Original Research Article

Determination of essential mineral content of maize (*zea mays* L.) produced and stocked from rural conditions in Côte d'Ivoire

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ABSTRACT

Aims: Maize (*Zea mays*) is a staple food in the traditional diet of rural populations in Cote d'Ivoire. It is a good source of nutrients. However, sometimes inefficient storage methods hamper its quality. It's in this context that this study was conducted to assess the essential mineral content of maize produced and stored in five regions of Côte d'Ivoire.
Study design: A total of 1500 samples of maize as grains, epis and spathes were collected at rate of 500 samples by region (Gbêkê, Poro, Hambol, Indénié-Djuablin and Gontougo) and sent to the laboratory in order to analyse their.
Place and Duration of Study: This study was carried out during March 2016 to January 2017. The collected samples were carried out at the Biochemistry and Food Sciences Laboratory of the Félix Houphouët-Boigny University, Abidjan.
Methodology: The determination of minerals was carried out using the energy dispersive spectrophotometry method.
Results: The results show a significant difference (P<0.001) between mineral contents of the different maize forms and regions. The average values are between: K (289.99±28.98-324±4.07 mg/100 g), P (256.98±28.99-302.1±3.10 mg/100 g), Na (46.08±15.08-63.87±4.09 mg/100 g), Ca (40.08±26.97 to 51.20±3.89 mg/100 g), Mg (100.78±4.89-111±2.08 mg/100 g) for macroelements and Fe (3.08±3.00-5.02±1.08 mg/100 g), Zn (3.78±3.00-5.20±0.47 mg/100 g), Cu (1.00±0.60-1.42±0.02 mg/100 g), Mn (0.68±0.52-1.01±0.03 mg/100 g), Se (0.05±0.01-0.25±0.04 mg/100 g) for oligoelements.
Conclusion: Maize grains have the highest contents of mineral element from overall samples except for selenium (Se). Oppositely, samples from Indénié-Djuablin and Gontougo regions showed lowest concentrations. Therefore, mineral content of maize sampled seems to be related to post-harvest treatments (drying), type of storage (grains, epis and spathes) and storage structure.

Keywords: essential minerals, maize, producing regions, Cote d'Ivoire

1. INTRODUCTION

Agriculture is a significant part of Cote d'Ivoire's economy, accounting for 28% of GDP. Within the agricultural sector, maize is the second most important cereal crop after rice [1]. Its annual national production rose from 760,000 tonnes in 2016 to 1,006,000 tonnes in 2018, for a total sown area of 386,633 ha [2]. Its nutritional (rich in starch, presence of lipids and minerals) and economic (simple crop to produce, harvest and store) advantages make it a competitive product that contributes to lowering the price of basic food products such as milk and meat [3]. Maize have great nutritional values and can be processed into various types of products such as cornmeal, grits, starch, flour, tortillas, snacks, and breakfast cereals. It can be eaten boiled, roasted, fried or popped [4]. According to WHO, the total average cereal consumption in the African diet is 291.7 g/person/day, including an average maize consumption of 106.2 g/person/day, i.e. 36% of cereals consumed [5]. In Cote

d'Ivoire, maize consumption is estimated at 28.4 g per capita per day, mainly in the form of flour (92%) [6].
Long considered a subsistence crop, maize is now receiving significant support from agricultural research institutions to increase its production [7, 8]. Despite this great importance, maize production is subject to constraints during cultivation, storage and preservation. Indeed, 70-80% of maize production is kept in village settings in traditional storage structures, and it is precisely at this level that the highest losses are recorded [9]. Post-harvest practices carried out by farmers contribute to the degradation of grain quality. Losses are sometimes around 30-40% of production after only a few months of storage. They are even higher in agro-ecological zones where atmospheric conditions are very favourable to the proliferation of pests [10]. Yet, crop conservation remains one of the key factors of food security. As a result, maize production is generally seasonal, whereas consumer needs extend throughout the year [11, 12]. There is limited study conducted in major maize producing areas on nutrients quality associated with stored maize in Cote d'Ivoire. Therefore, the objective of the current study is to assess the nutritive quality of stored maize, in particular the determination of the essential mineral content of maize produced and stored in Côte d'Ivoire.

2.1 Materials

2.1.1 Biological material

The biological material is composed of dry maize in the form of grains, epis and spathes deriving the major region production of this resource in Cote d'Ivoire.

2.1.2 Study site

The study was carried out in five maize-producing regions, namely Gbêkê (Centre), Poro (North), Hambol (Centre-North), Indenié-Djuablin (Northeast) and Gontougo (East). Each region has its own geographical specificity and climatic characteristics that influence maize production seasons. Indeed, the regions of Gbêkê (7◦50'North-5◦18'West), Hambol (8°10'North-5°40'West), Indenié-Djuablin (7◦02'North-3◦12'West) and Gontougo (8°30'North-3°20'West) are characterised by a humid tropical climate (Baoulean climate). It has four seasons, including two rainy seasons that favour maize production twice a year and two dry seasons. In opposition, the climate of the Poro region (9◦27'North-5◦38'West) is Sudanese type. It has two seasons: a rainy season from April to October suitable for maize production, followed by a harsh 5 month dry season between November and March [13, 14].

