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PHENOTYPIC PERFORMANCE OF NEW PRO-VITAMIN A MAIZE (*ZEA MAYS* L.) HYBRIDS USING THREE SELECTION INDICES

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The development of new bio-fortified maize hybrids is crucial for achieving food security and alleviation of micronutrient deficiencies. This study aims at assessing the performance of new pro-vitamin A maize hybrids and identifying potential high-yielding hybrids using base index, multivariate selection index, and rank summation index. Twenty-four pro-vitamin A maize hybrids and one hybrid check were evaluated in the rainy seasons of 2018 and 2019 at Ladoke Akintola University of Technology Teaching and Research farm in Ogbomoso, Nigeria. Hybrids were planted each year in a 5 × 5 α lattice design with three replications. Data collected on grain yield and agronomic traits were analysed. The hybrids showed significant ($P < 0.001$) variations for all measured traits except plant aspect and maize *streak* virus scores. The mean grain yield of hybrids over two years varied from 1,106 kg/ha (LY1312-12) to 5,144 kg/ha (LY1501-9). The highest yielding hybrid across the years had a 31% yield advantage over the single-cross hybrid used as a check. The base index had the highest selection differential (34%) for grain yield. The rank summation index had a strong correlation with the multivariate selection index ($r = -0.86^{+++}$) followed by base index ($r = -0.56^{+++}$). The three selection indices used identified three superior three-way cross hybrids (LY1409-21, LY1501-9 and LY1501-1) with a slight change in rank order. These outstanding hybrids which combine high productivity with nutrients may be considered for advanced multi-location and on-farm testing before their release to farmers in derived savanna agroecology of Nigeria.

Key words: agronomic traits, breeding programme, rank, selection differential, variation

Maize (*Zea mays* L.) is a staple cereal crop in Africa (Musundire *et al*. 2021) with increasing demand as food, animal feed and industrial products in Nigeria (Olaniyan 2015; Kolawole *et al*. 2018). The ever-increasing human population and demand led farmers in diverse agro-ecological zones of Nigeria to the cultivation of various maize genotypes with yield increase over open-pollinated varieties viz., synthetics, composites, non-conventional maize hybrids (top-cross, double top-cross, and varietal cross), and conventional maize hybrids (single, three-way and double-cross). Reif *et al*. (2003) described the development of maize hybrids as the most significant milestone in agriculture because of its uniformity and improved productivity. More so, established seed companies targets either the single or three-way cross hybrids considering the cost of production whereas, resource-limited farmers mostly grow the single-cross hybrids for increased productivity.

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In Nigeria, the elderly persons, preschool children, pregnant women, and lactating mothers depend mostly on products obtained from either white or yellow kernel maize for energy and nutrient intake. These maize varieties have low nutritional quality when compared with pro-vitamin A (PVA) maize (Pixley *et al*. 2013). Vitamin A is an essential micronutrient useful for improved eyesight and enhanced immune systems in humans (Obeng-Bio *et al*. 2019). Thus pro-vitamin A biofortified maize hybrid with approximately 15 µg/g carotenoids (Menkir *et al*. 2021) content is beneficial to both humans and animals. To enhance maize grain yield potential and nutritive value, the Maize Improvement Programme (MIP) of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria (IITA-MIP) developed diverse PVA enriched maize hybrids with yellow to orange endosperm colour that combines intermediate to late maturity with maize streak virus (MSV) resistance. However, the adoption rate for these maize hybrids is low. Therefore, evaluation, selection, and promotion of outstanding PVA maize hybrids are important to ensure food and nutrition security.

The selection of superior genotypes with desirable agronomic traits requires the utilization of a selection index. Two main categories of selection index are used in breeding programmes. The weight-based or weight-free selection indices that constitute a simultaneous selection of desirable traits have been used by researchers to select outstanding genotypes in maize improvement programmes. The weight-based selection indices have been reported as the most effective methods in the selection of superior genotypes (Dermail *et al*. 2022). However, these indices involve either assigning economic weights or estimating variances (phenotypic and genotypic) and covariance between pairs of traits (Smith 1936; Hazel 1943; Williams 1962). These indices display certain particularities in their calculations and inaccuracies may be associated with the variance and covariance matrices (de Azeredo *et al*. 2017). To overcome these bottlenecks, other authors proposed modified selection indices involving linear combinations of the phenotypic values (Brim *et al*.1959; Kempthorne & Nordskog 1959; Pesek & Baker 1969; Tai 1977; Smith *et al*.1981).

The weight-free index (Rank summation index) proposed by Mulumba and Mock (1978) ranks genotypes for selected traits in desirable order and the summed rank for each genotype becomes an index used for selection. This index is not affected by variance among traits, does not require estimation of genetic parameters and is simple to compute (Crosbie 1980). To increase selection efficiency, Elston (1963) proposed a multiplicative index, and Wricke and Weber (1986) suggested the use of the Euclidean and Mahalanobis distances as an index. In addition, a multivariate selection index, which involves principal components analysis eigenvectors computed from correlation among traits used as weights have also been used effectively in maize breeding programmes (Adebayo *et al*. 2017; Akbar *et al*. 2018; Anshori *et al*. 2019).

