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Suitable Hybrids and Synthetics Provitamin A Maize Selected for Release in the Democratic Republic of Congo

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Abstract

Six new provitamin A hybrids (LY1001-14, LY1001-22 and LY1001-23,) and synthetic maize varieties (PVASYN13, PVASYN9 and PVASYN7) were tested for their agronomic performance and compared to a locally adapted improved open pollinated variety (SAMARU) in the central and western conditions of DRC. A randomized complete block experiment with four replications was used. Following data were collected: 50% male and female flowering, plant and ear aspect, diseases incidence, plant height, ear aspect, ear rot and yield. The results showed non-significant differences ($p > 0.05$) in disease incidence and ears rot. Significant differences were observed ($p < 0.05$) for number of days to 50% of male and female flowering, anthesis-silking interval, plant height, plant aspect, ear aspect, and yield. For yield, two hybrids (LY100-14 and LY1001-22) respectively out-yielded local check by 71% and 56% while one synthetic (PVASYN 9) out-yielded the local check by 31% and the two others were comparable to the local check. Thus the hybrids (LY100-14 and LY1001-22) and synthetic varieties (PVASYN 9 and PVASYN13) are ready to be recommended for release to contribute to better production and nutrition for vulnerable people.

Subject Areas

Agricultural Science

Keywords

Bio-Fortification, Maize, Agronomic Performance, Provitamin A, INERA DRC

1. Introduction

Maize (Zea mays) is a staple food for more than 1.2 billion people in sub-Saharan Africa and Latin America and is considered a vital crop in the perspective of global nutrition [1] [2]. However, most maize produced and consumed is white and devoid of provitamin A carotenoids [3] [4]. This may partly explain why vitamin A deficiency (VAD) is a major public health problem in sub-Saharan Africa [2] [5] leading to widespread malnutrition [6]. Moreover, poverty makes it virtually impossible for the majority of consumers to obtain vitamin A of animal origin.

The VAD affects between 100 and 140 million children worldwide (FAO/WHO 2002, WHO 2003) and about 33 million pre-school children, pregnant and nursing mothers in Africa, 250,000 to 500,000 children [7] [8] and other diseases [9] [10]. The VAD is responsible for approximately 20% - 24% of infant mortality due to diarrhea and malaria and infectious diseases [11].

Selection of crops for better nutrition (often called bio-fortification) is one of the strategies to mitigate micronutrient deficiencies [12] [13]. Several initiatives have been launched to increase micronutrient levels in plant foods. The Harvest Plus Challenge Program of the Consultative Group on International Agricultural Research (CGIAR) seeks to combat VAD malnutrition by harnessing the power of plant breeding to develop staple foods such as rice, sweet potatoes, Maize, cassava, wheat and beans rich in iron, zinc or provitamin A [14] [15] [16]. Maize grain (Zea mays L.) has considerable phenotypic diversity for carotenoid profiles [17] [18] [19], including some of the highest concentrations of carotenoids for cereal crops [20].

Bio-fortification of maize varieties with provitamin A by conventional selection is considered as a long-term and sustainable strategy for attenuating VAD in certain target groups [21] [22]. Thus, it becomes necessary to study the agronomic performance of synthetic and hybrid varieties of maize to provitamin A with a goal of spreading superior varieties to vulnerable people.

2. Materials and Methods

2.1. Environment and Experimental Design

A study was carried out during the rainy season of 2015-2016 in two stations of INERA (Mvuazi and Gandajika) and on-farm at 4 sites (kilonga and kikonka, Muyembi and Musakitshi, respectively around Mvuazi and Gandajika stations). INERA Mvuazi research center, is located at an altitude of 470 m at 14˚54' East longitude and 5˚21' South latitude. The climate of Mvuazi is of Aw4 type with rainfall ranging from 800 to 1200 mm per year with monthly averages of the daily air temperature range from 24.5˚C to 25.5˚C during the rainy season. Feralsol soil [23] is characterized by low organic matter content and low water retention capacity resulting from low availability of nitrogen [24]. INERA Gandajika research center is located at 06˚48' South latitude, 23˚59' East longitude at altitude between 735 and 766 m. The Gandajika is between is characterized by

Aw4 climate type with annual rainfalls ranging from 1000 mm to 1420 mm and temperature ranging between 22˚C and 25˚C (Bado, 1993).