2.2 Methods

2.2.1 Sampling of stored maize

The strategy adopted involved two phases. The first phase involved identifying regions where maize is the main food crop. In each locality in these regions, meetings were held with the chiefdom to present the study. Then, samples of 1 kg of maize (grains, epis and spathes) were taken from March 2016 to January 2017 from the producers' stocks constituting the second phase. A total of 1500 samples were collected, comprising 500 samples of maize grain, 500 samples of maize epis and 500 samples of whole maize spathes (Table 1). Maize samples were then taken to the laboratory in sterile plastic bags for analysis.

Table 1. Number of samples collected according to maize variety and department

Regions	Grains	Epis	Spathes	Total
Gbêkê	100	100	100	300
Poro	100	100	100	300
Hambol	100	100	100	300
Indénié-Djablin	100	100	100	300
Gontougo	100	100	100	300
Total	500	500	500	1500

2.2.2 Samples mineralization

Samples were mineralized in ashes by incineration at 550±5°C using electric muffle furnace for 12 h. Thus, 5 g of maize flour were placed in porcelain incinerator capsules. The whole (capsule + maize flour) was put in a muffle furnace (PYROLABO) and then incinerated. The capsules were then removed from the oven and allowed to cool in a desiccator. The white ash was collected for analysis [15].

2.2.3 Mineral elements evaluation

The minerals contents of the maize samples were recovered from ashes using an Energy Dispersive Spectrometer device [16].

2.2.3.1 Operating conditions of the energy dispersion spectrometer (EDS)

The energy dispersive spectrophotometer apparatus used for the minerals determination was coupled with a scanning electronic microscope, operating at variable pressure (SEM-FEG Supra 40 Vp Zeiss), and equipped with an X-ray detector (Oxford instruments) bound to a flat shape of the EDS microanalyser (Inca cool dry, without liquid nitrogen). The operative conditions of the EDS-SEM device are:

• Zoom: 10x to 1000000x;
• Resolution: 2 nm;
• Variable voltage: 0.1 KeV and 30 KeV.

The chemical elements were acquired with following parameters: zoom, 50 x; probe diameter, 30 nm to 120 nm; probe energy, 20 KeV and 25 KeV; work distance (WD), 8.5 mm. The chemical composition was explored from 3 different zones, and then the data was transferred to MS Word and Excel software for treatment.

2.2.3.2 Validation test of the minerals determination method

The mineral analysis method has been validated according to standard procedure [17, 18], consisting in determination of the linearity, repeatability, reproducibility, extraction yields, and detection and quantification limits. The linearity of 10 mineral elements was valued using 5 standard points between 25% and 125% (25%, 50%, 75%, 100%, and 125%). The repeatability and reproducibility tests were achieved with standard of the different minerals at the content of 25%. A percentage of 5% was added on each mineral's standard content for determining the yield of mineral extraction. Ten separate tests were performed for the proportions added.

2.2.4 Contribution in Essential Minerals from Consumption of maize samples

The contributions in mineral elements have been estimated according to the method of the Codex Alimentarius that takes into account the concentrations in minerals recovered in maize sample and the daily consumption of an adult Ivoirian of maize. The contribution of maize in daily requirement has been calculated also from the values of daily recommended intakes [19]

Estimated Daily Intake (EDI) = C × Q
Contribution (%) = (EDI × 100)/DRI
With: C, mineral concentration measured; Q: maize daily consumption; DRI: Daily Recommended Intake.

2.2.5 Statistical analysis

The data were recorded with Excel file and statistically treated with Statistical Program for Social Sciences (SPSS 22.0 for Windows, USA). The statistical test consisted in a two-way analysis of variance (ANOVA) with the type of maize assessed and regions. From each parameter, means were compared using Tukey post-hoc test at 5% significance level. In addition, Multivariate Statistical Analysis (MSA) was performed through Principal Components Analysis (PCA) using STATISTICA software (version 7.1) for structuring correlation between the maize samples studied and their minerals traits.

3. RESULTS AND DISCUSSION

3.1 Validation of the method for the determination of essential minerals

The results of the validation tests are presented in Table 2. The determination coefficient (R^2) recovered from the standard lines are included between 0.99 and 1. The minerals limits of detection (LOD) vary from 104 ± 0.05 µg/kg to 581 ± 0.04 µg/kg, while the limits of quantification (LOQ) range from 146 ± 0.63 µg/kg to 796 ± 0.09 µg/kg. The coefficients of variation (CV) determined for the repeatability and reproducibility tests ranged from 1.1 ± 0.21% to 1.8 ± 0.95% and from 2.3 ± 0.93% to 4.7 ± 0.32%, respectively. About the minerals added, the extraction yields run from 97.3% to 99.5%, revealing minerals extraction defaults between 0.5% and 2.7%. These results indicate a satisfactory stability and accuracy of the X-ray microanalysis technique coupled to the scanning electron microscope (SEM/EDS). The method is therefore reliable and accurate.