The conditions that determine the usefulness of an appropriate selection index depend on the type of genetic material and the breeding objectives. Previous studies used diverse selection indices involving grain yield and other agronomic traits to identify genotypes with the highest breeding value in maize improvement programmes (Zaffar *et al*. 2005; Tardin *et al*. 2007; Ajala 2010; Berilli *et al*. 2013; Vieira *et al*. 2016; Adebayo *et al*. 2017; Crevelari *et al*. 2018; de Santiago *et al*. 2019; Oloyede-Kamiyo 2019). In spite of the efficiency of selection indices, reports on comparison of these indices in maize breeding programmes for identification of superior maize hybrids for a specified agro-ecology are limited. Thus, this study aims at assessing newly developed pro-vitamin A enriched maize hybrids for grain yield potential and other agronomic traits, and also compares the efficiency of weight-based and weight-free selection indices in identifying outstanding PVA maize hybrids under the derived savanna agro-ecology of Nigeria.

MATERIAL AND METHODS

Experimental site

The experiment was conducted during the growing seasons of 2018 and 2019 at the Teaching and Research (T&R) Farm of the Ladoke Akintola University of Technology (LAUTECH), Ogbomoso (8°10′N, 4°10′E, and altitude 341 m above sea level). The location is in the derived savanna agro-ecology of Nigeria. The annual mean rainfall of the experimental site ranges between 1,000 and 1,200 mm while the daily temperature is between 28°C and 30°C. The soils are characterized as alfisol (USDA 1999), which is generally low in nitrogen.

Planting materials

The study evaluated 25 maize genotypes comprising single and three-way cross hybrids. The commercial hybrid cultivated in the test environment (Oba super 6) was used as a local check (LC) while the other (24) were intermediate to late (110 – 120 days) maturing maize streak virus (MSV) resistant PVA hybrids developed by IITA-MIP (Table 1).

Experimental design and cultural practices

The maize hybrids were laid out in a 5 × 5 α-lattice design with three replicates, planted in a single row plot of 5 m long, with 0.75 m spacing between rows and 0.50 m spacing between hills. Three seeds were planted per hill, but 2 weeks after planting (WAP), thinning was done to keep two plants per hill. A maximum of 22 plants per plot was obtained, resulting in an optimum plant density of 53,333 plants/ha. At the time of sowing, a compound fertiliser (N:P:K 15:15:15) was applied at the rate of 60 kg/ha N, 60 kg/ha of P_2O_5 and 60 kg/ha of K_2O. Urea was applied as top-dressing at the rate of 60 kg/ha N 4 weeks later. Paraquat and atrazine were applied as pre-emergence herbicides at the rate of 5.0 L/ha each, followed by manual weeding, as and when required, to keep the plots weed-free.

Data collection

Data were recorded in each plot for the number of days to anthesis and silking as the number of days from planting to when 50% of the plants had shed pollen and had emerged silks, respectively. The anthesis-silking interval was computed as the interval in days between anthesis and silking. Plant and ear heights [cm] 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 the meter rule. Husk cover 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. Ear aspect was scored on a 1 to 5 scale, where 1 = clean, uniform, large, and well-filled ears, and 5 = rotten, variable, and small ears. Plant aspect was rated on a scale of 1 to 5, where 1 = excellent overall phenotypic appeal and 5 = poor overall phenotypic appeal. The number of ears per plant was determined as the total number of ears divided by the number of harvested plants per plot. Foliar diseases (*curvularia* leaf spot and maize streak virus) were rated on a scale of 1 to 5, where 1 = slight leaf infection, and 5 = severe leaf infec-

Table 1

Description of the pro-vitamin A enriched maize hybrids and a local check used in this study

Entry	Designation	Hybrid type	Source
1	A1702-28	3-Way cross	IITA
2	A1702-49	3-Way cross	IITA
3	A1702-53	3-Way cross	IITA
4	A1706-2	3-Way cross	IITA
5	A1736-12	3-Way cross	IITA
6	A1736-13	3-Way cross	IITA
7	A1736-6	3-Way cross	IITA
8	Ife Hybrid-3	Single-cross	IITA
9	Ife Hybrid-4	Single-cross	IITA
10	LY1001-18	3-Way cross	IITA
11	LY1001-23	3-Way cross	IITA
12	LY1302-9	3-Way cross	IITA
13	LY1312-11	Single cross	IITA
14	LY1312-12	Single cross	IITA
15	LY1312-4	3-Way cross	IITA
16	LY1409-14	Single cross	IITA
17	LY1409-21	3-Way cross	IITA
18	LY1501-1	3-Way cross	IITA
19	LY1501-3	3-Way cross	IITA
20	LY1501-5	3-Way cross	IITA
21	LY1501-6	3-Way cross	IITA
22	LY1501-7	3-Way cross	IITA
23	LY1501-8	3-Way cross	IITA
24	LY1501-9	3-Way cross	IITA
25	Oba super 6 (LC)	Single-cross	Ogbomoso