Three hybrids (LY1001-14, LY1001-22, LY1001-23) and three synthetics (PVA SYN 7, PVA SYN 9, PVA SYN 13) all rich in provitamin A from International Institute of Tropical Agriculture (IITA), were tested and compared with an improved control (SAMARU) already adapted in DRC maize producing areas. A randomized complete block experiment with four replications was used.

The soil was plowed and harrowed in late August 2015. Planting was done at a density of 53,333 plants per hectare at the spacing of 0.75 m × 0.50 m. Urea 46% and NPK 17-17-17 were used as fertilizers. NPK was applied at 250 kg/ha at planting time while urea (120 kg/ha) was applied in two halves, 15 and 30 days after sowing. Manuel weeding was used to maintain the field experiment clean.

During the growth phase, the data were collected on the vegetative parameters proposed by [25] the number of days at 50% of male flowering (POLLEN), 50% to female flowering (DYSK), the height of the plant (PLHT), plant aspect (PASP), and disease Symptom (D.S), ear height (EHT), interval between female and male flowering (IFM). At harvest, maize cobs were harvested on the two central rows of each plot. Data were collected on the ear rot (EROT), ear aspect (EASP) and yield (YIELD) evaluated at 14% grain moisture. To assess PASP and EASP, a rating scale of 1 to 5 was used (1 = excellent, 2 = very good, 3 = good, 4 = poor and 5 = very poor). For EROT and D.S we used: (1 = no symptoms, 2 = very few symptoms, 3 = moderate infection, 4 = severe infection and 5 = very severe infection) [26].

2.2. Statistical Analysis

All data collected were subjected to analysis of Variance (ANOVA) using the general linear model AnovaModel <- aov (y ~ variety + rep) of Ri3.1.3 to compute the means and to estimate the variety and site effects. The degree of variation was determined using the percentage of the coefficient of variation and the mean characters were measured using the smallest significant difference (LSD) at $P < 0.05$. Principal component analysis (PCA) was developed to show the levels of dependence between factors and variables studied.

3. Results and Discussion

Data related to plant development and yield components are summarized in Table 2. Based on data generated by the analysis of variance (Table 1) for all sites, the environment significantly and differently affected all parameters considered. Grain yield was determined by the pedigree while the interactions site*pedigree significantly influenced flowering period, plant and ear aspects.

3.1. Number of Days at 50% Bloom and Flowering Interval

The results presented in Table 2 show that there is a significant difference ($p < 0.05$) among the pedigrees for the male flowering (POLLEN).

Table 1. Analysis of variance for growth and yield variables (site and pedigree).

Source of variation	DF	DYSK	POLLEN	PLHT	EHT	PASP	EASP	EROT	YIELD	D.S
Site	1	<2.2e−16***	2.7e−10***	<2.2e−16***	<2e−16***	8.7e−09***	0.01*	7.40e−06***	0.2	0.0016**
Pedigree	6	1.26e−05***	0.0001***	0.01**	0.05.	6.7e−09***	7.16e−05***	0.63	0.01*	0.83
Site*Pedigree	6	1.24e−05***	6.4e−06***	0.27	0.55	1.07e−05***	0.026*	0.54	0.66	0.569

Signif. codes: 0 "***" 0.001 "**" 0.01 "*" 0.05 "." 0.1 " " 1.

Table 2. Regional averages of six sites for synthetics and hybrids varieties based on growth and yield data.

