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Assessment of the Effects of Genotype, Location, and Planting Season on the Nutritional Composition and the Metabolizable Energy of Advanced Twenty-Five Maize Hybrids

Emmanuel Oladeji Alamu [1,2,*,†], Abebe Menkir [3,†], Michael Adesokan [2,†], Segun Fawole [2,†] and Busie Maziya-Dixon [2,†]

[1] International Institute of Tropical Agriculture, Southern Africa Research and Administration Hub (SARAH) Campus, Lusaka 10100, Zambia
[2] Food and Nutrition Sciences Laboratory, International Institute of Tropical Agriculture (IITA), PMB 5320, Oyo Road, Ibadan 200001, Nigeria
[3] Maize Breeding Unit, International Institute of Tropical Agriculture (IITA), PMB 5320, Oyo Road, Ibadan 200001, Nigeria
* Correspondence: o.alamu@cgiar.org
† These authors contributed equally to this work.

Abstract: This study investigated the effects of genotype, location, and planting season on the proximate composition and metabolizable energy of advanced maize hybrids. Twenty-five hybrid maize and a local variety as control were harvested from five locations 100 days after planting for two seasons. The maize samples were sorted, cleaned, and pulverized using a laboratory mill and were analyzed for nutritional composition and metabolizable energy (ME) using standard laboratory methods. Moisture content, ash, fat, and protein had mean ± SD of 8.97 ± 0.40%, 1.48 ± 0.05%, 4.31 ± 0.19, and 8.88 ± 0.18%, respectively. ME had a mean ± SD of 379.77 ± 2.17 kJ, and total carbohydrates had values ranging from 74.68 and 77.20%, with an average of 76.68%. Results showed that most of the variations expressed in the proximate compositions of the maize hybrids were not significantly ($p > 0.05$) dependent on the genotypes. In contrast, locations significantly affected the maize hybrids' proximate composition and metabolizable energy ($p < 0.001$). In addition, there was no significant effect ($p > 0.05$) of location by genotype interaction on the proximate composition and ME of the maize samples. The planting season also exhibited a significant ($p < 0.001$) difference for all the proximate parameters. Fourteen out of the twenty-five maize hybrids were similar to the local variety in terms of proximate composition and metabolizable energy. Therefore, they could be recommended for advancement in the breeding stages for release for household and industrial uses.

Keywords: genetic; environment; proximate composition; season; maize varieties

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1. Introduction

The most widely cultivated crops globally are cereals because they are the primary sources of energy and protein in the diet of the populace [1]. Maize (*Zea mays* L.) is a staple crop, as it is widely consumed across the globe. It has a world production of about 967 million metric tons yearly [2,3], and, due to its taste and availability, maize is regarded as Mexico's most popular cereal crop [4]. It is also referred to as the nutritional backbone in central, southern, and eastern Zambia [5]. In Nigeria, the estimated annual production of maize is approximately 5.6 million metric tons and takes second position behind sorghum [1]. The utilization of maize as human food and livestock feed has given the cereal crop worldwide significance. Maize is one of the most nutritious non-legume green fodders [6] and the primary cereal used for poultry feed in the United States of America and most Asian countries [7]. In developing countries, such as Nigeria, maize is a multipurpose crop of immense nutritional value. It has found application not just as food for humans and livestock but also as raw materials for manufacturing the industrial product. Amongst other cereals, such as rice, wheat, and sorghum, maize also serves as a significant dietary energy source [1,3,5,8,9].

Many beneficial nutrients have been found in maize, ranging from carbohydrates, protein, macro elements, minerals, and vitamins to phytochemicals [2]. The cultivation of maize in different environments with highly variable weather conditions, especially in Sub-Saharan Africa, affects its nutritional characteristics and agronomic performance, such as grain yield [10]. Nigeria is divided into five agroecological zones characterized by different rainfall patterns, temperatures, and soil types. For instance, Ibadan is considered a Forest savanna area with an annual rainfall of 1312 mm, a temperature range of 20.3–33.8 °C, and Ferric Luvisols soil type. Ubiaja is a Subhumid Forest area with an annual rainfall of 1186 mm with temperatures ranging from 19.9 to 32.6 °C and Dystric Nitosols soil type. Mokwa, a Southern Guinea savanna area, has an annual rainfall of 1149 mm and a temperature range of 18.1–37.3 °C. Zaria is a Northern Guinea savanna area with an annual rainfall of 1076 mm and a temperature range of 13.9–35.5 °C. The soil type in Zaria is Ferric Luvisol [11].

