

Determination of Essential Mineral Content of Bambara Groundnut (*Vigna Subterranea L.*) Produced in North of Côte d'Ivoire

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Abstract The aim of this study was to assess the mineral content of bambara groundnut seeds in the Northern regions of Côte d'Ivoire and evaluate their nutritional value. A total of 120 bambara groundnut samples were collected from five regions and categorized into seven cultivars based on seed coat color. The seeds were then analyzed at the Nutrition and Food Technology Laboratory of Félix Houphouët-Boigny National Polytechnic Institute using energy dispersive spectrophotometry. The analysis revealed the presence of macro elements, including potassium, sodium, magnesium, calcium, and phosphorus, with varying concentrations. The microelements zinc, iron, manganese, and copper were also found in the seeds. The contribution of these minerals to daily intake requirements ranged from 0.11% to 20.94%. However, zinc was found to have a higher need for adequate intake. These findings indicate that bambara groundnut seeds, regardless of cultivar, are a good source of essential minerals. Promoting the consumption of bambara groundnut could help address food security and poverty alleviation in the region. Furthermore, these results emphasize the importance of this underutilized legume in combating hunger and malnutrition in Africa.

Keywords: Bambara groundnut; essential minerals, producing regions, Côte d'Ivoire

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1. Introduction

Micronutrient deficiencies pose a significant public health challenge in developing countries, particularly for infants and pregnant women [1,2]. Infants, in particular, require sufficient micronutrients for proper growth and development [3,4]. The most critical micronutrient deficiencies in terms of public health impact are zinc and iron deficiencies, which can lead to cognitive impairment, reduced work capacity, weakened immune system, pregnancy complications (such as low birth weight), poor learning ability, and diminished psychomotor skills [5,6]. Severe anemia has been identified as a direct cause of maternal and child mortality [7,8]. Lack of sufficient information regarding the composition of diverse feed resources in certain regions has been suggested as the main barrier to their utilization, rather than an actual scarcity [9]. For example, there is limited knowledge

about the mineral content of certain plants used for human and animal consumption in Côte d'Ivoire, especially the newly introduced diets and lesser-known legumes.

Legumes are a cheap source of protein and minerals in many African countries, legumes are a cost-effective source of protein and minerals, especially since animal protein is expensive. One such legume is the Bambara groundnut (*Vigna subterranea L.*), which is known for its protein and mineral content [10,11]. The seeds of this legume are considered a complete food due to their adequate amounts of protein, carbohydrates, and lipids [12]. Therefore, incorporating Bambara groundnut into diets can help improve food security and address nutritional deficiencies [13,14]. Despite its potential, Bambara groundnut has historically been underutilized and has only gained attention in recent years. This crop is resilient to drought, can thrive in poor soil conditions, and is resistant to pests and diseases [15]. In Africa, it is widely cultivated at a subsistence level and is the third most important legume crop, after cowpea and groundnut

[16,17]. Additionally, it is a popular food in Côte d'Ivoire [18]. The immature seeds are consumed as a boiled snack, while the mature seeds are boiled and incorporated into main meals or ground into flour for making porridge [19,20]. The dried seeds can also be soaked, the outer covering removed, and the seeds ground into a paste, which can then be used to make various steamed or fried products [21,22]. Efforts are being made to popularize the cultivation of this legume in Cote d'Ivoire, particularly among the rural population [18]. However, in order to promote this crop as a nutritious food source, it is important to determine its nutritional composition. Limited research has been conducted on the nutrient quality of bambara groundnut in major production areas of Cote d'Ivoire. Therefore, the objective of this study is to assess the nutritional quality of bambara groundnut, specifically by determining its essential mineral content in the Northern region of Côte d'Ivoire.

2. Materials and Method

2.1. Materials

2.1.1. Biological Material

The biological material used in this study includes seven different cultivars of bambara groundnut seeds. These cultivars are known as Uniform Black (NU), Uniform Red (RU), Uniform Beige (BU), Beige variegated with Red (BPR), Black Variegated with Beige (NPB), Beige with Grey Hilum outline (BHG), and Beige with black hilum outline (BHN) (Figure 1).