IITA – International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria; LC – local check.

tion. Grain yield was computed from ear weight per plot and converted to kilograms per hectare. A shelling percentage of 80% was assumed for all hybrids and grain yield was adjusted to 15% moisture content using the following formula:

$$\text{Grain yield [kg/ha]} = \text{ear weight [kg/m}^2\text{]} \times \frac{100 - MC}{85} \times \frac{10{,}000}{\text{plot area [m}^2\text{]}} \times 0.80$$

Where: MC – moisture content at harvest.

Data analysis

Analyses of variance (ANOVA) were computed for each year of evaluation separately in order to test the homogeneity of the mean square error, after which the combined ANOVA was computed for all traits measured using PROC GLM in SAS (SAS Institute 2010). Least-squares means for each trait were computed and means were separated using Fisher's least significant difference (*LSD*) test at 0.05 probability level. For the selection of outstanding maize hybrids, ten agronomic traits which showed significant differences from ANOVA were used to rank the performance of the PVA maize hybrids. Two weight-based (Base index and multivariate selection index – MSI) and one weight-free (Rank summation index – RSI) selection indices were used in this study. To compute the base index (Standardized selection index – SIN), weights were assigned based on the relative economic importance of the traits. The outstanding genotypes were those that showed the highest value for the SIN (Williams 1962; León *et al*. 2021). The standardized values (SV) for each trait was obtained by:

$$(\chi - \mu) / \delta$$

Where: χ is the individual mean for a trait; μ is the overall mean of the trait; and δ is the standard deviation value.

The base index was then computed as:

$$\text{Base index} = \Sigma\, [a_1\, (\text{SV Trait a}) + a_2\, (\text{SV Trait b}) + \ldots + a_n\, (\text{SV Trait n})]$$

Where: (a_1–a_n) represents weights assigned and trait means are the standardized values.

To compute the multivariate selection index (MSI), eigenvectors from principal component analysis (PCA) obtained from the correlation among traits were used as weights (Adebayo *et al*. 2017; Anshori *et al*. 2019). The multivariate selection index was estimated as:

$$MSI_1 = \Sigma\, [a_1\, (\text{Trait 1})_1 + a_2\, (\text{Trait 2})_1 + \ldots + a_n\, (\text{Trait n})_1]$$

Where: (a_1–a_n) = eigenvectors used as weights.

To construct the rank summation index (RSI), rank attached to each maize hybrid for each trait in favourable order was summed (Mulamba & Mock 1978; Kolawole *et al*. 2021) resulting in the following:

$$R\,SI_1 = \Sigma\, (a_1 + b_1 + \ldots + n_1)$$

Where: a_1 = rank of the mean of the trait "a" of hybrid$_1$, b_1 = rank of the mean of the trait "b" of hybrid$_1$, n_1 = rank of the mean of the trait "n" of hybrid$_1$.

Selection differential estimated as a proportion [%] of the mean of all PVA hybrids were calculated for the three selection indices as the difference between the mean of the selected top 5 and the overall mean of PVA maize hybrids to derive the relative efficiency of the indices for identifying superior hybrids.

$$\text{Selection differential} = \frac{\text{Mean of top 5 hybrids} - \text{overall mean}}{\text{overall mean}} \times 100$$

Spearman's rank correlation analysis was carried out to determine the relationship among the selection indices.

RESULTS AND DISCUSSION

Highly significant differences were observed between blocks for flowering-related traits, growth-related traits, and grain yield, indicating variation in the environmental conditions over the years of evaluation. Significant ($P < 0.001$) mean square of year for all measured traits except for flowering-related traits implied that the years 2018 and 2019 were discriminating enough to enable the detection of genetic differences among the maize hybrids (Ta-

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Mean squares of grain yield and other agronomic traits of pro-vitamin A enriched maize hybrids derived from combined ANOVA