Table 2. Data from validation parameters for evaluation of minerals contents using energy diffusion spectrometer (EDS)

	Linearity		CV Repet	CV Reprod	EYAM	LOD	LOQ
Minerals	**ESL**	**CD (R^2)**	**(%, n=10)**	**(%, n=15)**	**(%, n=10)**	**(µg/kg)**	**(µg/kg)**
Potassium	Y = 3838 + 3821x	1	1.3±0,04	4.7±0.32	98.4±1.51	581±0.04	796±0.09
Sodium	Y = 147 + 2083x	0.99	1.2±0,05	3.4±0.48	98.8±0.33	261±0.74	365±0.07
Calcium	Y = 5287 + 6581x	1	1.5±0,43	2.3±0.93	97.3±0.84	514±0.15	704±0.47
Phosphorus	Y = 1742 + 2667x	0.99	1.4±0,11	3.7±1.22	99.4±0.66	334±0.21	467±0.88
Magnesium	Y = 237 + 1452x	0.99	1.1±0,21	3.1±1.44	97.9±0.68	426±0.11	635±0.19
Iron	Y = - 88 + 2285x	0.99	1.4±0,07	3.6±0.01	99.5±0.17	107±0.32	149±0.55
Zinc	Y = - 523 + 4365x	0.99	1.3±0,51	3.2±0.96	98.3±0.03	281±0.58	396±0.29
Selenium	Y = - 332 + 4958x	1	1.0±0,06	2.8±0.07	97.6±0.92	57±0.52	108±0.001
Manganese	Y = 74454 + 3659x	1	1.2±1,01	2.9±0.77	99.0±0.78	337±0.81	488±0.60
Copper	Y = 6951 + 1953x	0.99	1.8±0,95	2.5±0.03	98.8±0.43	104±0.05	146±0.63

ESL, equation of standard lines; CD, coefficient of determination; CV repeat, coefficient of variation from repeatability test; CV reprod, coefficient of variation from reproducibility test; EYAM, extraction yield from added minerals; LOD, limit of detection; LOQ, limit of quantification.

3.2 Essential mineral content of maize samples

The overall maize samples from the five regions studied account ten mineral elements: five macroelements (K, P, Na, Ca and Mg) and five oligoelements (Fe, Zn, Cu, Mn and Se). Tables 3 and 4 reveal high divergence (P<.001) between maize samples and regions regarding each mineral.

3.2.1 Macroelements contents

Potassium and phosphorus are the major mineral elements with contents vary from 289.99 ± 8.98 to 334 ± 3.77 mg / 100 g DM and 256.98 ± 28.99 to 302.10 ± 3.10 mg / 100 g DM respectively. Localities of Gontougo and Indenié-Djuablin recorded the lowest contents for maize as epis and spathes. Regarding sodium contents, averages obtained for the different maize form (grains, epis and spathes) vary from 44.97 ± 9.10 to 63.87 ± 4.09 mg / 100 g DM. Maize samples from different regions show the highest levels. With regard to calcium, maize samples contents oscillate between 4 ± 0.27 and 5.12 ± 0.39 mg / 100 g DM. Maize spathes from Indenié-Djuablin and Gontougo regions recorded lower concentrations. With values ranging from 99.89 ± 7.99 to 111 ± 2.08 mg / 100 g; magnesium contents showed statistically significant differences. The high levels were recorded in Gbêkê (grains, epis and spathes), Poro (grains and epis), Hambol (grains, epis and spathes), Gontougo (grains and epis) and Indenié-Djuablin (grains and epis) region (Table 3).

3.2.2 Microelements contents

Regarding oligoelements, the contents vary statistically (P<.001) from the different maize forms and the five regions. Thus, maize samples exhibited highest concentrations while maize spathes exhibited the lowest micronutrient values. Iron concentrations are between 3.08 ± 0.30 and 5.02 ± 1.08 mg / 100 g DM. As regards zinc, concentrations vary between 1.89 ± 0.15 and 2.55 ± 0.32 mg / 100 g for the various maize samples. Regarding copper, Hambol regions record the highest value from maize grain (1.42 ± 0.02 mg / 100 g DM). With values fluctuating between 0.68 ± 0.05 and 0.73 ± 0.06 mg / 100 g, maize spathes from Indénié-Djuablin and Gontougo regions exhibited the lowest manganese contents. Statistically, maize as epis are with most contents of selenium contents regardless maize form and region, with average values ranging from 0.08 ± 0.01 to 0.25 ± 0.04 mg / 100 g DM (Table 4).