Several studies have been carried out to examine the effect of genotype and environment on the nutritional content of grain crops [11–13]. Previous authors [14,15] have reported that the environment affected the nutritional composition of rice and sorghum. It has also been established that genotypes × environmental interaction resulted in differential nutritional values of sorghum grains [14]. Genetic variability is an essential factor contributing to the biochemical and nutritional variations in maize samples [2,7]. In addition, genotype and environment interaction significantly affect the proximate content of maize grain samples in different parts of the world [9,16–18]. However, there is a lack of information on the effects of genotype, location, and planting season on the nutritional composition of maize hybrids grown across different agroecological zones in Nigeria. Most significantly, the effects of these factors on the advanced maize hybrids selected for release to farmers is lacking. Hence, this study aims to evaluate the effect of genotype, environment, and planting season on the nutritional composition of twenty-five advanced maize hybrids grown across different agroecological zones in Nigeria with distinct and varying environmental conditions. The effects of genotype by environment, genotype by planting season, and environment by planting season on the proximate composition of these maize hybrids were also evaluated. The findings of this experiment will provide the breeders with information about the nutritional profile of the maize hybrids and how these nutritional components are affected by the investigated factors.

2. Materials and Methods

2.1. Genetic Material

Twenty-five hybrid maize and one local variety as control were obtained from the experimental fields of the International Institute of Tropical Agriculture (IITA) at five different locations in Nigeria. The locations are Ibadan (7°22′ N, 3°58′ E, altitude 225 m), Ikenne (10°40′ N, 8°77′ E, altitude 61 m), Mokwa (9°17′ N, 5°03′ E, altitude 154 m), Zaria (11°06′ N, 7°43′ E, altitude 640 m), and Saminaka (10°24′ N, 8°41′ E, altitude 768 m). The samples were planted in two seasons, April to August 2020 and 2021, respectively, and were arranged in a randomized complete block design (RCBD).

Each entry was planted in a one-row plot, 5 m long, with an inter-row spacing of 0.75 m and an intra-row spacing of 0.50 m. Three seeds were planted per hill and later thinned to two plants/hill to give a plant population of 50,000 plants/ha. NPK 15:15:15 fertilizer was applied at 60 kg N, 60 kg P, and 60 kg K per hectare at the time of planting at each location. An additional 30 kg N in the form of urea was applied as top dressing four weeks later. Hybrid varieties were used for border rows in each trial. Gramazone and atrazine were applied as pre-emergence herbicides at 5 L ha^{-1} for each trial. Subsequently, manual weeding was done to keep the plots weed free. Five plants from each plot were self-pollinated, and ears harvested from self-pollinated plants were taken to the laboratory for nutritional analyses.

A total of 520 maize samples (26 hybrids × 2 reps × 5 locations × 2 seasons) were harvested 100 days (at maturity stage) after planting, dried with the cob on the field, and then shelled. The maize grain samples were sorted and pulverized using a Laboratory mill (Perten Lab Mill 3100, Upplands Väsby, Sweden) to a particle size of less than 1 µm and then transferred into a Whirl Park for further analysis.

2.2. Laboratory Analysis

The moisture content of the maize flour samples was determined using the Association of Official Analytical Chemists (AOAC) approved method 925.09. However, the samples' crude fat and ash contents were determined using the Association of Official Analytical Chemists' Approved methods 920.87 and 920.39, respectively. The total carbohydrate was determined by subtracting the other proximate parameters from 100 (i.e., by the difference method) [19]. Crude protein was determined by the Kjeldahl method using Kjeltec™ model 2300, as described in the FOSS Manual (FOSS, 2003) [20]. The metabolizable energy (ME) was estimated using the Codex Alimentarius formula (Codex 1991) [21]. ME indicates the estimate of energy value that can be available for body use and is calculated from the protein, fat, and carbohydrates content using the following equation:

$$ME(KJ) = (4 \times \%Protein + 9 \times \%Fat + 4 \times \%Total\ carbohydrate) \quad (1)$$

2.3. Statistical Analysis

The results of the analysis of the maize samples were subjected to statistical analyses using the XLSTAT (Addinsoft, New York, NY, USA) tools. Analysis of variance (ANOVA) was used to calculate the least squares means to estimate the differences among the means of the proximate composition and metabolizable energy for maize variety at 5% of the probability level. The mean, SD, and coefficient of variation (CV) were also computed.