Trait	Source							
	Year	Replication (Rep) (Year)	Block (Year × Rep)	Hybrid	Hybrid × Year	Error	R^2 [%]	CV [%]
	df = 1	df = 4	df = 24	df = 24	df = 24	df = 72		
Anthesis [days]	0.03	11.07^{+++}	7.46^{+++}	19.28^{+++}	6.28^{+++}	1.90	88	2.27
Silking [days]	0.03	9.53^{++}	14.04^{+++}	26.89^{+++}	9.41^{+++}	2.67	90	2.56
Anthesis-silking interval [days]	0.00	0.35	2.46^{+++}	3.39^{+++}	2.58^{+++}	0.87	82	30.07
Plant height [cm]	114,275.04^{+++}	39.10	396.42^{+++}	766.57^{+++}	387.88^{+++}	110.36	95	6.04
Ear height [cm]	41,660.00^{+++}	85.65	277.49^{+++}	240.28^{+++}	228.84^{+++}	92.77	91	12.47
Husk cover (1 – 5)	3.08^{+++}	0.36^{++}	0.19	0.28^{++}	0.17	0.11	71	15.83
Plant Aspect (1 – 5)	354.20^{+++}	0.47	1.05^{++}	0.56	0.45	0.43	93	18.25
Ear Aspect (1 – 5)	7.94^{+++}	0.03	0.18	0.63^{+++}	0.35	0.24	68	21.29
Number of ears per plant	5.88^{+++}	0.59^{++}	0.21	0.28^{+}	0.25	0.17	65	37.40
Maize *streak* virus (1 – 5)	21.66^{+++}	0.47^{+}	0.10	0.22	0.25	0.19	73	25.39
Curvularia leaf spot (1 – 5)	48.167^{+++}	3.14^{+}	4.51	11.84^{+++}	11.59^{+++}	2.75	79	70.02
Grain yield [kg/ha]	3,826,322.40^{+}	1,261,155.90	1,364,337.40^{++}	6,736,824.80^{+++}	4,846,878.10^{+++}	651,623.2	89	24.12

$^{+}$,$^{++}$,$^{++}$; $^{+}$, $^{++}$, $^{+++}$ 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; ANOVA – Analysis of variance ble 2). Similarly, the hybrids showed significant ($P < 0.001$ and $P < 0.05$) mean squares for grain yield and other agronomic traits except for plant aspect and maize streak virus. The observed variability could be due to the fact that the genotypes evaluated which include the single and three-way crosses were from diverse genetic backgrounds. This variation is desirable for the selection of superior hybrids for the test environments, as also reported by Emmanuel *et al*. (2017). The mean square for hybrid by year interaction were significant ($P < 0.001$) for all flowering-related traits, *curvularia* leaf spot, grain yield, plant, and ear heights. This implied that the responses of the maize hybrids were different across the years as a result of the edaphic conditions and climatic patterns. This is consistent with the report of Tripathi *et al*. (2016). To ensure the adaptability of the hybrids to the test environment, a multi-environment trial will be necessary for objective selection of outstanding hybrids.

The coefficient of determination (R^2) values was very high for all traits. Coefficient of variation (CV) was low (< 20%) for the number of days to anthesis and silking, plant and ear heights, husk cover, and plant aspect scores which shows high precision in the experimentation and data collection procedure. High CVs obtained for anthesis-silking anthesis, the number of ears per plant, and c*urvularia* leaf spot, ranging from 30 to 70% may be a result of inter-environments variability (Guimarães *et al*. 2021).

The two years showed comparable values for the number of days to anthesis and silking, but the hybrids had a shorter anthesis-silking intervals in 2018 than in 2019 (Table 3). The plants were taller with higher ear placement in the year 2018. Ratings for husk cover and ear aspect were generally below 3.0 for all the hybrids in the year 2018 but were on average of 4.0 in the year 2019. *Curvularia* leaf spot had desirable scores in the year 2019. Grain yield of hybrids in 2018 ranged between 240.7 kg/ha (LY1001-18) and 6,458 kg/ha (LY1501-9) with a mean of 3,506.8 kg/ha. This was comparable to the report of Ewool *et al*. (2016) and Ogunniyan *et al*. (2021). However, the grain yield varied from 1,501.4 kg/ha (LY1501-3) to 4,711.8 kg/ha (LY1501-6) with a mean of 3,186.6 kg/ha in the year 2019. The lower performance of the hybrids in 2019 for most traits could be linked to the duration and fluctuation with

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Means and ranges for grain yield and other agronomic traits of maize hybrids evaluated across years

Trait	Mean±SE			Range			*LSD* (0.05)
	2018	2019	Combined	2018	2019	Combined	
Anthesis [days]	60.7±0.47	60.8±0.47	60.7±0.42	57.26−67.1	57.3−66.6	57.90−65.4	1.6
Silking [days]	63.8±0.62	63.9±0.55	63.8±0.52	59.70−71.6	58.8−69.5	59.90−69.3	1.9
Anthesis – silking interval [days]	3.1±0.29	3.1±0.17	3.1±0.19	0.20−6.3	1.5−4.6	1.40−5.2	1.1
Plant height [cm]	201.6±4.37	146.4±1.90	174.1±2.68	130.20−236.6	127.6−165.0	135.60−196.8	12.1
Ear height [cm]	93.9±2.78	60.6±1.06	77.2±1.49	58.30−125.2	50.8−70.8	57.30−91.7	11.1
Husk cover (1−5)	2.0±0.04	2.3±0.08	2.1±0.05	1.50−2.5	1.6−3.3	1.60−2.8	0.4
Ear Aspect (1−5)	2.1±0.05	2.5±0.11	2.3±0.07	1.50−2.7	1.7−4.1	1.80−3.1	0.6
Number of ears per plant	1.3±0.11	0.9±0.02	1.1±0.05	0.40−2.6	0.7−1.1	0.60−1.7	0.5
Curvularia leaf spot (1−5)	3.0±0.59	1.8±0.04	2.4±0.31	1.70−4.8	1.4−2.1	0.30−8.6	1.9
Grain yield [kg/ha]	3,506.8±404.25	3,186.6±159.89	3,338.3±244.08	240.7−6,458.0	1,501.4−4,711.8	1,105.5−5,143.8	929.1