PEDIGREE	DYSK	POLLEN	IFM	PLHT (cm)	EHT (cm)	PASP (1 - 5)	EASP (1 - 5)	EROT (1 - 5)	YIELD (kg/ha)	D.S (1 - 5)
LY1001-22	63.5bc	58.7bc	4.75ab	187.8a	92.49abc	2.00d	2.31abc	1.56a	6.47a	1.75a
LY1001-14	64.5b	59.75b	4.75ab	186.15a	85.34bcd	2.18cd	1.8d	1.43a	5.90ab	1.62a
LY1001-23	67.5a	61.8a	5.37a	184.34ab	94.62a	2.43bc	2.06cd	1.93a	4.46cd	1.75a
PVASYN13	64.12b	59.7b	4.37ab	182.71ab	91.59abc	2.43bc	2.56ab	1.75a	4.40cd	1.5a
PVASYN9	62.8bc	59b	3.87b	188.49a	95.48a	2.18cd	2.68a	1.75a	4.97bc	1.62a
PVASYN7 F2	64.37b	60.12b	4.25ab	170.17ab	83.84cd	2.87a	2.62ab	1.62a	3.54d	1.5a
SAMARU	61.8c	57.3c	4.5a	162.65b	80.31d	2.56b	2.87a	1.75a	3.79cd	1.87a
Means	64.07	59.51	4.55	180.33	98.1	2.38	2.42	1.68	4.79	1.64
CV%	2.56	2.25	23.48	7.8	11.11	8.2	15.18	31.12	26.27	32.87
LSD (0.05%)	2.17	1.27	1.33	16.36	14.88	0.29	0.39	0.52	2.71	0.43

(a, b, c): Averages with the same letters are not significantly different at 5% of error.

Local (SAMARU) check flowered early at 57.3 days while LY1001-23 followed at 61.8 days. For female flowering, the significant difference was observed with SMARU with 61.8 days and LY1001-23 at 67.5 days. Similarly to the number of days 50% to flowering, there was a significant difference ($p < 0.05$) for the flowering interval (IFM) among the treatments. PVASYN9 exhibited a shorter IFM of 3.8 days while LY1001-22 and LY1001-14 presented a longer IFM of 4.75 days. [27] [28] working on high amino acid varieties showed that the flowering interval was significantly correlated with yield. Short IFM varieties (IFM < 4) had higher yields than long IFM (IFM > 3). Contrasting varieties rich in amino acids, hybrid varieties rich in provitamin A are fairly important beyond IFMs > 3 days. This implies that pollen production for these varieties would extend over a long period to the end of female flowering.

3.2. Plant Height

Results obtained from this study indicate that there was a significant difference ($p < 0.05$) among maize varieties for plant height. SAMARU showed a shorter size of 162.65cm while the highest genotype was the PVASYN9 with 188.49 cm (**Table 1**). Plant and ear heights are perceived as signs of vigor, so short, low-insertion plants are needed in the tropical breeding program to improve stem and root resistance and facilitate harvesting [29]. [30] found that the height of the plant was significantly correlated with grain yield while [31] showed that plant height reduction improved yield by giving the variety the ability to respond to high density without lodging by maintaining or reducing barrier levels.

3.3. Plant and Ear Aspect

Plant aspect is a visual measurement of how good and appealing the plants are morphologically. The results obtained in this study show that the plant aspect was not significantly affected for most varieties. For the ear aspect, the criterion included cobs uniformity and size, kernel arrangement, and ear rot tolerance. PVASYN7 was more affected with a worse plant aspect around 3. The other varieties presented a very good appearance for plants and ears.

3.4. Disease Incidence and Ear Rot Indexes

For all maize varieties evaluated, PVASYN13, PVASYN7, LY100-22 and LY1001-23 had low infection rates than 1.7. SAMARU showed infection rates around 1.9. However, no significant differences were observed among the varieties tested. As for the disease incidence, there were no significant differences among the varieties for ear rot indexes. All the seven varieties had a rotational ear rot index ranging from 1 to 1.7.

3.5. Grain Yield (t/ha) and Planting Sterile Rate (%)

The yield obtained was significantly influenced by the potential of the different maize varieties tested. Two hybrids LY1001-14 (5.9 t/ha) and LY1001-22 (6.5 t/ha) obtained significantly higher yields than the hybrid LY1001-23 (4.5 t/ha) and all synthetics except PVASYN9 which got a yield similar to that of one of the hybrids (LY1001-14), which makes it a best potential candidate for release. Grain yield is a complex trait. It is the product of several components including the number of ears per plant, the number of grains per ear and the grain weight. According to [32] [33] its heritability is low (0.09 to 0.38). The low correlations between the rate of sterile plants and the yield indicate that yield is not always influenced at low values < 10% of sterile plants. Genotypes LY1001-14, LY1001-22 and PVASYN13 have been reported as provitamin-A rich materials with high production, disease resistance and good returns in Ghana [6].

