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Research Article

ESSENTIAL MINERAL COMPOSITION OF PLANTAIN-BASED SNACKS CONSUMED IN CÔTE D'IVOIRE: NUTRITIONAL CONTRIBUTION AND PUBLIC HEALTH IMPLICATIONS

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ABSTRACT

Plantain banana holds a central place in Ivorian diets, where it is consumed daily either as staple dishes or as popular snacks such as *alloco*, chips, *claclo*, *doclou* and roasted plantain. While it is energetic role is well established, few studies have examined the mineral composition of these processed foods, despite the fact that cooking methods and salt addition can significantly alter their nutritional value. This study therefore aimed to characterize the levels of essential minerals in the main plantain-based snacks available on the Ivorian market, to compare their profiles according to processing techniques, and to estimate their potential contribution to daily nutritional requirements. Analyses were carried out on five representative products prepared from local plantain varieties at different maturity stages. Results showed that magnesium was the most abundant mineral, ranging from 45.2 to 60.4 mg/100 g DM, with particularly high levels in roasted plantain and *doclou*. calcium and zinc concentrations were modest (< 10 mg/100 g DM and < 1 mg/100 g DM, respectively), while iron was detected only in roasted plantain (2.3 mg/100 g DM). Sodium levels differed significantly among products, with doclou exhibiting exceptionally high concentrations (up to 614.8 mg/100 g DM), while roasted plantain maintained low levels. These findings show that plantain snacks are a good source of magnesium, but they also show that their high sodium content is a health risk. To improve the nutritional value of these foods that are important to both culture and the economy, it is important to encourage cooking methods that limit the amount of salt added.

Keywords: Plantain, Snacks, Minerals, Côte d'Ivoire, Nutrition.

INTRODUCTION

Plantain (*Musa spp*., AAB) is a major part of West African diets, especially in Côte d'Ivoire (Norgrove and Hauser, 2024). People eat it every day, both as a main dish and as a snack, like chips, *alloco*, or roasted plantain (Kouamé *et al.,* 2017). Its role as an energy source is well known, but its nutritional value as a source of micronutrients is not as well known, especially in its processed forms. Earlier research has demonstrated that plantain is a significant source of potassium, magnesium, and phosphorus (Odenigbo *et al.,* 2013). However, the mineral composition of plantain-derived products is still underexplored, even though processing methods particularly frying can significantly alter the concentration of certain elements, such as potassium or magnesium (FAO, 1991; Jiokap, 2002; Adeyeye *et al.,* 2019). Additionally, the prevalent practice of incorporating salt during preparation may result in a significant elevation in sodium levels (Anajekwu *et al.,* 2023). In various African contexts, including Cameroon, research indicates that banana and plantain derivatives, while energy-dense and high in beta-carotene, offer minimal quantities of iron and zinc due to their low bioavailability, frequently associated with the presence of phytates (Fernande *et al.,* 2007). These results indicate that

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the nutritional quality of plantain-based products is influenced by both their inherent composition and local culinary traditions (Agbemafle *et al.,* 2017).

In Côte d'Ivoire, the consumption of plantain-based snacks has surged, especially in urban regions where they have become synonymous with "street food" amid a continuing nutritional transition (Kouamé *et al.,* 2017; Bouafou *et al.,* 2021; Kouamé *et al.,* 2015). This trend raises a dual concern, on the one hand, such snacks may represent a non-negligible source of potassium and magnesium in the daily diet, on the other, their high sodium content, especially when prepared with added salt, could represent a significant risk factor for hypertension and cardiovascular diseases. Despite the importance of these foods in Ivorian dietary habits, few studies have comparatively evaluated their mineral profiles according to processing methods (frying, roasting, traditional cooking). In addition, the actual contribution of these snacks to meeting dietary reference intakes across different population groups remains largely unknown. The present study therefore aims to fill this gap by *(i)* characterizing the levels of essential minerals in the main plantain-based snacks available on the Ivorian market, *(ii)* comparing mineral profiles according to processing methods and production types, and *(iii)* estimating their potential contribution to meeting the daily nutritional requirements of consumers.