SE – standard error; *LSD* – least significant difference the pattern of rainfall in the second year of evaluation coupled with the armyworm (*Spodoptera frugiperda*) infestation in the field.

Across the years, the hybrids showed a wide range of variations for all traits measured which is an opportunity for selection. Grain yield ranged from 1,105.50 kg/ha for LY1312-12 to 5,143.77 kg/ha for LY1501-9 with a mean of 3,338.32 kg/ha. In comparison to the commercial hybrid (Oba super 6) used as a local check in this study, 33% of the hybrids had a significant (P < 0.05) earlier number of days to flowering, 29% of the hybrids had a significant (P < 0.05) earlier number of days to silking, 17% of the hybrids had significant a (P < 0.05) shorter anthesis-silking interval, 21% of the hybrids were significantly (P < 0.05) taller, 25% of the hybrids had a significant (P < 0.05) better husk cover scores, 42% of the hybrids had a significant (P < 0.05) improved overall phenotypic appeal for the plant and ear aspect and 21% of the hybrids had a significant (P < 0.05) superior grain yield. However, 50% of the hybrids out-yielded the local check, but only nine hybrids had a 10% yield advantage over the local check (Table 4).

The selection of outstanding PVA maize hybrids was based on three selection indices applied to ten agronomic traits which showed significant variations among the hybrids evaluated. The three selection indices used in this study (base index, multivariate selection index, and rank summation index) identified similar maize hybrids among the top five superior and poor performers (Table 5). All the superior hybrids selected by the three methods of selection had higher selection index values and out-yielded the commercial hybrid by 7% to 31%. These hybrids depict a combination of favourable alleles for plant heights which were important for green and dry matter production. The intermediate height for ear placement in these hybrids prevented root and stock lodging. Earliness to anthesis (57.9 days) and silking (63.9 days) allowed short growth duration and maturity, while the short number of days for synchronization of pollen shed and silking allowed improved fertilisation and cob fill which translated into improved (> 1) number of ears per plant. The phenotypic appeal scores of these hybrids, which determine their acceptability under farmers' conditions, were also desirable. Thus, these agronomic traits can be considered important grain yield attributes.

Interestingly, the three-way cross hybrid LY1409-21 showed a similar ranking in performance with the three selection indices as superior for grain yield and other agronomic traits. Additionally, the hybrids LY1501-9 which was the highest yielding (5,143.78 kg/ha) across the years of evaluation cut across the three selection indices among the top five outstanding hybrids. This is contrary to the earlier report of Lunezzo de Oliveira *et al*. (2014) that the highest yielding hybrids are not necessarily the best for other traits assessed. The only single-cross hybrid among the top five based on two out of the three selection indices used was Ife Hybrid-3. The change in rank order of hybrids for the three selection indices is a reflection of the importance of the weights attached to the traits for the computation of the indices. The three selection indices identified LY1409-21(out-yielded the local check by 18%), LY1501-9 (out-yielded the local check by 31%), and LY1501-1 (out-yielded the local check by 7%) as a three-way cross PVA maize hybrids that may enhance sustainable productivity in the derived savanna agro-ecology of Nigeria.

Selection differentials estimates were used to ascertain the effectiveness of the three selection indices in identifying the outstanding performance of maize hybrids. There were differences among the selection differentials estimates for the three selection indices (Table 6). Positive selection differentials (0.83 to 33.75%) were obtained for grain yield, the number of ears per plant, plant, and ear heights. The three selection indices had negative selection differentials for all flowering-related traits, foliar disease, and ear aspect score which ranged from −2.42 to −44.35%. The base index and MSI gave the highest selection differentials for four traits. Consequently, these two indices appear to be equally efficient in identifying superior PVA maize hybrids as regards the traits considered. Comparing the three selection indices used in this study, the base index had the highest positive and negative selection differentials for grain yield and *curvularia* leaf spot respectively. This result corroborates previous studies considering the identification of potentially high-yielding maize genotypes based on different selection index methods and found the base index to have a higher

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Combined mean performance of grain yield and other agronomic traits of maize hybrids evaluated