3.3 Estimated Daily Intakes of Minerals

Among all maize samples studied, maize grains from the different regions records the highest macroelements and oligoelements intakes except for selenium (Se). Potassium intake ranges from 82.36 ± 0.85 to 94.86 ± 1.07 mg/day, with more contribution from Hambol maize grains (94.86 mg/day). The daily intakes of phosphorus, sodium, calcium and magnesium are between 72.99 ± 8.24 to 85.48 ± 1.44 mg/day, 12.77 ± 5.42 to 18.14 ± 1.16 mg/day, 11.39 ± 0.08 to 14.54 ± 0.11 mg/day, 28.37 ± 2.27 to 31.52 ± 0.59 mg/day respectively. Regarding oligoelements, maize samples from the five regions recorded the daily intakes of iron, zinc, copper, manganese, respectively of (0.88 ± 0.09 and 1.42 ± 0.53 mg/day), (0.54 ± 0.04 and 0.74 ± 0.07 mg/day), (0.28 ± 0.17 and 0.38 ± 0.09 mg/day), (0.19 ± 0.01 and 0.29 ± 0.01 mg/day) and (0.01 and 0.07mg/day) for selenium (Table 5).
On the daily recommended intakes basis, all maize samples provide a significant contribution of oligoelements with percentages ranging from 5.37% to 118.34%. Besides from macroelements, maize grains from the five regions record more contributions in fitting

needs of mineral elements, from 0.67% to 12.26%. Copper and Selenium have higher needs fitting contributions from maize samples with percentages ranging from 28.4% to 40.33% and 17.99% to 118.34% respectively, as shown in Table 6.

Table 3. Macroelements composition in maize samples according to the regions

Parameters	Regions	Grains	Epis	Spathes
Potassium (mg/100g)	Gbêkê	330.66±4.08^{bA}	321.10±10.08^{bA}	310.82±10.08^{aB}
	Poro	334±5.10^{aA}	322.10±15.08^{bB}	308.81±15.08^{abC}
	Hambol	334±3.77^{aA}	328±9.67^{abB}	312.10±9.67^{aC}
	Indenié-Djuablin	324±4.08^{cA}	301.67±26.10^{cB}	300±6.10^{Bb}
	Gontougo	324±4.71^{cA}	305±29^{cB}	290±3^{Cc}
Phosphorus (mg/100g)	Gbêkê	301±5.08^{aA}	287.12±4.08^{aA}	279±14.91^{Ab}
	Poro	301.8±3.82^{aA}	298.8±6,08^{aA}	286.80±15.10^{aB}
	Hambol	302.1±3.10^{aA}	286.88±7^{aB}	280±18.10^{aC}
	Indenié-Djuablin	299±5.08^{aA}	276.30±13^{aB}	257±29^{cC}
	Gontougo	300±3.81^{aA}	276±21^{aB}	261.72±30.08^{bB}
Sodium (mg/100g)	Gbêkê	61.36±3.10^{aA}	50.10±10.08^{aB}	47.07±14.08^{aC}
	Poro	61.20±2.08^{aA}	52.08±10^{aB}	47.10±13.10^{aC}
	Hambol	63.87±4.10^{aA}	53.10±8.80^{aB}	50.20±12.88^{aC}
	Indenié-Djuablin	59±3.07^{aA}	49.87±16.08^{aB}	46.08±15.08^{aB}
	Gontougo	59±5.08^{aA}	47.8±18.91^{aB}	44.97±19.10^{aC}
Calcium (mg/100g)	Gbêkê	49.4±0.51^{aA}	48 ±0.88^{aA}	48.72±0.10^{aA}
	Poro	51.2±0.39^{aA}	50±0.71^{aA}	47.0±0.11^{aB}
	Hambol	49.1±0.31^{aA}	49.2±1^{aA}	46.0±1^{aB}
	Indenié-Djuablin	48.0±0.40^{bA}	48.0±0.16^{aA}	40.1±0.27^{bB}
	Gontougo	49.4±0.48^{aA}	48.0±0.19^{aB}	41.1±0.30^{bC}
Magnesium (mg/100g)	Gbêkê	110.20±1.08^{aA}	108.72±2.08^{aA}	105.92±3.08^{aB}
	Poro	111±2.08^{aA}	109.63±2.11^{aA}	100.78±4.89^{bB}
	Hambol	109.80±1.18^{aA}	109.8±2.92^{aA}	106±5.10^{aB}
	Indenié-Djuablin	110.3±2.07^{aA}	107.52±4^{aB}	99.90±8^{bC}
	Gontougo	110.33±3^{aA}	106.79±4.08^{aB}	101.88±9^{bC}

By column and row the averages with the same letters are statistically identical. Lower case letters are representative of columns and upper case letters are representative of rows

