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Nutritional and Physicochemical Quality of Nkumu (Gnetum spp) Culinary Preparations: Implications for Food Security and Well-being in Gabon.

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Abstract. This article analyzes the impact of consuming Nkumu (Gnetum spp) on the well-being of Gabonese populations, while highlighting the strategic importance of Non-Wood Forest Products (NWFPs) in food security and Gabonese gastronomy. Nkumu, a forest leafy vegetable widely consumed in Gabon, constitutes an NTFP with high nutritional, socio-economic, and cultural value. It is prepared according to various traditional recipes (fresh chopped, cooked in water, with peanut paste, with palm oil, O'fula), which are likely to influence its nutritional and physicochemical quality. The objective of this study is to evaluate the nutritional and physicochemical quality of different culinary preparations of Nkumu and to assess their contribution to the population's well-being. A questionnaire survey was conducted among 350 households to collect information on the most commonly used traditional culinary techniques, the places and methods of sourcing Nkumu, and the recipes, which allowed us to prepare our samples. The analyses focused on: nutritional parameters (water, dry matter, proteins, lipids, carbohydrates, fibers, minerals) and physicochemical parameters (pH, titratable acidity). The results show significant variations in nutritional and physicochemical parameters depending on the recipes, reflecting the influence of culinary techniques on the bioavailability of nutrients. Some preparations (fresh Nkumu, Nkumu O'fula) stand out for their mineral richness, while recipes rich in lipids show a dilution of micronutrients. This study confirms the central role of Nkumu in food, nutrition; and livelihoods. It emphasizes the necessity to promote optimized culinary practices in order to sustainably value NWFPs.

Keywords: Nutritional Physicochemical; Food Security; Well-being; Gnetum spp; Culinary Preparations.

1. Introduction

In Central Africa, Non-Wood Forest Products (NWFPs) play a fundamental role in food security, nutrition, and the livelihoods of populations (FAO, 2024). Within the framework of the United Nations 2030 Agenda, valuing traditional foods with high nutritional value aligns fully with several Sustainable Development Goals (SDGs). Optimizing culinary recipes based on Nkumu (Gnetum spp.) directly contributes to SDG 2 “Zero Hunger” by promoting a more nutritious, diversified, and accessible diet for populations. It also participates in SDG 3 “Good Health and Well-being” through improving the nutritional quality of food preparations and preventing diseases related to dietary imbalances.

By sustainably valuing a local forest resource, this approach supports SDG 12 "Responsible Consumption and Production" by promoting endogenous food resources and traditional culinary knowledge.Furthermore, recognizing the nutritional and economic potential of Nkumu contributes to SDG 1 “No Poverty” and SDG 8 “Decent Work and Economic Growth” by strengthening the incomes of actors involved in its collection, processing, and marketing (Darpy & Guillard, 2020). Finally, promoting NWFPs derived from the sustainable management of forest ecosystems participates in SDG 15 “Life on Land” by encouraging biodiversity conservation and the sustainable use of natural resources. Thus, studying the effects of culinary techniques on the nutritional quality of Nkumu goes beyond the food sector alone and fits into an integrated approach to sustainable development that reconciles food security, public health, biodiversity preservation, and the socio-economic development of local communities.

In Gabon, the dense forest constitutes an essential source of dietary biodiversity. Among these resources, Gnetum spp (Nkumu) occupies a strategic position due to:

- its high consumption,
- its nutritional value,
- its availability and accessibility,
- and its economic importance (Mialoundama, 1993).

Nkumu is recognized for:

- its richness in dietary fibers,
- its content of essential minerals (Ca, Fe, Mg),
- and its contribution to traditional diets (Uusiku et al., 2010).

In a context of nutritional transition in Africa, marked by:

- the increase in non-communicable diseases
- and dietary imbalances,

the study of traditional foods becomes essential (WHO, 2023b).

However, culinary techniques strongly influence:

1. nutritional composition,
2. nutrient bioavailability,
3. and sanitary quality (Ayoola & Adeyeye, 2010).

Yet, few studies have comparatively evaluated the effects of culinary techniques on the preparation of Nkumu.

2. Objectives of the Study
This study aims to:
- Evaluate the nutritional value of Gnetum spp.
- Analyze the impact of culinary techniques on the availability of nutrients and minerals in Nkumu (Beack Bayengue et al., 2017).
- Assess the role of Nkumu on the well-being and food security of the Gabonese population (FAO, 2024).

This study thus responds to international priorities regarding sustainable food systems, nutritional security, and the valuation of local food resources promoted by the United Nations within the framework of the 2030 Agenda (FAO, 2024; WHO, 2023b).

2. Objectives of the Study

The Gnetophytes group, to which Gnetum belongs, stands at the junction between Gymnosperms and Angiosperms. Gnetum belongs to the Gnetaceae family, which includes only one genus with about thirty species located in the tropical and equatorial regions of Africa, America, and Asia. Only two species, Gnetum africanum and Gnetum bucholzianum, grow spontaneously in tropical forests stretching from Nigeria to Angola, passing through Cameroon, Gabon, the Central African Republic, Congo-Brazzaville, and the Democratic Republic of Congo (Loubelo, 2012).

Gnetum africanum is a plant that grows in several different types of habitats: fallow lands, abandoned agricultural lands, dense or secondary forests (Loubelo, 2012). This plant grows luxuriantly and produces a large quantity of leaves. In humid forests, Gnetum vines tolerate different types of support.

Gnetum africanum and Gnetum bucholzianum are of great importance to many forest communities and are given different vernacular and commercial names. For example, in the Central African Republic, Gabon, Congo, the Democratic Republic of Congo, and Angola, both species are locally called KoKo (Kapemba et al., 2023). In the English-speaking part of Cameroon, the local name is eru, whereas in the French-speaking part, the name is okok (Ingram et al., 2012). Finally, in Nigeria, the Igbo tribe calls them ukasi, and the Efiki/Ibibio tribe calls them afang.

In Nigeria, G. africanum leaves are used as a treatment for an enlarged spleen, sore throat, or as a cathartic (Burkill, 1994). In Oubangui (Democratic Republic of Congo), it is used as a remedy for nausea and is considered an antidote against certain types of poison (Burkill, 1994). In Congo-Brazzaville, the leaves of both Gnetum species serve as dressings for warts and boils, and cuttings form the basis of herbal teas that relieve childbirth pains (Loubelo & Mialoundama, 2002). It is also worth noting that Gnetum africanum is used as a medicinal plant in Mozambique (Watt & Breyer-Brandwijk, 1962; Burkill, 1994).

According to a study conducted by Bakary Tarnagda et al. (2019), in Ouagadougou, food commodities come from three essential sources: the farming environment, imports, and urban and peri-urban agriculture. Urban and peri-urban vegetable production attracts more attention from the urban population because it is an integral part of the city and provides fresh vegetables across all seasons. Traditional African dishes use leafy vegetables in a common and specific way, with each vegetable bringing a unique characteristic to a sauce or a dish: Vernonia hymenolepis for Cameroonian ndolé, brèdes mafanes (Acmella oleracea) accompanying Malagasy romazava, and babenda for Burkinabé sauces made from local leaves (Tarnagda et al., 2019).