3. Results

3.1. Proximate Composition of the Hybrid Maize Samples

Table 1 shows the mean proximate composition of twenty-six maize samples used in the study. The mean ± SD of the moisture, ash, fat, and protein content are 8.97 ± 0.40 g/100 g, 1.48 ± 0.05 g/100 g, 4.31 ± 0.19 g/100 g, and 8.88 ± 0.18 g/100 g, respectively. Metabolizable energy had a mean ± SD of 379.77 ± 2.17 kJ, and total carbohydrate values ranged from 74.68 to 77.20 g/100 g.

Table 1. Mean proximate composition of maize hybrids across different locations (N = 520).

Hybrid	MC (g/100 g)	Ash (g/100 g)	Protein (g/100 g)	Fat (g/100 g)	ME (kJ)	TCHO (g/100 g)
A1706-2	8.90 ab	1.52 a	9.18 abc	4.47 a	380.67 ab	75.94 abc
A1736-12	8.59 ab	1.52 a	8.59 c	4.55 a	382.30 a	76.74 abc
LY1501-6	8.51 b	1.52 a	8.92 abc	4.44 a	382.09 a	76.60 abc
LY1001-18	8.79 ab	1.38 a	9.07 abc	4.69 a	382.76 a	76.08 abc
LOCAL VARIETY	8.95 ab	1.52 a	8.46 c	4.43 a	380.26 ab	76.63 abc
A1702-53	8.93 ab	1.51 a	8.58 c	4.43 a	380.39 ab	76.53 abc
A1702-28	8.61 ab	1.50 a	8.70 abc	4.32 a	381.16 ab	76.86 abc
LY1409-21	9.23 ab	1.46 a	8.78 abc	4.53 a	379.89 ab	76.00 abc
LY1501-8	8.67 ab	1.47 a	8.53 c	4.46 a	381.77 a	76.86 abc
LY1312-4	8.70 ab	1.49 a	8.55 c	4.33 a	380.89 ab	76.92 abc
LY1302-9	8.90 ab	1.54 a	8.66 c	4.30 a	379.76 ab	76.60 abc
LY1312-12	8.69 ab	1.52 a	8.66 bc	4.28 a	380.56 ab	76.85 abc
LY1312-11	9.21 ab	1.49 a	9.04 abc	4.39 a	379.15 ab	75.87 abc

Table 1. *Cont.*

Hybrid	MC (g/100 g)	Ash (g/100 g)	Protein (g/100 g)	Fat (g/100 g)	ME (kJ)	TCHO (g/100 g)
A1736-13	8.98 ab	1.45 a	8.67 bc	4.35 a	379.99 ab	76.54 abc
M1124-31	9.16 ab	1.51 a	8.90 abc	4.30 a	378.85 ab	76.13 abc
IFE HYBRID-3	8.91 ab	1.53 a	8.39 c	4.27 a	379.61 ab	76.89 abc
LY1409-14	9.11 ab	1.49 a	8.71 abc	4.32 a	379.24 ab	76.37 abc
A1702-49	8.59 ab	1.49 a	8.52 c	4.28 a	381.08 ab	77.12 a
A1736-6	8.78 ab	1.53 a	8.30 c	4.18 a	379.67 ab	77.20 a
LY1501-1	8.66 ab	1.45 a	8.95 abc	4.20 a	380.56 ab	76.73 abc
LY1501-9	8.66 ab	1.47 a	8.58 c	4.14 a	380.14 ab	77.14 a
LY1501-7	8.66 ab	1.47 a	8.76 abc	4.07 a	379.83 ab	77.04 ab
LY1501-5	8.87 ab	1.45 a	9.21 abc	4.20 a	379.71 ab	76.27 abc
LY1001-23	9.81 ab	1.43 a	9.36 abc	4.14 a	375.73 ab	75.26 abc
IFE HYBRID-4	9.73 ab	1.43 a	10.03 ab	4.06 a	375.65 ab	74.76 bc
LY1501-3	9.96 a	1.36 a	10.06 a	3.95 a	374.51 b	74.68 c
Minimum	8.51	1.36	8.30	3.95	374.51	74.68
Maximum	9.96	1.54	10.06	4.69	382.76	77.20
Mean	8.97	1.48	8.88	4.31	379.77	76.37
Standard deviation	0.42	0.05	0.48	0.19	2.17	0.73
Coefficient of Variation	4.66	3.38	5.45	4.34	0.57	0.96
p level	**	NS	***	NS	***	***