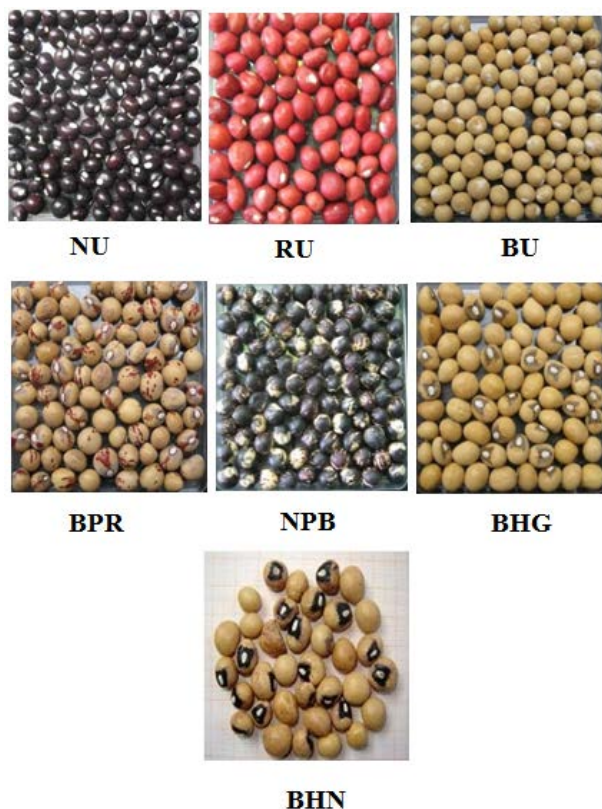


Figure 1. Morphological aspect of collected bambara groundnut samples

2.1.2. Study Site

The research was conducted in five different departments in the savannah zone of Côte d'Ivoire where bambara groundnut is produced. These departments include Korhogo, Ferkessedougou, Ouangolodougou, Sinématiali, and Boundiali (Figure 2). These areas have similar geographical and climatic conditions that impact the production of bambara groundnut. Specifically, the climate in these regions is of the Sudanese type, characterized by a rainy season from April to October, followed by a dry season lasting five harsh months from November to March [23].

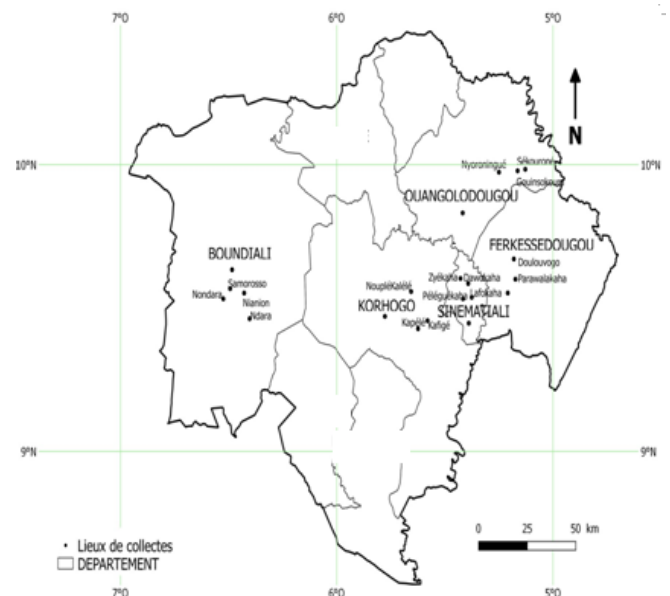


Figure 2. Collected localities of bambara groundnut in Côte d'Ivoire

2.2. Methods

2.2.1. Sampling of Bambara Groundnut

The survey was conducted between November 2017 and February 2018. Villages were chosen randomly within a 15 km radius of the five departments. Samples were collected from four randomly selected farmers or traders in each village. A total of 30 villages were visited and 120 bambara groundnut samples were collected. Each selected farmer or trader provided approximately 500 g of seed samples. The samples were categorized into seven cultivars based on seed coat color. The cultivars were then transported to the laboratory in polyethylene bags and stored in a cold room at -20°C for analysis.

