indicate changes in their performance under the years of evaluation. This corroborates the results reported by Thapa et al. [28] and Makinde et al. [29], who observed significant G × E mean square for grain yield and other traits for extra-early maturing maize hybrids. The results of this study highlighted that environmental yield-limiting factors, including climatic elements (rainfall, temperature, relative humidity) and soil conditions, varied in 2018 and 2019. The differential responses observed indicate the need to identify high-yielding and stable hybrids before commercialization [30]. In addition, the low coefficients of variation observed for most traits measured depict high precision in the experimentation and data collection techniques [2]. High CVs (>20) obtained for anthesis-silking interval may be attributed to the variability in the years of evaluation and the fact that it was mathematically derived as a secondary trait, which was not measured directly [31,32].

Overall, EEPVAH-48 was the most productive of the extra-early PVA maize hybrids, having yielded significantly higher than the local and IITA reference hybrids used as checks by 25%. The limited soil moisture in the cropping season (2019) had a negative effect on the flowering and growth-related traits, which may have translated into poor seed set and translocation of assimilate to grain filling, thereby limiting the expression of yield potential in the hybrids. The difference in mean grain yield between the favourable growing season in 2018 and the unfavourable season in 2019 was 2122 kg ha^{-1}, representing a 46% yield increase over the 2019 grain yield performance. The mean performance across years was greatly affected because of the poor performance recorded in 2019. However, the wide disparity in grain yields and significant hybrid × year interaction could be attributed to the instability in the performance of the hybrids. This necessitates the use of statistical selection indices to identify superior stable extra-early maturing PVA maize hybrids across the years of evaluation.

Selection based on grain yield only may not be adequate when the hybrid × year interaction is significant [33]. GY and anthesis-silking interval are traits that depict economic yield. These traits also determine the suitability of short-duration maize in areas with inconsistent rainfall patterns. Plant and ear aspects are equally important for acceptability by farmers. Therefore, ranking the hybrids based on these traits enables the selection of high-yielding hybrids with superior phenotypic appeal. In this study, EEPVAH-48, EEPVAH-39, EEPVAH-45, EEPVAH-40, and EEPVAH-41 were identified as high-yielding in combination with moderate anthesis-silking interval, desirable plant and ear aspect scores. Thus, these hybrids were the most productive in the two years of evaluations.

Furthermore, the hybrids were ranked according to their superiority index for grain yield, and the hybrids having the lowest superiority measure (P_i) value showed the highest mean grain yield across the years of evaluation. The two hybrids (EEPVA-48 and EEPVA-40) selected in common by the two statistical selection indices depict an average yield performance that is higher under favourable conditions and less fluctuating under unfavourable conditions, as we had in 2019. The consistent performance of these hybrids indicated the effectiveness of the breeding method used to incorporate favorable alleles for grain yield [34]. According to Yousaf et al. [35], EEPVA-48 and EEPVA-40 may be called ideal maize hybrids due to their high mean grain yield and minimal yield variability across different environmental conditions. These superior hybrids that combine grain yield with other desirable traits will be useful to farmers in agroecologies experiencing erratic rainfall patterns. They could be tested on farmers' fields for adaptation and possibly adoption after verification of their performance.

CONCLUSIONS

To replace existing maize varieties in an agroecological zone, new and improved varieties must be evaluated for high yield, desirable agronomic traits, and adaptation in farmers' fields. The results of this study demonstrated that the hybrid × year interaction significantly affected the yield performance of extra-early maturing PVA maize hybrids. The hybrids showed significant differences in grain yield and other agronomic traits measured. Most hybrids outperformed the checks in grain yield and other agronomic traits, despite poor grain yields in the 2019 cropping season. EEPVAH-48 and EEPVAH-40, selected by two statistical indices, were the most stable and productive extra-early maturing PVA maize hybrids, showing a yield advantage of over 20% compared to commercial checks. Their superior performance suggests adaptation to the erratic rainfall in the derived savanna zone, making them suitable for commercial production to enhance food security.