Means with the same alphabets within the same column are not significantly different; ($p > 0.05$), ** $p < 0.01$, *** $p < 0.001$.

The mean values of the metabolizable energy for all the samples were not significantly different ($p > 0.05$) except for hybrids A1736-12, LY1501-6, LY1001-18, LY1501-8, and LY1501-3, whose mean values were significantly ($p < 0.001$) different. Total carbohydrate mean values for A1702-49, A1736-6, LY1501-9, LY1501-7, IFE HYBRID-4, and LY1501-3 were significantly different from the mean values of other maize genotypes.

3.2. Effects of Genotype, Location, and Season on the Maize Hybrids

Table 2 shows the analysis of variance result of the effect of genotype, location, and season on the nutrition profile of maize hybrids. Genotype showed a highly significant ($p < 0.001$) effect on protein, metabolizable energy, and carbohydrate but no significant effect ($p > 0.05$) on the ash and fat content. However, both planting environment and season had a highly significant effect ($p \leq 0.001$) on the maize hybrids' proximate composition and ME. The interactive effect of location by season was also significant ($p \leq 0.001$) on metabolizable energy and proximate components, except for carbohydrate content, for which there was no significant effect ($p > 0.05$). Genotype showed a significant ($p > 0.001$) effect on the maize's protein, metabolizable energy, and carbohydrate content. There were no significant effects of hybrid by location, hybrid by season, and hybrid by location by season interactions on the maize samples' proximate content and metabolizable energy.

Table 3 further describes the significant effects ($p < 0.001$) of location and planting season on the evaluated traits of the maize. In Ibadan and Zaria, there was no significant difference in fat and carbohydrate content, and moisture content and ME were also not significantly affected across Saminaka, Ikenne, Ibadan, and Mokwa. Location significantly affected the ash and protein content of the maize hybrids. Planting season also showed a significant effect ($p < 0.001$) on all the analyzed parameters.

Table 2. Analysis of variance of proximate composition of the maize hybrids planted across five locations.

		MC	Ash	Protein	Fat	ME(KJ)	CHO
Source	**DF**	**MS**	**Mean Squares**	**Mean Squares**	**Mean Squares**	**Mean Squares**	**Mean Squares**
Hybrid Name	25	1.77 **	0.03 ns	2.77 ***	0.37 ns	47.85 ***	2.28 ***
Location	4	10.44 ***	0.189 ***	44.39 ***	5.06 ***	445.10 ***	35.33 ***
Season	1	452.00 ***	1.419 ***	449.47 ***	33.24 ***	10,961.94 ***	1348.36 ***
Hybrid Name * Location	100	1.29 ns	0.03 ns	1.04 ns	0.51 ns	36.00 ns	2.86 ns
Hybrid Name * Season	22	0.97 ns	0.02 ns	1.25 ns	0.41 ns	26.76 ns	2.49 ns
Location * Season	4	15.16 ***	0.44 ***	16.67 ***	4.74 ***	334.51 ***	27.02 ns
Hybrid Name * Location * Season	79	0.98 ns	0.02 ns	1.09 ns	0.33 ns	21.12 ns	2.84 ns

*, **, ***—Significant at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$ respectively; ns—not significant $p > 0.05$; ME = metabolizable energy. CHO = carbohydrate. Data were from duplicate values, two planting seasons, and five locations.

Table 3. Effects of locations and seasons on the proximate composition of maize hybrids.