Table 4 Oligoelements composition in maize samples according to the regions

Parameters	Regions	Grains	epis	Spathes
Iron (mg/100g)	Gbêkê	4.80 ± 0.97^{aA}	4.10 ± 0.10^{cA}	3.98 ± 0.69^{bA}
	Poro	5 ± 0.78^{aA}	4.97 ± 0.09^{aA}	4.18 ± 1.08^{aB}
	Hambol	5.02 ± 1.08^{aA}	5 ± 1.87^{aA}	4.29 ± 0.89^{aB}
	Indenié-Djuablin	4.94 ± 0.57^{aA}	4.88 ± 1.01^{aB}	3.57 ± 0.10^{cC}
	Gontougo	4.94 ± 1^{aA}	4.57 ± 0.10^{bB}	3.08 ± 0.30^{dC}
Zinc (mg/100g)	Gbêkê	2.49 ± 0.50^{abA}	2.38 ± 0.44^{aA}	2.89 ± 0.54^{bB}
	Poro	2.60 ± 0.24^{aA}	2.49 ± 0.44^{aA}	2.29 ± 0.50^{aB}
	Hambol	2.55 ± 0.32^{aA}	2.43 ± 0.60^{aB}	2.38 ± 0.43^{aB}
	Indenié-Djuablin	2.48 ± 0.11^{abA}	2.01 ± 0.10^{bB}	2 ± 0.50^{bB}
	Gontougo	2.30 ± 0.64^{bA}	2.10 ± 0.44^{bB}	1.89 ± 0.15^{bC}
Copper (mg/100g)	Gbêkê	1.30 ± 0.05^{cA}	1.28 ± 0.04^{aA}	1.10 ± 0.03^{aB}
	Poro	1.30 ± 0.05^{cA}	1.28 ± 0.04^{aA}	1.10 ± 0.97^{aB}
	Hambol	1.42 ± 0.02^{aA}	1.30 ± 0.03^{aB}	1.18 ± 0.78^{aC}
	Indenié-Djuablin	1.34 ± 0.33^{bA}	1.21 ± 0.08^{bB}	1.02 ± 0.07^{bC}
	Gontougo	1.34 ± 0.04^{bA}	1.21 ± 0.07^{bB}	1.00 ± 0.60^{bC}
Manganese (mg/100g)	Gbêkê	1.00 ± 0.04^{aA}	1.00 ± 0.06^{aA}	0.89 ± 0.08^{aB}
	Poro	1.00 ± 0.02^{aB}	1.10 ± 0.07^{aA}	0.91 ± 0.01^{aB}
	Hambol	1.01 ± 0.03^{aA}	0.90 ± 0.08^{abA}	0.82 ± 0.07^{bB}
	Indenié-Djuablin	1.00 ± 0.02^{aA}	0.78 ± 0.07^{cB}	0.68 ± 0.05^{cC}
	Gontougo	1.00 ± 0.03^{aA}	0.86 ± 0.07^{bB}	0.73 ± 0.06^{cC}
Selenium (mg/kg)	Gbêkê	0.05 ± 0.01^{aA}	0.20 ± 0.04^{1aA}	0.05 ± 0.01^{aA}
	Poro	0.05 ± 0.01^{aA}	0.24 ± 0.05^{aA}	0.05 ± 0.01^{aA}
	Hambol	0.05 ± 0.02^{aA}	0.25 ± 0.04^{aA}	0.05 ± 0.02^{aA}
	Indenié-Djuablin	0.05 ± 0.02^{aA}	0.09 ± 0.01^{aA}	0.04 ± 0.01^{aA}
	Gontougo	0.05 ± 0.02^{aA}	0.08 ± 0.01^{aA}	0.04 ± 0.01^{aA}

By column and row the averages with the same letters are statistically identical. Lower case letters are representative of columns and upper case letters are representative of rows

Table 5 Estimated daily intakes of minerals provided by maize consumption from an adult individual