MATERIALS AND METHODS

Study site

The study was conducted in Abidjan, Côte d'Ivoire, at the Department of Food Science and Technology (UFR-STA) of NANGUI ABROGOUA University (UNA), where the food preparations were carried out and preliminary analyses performed. Mineral assays were subsequently conducted at the Department of Food, Environmental and Nutritional Sciences (DeFENS), University of Milan (UNIMI, Italy), in an accredited laboratory for food composition analyses.

Biological material

The plantain samples used in this study were obtained from local varieties commonly consumed in Côte d'Ivoire. To ensure representativeness of dietary practices, fruits were selected at different ripening stages and processed into typical Ivorian snacks. This study evaluated snacks prepared from local varieties (*Agnrin*, *Ameletiha, Afoto*; Table 1) at different maturity stages. Five product types were analysed, *(i)* alloco, prepared from fully yellow ripe fruits (AAgJ) and yellow fruits with black spots (AAgT); *(ii)* claclo, a traditional fritter made from overripe plantains (KAmTN); *(iii)* plantain chips, obtained from green fruits (CAmV); *(iv)* roasted plantain, grilled directly over charcoal from light-green fruits (BAfVC); and *(v)* doclou, a local cake prepared from overripe plantains (Figure 1).

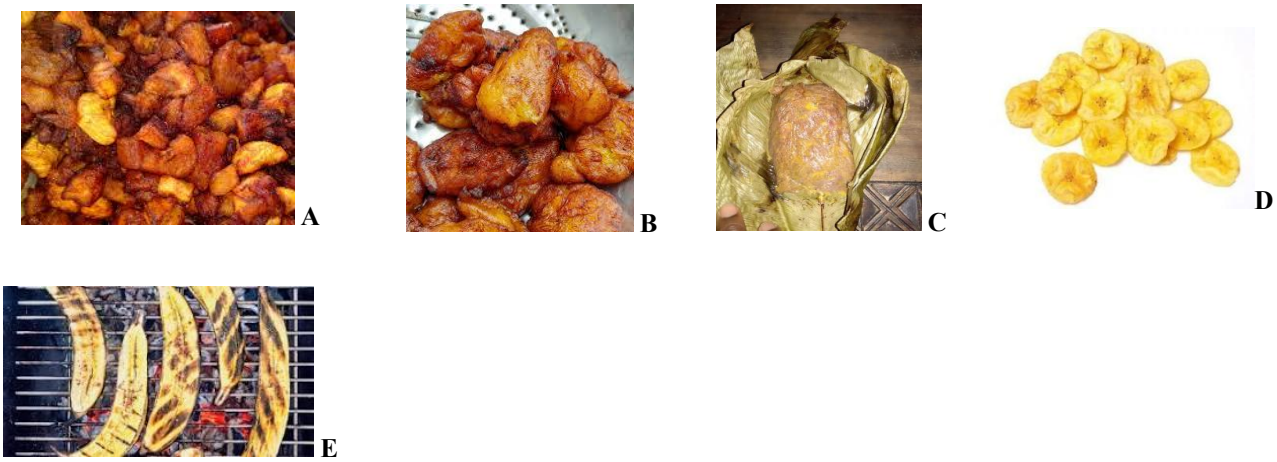

Figure 1. Plantain snacks including (A) *alloco*; (B) *claclo*; (C) *doclou*; (D) plantain chips (E) braised banana.

Table 1. Different types of plantain that are used when preparing meals.