	MC (g/100 g)	Ash (g/100 g)	Protein (g/100 g)	Fat (g/100 g)	ME (KJ)	TCHO (g/100 g)
Saminaka	8.75 b	1.55 a	8.72 c	4.58 a	381.70 a	76.41 b
Ikenne	8.97 b	1.45 c	7.87 d	4.50 ab	380.85 a	77.21 a
Ibadan	8.63 b	1.51 ab	9.53 a	4.18 c	380.33 a	76.14 b
Mokwa	8.86 b	1.42 c	8.96 bc	4.25 bc	380.14 a	76.52 ab
Zaria	9.52 a	1.48 bc	9.19 ab	4.04 c	376.25 b	75.77 b
p level (Location)	***	***	***	***	***	***
Year 1	7.88 b	1.55 a	7.81 b	4.59 a	385.23 a	78.17 a
Year 2	10.01 a	1.42 b	9.90 a	4.03 b	374.48 b	74.65 b
p level (Season)	***	***	***	***	***	***

Means with the same alphabets within the same column are not significantly different; *** $p < 0.001$.

3.3. Principal Component Analysis (PCA) of Proximate Components of Maize Hybrids

The principal component analysis conducted on the dataset indicated the contribution of the six variables, with PC 1 and 2 explaining, respectively, 37.87% and 32.77% of the total variance (Figure 1). In PC1, ash and moisture content are the dominant parameters that showed the highest positive value, whereas PC2 was constituted mainly of protein, fat, and metabolizable energy. In PC2, metabolizable energy had the most positive score, followed by fat content. These two traits explained the classification of the maize genotypes such as IFE HYBRID4, A1706-2, and LY1501-6, respectively. Total carbohydrate being the dominant parameter in the positive side of PC1 influenced the grouping of A1736-12, LY501-7, A1702-28, LY501-8, LY501-1, and LY312-12, respectively. The eigenvalues of protein (0.08) and carbohydrates (0.16) were close to zero in principal component 2, which showed minimal effects in the variation of the classification of the maize genotypes in PC2 (Table 4).

Table 4. Eigenvectors for the principal component analysis.

	F1	F2	F3	F4
%MC	−0.33	−0.57	0.21	−0.33
%Ash	0.28	−0.24	0.57	0.72
%Protein	−0.48	0.08	−0.48	0.55
%Fat	−0.41	0.32	0.60	−0.17
ME(KJ)	−0.07	0.70	0.17	0.04
%TCHO	0.64	0.16	−0.10	−0.18