Regions	Maize forms	Estimated intakes (mg/day) from an adult individual									
		Macroelements					Oligoelements				
		Potassium	Phosphorus	Sodium	Calcium	Magnesium	Iron	Zinc	Copper	Manganese	Selenium
Gbêkê	Grains	93.72±1.16	85.48±1.44	17.43±0.88	14.04±0.14	31.3±0.31	1.36±0.28	0.71±0.14	0.37±0.01	0.28±0.01	0.01±0
	Epis	91.19±2.86	81.54±1.16	14.23±2.86	13.63±0.25	30.88±0.59	1.16±0.03	0.68±0.12	0.36±0.01	0.28±0.02	0.01±0
	Spathes	88.27±2.86	79.24±4.23	13.37±4	13.84±0.03	30.08±0.88	1.14±0.2	0.82±0.15	0.31±0.01	0.25±0.02	0.01±0
Poro	Grains	94.86±1.45	85.71±1.08	17.38±0.59	14.54±0.11	31.52±0.59	1.42±0.22	0.74±0.07	0.37±0.01	0.28±0	0.01±0
	Epis	91.48±4.28	84.85±1.73	14.79±2.75	14.2±0.20	31.13±0.6	1.41±0.02	0.71±0.12	0.36±0.01	0.31±0,02	0.01±0
	Spathes	87.7±4.28	81.45±4.29	13.38±3.72	13.35±0.03	28.62±1.39	1.19±0.31	0.65±0.14	0.31±0.28	0.26±0	0.01±0
Hambol	Grains	94.86±1.07	85.8±0.88	18.14±1.16	13.95±0.09	31.52±0.34	1.43±0.31	0.72±0.09	0.4±0.01	0.29±0.01	0.01±0
	Epis	93.15±2.75	81.47±1.99	15.08±2.49	13.95±0.28	30.53±0.83	1.42±0.53	0.69±0.17	0.37±0.01	0.25±0.02	0.01±0
	Spathes	88.64±2.75	79.52±5.14	14.26±3.66	13.06±0.28	30.1±1.45	1.22±0.25	0.68±0.12	0.34±0.22	0.23±0.02	0.01±0.01
Indenié-Djuablin	Grains	92.02±1.16	84.92±1.44	16.76±0.88	13.63±0.11	31.18±0.59	1.4±0.16	0.7±0.03	0.38±0.09	0.28±0.01	0.01±0
	Epis	85.67±7.41	78.47±3.69	14.16±4.57	13.63±0.05	30.53±1.14	1.38±0.29	0.57±0.03	0.34±0.02	0.22±0.02	0.01±0
	Spathes	85.2±1.73	72.99±8.24	13.09±4.28	11.39±0.08	28.37±2.27	1.01±0.6	0.57±0.14	0.29±0.02	0.19±0.01	0.01±0
Gontougo	Grains	92.02±1.34	85.2±1.08	16.76±1.44	14.04±0.14	31.33±0.85	1.4±0.28	0.65±0.18	0.38±0.01	0.28±0.01	0.01±0
	Epis	86.62±8.24	78.38±5.96	13.58±5.37	13.63±0.05	30.33±1.16	1.3±0.03	0.6±0.12	0.34±0.02	0.24±0.02	0.01±0
	Spathes	82.36±0.85	74.33±8.54	12.77±5.42	11.67±0.09	28.93±2.56	0.88±0.09	0.54±0.04	0.28±0.17	0.21±0.02	0.01±0

Table 6. Daily minerals recommended intakes and contribution of maize samples

Regions	Maize forms	Contribution (%)									
		Macroelements					Oligoelements				
		Potassium	Phosphorus	Sodium	Calcium	Magnesium	Iron	Zinc	Copper	Manganese	Selenium
Gbêkê	Grains	4.69	12.21	0.7	1.4	8.35	9.74	7.07	36.92	11.36	21.3
	Epis	4.56	11.65	0.57	1.36	8.23	8.32	6.76	36.45	11.33	23.61
	Spathes	4.41	11.32	0.53	1.38	8.02	8.11	8.21	31.3	10.12	21.39
Poro	Grains	4.74	12.24	0.7	1.45	8.41	10.14	7.38	36.98	11.35	23.67
	Epis	4.57	12.12	0.59	1.42	8.3	10.08	7.07	36.46	12.5	19.79
	Spathes	4.39	11.64	0.54	1.33	7.63	8.49	6.5	31.16	10.36	22.32
Hambol	Grains	4.742	12.26	0.73	1.4	8.32	10.18	7.24	40.33	11.47	22.53
	Epis	4.66	11.64	0.6	1.4	8.32	10.14	6.9	36.84	10.19	23.67
	Spathes	4.43	11.36	0.57	1.31	8.03	8.71	6.76	33.57	9.27	23.61
Indenié-Djuablin	Grains	4.6	12.13	0.67	1.36	8.36	10.02	7.04	38.07	11.39	22.5
	Epis	4.28	11.21	0.57	1.36	8.14	9.89	5.71	34.36	8.87	20.36
	Spathes	4.26	10.43	0.52	1.14	7.57	7.24	5.68	28.97	7.7	18.46
Gontougo	Grains	4.6	12.17	0.67	1.4	8.36	10.02	6.53	38.07	11.39	22.5
	Epis	4.33	11.2	0.54	1.36	8.09	9.27	5.97	34.31	9.78	19.45
	Spathes	4.12	10.62	0.51	1.17	7.72	6.25	5.37	28.4	8.25	17.99
DRI		**2000**	**700**	**2500**	**1000**	**375**	**14**	**10**	**1**	**2.5**	**0.06**

Dri, daily recommended intake (mg/day)