Varieties	Agronomic characteristics
 **False Horn variety *cv* "afoto" (Horn 1)**	- Scientific name: *Musa spp* - Varietal group: False Horn (local cultivar) - Geographical origin: Cote d'Ivoire - Genetic origin: *Musa accuminata* AA x *Musa balbisiana* - Cultivation areas: Wetland - Breeder: CNRA* - Maintainer: CNRA
 **French giant variety *cv* "Agnrin"**	- Scientific name: *Musa spp* - Variety group: French giant (local cultivar) - Geographical origin: Cote d'Ivoire - Genetic origin: *Musa accuminata* AA x *Musa balbisiana* - Cultivation areas: Wetland - Breeder: CNRA - Maintainer: CNRA
 **Medium French variety cv "ameletiha"**	- Scientific name:: *Musa spp* - Variety group: Medium French (local cultivar) - Geographical origin: Cote d'Ivoire - Genetic origin: *Musa accuminata* AA x *Musa balbisiana* - Cultivation areas: Wetland - Breeder: CNRA - Maintainer: CNRA

Source : Centre National de Recherche Agronomique (Thiémélé *et al.,* 2017)

These products were selected as they represent the main forms in which plantain is consumed as a snack in Côte d'Ivoire, thereby faithfully reflecting local culinary practices.

Reagents and materials

All reagents were of analytical grade. Hydrochloric acid (HCl, 37 %, Merck, Germany) was diluted to 0.1 N for sample mineralization. Solution preparation and dilution involved the use of Milli-Q water (Millipore, Bedford, MA, USA), which was of an ultra-pure quality. Standard solutions of sodium, calcium, magnesium, iron and zinc were prepared from certified pure salts (Sigma-Aldrich, St. Louis, MO, USA). Porcelain crucibles, beakers and pipettes were pre-treated in 10 % HNO_3 for 24 h and rinsed thoroughly with ultrapure water before use. Instrumental analyses were performed using a Perkin-Elmer Analyst 800 atomic absorption spectrometer (Waltham, MA, USA), calibrated before each series of measurements.

Sample preparation

Fresh plantain fruits were purchased from the Yopougon SIPOREX central market in Abidjan and transported to the laboratory in ventilated crates to minimize post-harvest deterioration. After careful washing with potable water, the fruits were peeled manually with disinfected stainless-steel knives and cut according to the intended preparation. For chips, plantain fingers were sliced into thin slices (2 mm) and deep-fried in vegetable oil at 180 °C until crisp. For *alloco*, ripe fruits were cut into 1 - 2 cm cubes and fried at 170 °C until golden brown. Roasted plantains were prepared by placing whole fruits on a charcoal grill until the pulp softened. *Claclo* and *doclou* were prepared according to traditional methods described by Kouamé *et al.* (2017) and Akoa *et al.* (2014), respectively. After cooking, fried products were drained and cooled to room temperature on absorbent paper to reduce excess oil. All samples were homogenised in a stainless-steel blender, packed in airtight polyethylene bags, stored at 20 °C, and subsequently freeze-dried for mineral analysis. All procedures were carried out in full accordance with food hygiene standards, as recommended by the FAO and WHO (FAO/WHO, 2008).

Mineral analysis

The AOAC (1983) method was used to determine the ash content. In brief, 0.2 g of the freeze-dried sample was placed in a pre-weighed porcelain crucible and incinerated in a muffle furnace until a white or light grey residue was obtained. The resulting ash was mineralized with 20 mL of hydrochloric acid (0.1 N) using a microwave digestion system (Ethos TC, Milestone, Italy). The clear solution was filtered and diluted with ultrapure Milli-Q water to obtain stock solutions for mineral assays. Sodium (Na), calcium (Ca), magnesium (Mg), iron (Fe) and zinc (Zn) concentrations were determined by atomic absorption spectrometry (AAS) using a Perkin-Elmer Analyst 800 spectrometer (Waltham, MA, USA) equipped with an air–acetylene flame (Figure 2). Instrumental conditions followed official recommendations, with specific wavelengths for each element: Ca (422.7 nm), Mg (285.2 nm), Zn (213.9 nm), Na (589.0 nm), and Fe (248.3 nm). Calibration was performed using standard solutions of increasing concentrations prepared from pure salts of each element, in accordance with analytical validation protocols. Each analytical run included blanks and duplicates to ensure measurement accuracy and reproducibility.