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)	Number of ears per plant	Maize *streak* virus (1–5)	*Curvularia* leaf spot (1–5)	Grain yield [kg/ha]
A1702-28	60.18±0.67	63.93±0.80	3.75±0.46	157.48±5.12	74.93±4.70	1.96±0.16	4.08±0.32	2.72±0.24	1.16±0.20	2.36±0.21	1.76±0.81	3,608.82±393.75
A1702-49	61.73±0.67	64.83±0.80	3.10±0.46	169.00±5.13	79.69±4.70	2.40±0.17	3.55±0.32	2.51±0.24	1.06±0.20	1.86±0.21	2.04±0.81	3,969.08±394.28
A1702-53	61.37±0.67	65.21±0.80	3.85±0.46	167.58±5.12	74.05±4.70	2.32±0.16	4.08±0.32	2.58±0.24	1.70±0.20	1.85±0.21	0.89±0.81	3,552.08±393.71
A1706-2	60.37±0.66	63.17±0.78	2.80±0.45	185.35±5.01	84.08±4.59	1.97±0.16	3.26±0.31	1.99±0.24	0.98±0.20	1.54±0.21	2.35±0.79	4,539.73±385.00
A1736-12	58.30±0.67	61.14±0.79	2.84±0.45	188.24±5.08	79.24±4.66	2.78±0.16	3.73±0.32	2.88±0.24	1.00±0.20	1.67±0.21	3.17±0.80	4,024.42±390.46
A1736-13	59.51±0.65	62.15±0.78	2.64±0.44	180.94±4.99	72.31±4.58	2.26±0.16	3.03±0.31	2.33±0.23	0.65±0.20	1.68±0.21	3.02±0.79	3,277.07±383.70
A1736-6	59.48±0.67	60.83±0.80	1.35±0.46	162.31±5.14	64.27±4.71	2.26±0.17	3.66±0.32	3.13±0.24	0.78±0.20	1.55±0.21	2.45±0.81	3,536.24±394.86
Ife Hybrid-3	59.21±0.66	62.40±0.78	3.19±0.45	166.70±5.04	79.98±4.62	1.62±0.16	3.49±0.32	2.58±0.24	1.30±0.20	1.92±0.21	0.39±0.80	4,009.94±387.45
Ife Hybrid-4	60.18±0.67	62.60±0.79	2.42±0.45	181.25±5.08	77.89±4.66	2.15±0.16	3.44±0.32	1.96±0.24	0.87±0.20	1.44±0.21	2.48±0.80	2,367.38±390.36
LY1001-18	58.55±0.66	61.31±0.78	2.76±0.45	173.32±5.01	76.38±4.60	1.91±0.16	3.60±0.31	2.15±0.24	1.40±0.20	1.98±0.21	2.54±0.79	1,831.39±385.32
LY1001-23	60.36±0.68	63.93±0.81	3.57±0.46	177.67±5.22	70.97±4.78	2.04±0.17	3.04±0.33	1.81±0.24	1.09±0.21	1.75±0.22	2.13±0.82	5,059.32±400.89
LY1302-9	62.39±0.66	64.25±0.79	1.86±0.45	172.39±5.06	76.10±4.64	1.81±0.16	3.72±0.32	2.67±0.24	0.87±0.20	1.99±0.21	1.93±0.80	1,411.81±388.76
LY1312-11	63.63±0.66	68.80±0.78	5.18±0.44	167.37±5.00	57.32±4.59	1.82±0.16	3.78±0.31	1.96±0.23	1.13±0.20	1.55±0.21	2.28±0.79	2,428.17±384.50
LY1312-12	65.41±0.67	69.28±0.80	3.87±0.46	135.57±5.14	91.69±4.72	1.88±0.17	3.89±0.32	2.69±0.24	0.70±0.20	1.92±0.21	2.19±0.81	1,105.50±395.19
LY1312-4	60.84±0.67	64.96±0.80	4.12±0.46	169.40±5.12	72.18±4.69	2.17±0.16	3.83±0.32	2.16±0.24	0.95±0.20	1.59±0.21	2.56±0.81	3,404.09±393.43
LY1409 -14	63.92±0.66	67.33±0.78	3.41±0.44	179.89±5.00	82.97±4.58	2.32±0.16	3.95±0.31	1.99±0.23	1.30±0.20	1.68±0.21	3.65±0.79	1,241.19±384.25
LY1409-21	57.85±0.67	59.89±0.80	2.04±0.45	172.40±5.11	79.51±4.69	2.07±0.16	3.35±0.32	2.13±0.24	1.54±0.20	1.60±0.21	0.27±0.81	4,301.51±392.74
LY1501-1	60.09±0.66	61.70±0.78	1.61±0.44	173.87±5.00	84.06±4.59	2.02±0.16	3.34±0.31	2.01±0.23	1.49±0.20	1.65±0.21	1.91±0.79	3,810.13±384.36
LY1501-3	65.24±0.66	68.10±0.79	2.86±0.45	160.87±5.05	73.38±4.63	2.29±0.16	4.10±0.32	2.60±0.24	1.05±0.20	1.91±0.21	2.61±0.80	1,851.60±387.78
LY1501-5	59.73±0.67	62.42±0.80	2.69±0.46	179.83±5.14	78.72±4.71	2.29±0.17	3.25±0.32	2.02±0.24	1.19±0.20	1.47±0.21	3.24±0.81	3,524.62±394.61
LY1501-6	59.76±0.69	63.42±0.81	3.66±0.47	176.22±5.24	74.98±4.80	2.37±0.17	3.22±0.33	2.08±0.25	0.88±0.21	1.36±0.22	1.75±0.83	2,968.62±402.52
LY1501-7	59.45±0.68	62.62±0.81	3.17±0.46	196.80±5.21	88.02±4.77	2.41±0.17	3.48±0.33	2.14±0.24	1.04±0.21	1.57±0.22	3.36±0.82	4,583.16±399.98
LY1501-8	61.20±0.66	65.91±0.79	4.71±0.45	196.37±5.05	74.94±4.63	1.82±0.16	3.38±0.32	2.07±0.24	0.83±0.20	1.90±0.21	2.52±0.80	4,569.94±387.98
LY1501-9	58.77±0.66	61.92±0.78	3.14±0.45	186.94±5.02	84.42±4.61	2.09±0.16	3.42±0.31	2.08±0.24	1.14±0.20	1.61±0.21	2.10±0.79	5,143.77±386.04
Grand mean	60.73±0.42	63.84±0.52	3.11±0.19	174.07±2.68	77.17±1.49	2.13±0.05	3.57±0.06	2.30±0.07	1.09±0.05	1.72±0.05	2.44±0.31	3,338.32±244.08
LSD (0.05)	1.59	1.88	1.08	12.09	11.09	0.39	0.76	0.57	0.48	0.50	1.91	929.06
Oba super 6 (LC)	61.14±0.67	64.24±0.79	3.10±0.45	172.20±5.09	79.29±4.66	2.39±0.16	4.26±0.32	2.70±0.24	1.58±0.20	1.78±0.21	0.58±0.80	3,539.00±390.75