3.4. Grouping of samples according to minerals

Principal component analysis (PCA) was carried out by considering components F1 and F2 (Table 7), which have an eigenvalue greater than 1, according to the Kaïser statistical rule. Fig. 1.A shows the circle of correlations of the factorial axes F1 and F2, which express 89.03% of the total variability of the studied parameters. The component F1 with an eigenvalue of 7.97, expresses 79.70% of the variance. It is predominantly established by positive correlations with selenium contents and a negative correlation with the other macroelements and oligoelements contents. The component F2, with its own value 0.93, expresses 9.33% of the variance and is mainly formed by the macroelements and oligoelements contents with negative correlations (Table 7). The projections of the characteristics and of the samples in the plane formed by the components F1 and F2 highlight three groups of maize. Group 1 consisted essentially of maize grains from the five regions. Those are characterized by contents of potassium, phosphorus sodium, calcium, magnesium, iron, zinc, copper and of manganese higher compared to the values resulting from all maize samples. Group 2 contains on the one hand maize as epis and spathes from Gbêkê, Poro and Hambol regions and on the other hand maize as epis samples from Indénié-Djuablin and Gontougo regions. They provide higher levels of selenium. The third group consists of maize as spathes from Indénié-Djuablin and Gontougo regions. They are distinguished by lower values in macro and oligoelements (Fig. 1.B).

Table 7. Matrix of eigenvalues and percentage of variance expressed for the PCA components

Factors	Eigen values	Variance (%)	Cumul valeur proper	Cumul variance (%)
1	7.97	79.7	7.97	79.7
2	0.93	9.33	8.9	89.04

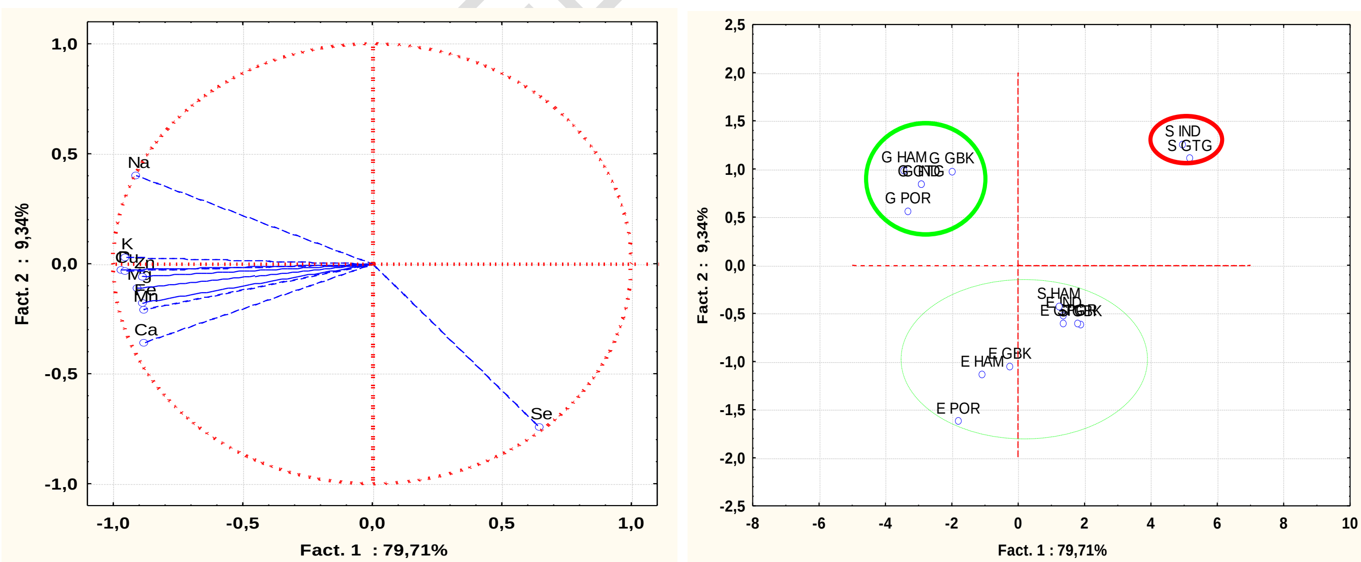

Figure 1: Projection of essential minerals (a) and regions (b) in the factorial plane F.1 and F. 2 of the principal component analysis (PCA

GBK : Gbêkê ; POR : Poro ; HAM : Hambol ; IND : Indénié-Djuablin ; GTG : Gontougo; G : Grains ; E : Epis ; S:Spathes Magnesium (Mg), phosphorus (P), potassium (K), sodium (Na), calcium (Ca), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu) and selenium (Se)