DATA AVAILABILITY

The dataset of the study is available from the author upon reasonable request.

CONFLICTS OF INTEREST

The author declared that there is no conflicts of interest.

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REFERENCES

1. Cicero TSC, Iedo T, Samuel S, Fernando NC, Marconi BT, Frederico ALS, et al. Agronomic performance, production components, and agricultural productivity of maize (*Zea mays* L.) cultivars. Afr J Agric Res. 2016;11:4375–83.
2. Kolawole AO, Olayinka AF. Phenotypic performance of new pro-vitamin A maize (*Zea mays* L.) hybrids using three selection indices. Agric Pol'nohospodárstvo. 2022;68(1):1–12.
3. Ranum P, Peña-Rosas JP, Garcia-Casal MN. Global maize production, utilization, and consumption. Ann N Acad Sci. 2014;1312:105–12.
4. Alhassan A, Salifu H, Adebanji AO. Discriminant analysis of farmers' adoption of improved maize varieties in Wa Municipality, Upper West Region of Ghana. Springerplus. 2016;5(1):1514.
5. Beah A, Kamara AY, Jibrin JM, Akinseye FM, Tofa AI, Adam AM. Simulating the response of drought-tolerant maize varieties to nitrogen application in contrasting environments in the Nigerian Savannas using the APSIM model. Agronomy. 2020;11(1):76.
6. Pingali PL. Green Revolution: Impacts, limits, and the path ahead. Proc Natl Acad Sci. 2012;109:12302–8.
7. Reif JC, Melchinger AE, Xia XC, Warburton ML, Hoisington DA, Vasal SK, et al. Genetic distance based on simple sequence repeats and heterosis in tropical maize populations. Crop Sci. 2003;43:1275–82.
8. Kafle S, Adhikari N, Sharma S, Shrestha J. Evaluation of single-cross maize hybrids for flowering and grain yield traits. Fundam Appl Agric. 2020;5:590–7.
9. Tonk FA, Ilker E, Tosun M. Evaluation of genotype x environment interactions in maize hybrids using GGE biplot analysis. Crop Breed Appl Biotechnol. 2011;11:1–9.
10. Mitrović B, Stanisavljević D, Treskić S, Stojaković M, Ivanović M, Bekavac G, et al. Evaluation of experimental maize hybrids tested in multi-location trials using AMMI and GGE biplot analyses. Turk J Field Crops. 2012;17:35–40.
11. Cairns JE, Sonder K, Zaidi PH, Verhulst N, Mahuku G, Babu R, et al. Maize production in a changing climate: impacts, adaptation, and mitigation strategies. Adv Agron. 2012;114:1–58.
12. Charles BC, Elijah P, Vernon RNC. Climate change impact on maize (*Zea mays* L.) yield using crop simulation and statistical downscaling models: A review. Sci Res Essays. 2017;12:167–87.
13. Laux P, Jäckel G, Tingem RM, Kunstmann H. Impact of climate change on agricultural productivity under rainfed conditions in Cameroon—A method to improve attainable crop yields by planting date adaptations. Agric Meteorol. 2010;150:1258–71.
14. Adegbite KA, Adekiya AO, Adebiyi OTV, Alori ET, Ejue WS, Olayanju A, et al. Baseline fertility status of a gravelly Alfisol in a derived savanna agro-ecological zone of Nigeria. Open Agric. 2020;5:573–81.
15. Fosu-Mensah BY, Manchadi A, Vlek PG. Impacts of climate change and climate variability on maize yield under rainfed conditions in the sub-humid zone of

Ghana: A scenario analysis using APSIM. West Afr J Appl Ecol. 2019;27:108–26.