2.2.2. Production of Raw Bambara Groundnut Powders

The seeds of each bambara groundnut cultivar were washed with water, then dried in a ventilated oven (Minergy Atie Process, France) at 65°C for 6 hours. After drying, the seeds were ground using a hammer mill (Forplex). The resulting powders were filtered through sieves with a diameter of 250 µm. The filtered products were then stored in polyethylene hermetic bags in a dry place until further analysis.

2.2.3. Mineral Elements Evaluation

The mineral content of bambara groundnut samples was determined by analyzing powders using an Energy Dispersive Spectrometer device [24].

2.2.3.1. Operating Conditions of the Energy Dispersion Spectrometer (EDS)

The mineral composition of the seeds was determined using an energy dispersive spectrophotometer apparatus coupled with a scanning electronic microscope. The microscope used was the SEM-FEG Supra 40 Vp Zeiss, which operated at variable pressure. It was equipped with an X-ray detector from Oxford Instruments, which was connected to a flat shape of the EDS microanalyser (Inca cool dry, without liquid nitrogen). The operative conditions of the EDS-SEM device included a zoom range of 10x to 1000000x, a resolution of 2 nm, and a variable voltage of 0.1 KeV to 30 KeV. The chemical elements were acquired using a zoom of 50x, a probe diameter of 30 nm to 120 nm, a probe energy of 20 KeV and 25 KeV, and a work distance of 8.5 mm. The chemical composition was explored in three different zones, and the data was then transferred to MS Word and Excel software for further analysis.

2.2.3.2. Validation Test of the Mineral's Determination Method

The mineral analysis method was validated following standard procedures [25,26], which included assessing linearity, repeatability, reproducibility, extraction yields, and detection and quantification limits. The linearity of nine mineral elements was determined using five standard points ranging from 25% to 125% (25%, 50%, 75%, 100%, and 125%). Repeatability and reproducibility tests were conducted using standards with a mineral content of 25%. A 5% percentage was added to the standard content of each mineral to determine the yield of mineral extraction. Ten separate tests were conducted for the added proportions.

2.2.4. Contribution in Essential Minerals from Consumption of Bambara Groundnut Samples

The mineral contributions were determined using the Codex Alimentarius method, which considers the mineral concentrations in the bambara groundnut samples and the daily consumption of this food by a child aged 1 to 3 years, as described by Langyintuo et al. (2003) [27]. The contribution of bambara groundnut to the daily requirement was also calculated based on the recommended daily intake values [28, 29]. The Estimated Daily Intake (EDI) was calculated using the formula:

$$\text{Estimated Daily Intake (EDI)} = C \times Q \quad (1)$$

$$\text{Contribution (\%)} = (\text{EDI} \times 100) / \text{DRI} \quad (2)$$

With: C, mineral concentration measured; Q: bambara groundnut daily consumption (4.93 g per capita/day); DRI: Daily Recommended Intake.

2.2.5. Statistical Analysis

The information was recorded using Microsoft Excel and analyzed using the Statistical Program for Social

Sciences (SPSS 22.0 for Windows, USA). To compare the different cultivars of bambara groundnut, a one-way analysis of variance (ANOVA) was conducted. The mean values for each parameter were compared using the Tukey post-hoc test at a significance level of 5%. Additionally, Multivariate Statistical Analysis (MSA) was performed using Principal Components Analysis (PCA) with the XLSTAT software version 2016 to explore the relationship between the bambara groundnut samples and their mineral traits.