3.5. Discussion

The R^2 determination coefficients got from the calibrations tests were close to 1, forecasting a quasi-linear estimation of the mineral nutrients according to their concentration from in the meals. Also, the lower coefficients of variation (<5%) resulting from reproducibility and repeatability translate quite stability of the EDS method used, which is as fitted as the full amount of each mineral nutrient is revealed, as shown by the weak extraction defaults below 2.7% from the added minerals. Thus, these characteristics highlight the reliability and precision of the outcomes in the minerals contents determination using the EDS method (Mahan *et al.,* 2017). Subsequently, a total of ten mineral macro (potassium, phosphorus, sodium, calcium, magnesium) and microelements (iron, zinc, copper, manganese, selenium) were detected and analyzed during this study. These mineral elements, considered essential nutrients for life, ensure various biochemical functions such as maintenance of tissue homeostasis. These nutrients must be provided in the diet to stimulate cell growth and metabolism [20]. The study of these nutrients during the storage of maize is of paramount importance due to their involvement in the physiological and metabolic functions of the body. However, under unsuitable storage and / or conservation conditions (traditional storage) these elements undergo modifications [21]. Storing maize is an important step in preserving food security and increasing the income of rural populations. Maize is not only grown for family food because it allows some farmers to get through the lean season, but also helps to increase their income [22]. Analysis of the minerals substances showed that compositions of maize samples vary considerably with the forms and regions. In general, grains maize samples from different regions show high levels of macro and oligoelements except for selenium. This variation can be explained by the difference in postharvest maize storage technology [23, 24]. Samples from Indenié-Djuablin and Gontougo, especially spathes, reported the lowest levels. This situation could be explained by the growing conditions and climatic (type of soil, fertilizer input, crop period) and also by genetics varietal differences in cultivated maize [4]. Overall, the mineral contents obtained are similar than those (262-322 mg / 100 g for K; 245-297 mg / 100 g for P and 11.47; 0.25; 0.02 mg / 100 g) reported by [5] for ordinary and QPM maize varieties grown in Côte d'Ivoire. The same observations have been made in north-central Côte d'Ivoire [8]. These authors reported that in addition to local varieties of cultivated maize, producers were turning to new and improved varieties because of their productivity and drought resistance. In addition, according to [25], the method of storage is also an important factor influencing the composition of stored cereals. In addition, a survey on maize storage typologies in five regions of Côte d'Ivoire carried out by [9] revealed that the seeds used by producers in these regions come from different sources. Indeed, these grains come from previous harvests or are bought on the market or obtained from institutional structures or obtained thanks to a close relative. Among the minerals, potassium, phosphorus and magnesium are the most abundant in the samples which is in agreement with the findings of [26].These authors concluded that these elements are the most abundant mineral in agricultural products. Various conditions such as climate, soil quality and agronomic practices often could give rise to variability in these minerals concentrations in crop plants [27]. Potassium ions are very important in intracellular fluids and play a key role in acid-base balance, osmotic pressure regulation and transfer of nerve impulse, contraction of cardiac muscles, cell membrane function and in glycogenesis. It also helps in the transfer of phosphate from ATP to pyruvic acid [28]. Phosphorus functions as a constituent of bones, teeth, adenosine triphosphate (ATP), phosphorylated metabolic intermediates and nucleic acids. It is also involved in the synthesis of phospholipids and phosphoproteins [29]. Magnesium is effective for prevention against muscles degeneration, development delay and congenital malformations [30]. It is an excellent cohesion agent for proteins for which it activates many enzymatic functions. Calcium is a major constituent of bones and teeth and takes part in the regulation of nerve and muscle function. During the coagulation of blood, calcium activates the conversion of prothrombin to thrombin. It

activates large number of enzymes and is also required for membrane permeability. Iron is significant component of blood hemoglobin and myoglobin. It supports the blood oxygenation, prevents anemia and fits resistance to organism against infections. Zinc is cofactor for the metabolism of vitamins A and E. It is useful for the fœtal development during the pregnancy. Copper has significant role in the synthesis and maintenance of myelin. It's also a cofactor in the anti-radicalizing processes. Manganese helps in the synthesis of proteoglycans in cartilage and is involved in the biosynthesis of connective tissues, formation of urea and metabolism of pyruvate. Selenium helps in the synthesis of antioxidant enzymes and proteins that play critical roles in protecting cells against damage [31].
The daily maize consumption from an Ivorian adult is about 24.8 g and the daily recommended intake (RDI) of potassium is 2 g for adults, that of phosphorus 700 mg, that of sodium 2.5 g, that of calcium 1 g, that of magnesium 375 mg, that of iron 14 mg, that of zinc 10 mg, that of copper 1mg, that of manganese 2.5 mg and that of selenium 600µg. Using the RDI of these minerals, this study revealed that the maize grains and epis from the five regions were a good source of selenium, copper, iron, manganese, zinc, magnesium and phosphorus. Therefore, eating maize with respect to the considerable amount of oligoelements in it could be relevant in the prevention of oligoelement deficiency for people that reside in the five regions.

4. CONCLUSION

This study assessed the mineral content of maize produced and stored as grains, epis and spathes in five production regions of Côte d'Ivoire. The results show that regardless of the region, maize grains indicated high levels of the minerals studied except for selenium. Also maize spathes from Indénié-Djuablin and Gontougo regions showed lower contents of these minerals. Thus, it would be important to sensitize producers on good post-harvest practices and the use of structures adapted to store different forms of maize in order to help improve the profitability of their agricultural production and ensure food security.

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