They serve a social function in Southern countries, gathering family and friends around meals during festivals or ceremonies, marking belonging to a group, an ethnicity, or a cultural identity. This inseparable combination of a carbohydrate dish and a vegetable-based sauce carries social, economic, and nutritional meanings (Uusiku et al., 2010). As non-timber forest products are consumer goods, their demand fits within the literature of consumer theory. This consumer choice depends on many factors, notably those related to wealth, current income, future income, and preferences. Within households, the determinants of consumption can be grouped into economic, socio-cultural, socio-demographic, and institutional factors (Darpy & Guillard, 2020).

Daily nutrition in southeastern Nigeria is dominated by staple starches, with indigenous vegetables being the cheapest and most readily available sources of fiber, micronutrients, proteins, and antioxidant compounds (Uusiku et al., 2010). Indigenous vegetables occupy an important place in the food security, socio-economics, and livelihood activities of rural populations. They serve as food for households, and some income-generating activities—primarily for women—are based on these crops. Common indigenous vegetables include, but are not limited to, Vernonia amygdalina (onugbu), Gnetum africanum (okazi), Ocimum gratissimum (nchuanwu), Solanum melongena L. (anara), Gongronema latifolium (utazi), and Piper guineense (uziza) (Ukom et al., 2023; Moyo et al., 2018).

The Igbo people of southeastern Nigeria savor foods prepared with these vegetables in soups for daily meals and during special occasions like weddings, funerals, child dedications, or chieftaincy title coronation ceremonies. In most cases, these vegetables are used in combination with other ingredients for soups and sauces, such as Vernonia amygdalina soup, melon seed soup (egusi), Gnetum africanum soup, Solanum melongena L. soup, or spices used for pepper soup with fish/chicken/goat meat (Ukom et al., 2023). As an integral part of the population's meals, soups are served and consumed with gari/fufu, boiled or roasted yam and plantain, rice, or simply spices in others like Abacha forming part of southeastern Nigerian cuisine. They are also prepared, sold, and served in restaurants and diners.

These vegetables abound along the coastlines of West African states like Ghana, Benin, Nigeria, and Cameroon. Vegetables are already part of a local and international trade involving millions of dollars, especially among southeastern inhabitants in other regions of Nigeria and those in the diaspora, where they are marketed in dehydrated forms and used in diaspora kitchens (Ukom et al., 2023).

Urbanization is progressing in many countries, and reports show that it modifies agrifood systems in a way that can no longer be understood through the simple dichotomy between rural and urban environments (FAO, 2024). Green leafy vegetables contain a range of bioactive compounds, including carotenoids and other phytochemicals, which may contribute to their nutritional and health-promoting value (Gupta et al., 2005). The work of Kenfack et al. (2023) also highlights the possibilities for modern gastronomic valuation of Gnetum spp. in innovative culinary approaches and sustainable food systems. The evolution of settlements along the rural-urban continuum modifies agrifood systems and has consequences for the availability and affordability of healthy foods, and thus for food security and nutrition (FAO, 2024).

Another series of studies has documented the socio-economic importance, markets, and nutritional value of useful plants from the forests of the Congo Basin (Ingram et al., 2012). Strong demand coming from major urban centers reveals an increase in anthropogenic pressure on wild species (Ingram et al., 2012). This is the case, for example, with the demand for gathered plant resources (Ndoye, 1995). This urban demand trend is expected to continue or even increase due to urbanization, population growth in cities like Libreville, Kinshasa, and Yaoundé, and the development of cross-border and regional trade (Ingram et al., 2012; Ingram et al., 2012).

The low regeneration of certain natural resources providing dietary NWFPs is caused by inappropriate and excessive harvesting methods (Mwengi et al., 2009). Pressure is greater for species:

- Whose generative parts are exploited, such as fruits and kernels (e.g., Irvingia gabonensis, Garcinia kola, etc.)
- that have a well-developed market, whether national, regional, or international, such as Gnetum spp. (Ingram et al., 2012).

The poverty of riparian populations is, in most cases, the root cause of the pressure from exploitation on natural resources (Darpy & Guillard, 2020). While the seasonality and annual variability of NTFP production make it difficult to establish them as a primary income-generating activity, the lack of alternatives forces households to exert strong pressure (Darpy & Guillard, 2020). Unfortunately, insufficient knowledge of regeneration and domestication practices may hinder the sustainable management and valorization of Gnetum africanum, particularly in areas experiencing increasing harvesting pressure (Ndam et al., 2001).

Just as in Gabon, the restaurant sector occupies a prime spot in the lives of populations. Vegetables are widely used in gastronomy and serve as identity markers because of the important role they play in tradition and health. Several authors have demonstrated that African leafy vegetables play an essential role in preventing non-communicable diseases thanks to their high content of antioxidants, fibers, and micronutrients (WHO, 2020; Uusiku et al., 2010). In contrast, in the provinces of Ogooué Lolo and Haut Ogooué, Gnetum is often prepared and mixed with smoked fish or dried bushmeat. In major cities like Libreville and Port-Gentil, dishes are sometimes made solely of vegetables.

However, Gnetum is prized particularly for its nutritional value. The leaves can be consumed raw or finely chopped and added to soups and stews (Burkill, 1994). Although G. bucholzianum leaves are also nutritious, they are harder to find in commerce (Burkill, 1994). Both G. africanum and G. bucholzianum leaves have high nutritional value and constitute important sources of proteins, amino acids, and minerals (Uusiku et al., 2010). Gnetum africanum and Gnetum bucholzianum leaves represent an important commercial commodity in Central Africa (Ingram et al., 2012; Ingram et al., 2012).

In markets, edible NWFPs are presented in a ready-to-cook form. However, an examination of their dietary use shows that they are divided into main groups. First,

- NWFPs of major commercial importance, used as a main dish or seasoning, including Gnetum africanum, Irvingia gabonensis, Dacryodes edulis, Garcinia kola, etc. (Ingram et al., 2012).
- Second, NWFPs with a low level of commercialization, mainly fruits that ripen on trees before harvesting, such as Aframomum species. The primary constraint regarding the packaging of NWFPs remains the nature of the products, which are perishable items that are difficult to transport and store (Ingram et al., 2012). Their processing requires a know-how passed down from generation to generation.

Gnetum leaves form part of the diets of all social classes and constitute a highly valuable source of proteins and mineral elements (Loubelo, 2012). Indeed, Gnetum leaves have a relatively high content of mineral substances and proteins, 16% to 18% depending on the species considered (Loubelo, 2012). The presence of essential amino acids in Gnetum leaves confers a high nutritional value to this food; moreover, leafy vegetables generally constitute a valuable supplement regarding vitamin and mineral salt intake (Loubelo, 2012). Gnetum bucholzianum has the same characteristics as Gnetum africanum. The essential difference lies in the biotope, the width and color of the leaves, and finally the chemical composition (Loubelo, 2012).