LSD – least significant difference; LC – local check

T a b l e 5

Overall performance of maize hybrids based on weight-based and weight-free selection indices

Hybrid	Anthesis [days]	Silking [days]	Anthesis-silking interval [days]	Plant height [cm]	Ear height [cm]	Husk cover (1 – 5)	Ear aspect (1 – 5)	Number of ears per plant	Curvularia leaf spot (1 – 5)	Grain yield [kg/ha]	Yield increase over check [%]
Base index											
Top 5											
LY1409-21	57.9	59.9	2.0	172.4	79.5	2.1	2.1	1.5	0.3	4,301.5	17.7
LY1501-9	58.8	61.9	3.1	186.9	84.4	2.1	2.1	1.1	2.1	5,143.8	31.2
Ife Hybrid-3	59.2	62.4	3.2	166.7	80.0	1.6	2.6	1.3	0.4	4,009.9	11.7
LY1001-23	60.4	63.9	3.6	177.7	71.0	2.0	1.8	1.1	2.1	5,059.3	30.0
LY1501-1	60.1	61.7	1.6	173.9	84.1	2.0	2.0	1.5	1.9	3,810.1	7.1
Bottom 5											
A1736-6	59.5	60.8	1.4	162.3	64.3	2.3	3.1	0.8	2.4	3,536.2	–
A1736-12	58.3	61.1	2.8	188.2	79.2	2.8	2.9	1.0	3.2	4,024.4	–
LY1501-3	65.2	68.1	2.9	160.9	73.4	2.3	2.6	1.1	2.6	1,851.6	–
LY1312-12	65.4	69.3	3.9	135.6	91.7	1.9	2.7	0.7	2.2	1,105.5	–
LY1409-14	63.9	67.3	3.4	179.9	83.0	2.3	2.0	1.3	3.6	1,241.2	–
Multivariate selection index											
Top 5											
LY1409-21	57.9	59.9	2.0	172.4	79.5	2.1	2.1	1.5	0.3	4,301.5	17.7
LY1501-9	58.8	61.9	3.1	186.9	84.4	2.1	2.1	1.1	2.1	5,143.8	31.2
A1736-12	58.3	61.1	2.8	188.2	79.2	2.8	2.9	1.0	3.2	4,024.4	12.1
LY1501-1	60.1	61.7	1.6	173.9	84.1	2.0	2.0	1.5	1.9	3,810.1	7.1
LY1501-7	59.4	62.6	3.2	196.8	88.0	2.4	2.1	1.0	3.4	4,583.2	22.8
Bottom 5											
LY1312-4	60.8	65.0	4.1	169.4	72.2	2.2	2.2	0.9	2.6	3,404.1	–
LY1501-3	65.2	68.1	2.9	160.9	73.4	2.3	2.6	1.1	2.6	1,851.6	–
LY1409-14	63.9	67.3	3.4	179.9	83.0	2.3	2.0	1.3	3.6	1,241.2	–
LY1312-12	65.4	69.3	3.9	135.6	91.7	1.9	2.7	0.7	2.2	1,105.5	–
LY1312-11	63.6	68.8	5.2	167.4	57.3	1.8	2.0	1.1	2.3	2,428.2	–
Rank summation index											
Top 5											
LY1409-21	57.9	59.9	2.0	172.4	79.5	2.1	2.1	1.5	0.3	4,301.5	17.7
LY1501-1	60.1	61.7	1.6	173.9	84.1	2.0	2.0	1.5	1.9	3,810.1	7.1
LY1501-9	58.8	61.9	3.1	186.9	84.4	2.1	2.1	1.1	2.1	5,143.8	31.2
Ife Hybrid-3	59.2	62.4	3.2	166.7	80.0	1.6	2.6	1.3	0.4	4,009.9	11.7
A1706-2	60.4	63.2	2.8	185.3	84.1	2.0	2.0	1.0	2.3	4,539.7	22.0
Bottom 5											
LY1409-14	63.9	67.3	3.4	179.9	83.0	2.3	2.0	1.3	3.6	1,241.2	–
LY1312-11	63.6	68.8	5.2	167.4	57.3	1.8	2.0	1.1	2.3	2,428.2	–
LY1312-4	60.8	65.0	4.1	169.4	72.2	2.2	2.2	0.9	2.6	3,404.1	–
LY1312-12	65.4	69.3	3.9	135.6	91.7	1.9	2.7	0.7	2.2	1,105.5	–
LY1501-3	65.2	68.1	2.9	160.9	73.4	2.3	2.6	1.1	2.6	1,851.6	–