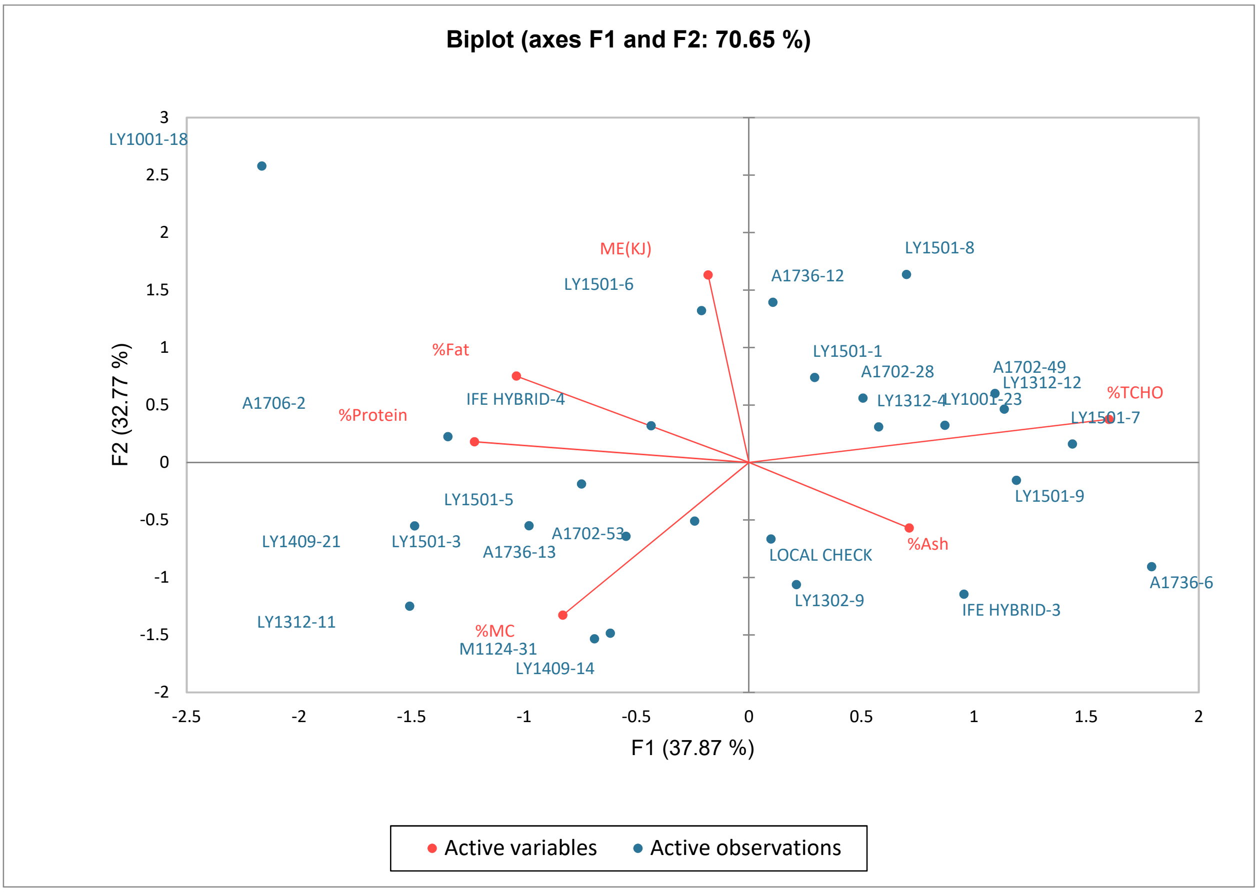

Figure 1. Principal component analysis of maize genotypes.

3.4. Cluster Analysis of Maize Hybrids Using the Proximate Components

Cluster analysis based on the PCA loadings showed the percent similarities in the maize hybrids (Figure 2). The dendrogram showed the similarity between maize hybrids forming two major clusters. Cluster I was further divided into two subgroups, where the first subgroup included IFE HYBRID-3, A173-6, LOCAL VARIETY, LY1302-9, and A17025-2. The second subgroup of the first cluster had LY1501-1, LY1501-7, LY1501-9, LY1501-8, LY1001-23, LY1312-4, A1702-2B, and LY1312-12. The second cluster also had two subgroups, where the first group had most of the maize hybrids clustered together, namely, LY1501-3, LY1501-5, LY1312-11, M1124-31, A1736-13 and LY1409-21. The maize hybrids in the same cluster group show high similarities in their proximate composition.