Indeed, Gnetum leaves contain carbohydrates, lipids, proteins, and minerals (Loubelo, 2012). The tables below (Table 1) show the percentage of each of these nutrients based on literature data (Loubelo, 2012).

Table 1. Percentage of dry matter

Species	Proteins	Lipids	Carbohydrates		Minerals
			Total	Cellulose	
Gnetum africanum	16.5	5.9	70.6	40.0	7.0
Gnetum bucholzianum	18.2	6.2	-	39.5	-

Mialoundama, cited by Enoch L. (2012)

The analysis of Table 1 reveals that Gnetum bucholzianum contains more proteins and lipids than Gnetum africanum. On the other hand, the percentage of cellulose in Gnetum africanum is slightly higher than that of Gnetum bucholzianum.

Table 2 shows that in the species Gnetum africanum, the potassium (K) content is higher, while it is very low in sodium. In contrast, the potassium content is lower in the species Gnetum bucholzianum and lower in sodium. This genus contains almost no chlorine.

Table 2. Macroelement content of Gnetum leaves

Elements	Gnetum Africanum	Gnetum Bulchholzianum
Potassium (K)	0,978	0,544
Phosphorus (P)	0,167	0,544
Calcium (ca)	0,830	0,108
Magnesium (Mg)	0,395	0,334
Sodium (Na)	0,157	0,184
Chlorine (cl)	0,384	0,016
Sulfur (S)	0,381	0,030
Silicon dioxide (SiO2)	0,169	0,131

Mialoundama, cited by Enoch L. (2012)

The analysis in Table 3 shows that manganese is highly abundant in the species Gnetum africanum. There is almost no copper in the species Gnetum bucholzianum.

Table 3. Microelement content of Gnetum leaves

Elements	Gnetum Africanum	Gnetum Bulchholzianum
Manganese (Mn)	243,1	231,4
Iron (Fe)	162,6	168,6
Aluminum (Al)	133,5	106,5
Boron (B)	24,4	22,9
Copper (Cu)	12,5	3,4
Zinc (Zn)	24,1	12,1

Mialoundama, cited by Enoch L. (2012)

The same applies to the species Gnetum africanum regarding this microelement. As non-timber forest products are part of consumer goods, their demand fits within the literature on consumer theory. This consumer choice depends on numerous factors, notably those related to wealth, current income, future income, and preferences. Within households, the determinants of consumption can be grouped into economic factors, socio-cultural factors, socio-demographic factors, and institutional factors (Darpy & Guillard, 2020).

In economic history, three currents are identified in explaining consumer theory. First, for the classical and neoclassical economists, individuals face a trade-off between consumption and savings when allocating their income, taking into account the interest rate. For them, consumption is nothing more than the residue of savings. The consumer makes a choice of a consumer good that can maximize satisfaction under income constraints.

Second, unlike the classical and neoclassical economists who analyze consumption using a microeconomic approach, Keynesians approach this theory from a macroeconomic perspective, considering that consumption increases with national income, a portion of which is saved. According to Keynes, consumption remains stable because it reflects short-term household habits. Third, Friedman divides income into two components: transitory income and permanent income. Consumption is therefore a function of long-term variations in permanent income, and any change in transitory income has no effect on consumer behavior. It is evident that the demand for NWFPs is bound to increase considerably as purchasing power rises, the population grows, rural-to-urban migration becomes easier, and agricultural products from rudimentary production systems prove insufficient to ensure food security; reducing transport costs and increasing demand make the NTFP trade more lucrative, encouraging more people to enter it (Darpy & Guillard, 2020).

For several years, NWFPs have drawn considerable global interest. This is explained by the increased awareness of their contribution to certain environmental objectives such as the conservation of biological diversity, consumption, and certain medical practices. Several non-timber forest products provide raw materials for small-scale, semi-industrial processing operations (FAO, 2010).

Consequently, several studies conducted in different contexts have highlighted the importance and value of Gnetum africanum. Among these, Kapemba et al. (2023) examined the consumption of Gnetum africanum in Kananga and highlighted its importance as a non-timber forest product in Central Africa. The authors also emphasized the pressure exerted on wild populations by harvesting practices, underscoring the need to promote domestication and sustainable management of this valuable leafy vegetable.

They constitute, they affirm, the object of a considerable national and cross-border trade. This trade has experienced a dramatic increase, and the resource is seriously threatened by unsustainable harvesting methods, which causes the progressive disappearance of their habitat. His objective was to invite local populations to domesticate these resources in fallow lands with the aim of ensuring and reinforcing their sustainability through rational and sustainable exploitation. This is crucial because human growth inevitably depends on a qualitatively and quantitatively balanced diet, providing proteins, lipids, carbohydrates, as well as vitamins and proteins that are rarely of animal origin; this diet is based on leaves, vegetables, or fruits that are financially affordable for the lower class of the population.

Mpanzu Balomba (2009) analyzes the socio-economic contribution of the Gnetum africanum value chain in the Democratic Republic of Congo (DRC). Focusing on the case of supplying Kinshasa from Kananga, he estimates in his analysis that the Gnetum value chain plays a major role in diversifying the income of smallholders, as this chain, he adds, is particularly long and involves several actors. Gnetum africanum, as a food, but also as a source of income, contributes significantly to the food security of the households of the actors involved in the value chain, notably the producers or gatherers, but also the consumers. He shows that the profit margin generated by gatherers—particularly women in remote regions where local consumption is low—is not significant. Instead, the actors who achieve the best profit profiles are those located far from the gathering zones, precisely those in Kinshasa.

The socio-economic approach used to analyze the said value chain demonstrated the importance of considering factors located outside the immediate field of the commercial activity of the value chain's actors. Such an approach, which places economic activity within the context of the social structure, allowed for a coherent analysis capable of driving effective policy actions regarding the urban supply system of non-timber forest products.

In another context, Mwengi et al., (2009) addresses a socio-economic analysis of Gnetum africanum gathering in the Monkoto territory in Équateur. He showed that the exploitation of Gnetum africanum in the Monkoto territory plays an important role in diversifying household income, but the gathering techniques practiced remain less sustainable for the regeneration of the species in its natural habitat. He demonstrates the dietary importance of Gnetum africanum in urban environments, noting that the income generated by households drives high pressure on resources; the distance of the gathering environment relative to residential areas is one of the indicators of scarcity. He states that in Monkoto, women are more active in gathering Gnetum africanum, accounting for 89%, and that it forms part of the diet of a significant portion of the population, while a large share is intended for sale. The Gnetum harvesting practices he identified in this region include: the single removal of leaves, leaving the plant bare, and the pulling up or uprooting of the entire plant before removing the leaves. All of these harvesting practices identified for Gnetum africanum compromise any possibility of the plant's renewal.