3. Results and Discussion

3.1. Macroelements Contents

The study found significant variations in the macroelement content of bambara groundnut seeds (Table 2). Potassium was the main mineral element, ranging from 12308 ± 12.3 to 16425 ± 4.6 mg/kg DM, with the highest content in the NPB cultivar and the lowest in the BPR cultivar. Sodium content ranged from 1319 ± 25.5 (RU) to 9893 ± 3.2 mg/kg DM (NPB), and magnesium content ranged from 1376 ± 5.5 (BPR) to 1879 ± 18.8 mg/kg DM (RU). NPB and BPR cultivars had higher sodium content compared to RU and BU cultivars, while RU and BU cultivars had higher magnesium content compared to NPB and BPR cultivars. Calcium content varied between 3149 ± 4.6 and 6267 ± 3 mg/kg DM, with the highest values observed in the BHG, BHN, and NPB cultivars, and the lowest in the BU and BPR cultivars (3726 ± 0.8 to 3149 ± 4.6 mg/kg). Phosphorus content ranged from 104 ± 3.5 to 307 ± 3.8 mg/kg, with lower concentrations in the NU and BPR cultivars (Table 1).

Table 1. Macroelements content of Bambara groundnut seeds samples

Cultivars	K (mg/kg)	Na (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	P (mg/kg)
BHG	14196 ± 1.95 ^e	1653 ± 2.20 ^d	1422 ± 2.42 ^e	6267 ± 3.03 ^a	178 ± 2.54 ^d
	13754 ± 3.81 ^f	4017 ± 2.18 ^b	1782 ± 4.35 ^c	5507 ± 3.10 ^b	307 ± 3.83 ^a
BHN	12308 ± 12.3 ^g	3395 ± 5.43 ^c	1376 ± 5.51 ^f	3149 ± 4.60 ^g	104 ± 3.50 ^f
	15589 ± 23 ^b	1319 ± 25.53 ^f	1879 ± 18.75 ^a	4232 ± 9.12 ^e	253 ± 9.30 ^b
BPR	15301 ± 0.74 ^c	1547 ± 11.1 ^e	1696 ± 16.04 ^d	5165 ± 17.80 ^d	156 ± 11.26 ^e
	14595 ± 5.25 ^d	1676 ± 3.81 ^d	1838 ± 5.10 ^b	3726 ± 0.78 ^f	206 ± 3.63 ^c
RU	16425 ± 4.63 ^a	9893 ± 3.15 ^a	1413 ± 7.11 ^e	5232 ± 11.02 ^c	297 ± 6.38 ^a
NU					
BU					
NPB					

By column the levels with different letters in the same column are significantly different (risk of 5%)

3.2. Trace Elements Contents

The analysis detected four trace elements (iron, copper, manganese, and zinc) in the samples of Bambara groundnut seeds from the seven cultivars. Table 3 shows that there is significant variation ($P < .001$) in the mineral content among the samples. Zinc is the dominant trace element, with the BHN and NPB cultivars having lower content (79 ± 2.1 to 142 ± 3 mg/kg DM), while the BU cultivar has the highest zinc content of 425 ± 3.8 mg/kg

DM. The BU cultivar also has the highest content ($P < .001$) of copper and iron, ranging from 13 ± 0.7 mg/kg DM to 151 ± 0.2 mg/kg DM. The BHG cultivars have lower contents of these minerals, ranging from 7.12 ± 0.6 mg/kg DM to 95 ± 1.5 mg/kg DM, while the NU cultivar records contents of 11 ± 0.2 to 137 ± 8.5 mg/kg DM. Manganese is found in contents of 16 ± 0.6 mg/kg DM to 35 ± 1.9 mg/kg DM, with the NPB cultivar having the highest content (Table 2).