3.6. Principal Component Analysis (PCA)

Only four of the ten dimensions obtained Eigen values greater than 1. These dimensions provide 76.08% of the total variance (**Figure 1**). The first two axes PC1 and PC2 account for 64% of information. The PC1 axis better explains plant height (PLHT) and ear height (EHT) and female flowering (DYSK) and male flowering (POLLEN). The axis PC2 explains better YIELD and ear aspect (EASP).

The PC1 is defined by male flowering (POLLEN), female flowering (DYSK),

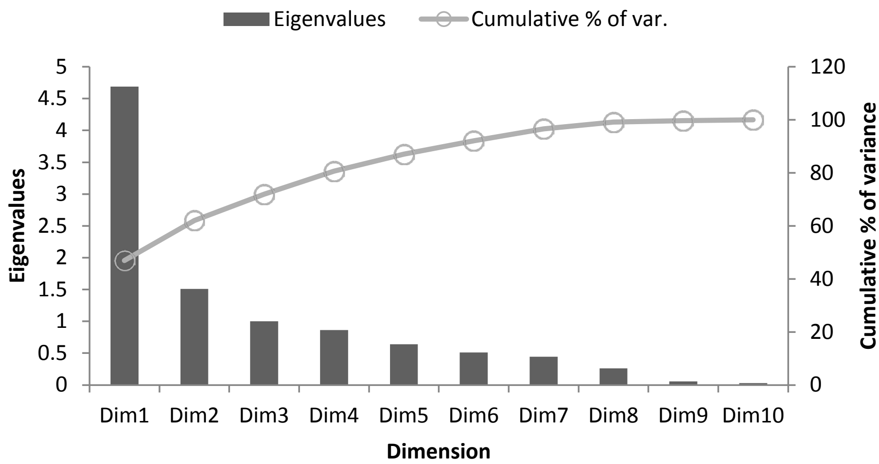

Figure 1. Eigenvalues of factors and cumulative% of factor variance.

PLHT et EHT and the ear aspect (EASP), plant aspect and flowering interval (IFM).

This dimension contrasts early maturing varieties with a high yield to late maturing varieties at long IFM. The PC2, mainly defined by the flowering interval (IFM), female flowering and plant aspect, two contrasts groups, 1) the more synchronized varieties in flowering with a noticeable plant and ears aspect, and 2) the varieties having a longer flowering interval, undesirable ear aspect and low yield (**Figure 2**). PC3 characterizes varieties plant height. The PC4, characterized by yield and the sterile plants rate, contrasts high yielding genotypes with fewer sterile plants with less productive genotypes with a high sterile plant rate. The first dimension categorizes synthetic varieties (PVASYN9 and PVASYN13) having medium plant height, good aspect and high yield (**Figure 3**). The second dimension characterizes the hybrids varieties

(LY1001-22, LY1001-14 and LY1001-23) having a good plant and ear aspect and a longer or shorter IFM. However, the PVASYN7 variety was opposed to the two groups of varieties. It has a high plant aspect index and low grain yield. The local check (SAMARU) showed to be an intermediate variety from the two types of varieties. It is short sized, with good plant and very good ear aspects.

Figure 3 shows a clear separation between varieties types. This separation of hybrids and synthetics varieties has been reported by [6] [29]. PVAs have a low yield compared to LYxxx.

Table 3 presents four groups from the PCA for the parameters studied. These are groups formed of PVA syn 9 and PVA syn 13, PVA syn7 and Local check, LY1001-14 and LY1001-22, and LY1001-23.

In the first case, the PVASYN13 and PVASYN9 varieties were more effective in disease resistance and good yield in an assessment in Nigeria. In the second case, the hybrids (LY1001-14 and LY1001-22) were tested in Ghana for their yield performance, provitamin A content, and plant and ear aspects. In both cases the results remained similar to those obtained in our study.