However, Loubelo and Mialoundama (2002) showed that female retailers in the Gnetum trade in Congo Brazzaville had a monthly income higher than that of civil servants in the 5th or even 6th category of the Congolese public service. They place themselves clearly above the minimum wage (SMIG) in the Republic of the Congo. Gnetum leaves can be consumed raw, but in general, they constitute a supplementary food added to meat or fish dishes. In the book "La cuisine congolaise" (Mialoundama et al., 2001), numerous recipes involving Gnetum leaves are described in the Republic of the Congo, notably the "trois pièces" (three pieces) recipe. In this recipe, the main ingredients are Gnetum leaves, peanut paste, and smoked or salted fish, thereby justifying the name given to it (Loubelo, 2012).

Regional literature confirms the economic and food-security importance of non-timber forest products and the particular role of Gnetum in Central African value chains. Studies in Cameroon and the Congo Basin show that Gnetum contributes to household livelihoods and is traded through several market channels (Ndoye, 1995; Ingram et al., 2012; Loubelo, 2012).

The majority of NWFPs do not keep well due to poor packaging. Consequently, it is impossible in the medium and long term to defer consumption over time and space. Furthermore, significant post-harvest losses are observed, leading to a waste of the resource and a reduction in income for the actors in the value chain (Nguimbi, 2006). According to Loubelo (2012), based on Mialoundama (1993), specialties based on Gnetum leaves play a role that goes beyond their dietary use. Central African populations express their cultural identity through the use of these dishes, which take on an emblematic value. This explains why an individual far from their country of origin seeks out and prefers dishes based on Gnetum leaves. People search for the plant that was consumed both during ceremonies and in everyday meals in their country of origin.

Many authors have worked on plant-based NWFPs and other domesticated leafy vegetables, but very few have evaluated the impact of cooking techniques on the qualitative and quantitative availability of nutrients for the well-being of the consumers of these NWFPs.

Cooking methods have a significant influence on the bioavailability of dietary nutrients and gastronomy (Ukom et al., 2023). Cooking induces significant changes in the chemical composition, concentration, and bioavailability of nutrients and bioactive compounds in vegetables (Ukom et al., 2023). Cooking methods have both positive and negative effects on the nutrients and antioxidant potential of vegetables. The phenolic content and antioxidant activity of vegetables increased when they were blanched, boiled, fried, steamed, or microwaved (Ukom et al., 2023). However, blanching at 98 °C for 2 minutes reduced the phenolic compounds and antioxidant capacity of certain vegetables (Ukom et al., 2023).

The proportion to which nutrients contained in vegetables are preserved after cooking compared to the quantity of nutritive elements present in the raw vegetables before processing is called nutrient retention. Nutrient retention after processing is important to ensure the consumption of nutrient-dense foods for proper human growth, development, and disease prevention (Ukom et al., 2023). This is crucial for the nutrition of indigenous peoples, whose primary source of micronutrients to improve their physiological health depends on these vegetables as food. It becomes imperative to evaluate the concentration of essential nutrients in these cooked vegetables compared to uncooked vegetables for their nutrient retention and health benefits (Ukom et al., 2023).

Studies of non-timber forest products in Central Africa show that these resources contribute to household income, employment, food supply, and market activity. For Gnetum specifically, value-chain research in Cameroon and Nigeria highlights the importance of harvesters, traders, transporters, exporters, and consumers, as well as the economic and sustainability challenges associated with increasing demand (Ndoye, 1995; Ingram et al., 2012).

They represent a significant fraction of the monetary income of agricultural households. Some households have, moreover, undertaken to integrate NWFPs more closely into their income-generation strategies. The study reveals a relatively sophisticated knowledge among farmers regarding the cultivation conditions and requirements of different species. There are many other species that, through the commercialization of these NWFPs, can provide substantial incomes that are far from negligible. If there were still any doubt, we have proof here that preserving trees in agroforestry parks is not merely an environmental issue: it is also, very often, a matter of food security and significant financial income.

In India, for example, as in other countries, forest management was traditionally centered on timber production; NWFPs, including fuel and fodder biomass, grasses, oils, resins, and medicinal herbs, were generally relegated to the status of by-products of the timber production process. As revenues from NWFPs or "minor forest products" significantly increased, sometimes reaching the levels of timber sales, several Indian states established forest development corporations to organize the collection and marketing of NWFPs on a professional basis.

The objectives were to eliminate intermediaries in order to maximize the benefits transferred to tribal populations or the rural poor who gather NWFPs; to improve the marketing of these products both qualitatively and quantitatively; and to exploit NWFPs on a sustainable basis (Ouédraogo et al., 2013). Their surveys, which were conducted among 583 households, show that the economic dependence of households on NWFPs is estimated at 12%. This dependence decreases as income rises, reflecting a greater reliance of poor households on NWFPs. Furthermore, men are economically less dependent on NWFPs than women. Other determinants of NTFP dependence include indigenous status, household size, forest area, and the population density of the department, all of which positively affect dependence on NWFPs.

Tiemtore (2004), in his descriptive analyses of the results, shows that these products are largely consumed in low-income households, where they represent larger shares of household income. His results also indicate the predominant position of Soumbala in household diets. Kapok flowers, baobab leaves, and tamarind come in second, third, and fourth positions, respectively. Shea butter and Acacia macrostachya seeds represent less significant shares in household nutrition. Econometrically, his results attest that income, the age of the household head, household size, the gender of the household head, the number of years spent in the city by the household head, and the marital status of the household head jointly contribute to explaining the demand for non-timber forest products. Moyene (2009), in his study, focused on the valuation of NWFPs on the Batéké plateaus.

Under the category of vegetables, two species are characteristic: Nkumu, which groups two species (Gnetum africanum and G. bucholzianum), and Begonia sp. But it is Nkumu that constitutes the highly prized vegetable of the Gabonese populations. Indeed, the leaves of this species, well known to the populations, are consumed by them. The leaves are finely cut, subsequently consumed after cooking by the populations, or sold on local markets. This is a species with a wide distribution spectrum that covers all of Central Africa, extending from Angola to Cameroon, passing through the Congos, Nigeria, and the Central African Republic. The species, which is often a very long vine with red fruits (fleshy and red aril) containing a white seed, colonizes primary and secondary forest formations.

In Gabon, it is found virtually throughout the entire country and particularly in the south, west, and northeast formations. In the southeast, the species colonizes forest galleries and forest patches in the savanna, principally on the Batéké plateaus where the populations are extremely fond of it. Edible NWFPs are numerous and highly varied; some are well known and systematically cataloged, while a large majority remains unknown to most people. Their use can vary from one region to another or from one community to another. Similarly, for the same species, several uses are recorded, always depending on the type of community, region, or even country (Mialoundama, 1993).

The documentary review carried out on NWFPs in Africa, and specifically in Gabon, allows us to understand that studies have been conducted on natural habitats, regeneration, harvesting methods, and rational, regulated exploitation for the survival of resources. Furthermore, the value chain of most NWFPs has not been fully studied, with the notable exception of Gnetum, which has been investigated in several countries of the sub-region. Certain equally important yet neglected aspects include the study of cooking techniques and their impacts on the nutritional quality of main plant NWFPs. However, Gnetum, having benefited from numerous studies, should benefit from even more so that this plant can be better utilized and contribute to the fight against undernourishment and malnutrition in Africa and worldwide.