Table 2. Oligoelements content of Bambara groundnut seeds samples

Cultivars	Zn (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)
BHG	290 ± 4.93^b	95 ± 1.5^c	22 ± 1.7^b	7 ± 0.63^d
BHN	142 ± 3.04^e	129 ± 2.8^b	16 ± 1.5^c	8 ± 0.74^{cd}
BPR	209 ± 4.76^d	133 ± 7.8^b	17 ± 2.9^c	8 ± 1.28^d
RU	228 ± 3.21^d	127 ± 6.1^b	18 ± 0.2^c	10 ± 0.31^{bc}
NU	261 ± 2.0^c	137 ± 8.5^{ab}	$20 \pm 1b^c$	11 ± 0.18^{ab}
BU	425 ± 3.80^a	151 ± 0.2^a	16 ± 0.6^c	13 ± 0.65^a
NPB	79 ± 2.13^f	124 ± 4.6^b	35 ± 1.9^a	9 ± 0.84^{bc}

By column the levels with different letters in the same column are significantly different (risk of 5%).

Table 3. Daily intakes of minerals resulting from the consumption of bambara groundnut samples

Cultivars	Macroelements					Oligoelements				
	K	Na	Mg	Ca	P	Zn	Fe	Mn	Cu	
BHG	69.99	8.15	7.01	30.9	0.87	1.43	0.47	0.11	0.04	
BHN	67.81	19.8	8.79	27.15	1.51	0.7	0.64	0.08	0.04	
BPR	60.68	16.74	6.78	15.53	0.51	1.03	0.65	0.08	0.04	
RU	76.86	6.5	9.26	20.86	1.25	1.13	0.62	0.09	0.05	
NU	75.43	7.63	8.36	25.47	0.77	1.29	0.67	0.1	0.05	
BU	71.95	8.26	9.06	18.37	1.02	2.09	0.75	0.08	0.06	
NPB	80.98	48.77	6.97	25.79	1.46	0.39	0.61	0.17	0.05	
DRI	2000	2500	375	1000	700	10	14	2.5	1	

3.3. Estimated Daily Intakes of Minerals

Among the bambara groundnut seeds studied, the NPB cultivar had the highest daily intakes of potassium (80.98 mg/day), sodium (48.77 mg/day), calcium (25.79 mg/day), and manganese (0.17 mg/day). The NPB cultivar also provided 9.26 mg/day, 2.09 mg/day, 0.75 mg/day, and 0.06 mg/day of magnesium, zinc, iron, and copper, respectively. The BHN cultivar had the highest total phosphorous intake ranging from 0.51 mg/day to 1.51 mg/day, while the BPR cultivar had a lower intake of 0.6 mg/day. The BHG cultivar contributed 7.01 mg/day, 8.15 mg/day, and 30.9 mg/day to the daily intakes of magnesium, sodium, and calcium, respectively. The bambara groundnut seeds studied provided low intakes of copper, zinc, manganese, and iron, ranging from 0.04 mg/day to 2.09 mg/day. In terms of daily recommended intakes, the bambara groundnut seeds contributed macro and microelements in percentages ranging from 0.11% to 20.94%. Zinc had the highest contribution from the bambara groundnut cultivars, ranging from 7% to 20.94% (Table 4).

3.4. Categorization of Samples Based on Their Mineral Composition

The Kaiser statistical rule was used to carry out principal component analysis (PCA), considering components F1 and F2 with eigenvalues greater than 1

(Table 5). Figure 3.A illustrates the correlation between the factorial axes F1 and F2, which account for 69.28% of the total variability of the parameters studied. F1, with an eigenvalue of 3.81, explains 42.35% of the variance and is primarily influenced by positive correlations with sodium, calcium, and manganese, and a negative correlation with magnesium, zinc, iron, and copper. F2, with an eigenvalue of 2.42, explains 26.93% of the variance and is mainly influenced by positive correlations with potassium, phosphorus, and copper (Table 5). The projection of characteristics and samples onto the F1-F2 plane reveals four groups of bambara groundnut cultivars. Group 1 consists primarily of the NPB cultivar, characterized by higher levels of potassium, phosphorus, sodium, manganese, and calcium compared to other cultivars. Group 2 consists of BU cultivars, which have higher levels of copper, magnesium, iron, and zinc compared to all other cultivars (Figure 3.B). Groups 3 and 4 include individuals with intermediate and lower levels of the nine minerals, respectively.