T a b l e 6

Selection differentials [%] under various selection indices for grain yield and other agronomic traits

Estimate	Anthesis [days]	Silking [days]	Anthesis-silking interval [days]	Plant height [cm]	Ear height [cm]	Husk cover (1−5)	Ear Aspect (1−5)	Number of ears per plant	*Curvularia* leaf spot (1−5)	Grain yield [kg/ha]
Base index										
Mean of top 5	59.26	61.97	2.71	175.52	79.79	1.97	2.12	1.31	1.36	4,464.93
Grand mean	60.73	63.84	3.11	174.07	77.17	2.13	2.30	1.09	2.44	3,338.32
Selection differential [%]	–2.43	–2.93	–12.76	0.83	3.40	–7.41	–7.81	20.86	–44.35	33.75
Multivariate selection index										
Mean of top 5	58.89	61.45	2.56	183.65	83.05	2.27	2.25	1.24	2.16	4,372.60
Grand mean	60.73	63.84	3.11	174.07	77.17	2.13	2.30	1.09	2.44	3,338.32
Selection differential [%]	–3.03	–3.74	–17.59	5.50	7.62	6.95	–2.40	14.23	–11.50	30.98
Rank summation index										
Mean of top 5	59.26	61.81	2.56	177.05	82.41	1.95	2.16	1.29	1.40	4,361.02
Grand mean	60.73	63.84	3.11	174.07	77.17	2.13	2.30	1.09	2.44	3,338.32
Selection differential [%]	–2.42	–3.17	–17.76	1.71	6.79	–8.07	–6.24	18.68	–42.57	30.64

selection differential for grain yield (Adebayo *et al*. 2017; de Santiago *et al*. 2019; Silva *et al*. 2020). The selection differentials under RSI were highest only for anthesis-silking interval and husk cover rating, although comparable with the other two indices for grain yield and other agronomic. This result highlights the efficiency of the weight-free selection index (RSI) which does not require assigning economic weights to each trait, the parameters are easier to compute and handle (Crosbie 1980; Ajala 2010; Crevelari *et al*. 2018). Furthermore, the ranking of values of RSI had a strong negative correlation with the ranking of values of MSI (r = –0.86; $P < 0.001$) and base index (r = –0.56; $P < 0.01$). The negative association was due to the ranking method used in RSI. With the use of the RSI approach, the lower the rank summed values the better, whereas for the base index and MSI the higher the index values the better. The strong significant correlation between these indices indicates the similarity in their ability to rank the PVA maize hybrids based on the traits considered. The multivariate index values were not significantly correlated with base index values.

CONCLUSIONS

The results obtained showed wide genetic variability among the newly developed pro-vitamin A (PVA) enriched maize hybrids evaluated under the derived savanna agroecology. The three selection indices used in this study identified similar hybrids as superior for grain yield and other agronomic traits. The base index had good selection differential values for all traits measured indicating its efficiency in identifying outstanding performance. The identified superior three-way cross PVA maize hybrids (LY1409-21, LY1501-9 and LY1501-1) with improved productivity and nutrition require further evaluations across environments to ascertain the stability of their performance and hasten their adoption by farmers' in the derived savanna and similar agro-ecologies.

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