Thus, this study stands out from those cited above, not only due to its context—as it focuses here on studying the impacts of the most common cooking techniques used in Gnetum recipes on the quality and quantity of its nutrients (proteins and mineral salts)—but also on studying aspects related to the place of NWFPs in Gabonese gastronomy. Gnetum, as a food, but also as a source of income and for its medicinal virtues, contributes significantly to the food security of the households of the actors involved in the value chain, notably small producers (gatherers) but also consumers (Loubelo, 2012).

4. Approach to the Object of Study

4.1. General Context

According to the FAO (2003), non-timber forest products are "products of biological origin, other than wood, derived from forests, other wooded lands, and trees outside forests, and intended for human consumption, animal feed, agro-industrial processing, and marketing". They can be harvested in the wild, produced in forest plantations, within agroforestry perimeters, or from trees outside forests.

In Central Africa, particularly in Gabon, we have observed a frequent and customary consumption of fruits and vegetables, and we have focused our attention specifically on some of these plant-based NWFPs. Gnetum africanum is of great importance to many forest communities and is given various vernacular and commercial names; for example, in the Central African Republic, Gabon, Congo, and Angola, the species is called KOKO (Kapemba et al., 2023). Bioactive substances have aroused considerable interest among food researchers due to their positive impact on human health. Bioactive compounds are naturally occurring constituents of plants, including secondary metabolites such as phenolic compounds, flavonoids, carotenoids, and other phytochemicals, which may contribute to the nutritional and health-promoting properties of plant foods (Ukom et al., 2023; Moyo et al., 2018).

This choice is justified because we are in a forested country where certain species of plants and trees are protected, and whose logging and overexploitation are prohibited by the government. The majority of fruits and vegetables consumed come from home gardens or plantations established by humans, while a minority comes from the forest. Gnetum africanum, which belongs to this minority of NWFPs consumed in Gabon, is highly appreciated in certain provinces. “This product, widely used as a vegetable, constitutes a highly valuable source of proteins, essential amino acids, and mineral salts” (Loubelo, 2012). Our interest in NWFPs is sparked by the different ways in which they are exploited. An unqualitative and very poorly rationalized exploitation drew our attention and prompted this research idea.

This preferred vegetable among populations in Northern and Southern Gabon is sometimes irreplaceable. Abia et al. (2007) analyzed the energy and nutrient contents of the traditional Cameroonian dish “waterfufu and eru” to assess its contribution to recommended dietary allowances. The results showed that the average portion size of the dish was 409 g. This quantity provides 601 kcal of energy, 281 g of moisture, 82 g of carbohydrates, 30 g of lipids, 11 g of protein, and 5 g of ash on a fresh weight basis. Micronutrients were also identified, notably iron (14.02 mg) and zinc (1.23 mg). The authors suggested improving the dietary contribution of the dish through appropriate fortification or supplementation (Abia et al., 2007). Cassava pieces (38%) are used as a complement to KOKO. Alongside these foods with which Gnetum is most frequently consumed in the city of Douala, Gnetum is also eaten with ripe plantain, macabo, yam, and sweet potato (Loubelo, 2012).

NWFPs play a very important socio-economic role, as demonstrated by the work of several authors (Ndoye, 1995; Ingram et al., 2012). They offer diverse benefits to forest communities, for example, by providing food, medicines, and income. In an article published in 2002, Isabel Chabot states that “The results showed that in Gabon, a significant quantity of NWFPs are transported to Libreville to feed the urban population, and it turns out that gatherers and hunters are going further and further to restock. It is therefore necessary to know which species are threatened. Furthermore, it is important to differentiate between the use of NWFPs by populations for their subsistence and commercial use (this is especially the case for hunting and rattan)”. She refers to forest products as a whole, but our study will be oriented toward research conducted on these NWFPs, focusing on the techniques and preparation methods of Gnetum africanum on the well-being of local populations, and the place of NWFPs in Gabonese gastronomy.

According to Bikoue et al. (2007), numerous studies in plant biology and physiology have well-documented NWFPs, allowing for their domestication and sustainable production for the benefit of consumers and the diversification of Central Africa's economy. Their processing, currently limited to households, could be useful to agri-food SMEs.

As a regional comparison, Kapemba et al. (2023) reported that consumption of Gnetum africanum in Kananga was associated with household and socio-cultural factors. These findings are cited only to situate the present study within the broader Central African literature and are not results from the Greater Libreville survey.

In this study, we will investigate the impact of the preparation techniques of Gnetum africanum on its nutritional quality and determine the place of NWFPs in Gabonese gastronomy. For edible NWFPs (Gnetum, Irvingia), gathering, collecting, and distribution operations are carried out by women. Bushmeat and Dacryodes edulis are produced by men, who deliver them to women for insertion into marketing channels. In all cases, the transport of NWFPs, even if paid for by female traders, is carried out by men (Nguimbi, 2006).

According to the Global Forest Resources Assessment, Bikoue et al. classify NWFPs into 16 categories, namely:

- Eight categories of plant products: food, forage, raw material for the preparation of medicines and aromatic products, raw material for the preparation of colorants and dyes, raw material for the manufacturing of utensils, handicrafts, and construction, ornamental plants, and other plant products.
- Eight categories of animal products: live animals, hides, skins, wild honey, and beeswax, bushmeat, raw material for the preparation of medicines, raw materials for the preparation of colorants, other edible animal products, and other non-edible animal products.

Our study, which will be oriented toward plant-based NWFPs intended for food, could enable the creation of a sustainable, rational, and optimal exploitation model for this resource. Fruits and vegetables are, without a doubt, important components of a healthy and balanced diet. They provide significant amounts of minerals, vitamins, carbohydrates, proteins, dietary fiber, as well as various phytochemical compounds including antioxidants (carotenoids, polyphenols, etc.). The latter are involved in protection against various chronic pathologies such as cardiovascular diseases and cancers (Ukom et al., 2023).

The scientific interest of this study is to determine the technique or techniques that best preserve the organoleptic and nutritional properties of these nutrient-rich products. This study will help provide appropriate gastronomic guidance to populations without, however, impacting their dietary habits or culture; to a certain extent, it will improve the nutritional quality of this product within certain communities, and finally, enable better environmental management and preserve certain forest species.

Nowadays, the consumption of Gnetum africanum leaves is experiencing a considerable expansion. These leaves are gathered from the forest, properly washed with water, bunched together, and cut into fine shreds of vegetables, and then boiled in water for a certain duration until the water has completely evaporated. After this evaporation, peanut paste and a little palm oil are added, along with either smoked fish, smoked meat, or salted fish and condiments; it is then boiled one last time. Alternatively, this final step may call for strained palm-nut juice instead of peanut paste and palm oil, which creates an entire value chain (Loubelo, 2012).