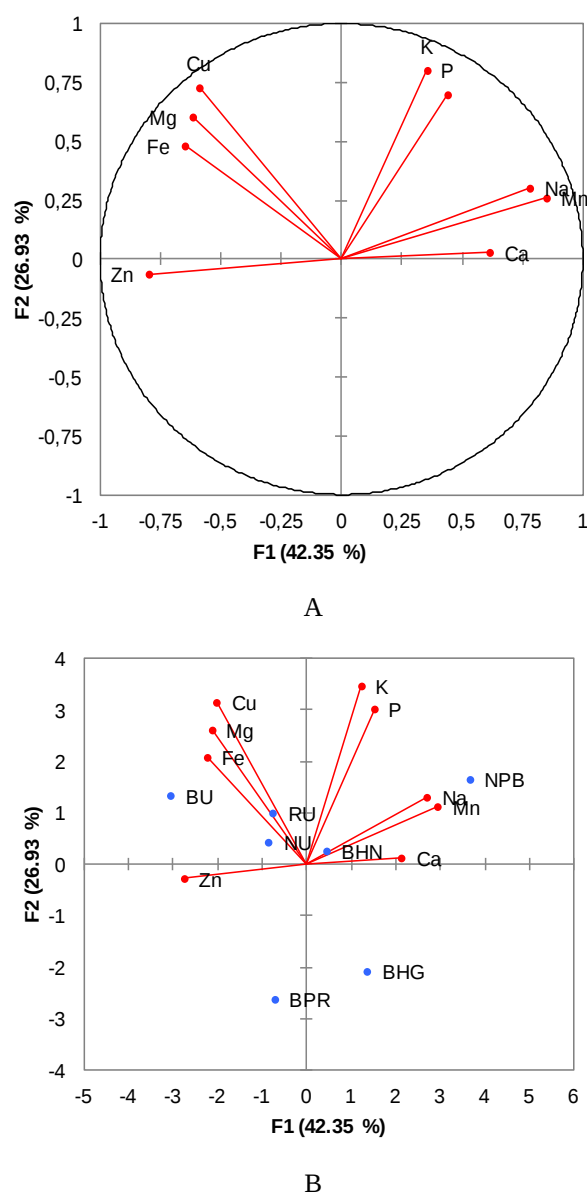


Figure 3. Correlations drawn between the F1-F2 factorial design of the PCA and the mineral parameters (A) and samples (B) of the bambara groundnut cultivars

Table 4. Daily minerals recommended intakes and contribution of bambara groundnut samples

Cultivars	Contribution (%)								
	K	Na	Mg	Ca	P	Zn	Fe	Mn	Cu
BHG	3.5	0.33	1.87	3.09	0.12	14.3	3.33	4.41	3.51
BHN	3.39	0.79	2.34	2.71	0.22	7	4.55	3.06	4.07
BPR	3.03	0.67	1.81	1.55	0.07	10.32	4.68	3.38	3.71
RU	3.84	0.26	2.47	2.09	0.18	11.25	4.46	3.51	4.78
NU	3.77	0.31	2.23	2.55	0.11	12.87	4.81	3.94	5.26
BU	3.60	0.33	2.42	1.84	0.15	20.94	5.32	3.06	6.24
NPB	4.05	1.95	1.86	2.58	0.21	3.91	4.35	6.89	4.52
DRI	2000	2500	375	1000	700	10	14	2.5	1

Table 5. Eigenvalue matrix and correlations of the mineral parameters of bambara groundnut cultivars studied with components F1 and F2 of the principal component analysis

Components	F1	F2
Eigenvalue	3.81	2.42
Validity expressed (%)	42.35	26.93
Cumulative validity expressed (%)	42.35	69.28
K	0.35	0.80
Na	0.78	0.30
Mg	-0.62	0.60
Ca	0.61	0.03
P	0.44	0.70
Zn	-0.80	-0.06
Fe	-0.65	0.48
Mn	0.85	0.26
Cu	-0.59	0.73