Figure 2. Perkins-Elmer Analyst 800 atomic absorption spectrometer used for mineral analysis.

Quality control and quality assurance

Limits of detection (LOD) and quantification (LOQ) were set at three and ten times the standard deviation of analytical blanks, respectively. Certified reference material (NIST SRM 1570a – spinach, Gaithersburg, MD, USA) was analysed in parallel, with recovery rates ranging between 92 % and 105 %. Repeatability was verified on 10 % of samples, with intra-assay coefficients of variation below 5 %. To minimize contamination, all containers were acid-washed before use, and each series of analyses included blanks to correct for possible background contamination.

Statistical analysis

The data were presented as means ± standard deviation (SD) from three independent replicates (n = 3). SPSS software version 20.0 (IBM Corp., Armonk, NY, USA) was used to do the statistical analysis. One-way analysis of variance (ANOVA) was used to find differences between means, and then Tukey's multiple comparison test was used to find significant differences between samples. The significance level was established at $p < 0.05$.

RESULTS AND DISCUSSION

The essential mineral contents of the main plantain-derived snacks are presented in figure 3 (a,b,c,d and e). Magnesium (Mg) appeared as the most abundant element, with values ranging from 45.2 to 60.4 mg/100 g DM. Roasted plantain (60.4 ± 0.4 mg/100 g DM) and *doclou* (54.9 - 57.4 mg/100 g DM) were the richest sources, followed by the other products (chips, *alloco*, *claclo*), which showed slightly lower levels. These findings validate that plantain can substantially enhance dietary magnesium consumption in Côte d'Ivoire, as previously indicated by Odenigbo *et al.* (2013). Calcium (Ca) and zinc (Zn) levels, on the other hand, were not very high. Calcium levels did not surpass 9.0 mg/100 g DM (*claclo*), and zinc levels consistently remained under 1 mg/100 g DM in all samples. These concentrations are low compared to what people need every day, which means that these snacks aren't good sources of Ca and Zn, which is what Fernande *et al.* (2007) found. Iron (Fe) was only found in roasted plantain (2.3 ± 0.0 mg/100 g DM), which shows how cooking can affect how minerals are absorbed by the body. The absence of measurable iron in other preparations may be linked to losses during frying or matrix effects, confirming the limited contribution of plantain products to dietary iron intake (Fernande *et al.,* 2007). Sodium (Na) displayed the greatest variability. While roasted plantain had the lowest value (6.9 ± 0.1 mg/100 g DM), fried products and *doclou* exhibited very high concentrations, reaching up to 614.8 ± 15.3 mg/100 g DM in artisanal *doclou*. These differences are mainly explained by table salt addition and processing practices, confirming that sodium is the most preparation-sensitive element (Adeyeye *et al.,* 2019; Anajekwu *et al.,* 2023).

Mineral profiles varied considerably according to processing techniques. Frying (*alloco*, *claclo*, chips) resulted in high sodium concentrations, a direct consequence of salt or condiment addition, but did not improve calcium, zinc, or iron availability. Roasting (roasted plantain) was characterised by low sodium levels and relatively good preservation of magnesium and iron. *Doclou*, which involves fermentation, prolonged cooking, and salt addition, showed the most concerning sodium concentrations. These results are consistent with Jiokap (2002) and Adeyeye et al. (2019), who reported that repeated frying and excessive seasoning markedly affect the mineral composition of plantains.

The estimated contribution of these snacks to daily nutritional requirements shows striking contrasts. A 100 g portion of roasted plantain provides about 15 % of the daily magnesium requirement for an adult (recommended intake: 350 - 400 mg/day, FAO/WHO, 2015), and 2.3 mg of iron, equivalent to nearly 15 % of the daily requirement for women (16 - 18 mg/day). Conversely, calcium (< 3 % of DRIs) and zinc (< 5 % of DRIs) contributions remain negligible. Sodium intake represents the most critical factor. A 100 g portion of artisanal *doclou* supplies more than 600 mg of sodium, nearly 30 % of the WHO recommended maximum intake (< 2000 mg/day). So, eating these kinds of foods on a regular basis may lead to too much sodium intake, which raises the risk of high blood pressure and heart disease, which are already on the rise in West Africa (Bouafou *et al.,* 2021). On the other hand, roasted plantain seems like a better choice because it has a lot of magnesium and iron but not much sodium. This makes it a good snack for public health.