The commercialization of Gnetum africanum in the D.R. Congo is both an economic and a social phenomenon. It is economic because it generates monetary exchanges within a large circulating environment for this product, involving a division of labor and a certain homogeneous framework of marketing methods. It also touches upon the social aspect because, in dealing with multiple consumers of Gnetum leaves, it prompts an inquiry into their socio-professional categories, uncovering the class of the heaviest consumers of this product. In other words, what explains the choice to consume this product (Darpy & Guillard, 2020).

Most vegetables are consumed after cooking. They are cooked in different ways depending on the recipes and culinary traditions of each country. The application of thermal treatment during domestic cooking encompasses a variety of processes such as boiling, frying, steaming, baking, sous-vide, or microwaving (Ukom et al., 2023).

The cooking of leafy vegetables results in the destruction of germs or parasites, the elimination of toxic substances, and the improvement of nutritional quality. These phenomena depend on the texture of the leaves, temperature, and cooking time (Bayengue et al., 2017). Gnetum spp vegetables are tough and have a low water content of less than 40% (Mialoundama, 1993; Bayengue et al., 2017). In order to soften these leathery leaves and facilitate digestion, they are generally cut into small pieces by housewives and boiled in water for over 1 hour. Some nutrients and anti-nutrients are lost when food is cooked (Bayengue et al., 2017).

Reducing the anti-nutrient content of a food, particularly regarding proteins, could improve its nutritional value. The extent of anti-nutrient reduction is not known to the local population until now. Where Gnetum spp leaves are concerned, determining the effect of prolonged cooking on protein content and digestibility could lead to a better nutritional utilization of these vegetables, knowing the changes that occur in the food. From preparation to the table, this is essential not only for scientific research but also for the consumer, who can make decisions on how to prepare and cook a number of healthy vegetables and legumes (Bayengue et al., 2017).

5. Methodology

5.1. Study Area

Data collection was carried out primarily among individuals in the Estuaire Province, which is a cosmopolitan city containing more than half of the Gabonese population, and more precisely within Greater Libreville, which is the most densely populated city in Gabon; the Estuaire Province (Libreville) represents ≈50% of the Gabonese population (Direction Générale de la Statistique, 2015).

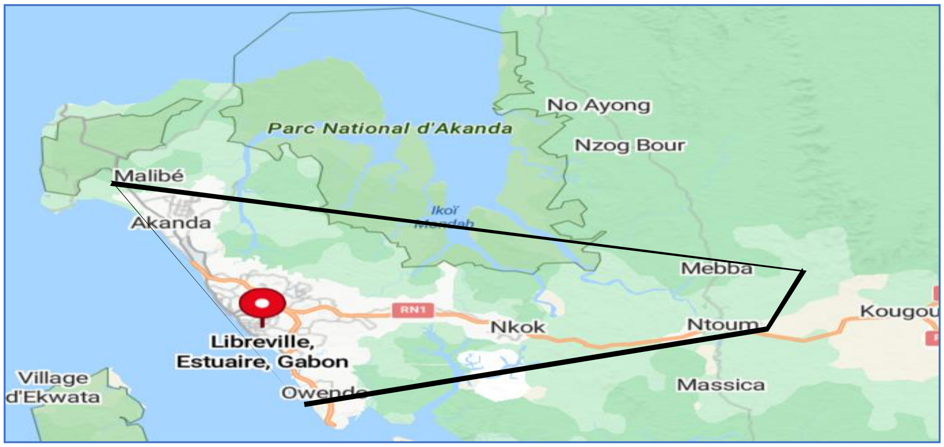

Figure 1. Zone of study

This region, being the most densely populated in terms of population, allows us to obtain a balanced, homogeneous, and culturally diversified sampling.

5.2. Sampling and Data Collection

Information was collected on the consumption frequency of Gnetum in approximately 350 households; on the culinary techniques used, the reasons for choosing those specific techniques, and the other plant-based non-timber forest products consumed along with their frequency. Gnetum leaves were collected from 5 different supply points where households restock, namely: the small Akanda market after the GIGI intersection, the small markets of Akournam 2 and Awoungou in Owendo, the Mont Bouet market in Libreville, and the PK 12 market in the commune of Ntoum, in order to obtain concrete and realistic data regarding the plant sample.

The samples were collected over a 3-day period and in the most ordinary manner possible, reflecting the daily living conditions of consumers. A pooling or mixing of the different samples from the various collection points was carried out to obtain an average sample, which served as the basis for our different preparations to be analysed (Fig. 2).

Figure 2. Chopped Nkumu detailed in heaps for sale

5.3. Sample Preparation

Traditional cuisine maintains 4 traditional recipes: Nkumu in water, Nkumu with peanut paste, Nkumu Nyembouè, Nkumu O'fula (Table 4).

Table 4. Tradicional recipes

Raw samples of chopped Gnetum spp.	Sample 0 Fresh chopped Nkumu (control)	
• Fresh chopped Nkumu (control) • Boil water and palm oil for 5 minutes in a pot. • Add the bouillon cube and a pinch of salt, let boil for 5 min. • Simultaneously add the mushrooms, shrimp, and fish (previously cleaned), then let boil for 5 to 8 min. • Add the nkumu, stir very gently, leave over low heat for 5 min, and remove from the heat; do not cover the pot, otherwise the nkumu will turn red. • Taste and adjust seasoning if possible.	Sample 1 Nkumu in water	
• Heat a sufficient amount of oil in a pot. • Add the peanut paste. • Stir the mixture, then add the meat, fish, or shrimp. • Stir until the proteins are well coated. • Add water and let boil for about 5 to 10 minutes. • Finally, add the nkumu and stir gently to mix everything. • Let cook for 10 to 15 minutes. • Taste and adjust seasoning if possible.	Sample 2 Nkumu with peanut paste	
• Extract the palm nut juice (if whole nuts are available). • Cook the palm nut juice in the pot until a thick sauce is obtained. • Add onions, pepper, or chili. • Add the smoked fish, dried or fried shrimp, or smoked meat (optional). • Add the finely cut NKUMU leaves. • Let simmer until thoroughly cooked. • Taste and adjust seasoning if possible.	Sample 3 Nkumu in palm oil or Nyembouè	

• Wash the NKUMU leaves carefully and cut them very finely. • Mix the indigenous salt with water, and boil the mixture in a pot for about 5 minutes. • When the mixture is hot, add the fish (smoked or fried), smoked meat, or shrimp. • Stir everything until the proteins are well coated. • Add the chopped nkumu into the pot. • Stir gently to thoroughly mix the nkumu with the other ingredients. • Allow the liquid to reduce and let everything cook. • Add hot or cold palm oil (optional). • Taste and adjust seasoning if possible.	Sample 4 Nkumu O'fula	

5.4. Analytical Methods

5.4.1. Determination of Total Lipid Content

The total lipid content of the samples was determined following the 1980 AOAC method, after hot extraction in a Soxhlet extractor followed by distillation using a vacuum rotary evaporator in a water bath at 60 °C. Approximately 5 g of dry matter (P0) was weighed, carefully wrapped in Whatman No. 3 filter paper, and placed in a cellulose thimble. The assembly was introduced into the extractor of the Soxhlet apparatus, mounted on a flask (washed and dried) containing 3 glass beads. The solvent was poured into the extractor until siphoning occurred, and an additional amount of solvent was added to the extractor up to half of the siphon. The condenser was mounted on the extractor, and the flask was heated for at least 6 hours.