Based on of the results obtained during this evaluation, the two types of

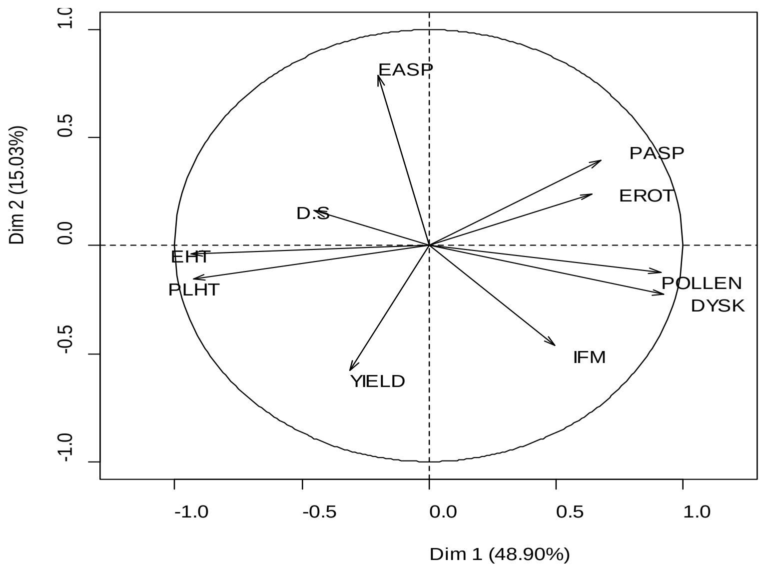

Figure 2. Vector projection from the ACP.

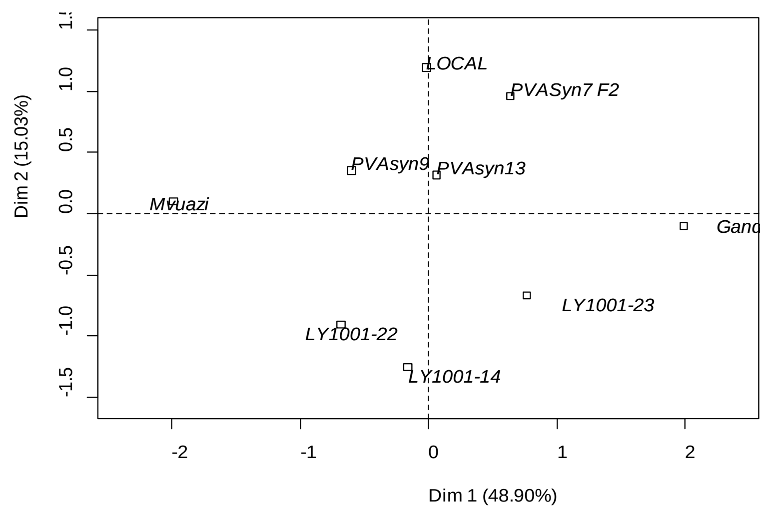

Figure 3. Biplot showing the separation of genotypes according to the studied parameters.

Table 3. Morphological, phenological and varieties characteristics studied in all sites.

Variables	I	II	III	IV
	PVA Syn 9	LY1001-22	LY1001-23	PVA Syn7
EASP	Hight	Low	Low	Hight
EHT PLHT	Hight	Hight	Low	Low
YIELD	Low	Hight	Hight	Low
PASP	Low	Low	Hight	Hight
EROT	Low	Low	Low	Low
POLLEN DYSK	Low	Low	Hight	Hight
IFM	Low	Hight	Hight	Low
DS	Hight	Low	Low	Light

genotypes performed differently in comparison with the improved non-bio-fortified control. Synthetic varieties with earlier synchronized flowering have been characterized by their low sterility compared to intermediate maturing hybrids. The ear aspect, sterility rate, plant height and flowering interval indicated of genotype productivity potential.

4. Conclusion

Three new provitamin A hybrids (LY1001-14, LY1001-22 and LY1001-23) and three synthetic maize varieties (PVASYN13, PVASYN9 and PVASYN7) were tested for their agronomic performance. Out of them, two hybrids (LY100-14 and LY1001-22) and two synthetics (PVASYN9 and PVASYN13) performed well with high yield potential. Thus they are good candidates to be recommended for release for the first time to contribute to better production and nutrition for vulnerable people in DRC.

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