4. Discussion

During this study, the presence and analysis of five macro minerals (potassium, sodium, magnesium, calcium, phosphorus) and four microelements (zinc, iron, manganese, copper) were examined. These nutrients play a crucial role in cell growth and metabolism [30]. Analysis of the bambara groundnut samples revealed that potassium, sodium, calcium, and magnesium were the most abundant macro mineral elements. These findings align with previous studies by Olaleye *et al.* [31] and Chelangat *et al.* [12]. However, the results were relatively higher compared to the values reported by Aremu *et al.* [32] and Ijarotimi and Esho [33]. Among the different cultivars, the black variegated with beige (NPB) cultivar exhibited the highest levels of potassium and sodium. The uniform beige (BU) cultivar had the highest levels of magnesium, while the beige with grey hilum outline (BHG) cultivar had the highest calcium levels. The variations observed in the results were attributed to the genetic origin, soil fertility level, and geographical source of the bambara groundnut seeds [34,35]. The phosphorus levels (104 – 307 mg/kg) were lower than those reported by Olaleye *et al.* [31] but comparatively lower than the 313–563 mg/100 g reported by Dansi *et al.* [36].

Potassium is important for protecting against high blood pressure and other cardiovascular risks. It also plays a crucial role in the synthesis of amino acids and proteins [37]. Sodium is involved in regulating the osmotic pressure between blood and cells due to imbalanced ionic concentrations [38]. Calcium is essential for children and adults as it helps strengthen bones and develop teeth [39].

It also aids in the formation of muscles, the heart, and the digestive system [40]. Magnesium helps regulate the body's acid-base balance and maintains normal muscle and nerve function [41]. It is also involved in over 300 biochemical reactions in the body, maintaining regular heart rhythms and regulating blood sugar levels [41]. Phosphorus is primarily involved in energy production through phosphorylation reactions [42].

The mineral composition analysis shows that Bambara groundnut seeds samples have significant amounts of essential trace elements (zinc, iron, manganese, and copper) that are beneficial for children, pregnant or nursing women, and athletes [43]. Among all the samples collected from different regions, the BU cultivar has the highest zinc, iron, and copper content, while the NPB cultivar has the highest manganese level.

The levels of copper, iron, and zinc in the different cultivars of Bambara groundnut seeds examined in this study were comparatively lower compared to the findings of Dansi *et al.* [36] and Chelangat *et al.* [12]. Copper plays a crucial role in various enzymatic systems such as cytochrome oxidase and tyrosinase [44]. It also contributes significantly to the synthesis and maintenance of myelin and acts as a cofactor in anti-radical processes [23]. Iron is an important element, particularly in the synthesis of hemoglobin in the blood [45]. Additionally, it aids in the oxidation of carbohydrates, proteins, and lipids [46]. Zinc is referred to as a vital metal as it is a component of over 300 enzymes found in various body tissues. It helps prevent organ inflammation and damage by reducing oxidative stress and plays a role in blood pressure regulation [47].

The study found that consuming bambara groundnut seeds from different regions in Côte d'Ivoire can provide significant amounts of essential minerals. The recommended daily intake of these minerals was compared to the mineral content of the seeds, and it was determined that bambara groundnut is a good source of potassium, zinc, copper, and iron.

Therefore, incorporating bambara groundnut into the diet could help prevent mineral deficiencies in the population residing in these regions.

5. Conclusion

The objective of this research was to analyze the mineral composition of bambara groundnut seeds grown in different regions of Northern Côte d'Ivoire. The findings indicate that regardless of the cultivar, bambara groundnut contains substantial levels of the minerals examined. As a result, incorporating bambara groundnut into a balanced diet can be beneficial. Additionally, in regions where these minerals are lacking in the diet, bambara groundnut can serve as a valuable source. These findings emphasize the significance of this local and underutilized legume in addressing hunger and malnutrition in Africa.

Conflict of Interest

The authors declare that there are no conflicts of interest in relation to this manuscript. The authors declare

that they have no competing interests.

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