It was subsequently placed in the rotary evaporator to remove the solvent from the collected oil. The flask was placed to dry in an oven at 65 °C for 24 hours to eliminate any trace of solvent and moisture from the flask. It was then cooled in a desiccator and weighed. Let P1 be the weight of the flask plus glass beads before extraction, and P2 the weight of the flask plus glass beads after extraction. The lipid content was given by the following formula (1):

$$\boldsymbol{Lipid\ Content}\ (\%) = \left(\frac{P_2 - P_1}{P_0}\right) \times 100 \tag{1}$$

P_2: Weight of the flask + glass beads after extraction (g); P_1: Weight of the flask + glass beads before extraction (g); P_0: Weight of the dry matter (g).

5.4.2. Determination of Dry Matter Content

The dry matter content of the different leaves extracts was determined according to the method described by the Horwitz & Association of Official Analytical Chemists (1990). Five (5) g of each sample were placed in an oven at 105 °C until a constant weight was obtained (based on three trials for each variety). The dry matter content was determined by differential weighing according to the following formula (2):

$$\boldsymbol{Dry\ Matter}\ (\%) = \left(\frac{P_2 - P_0}{P_1}\right) \times 100 \tag{2}$$

P_0: Empty weight of the crucible (g); P_1: Weight of the fresh sample (g); P_2: Weight of the dried sample and the crucible (g). The final dry matter content is obtained by averaging the three trials.

5.4.3. Determination of Moisture Content

Moisture content is the effective proportion (total, measurable) of water in the different leaves. Moisture content was determined by the gravimetric method described by the AOAC in 1980. Approximately 1.5 g of fresh food, P_1, weighed in an aluminum dish, was placed in an oven at a temperature of 105 °C and then weighed regularly until a constant weight was achieved. The dry matter was allowed to cool in a desiccator containing a desiccant for 1 hour (h), and its weight P_2 was determined by weighing the dish to the nearest 0.001 g according to the following formula (3):

$$\boldsymbol{MC}(\%) = \left(\frac{P_2 - P_0}{P_1}\right) \times 100 \tag{3}$$

P_0: Empty weight of the dish (g); P_1: Weight of the moist sample + dish (g); P_2: Weight of the dried sample + dish (g); MC: Moisture content expressed as a % of dry matter.

5.4.4. Determination of Ash Content

Total ash content was determined by the AOAC method (1980). A porcelain crucible, carefully washed with water and rinsed with 10% nitric acid to remove any trace of mineral matter, was dried in an oven at 65 °C for 1 hour. It was then placed in a muffle furnace at 550 °C for 3 hours to destroy any trace of organic matter. Upon removal from the furnace, it was cooled in a desiccator for 1 hour, and its empty weight P_1 was determined. Approximately 2 g of dry matter (P_0) of the sample was weighed into the crucible. The assembly was placed in the furnace at 550 °C for 48 hours. Upon removal from the furnace, the crucible containing the ash was cooled in a desiccator for 1 hour and weighed (P_2) to the nearest 0.001 g. Following the incineration of the leaves at 550 °C for approximately 12 hours in an electric furnace, it was determined by differential weighing according to the following formula (4):

$$\boldsymbol{AC}\ (\%) = \left(\frac{P_2 - P_0}{P_1}\right) \times 100 \tag{4}$$

P_0: Weight of the dry sample (g); P_1: Empty weight of the crucible (g); P_2: Weight of the crucible + ash (g); AC: Ash content expressed in g of ash / 100g of dry matter (MS).

5.4.5. Determination of Crude Fiber Content

Crude fibers or insoluble fibers include cellulose, some hemicelluloses, and lignin. The crude fiber content was determined according to the Weende method (International Organization for Standardization [ISO], 1981). This method consists of treating the sample at the boiling point with sulfuric acid and subsequently with sodium hydroxide. The resulting residue is dried, then calcined and weighed. A quantity M of the sample was introduced into a beaker containing sulfuric acid (H_2SO_4 98%, 0.255 N). The mixture was then brought to a boil for 30 min and filtered. To the residue, sodium hydroxide (NaOH, 0.313 N) was added, and the mixture was again brought to a boil for 30 min. After filtration, the residue was washed 3 times with hot distilled water and 2 times with acetone. The obtained insoluble matter was dried at 105 °C for 8 hours and weighed (P_1). This dry residue was subjected to incineration at 550 °C for 3 hours, and the ash was weighed (P_2). The crude fiber content (g/100g MS) was given by the following relationship (5):

$$\textbf{\textit{Crude Fiber}}\ (\%) = [\frac{(P_1 - P_2)(100 - Te)}{M * (100 - Te)}] \times 100 \quad (5)$$

P_2: weight of food + glass before extraction (g); P_1: weight of food + glass after extraction (g); M: mass of sample (g).

5.4.6. Determination of Total Protein Content

Crude protein content was determined on the different extracts of Nkumu samples following the Kjeldahl method (AOAC, 1980), through three steps:

Digestion: In a digestion flask (matrass) carefully washed and dried in an oven, approximately 0.5 g of dry matter of the food sample, 10 mL of concentrated sulfuric acid, and a pinch of digestion catalyst were added. The assembly was heated on a digestion bench placed under a fume hood for 2 to 3 hours, with the neck of the flask engaged in a smoke collector tube. Digestion is complete when the syrupy black mixture at the start of heating becomes colorless. The digest thus obtained was allowed to cool for 24 hours.

Distillation: This takes place in a distillation apparatus, specifically the "Semi-automatic Kjeldahl Distillation system, Shijiazhuang Qintong Imp&Exp Trade Co., Ltd". In an Erlenmeyer flask, 50 mL of boric acid solution (H_3BO_3, 4%) and four drops of Tashiro indicator (methyl red + bromocresol green) were introduced; this solution serves to trap the nitrogen from the digest. A volume of 10 mL of distilled water was added to the contents of the digestion flask to mitigate the acidity of the medium.