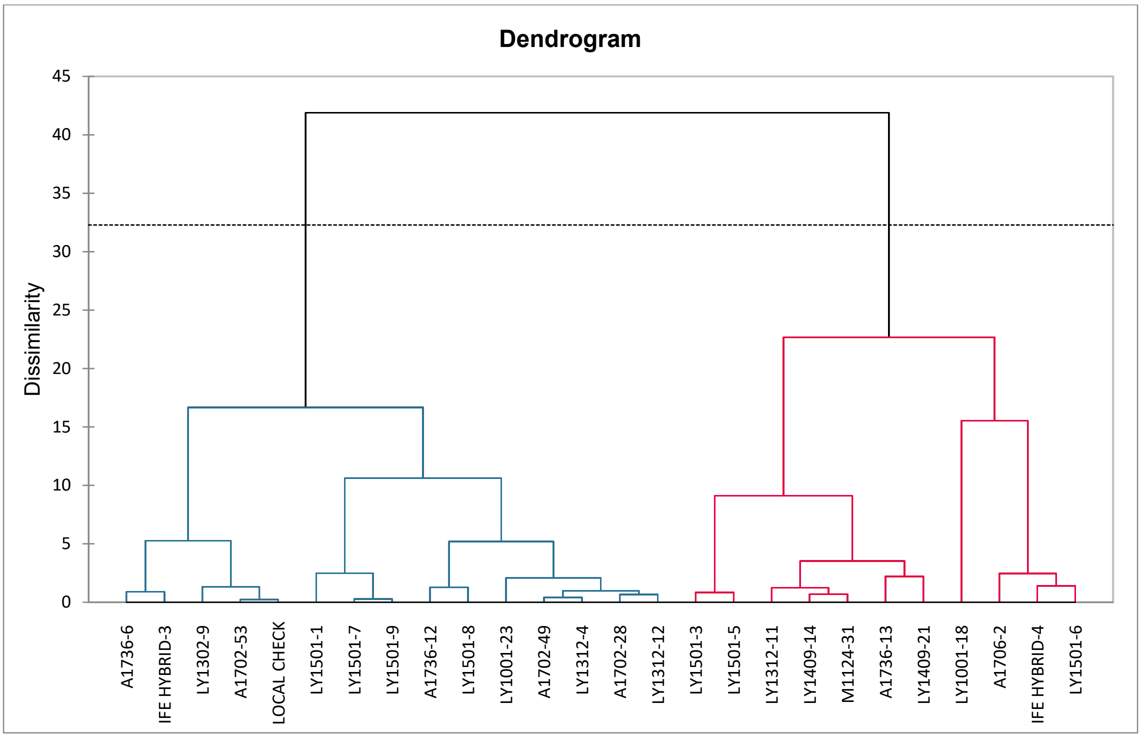

Figure 2. Dendrograms of maize genotypes.

4. Discussion

The proximate composition of the maize hybrid provides information on the essential nutrients required for human or animal growth and development [22]. Moisture content, for instance, determines the stability and quality of maize food products. High moisture content subjects food products to rapid deterioration from microbial growth and insect damage [17,23]. The average moisture content of 8.97 ± 0.40 g/100 g observed for the flour samples from the hybrids was appropriate to delay microbial deterioration. The values obtained in this study were lower when compared with the range of 11.10 ± 0.01 to 13.96 ± 0.00% reported by [2], but consistent with the average of 7.16% reported by [1]. Crude fat also plays a significant role in human health, as it is a vehicle for fat-soluble vitamins [24]. The crude fat obtained in this study had a mean ± SD of 4.31 ± 0.19%, which was higher than 4.07 ± 0.02% reported by [25]. The percent ash content ranged from 1.36 to 1.54%, slightly lower than the average value of 2.19% reported by [1]. Ash content is the non-organic residual component of a foodstuff after incineration, and it gives an idea of its total mineral content. Protein provides amino acids that build and maintain the body system. They produce nitrogen-containing substances such as enzymes and antibodies essential for average body physiological functions. Protein content in the present study ranged from 8.30 to 10.66%. Maize is one of the cereals that contributes a good source of protein. The present value is lower than the previously reported range of 9.92 to 15.75% [25]. Protein has been reported as a sensitive environmental trait [16,26], consistent with this study's findings that the planting environment significantly influenced protein content variability.

Maize generally has high carbohydrates and is a source of calories [27]; hence the analyzed hybrids in this study can be a good source of calories and good quality because the quality of grains is determined by their carbohydrate, protein, and oil content [9]. The proximate composition of the maize hybrids analyzed in this experiment agreed with previous authors [1,2,4,6,8,28–31]. Maize quality traits such as carbohydrates, protein, and fat are more affected by the environment than the genotype [9]. This report is consistent with our study's findings in that the variations observed in the samples were more prominent with environmental effects than genotypic effects. The planting environment had a strong significant effect ($p < 0.001$) on all the quality traits. The location of planting with a different climatic pattern of rainfall and temperature tends to influence the nutritional composition of most crops. Locations and crop management have been reported to affect maize kernels' protein and starch content [13]. However, the similar soil type (Ferric Luvisols) at Ibadan and Zaria could be responsible for the non-significant effect observed for fat and total carbohydrate content in these locations.

In contrast, moisture content and ME were not significantly different in locations such as Saminaka, Ikenne, Ibadan, and Mokwa. This could be an indication that the variability of these traits is not influenced by differences in environmental conditions. Planting season significantly affected all the quality traits of the maize hybrids analyzed. This results from the disparity in the two seasons' climatic conditions, which imposed different production environments on the maize hybrids during growth [32,33].

5. Conclusions

The present study has shown that genotype, planting environment, and season significantly affect hybrid maize samples' proximate composition and ME. Also, fourteen out of the twenty-five maize genotypes have similarities with the local variety considering their proximate composition. This informs the breeders about the characteristics of the hybrid maize samples across different locations and highlights hybrids that farmers and processors can adopt for product development. Maize hybrids LY1501, LY100-18, and LY1501 seem to have the highest protein, metabolizable energy, and total carbohydrates among the hybrids, which makes them potential candidates to be selected to produce consumer-preferred maize-based food products.

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