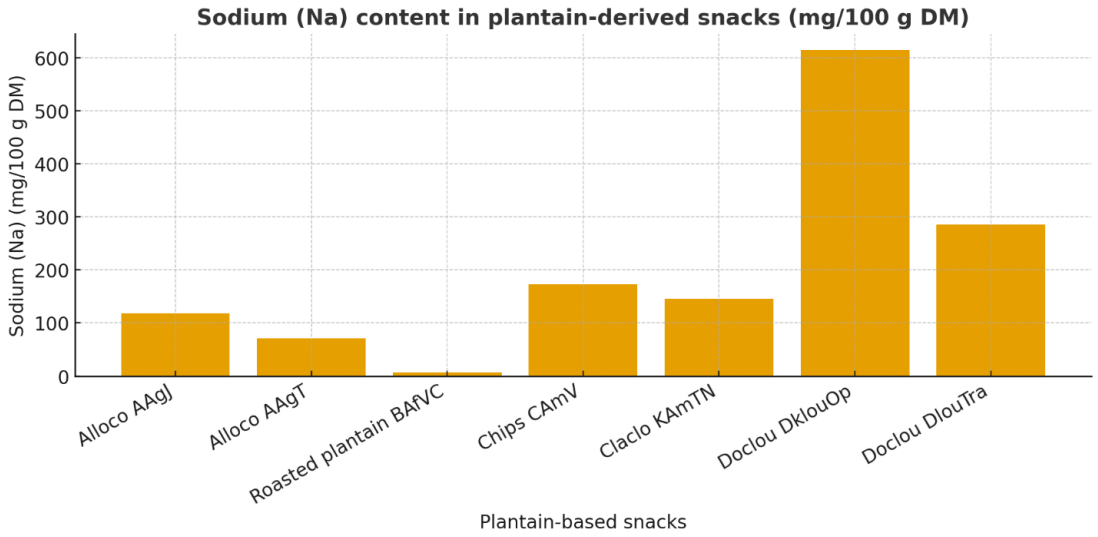

Figure 3a. Sodium (Na) content of plantain-derived snacks (mg/100 g DM).

Abbreviations of samples
AAgJ = Alloco prepared from plantain variety Agnrin at "yellow" maturity stage
AAgT = Alloco prepared from plantain variety Agnrin at "tiger-striped" maturity stage
BAfVC = Roasted plantain prepared from plantain variety Afoto at "light-green" maturity stage
KAmTN = Claclo prepared from plantain variety Ameletiha at "fully black" maturity stage
CAmV = Chips prepared from plantain variety Ameletiha at "green" maturity stage
DklouOp = Doclou (optimised version) prepared from plantain variety Ameletiha at "fully black" maturity stage
DlouTra = Doclou (traditional version) prepared from plantain variety Ameletiha at "fully black" maturity stage