16. Kolawole AO, Raji IA, Oyekale SA. The performance of new early maturing pro-vitamin A maize (*Zea mays* L.) hybrids in the derived savanna agro-ecology of Nigeria. J Agric Sci Belgrade. 2021;66(3):231–45.
17. Scapim CA, Oliveira VR, Braccini ADL, Cruz CD, Andrade CADB, Vidigal MCG. Yield stability in maize (*Zea mays* L.) and correlations among the parameters of the Eberhart and Russell. Lin Binns Huehn Models Genet Mol Biol. 2000;23:387–93.
18. Rosa TC da, Carvalho IR, Szareski VJ, Pelegrin AJ de, Barbosa MH, Santos NL dos, et al. Agronomic performance and multivariate analysis applied to three-way cross maize hybrids. J Agric Sci. 2018;10:319–28.
19. Lee EA, Tollenaar M. Physiological basis of successful breeding strategies for maize grain yield. Crop Sci. 2007;47:202–15.
20. Institute SAS. SAS System for Windows. In: Release 94. Cary (NC, US): SAS Institute Inc.; 2011.
21. Gomez KA, Gomez AA. Statistical Procedures for Agricultural Research. 2nd ed. New York (NY, US): Wiley; 1984. 1–680p.
22. Steel RGD, Torrie JH. Principles and Procedures for Statistics. 2nd ed. New York (NY, US): McGraw-Hill Book Co.; 1980.
23. Mulamba NN, Mock JJ. Improvement of yield potential of the ETO Blanco maize (*Zea mays* L.) population by breeding for plant traits [Mexico]. Egypt J Genet Cytol. 1978;7:40–51.
24. Lin CS, Binns MR. A superiority measure of cultivar performance for cultivar × location data. Can J Plant Sci. 1988;68:193–8.
25. Silva TDCR, Amaral Júnior AT do, Gonçalves LSA, Candido LS, Vittorazzi C, Scapim CA. Agronomic performance of popcorn genotypes in Northern and Northwestern Rio de Janeiro State. Acta Sci Agron. 2013;35:57–63.
26. Sserumaga JP, Oikeh SO, Mugo S, Asea G, Otim M, Beyene Y, et al. Correction to: Genotype by environment interactions and agronomic performance of doubled haploids testcross maize (*Zea mays* L.) hybrids. Euphytica. 2016;207:353–65.
27. Amzeri A, Pawana G, Ma'arif A, Suwarno I. Genotype by Environment Interaction on Early-Maturing and High-Yield Maize Hybrids. J Hum Earth Future. 2023;4:54–69.
28. Thapa S, Rawal S, Adhikari S. Varietal evaluation of hybrid maize in the summer and winter seasons in Terai region of Nepal. Heliyon. 2022;8:e11619.
29. Makinde SA, Badu-Apraku B, Ariyo OJ, Porbeni JB. Combining ability of extra-early maturing pro-vitamin A maize (*Zea mays* L.) inbred lines and performance of derived hybrids under Striga hermonthica infestation and low soil nitrogen. PLoS ONE. 2023;18:e0280814.
30. Sabaghnia N, Sabaghpour SH, Dehghani H. The use of an AMMI model and its parameters to analyse yield stability in multi-environment trials. J Agric Sci. 2008;146:571–81.

31. Ajala SO, Ago CE, Olaoye G. Comparison of predicted responses to three types of recurrent selection procedures for the improvement of a maize (*Zea mays* L.) population. J Plant Breed Crop Sci. 2009;1(8):284–92.
32. Guimarães PHR, Melo PGS, Cordeiro ACC, Torga PP, Rangel PHN, Castro AP. Index selection can improve the selection efficiency in a rice recurrent selection population. Euphytica. 2021;217:1–16.
33. Kang MS, Gorman DP, Pham HN. Application of a stability statistic to international maize yield trials. Theor Appl Genet. 1991;81:162–5.
34. Konate L, Badu-Apraku B, Coulibaly M, Menkir A, Laouali MN, Meseka S, et al. Agronomic performance and yield stability of extra-early maturing maize hybrids in multiple environments in the Sahel. Heliyon. 2023;9:21659.
35. Yousaf MI, Akhtar N, Mumtaz A, Shehzad A, Arshad M, Shoaib M, et al. Yield stability studies in indigenous and exotic maize hybrids under genotype by environment interaction. Pak J Bot. 2021;53:941–8.

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