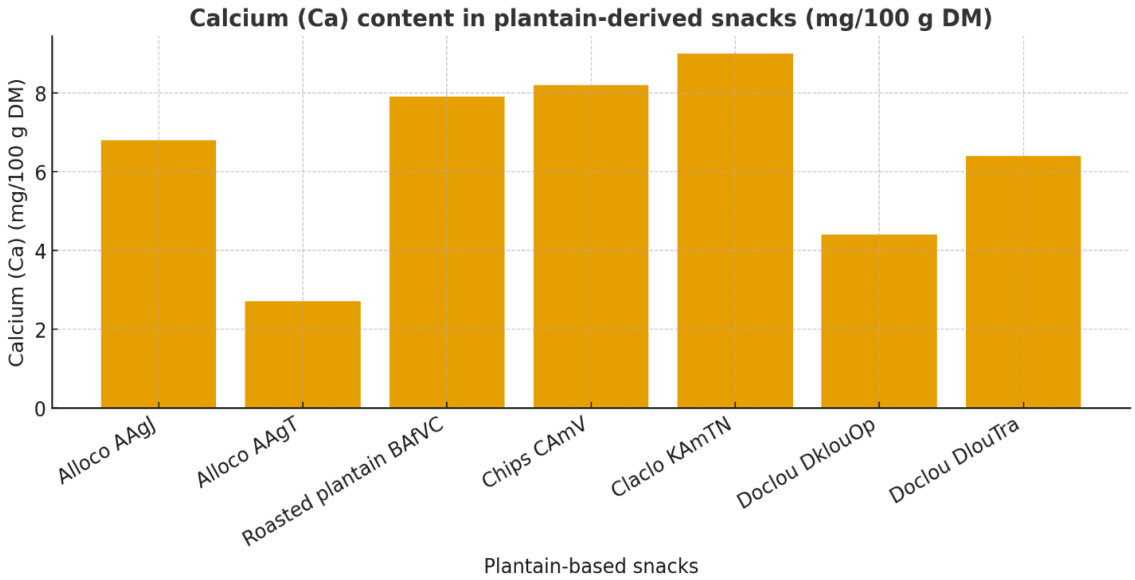

Figure 3b. Calcium (Ca) content of plantain-derived snacks (mg/100 g DM).

Abbreviations of samples
AAgJ = Alloco prepared from plantain variety Agnrin at "yellow" maturity stage
AAgT = Alloco prepared from plantain variety Agnrin at "tiger-striped" maturity stage
BAfVC = Roasted plantain prepared from plantain variety Afoto at "light-green" maturity stage
KAmTN = Claclo prepared from plantain variety Ameletiha at "fully black" maturity stage
CAmV = Chips prepared from plantain variety Ameletiha at "green" maturity stage

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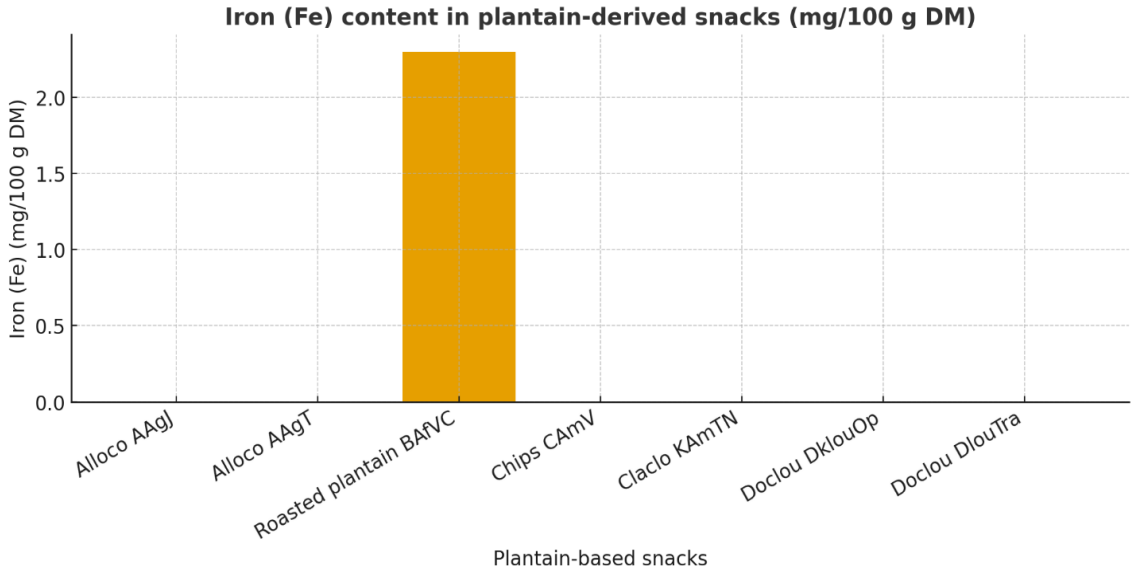

Figure 3c. Iron (Fe) content of plantain-derived snacks (mg/100 g DM).

Abbreviations of samples
AAgJ = Alloco prepared from plantain variety Agnrin at "yellow" maturity stage
AAgT = Alloco prepared from plantain variety Agnrin at "tiger-striped" maturity stage
BAfVC = Roasted plantain prepared from plantain variety Afoto at "light-green" maturity stage
KAmTN = Claclo prepared from plantain variety Ameletiha at "fully black" maturity stage
CAmV = Chips prepared from plantain variety Ameletiha at "green" maturity stage
DklouOp = Doclou (optimised version) prepared from plantain variety Ameletiha at "fully black" maturity stage
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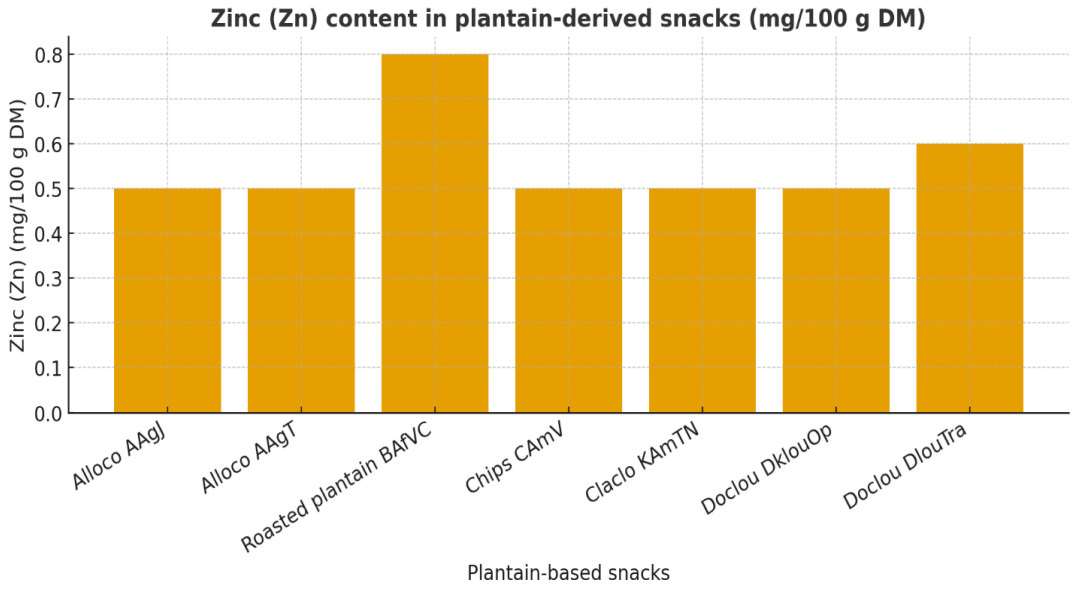

Figure 3d. Zinc (Zn) content of plantain-derived snacks (mg/100 g DM).

Abbreviations of samples:
AAgJ = Alloco prepared from plantain variety Agnrin at "yellow" maturity stage
AAgT = Alloco prepared from plantain variety Agnrin at "tiger-striped" maturity stage
BAfVC = Roasted plantain prepared from plantain variety Afoto at "light-green" maturity stage
KAmTN = Claclo prepared from plantain variety Ameletiha at "fully black" maturity stage
CAmV = Chips prepared from plantain variety Ameletiha at "green" maturity stage
DklouOp = Doclou (optimised version) prepared from plantain variety Ameletiha at "fully black" maturity stage
DlouTra = Doclou (traditional version) prepared from plantain variety Ameletiha at "fully black" maturity stage

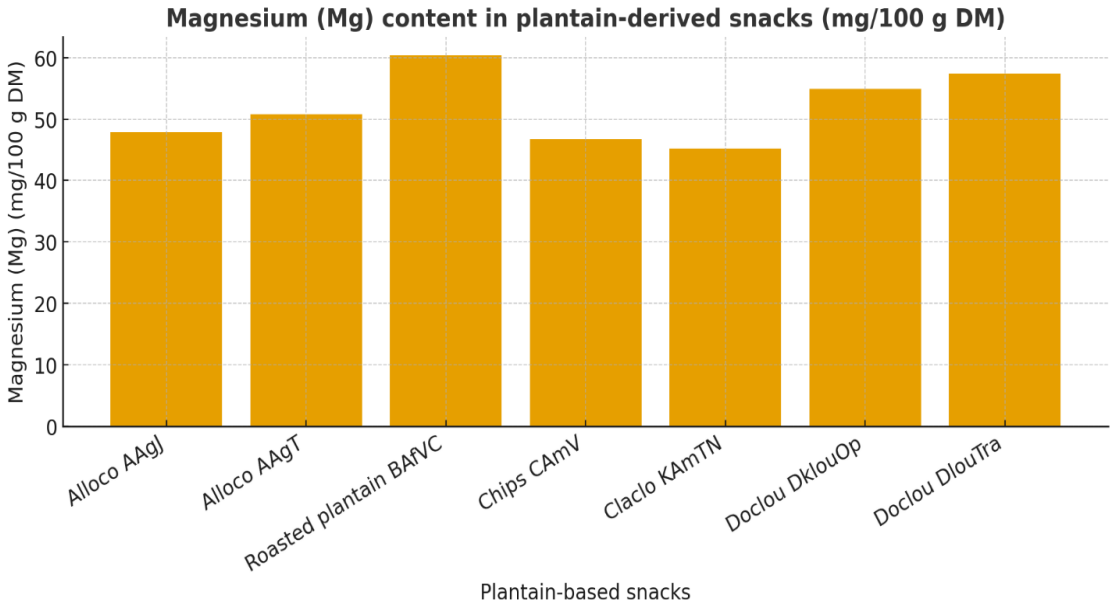

Figure 3e. Magnesium (Mg) content of plantain-derived snacks (mg/100 g DM).

Abbreviations of samples
AAgJ = Alloco prepared from plantain variety Agnrin at "yellow" maturity stage
AAgT = Alloco prepared from plantain variety Agnrin at "tiger-striped" maturity stage
BAfVC = Roasted plantain prepared from plantain variety Afoto at "light-green" maturity stage
KAmTN = Claclo prepared from plantain variety Ameletiha at "fully black" maturity stage
CAmV = Chips prepared from plantain variety Ameletiha at "green" maturity stage
DklouOp = Doclou (optimised version) prepared from plantain variety Ameletiha at "fully black" maturity stage
DlouTra = Doclou (traditional version) prepared from plantain variety Ameletiha at "fully black" maturity stage

CONCLUSION

This study assessed the essential mineral composition of the main plantain-based snacks consumed in Côte d'Ivoire, highlighting the influence of processing methods on their nutritional value. Magnesium was identified as the predominant mineral, particularly in roasted plantain and *doclou*, confirming the role of plantain as a relevant source of this nutrient in local diets. Calcium and zinc, on the other hand, were only found in small amounts, and iron was only found in roasted plantain. This shows that processed plantain products do not add much to these micronutrients. Sodium was the most important element, with levels ranging from very low in roasted plantain to very high in *doclou* and fried foods like *alloco*, chips, and *claclo*. Because high blood pressure and heart disease are common in West Africa, these results raise public health concerns about eating too much salt from popular snacks. In general, plantain-based snacks serve two nutritional purposes, they help you get more magnesium (and maybe potassium), but eating too many salted snacks can lead to too much sodium in your diet. Public health strategies should therefore encourage preparation methods that limit salt addition and preserve mineral content, particularly roasting, as a means of promoting healthier plantain-based foods while maintaining their cultural and economic importance.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

FUNDING

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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