The digestion flask and the Erlenmeyer flask were placed in their respective positions within the distillation unit. Using a lever, the volume of the digestion flask was adjusted to 50 mL by introducing sodium hydroxide (NaOH, 40%) contained in a tank to neutralize the acidity of the digestion flask contents. The ammonia (NH_4OH) displaced by the sodium hydroxide is carried over as vapor and condensed in the condenser, which is constantly supplied with tap water. The distillate, collected in the Erlenmeyer flask containing the "trapping" solution, was condensed in the form of ammonium borate. As soon as the first drop of distillate falls into the Erlenmeyer flask, the initially pink-violet coloration progressively turns green. Distillation is complete after 4 min and is expressed by two equations (6, 7):

$$(NH_4)_2SO_4 + 2NaOH \rightarrow 2NH_4OH + Na_2SO_4 \quad (6)$$
Sulfuric acid derivative + Sodium hydroxide → Ammonium + Sodium sulfate

$$H_3BO_3 + 3NH_4OH \rightarrow (NH_4)_3BO_3 + 3H_sO \quad (7)$$
Boric acid + Ammonium → Ammonium borate

Titration: The distillate was titrated with sulfuric acid (0.1 N). During this step, ammonium sulfate is formed, and boric acid is regenerated according to the following equation (8):

$$(NH_4)_3BO_3 + \frac{3}{2}H_2SO_4 \rightarrow \frac{3}{2}(NH_4)_4 + H_3BO_3 \quad (8)$$
Ammonium borate + Sulfuric acid → Ammonium sulfate + Boric acid

A digestion flask containing no dry food sample ("blank") was subjected to the same operating procedure. It allows for the evaluation of trace nitrogen that might originate from the reagents. Let N be the normality of the sulfuric acid, and V_e and V_t the volumes in mL of acid required to titrate the sample and the blank, respectively. The protein content was obtained by multiplying the nitrogen content (%) by the general conversion factor (F=6.25) recommended for complex foods (Eq. 9, 10):

$$\boldsymbol{Nitrogen}\ (\%) = \frac{(V_{e-}V_t) \times N \times 1.401}{M} \quad (9)$$

$$\boldsymbol{Protein\ Content}\ (\%) = Nitrogen\ (\%) \times 6.25 \quad (10)$$

V_e: Volume of HCl used for sample titration (mL); V_t: Volume of HCl used for blank titration (mL); N: Normality of the acid used for titration; M: Mass of the sample (g); 6.25: Conversion factor from nitrogen to protein; 1.401: Constant.

5.4.7. Determination of Total Carbohydrate Content

According to the 1980 AOAC method, the measurement of the total quantity of carbohydrates (or assimilable carbohydrates) in a foodstuff is generally performed by calculation (difference from other nutrients). When it is not necessary to know the individual sugars present in a food, one can rely on calculating the overall carbohydrate content by difference with the other constituents (11):

$$\boldsymbol{Carbohydrates} = total - [Moisture + Protein + Fiber + Lipids + Ash] \quad (11)$$

5.4.8. Mineral Assay

The mineralization of plant or organic raw material is necessary to bring mineral elements into a soluble state suitable for analysis using classic analytical means (complexometry and gravimetry) and measuring instruments based on spectrophotometry (colorimetry, nephelometry, flame photometry, and atomic absorption). The principle consists of destroying organic compounds by calcination followed by the solubilization of elements via digestion with a strong mineral acid (concentrated sulfuric acid: H_2SO_4, 98%). Several methods exist depending on the elements to be determined.

5.5. Determination of elements P, K, Na, Ca, Mg, Fe, Mn, Zn, Cu

Calcination of one (1) g of dry matter (MS) at 450–500 °C (a higher temperature could lead to the loss of elements by volatilization), followed by digestion of the ash with nitric acid (HNO_3).

5.5.1. The Experiment

Reagents and Consumable Material:

- Nitric acid solution (HNO_3, 1 M): In two liters (2L) of distilled water, introduce a volume of 143 mL of concentrated nitric acid (d=1.4) and homogenize the mixture.
- Ashless filter paper, 125 mm diameter.

Instruments and Glassware: Adjustable oven at 105 °C, desiccator, precision balance (0.001 g), hotplate, fume hood, muffle furnace and calcination smoke evacuation system, protective gloves and tongs for the muffle furnace, beaker (100 mL) and watch glass for covering, porcelain crucible for calcination (capacity of ≈ 20 mL), glass rod (length ≈ 10–12 cm), glass funnel, volumetric flask (50 mL), and an enameled iron tray.

Operating Procedure: Place one gram (1g) of plant dry matter into a porcelain crucible. Pre-calcine on a hotplate or in a muffle furnace at 200 °C if the latter is equipped with a chimney. For at least 2 hours, calcine the dry matter at 450 °C until complete mineralization of the sample is achieved (the ash should be detached from the crucible wall and be white or a uniform gray color, more or less light depending on the plant species). Remove from the muffle furnace and allow to cool on a heat-resistant surface away from dust and air currents (place in an enameled iron tray and cover with a second tray). Quantitatively transfer the ash into a 100 mL beaker using 100 mL of a nitric acid solution (HNO_3, 1M). Place a glass rod in the beaker (resting in the spout notch) and cover with a watch glass. Digest at a gentle boil on a hotplate for 30 minutes. Monitor the digestion and ensure that evaporation does not leave less than 5 mL. Filter into a 50 mL volumetric flask. Rinse the watch glass, the rod, and the beaker with hot water, collect the filtrate, and bring the flask to volume with water. Close the flask with a stopper or with paraffin paper. Use the extract for the assay of elements: P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu, Co, Al, Pb, Ni, Cr, and Cd.

Absorption Spectrophotometry: The principle relies on calcination at 450 °C and extraction of the ash with nitric acid (1N), followed by atomic absorption spectrophotometry assay of the minerals. The influence of wavelength-integrated absorbance on sensitivity and precision for the assay of Ca, Fe, and Zn was performed in 3 passes according to the air/acetylene flame sequence. Measurements were carried out on the main atomic lines for Fe (248.327 nm) and Zn (213.857 nm), and on secondary lines for Ca (239.856 nm), using a selected wavelength absorbance equivalent to 3 pixels for Ca, Fe, Mg, K, Na, P, and Zn. Recovery tests for spiked samples were performed by adding appropriate aliquots of 5000, 1000, or 100 mg/L of unique standard solution into the sample digestions to obtain extracts containing 10 mg/L Ca, 0.5 mg/L Fe, and 0.2 mg/L Zn. Limits of detection (LOD) and limits of quantification (LOQ) for all analytes were calculated in accordance with IUPAC recommendations.

pH Measurements: The pH of a solution is the decimal co-logarithm of the hydrogen ion activity in the solution and is expressed in pH units. Its principle is based on the potential difference existing between a glass electrode and a reference electrode immersed in the same solution, which is a linear function of its pH. Indeed, according to NERNST's laws, the electrode potential is linked to the activity of the H^+ ions present by the relationship $E = E_o + (RT/F) \ln a(H^+)$ where E_0 represents the standard electrode potential (in Volts), R represents the gas constant (in joules/degree), T the absolute temperature (°K), F the Faraday symbol (96,500 coulombs), $a(H^+)$ is the activity of H^+ ions, and k is a constant depending on the nature of the electrode glass and the measuring system.

Once the device has been calibrated, wash the electrodes and the measuring vessel first with demineralized or distilled water, and then with the test solution. Homogenize the test solution, introduce a sufficient volume into the measuring vessel, and immerse the electrodes. Stir the test solution gently. Verify that the reading given by the pH meter is stable and record it. Under the described operating conditions, the precision of the determination is ≈ 0.02 pH units. Results are expressed in pH units at a temperature of 20 °C, in the form: pH at 20 °C=xx.xx.

Determination of Titratable Acidity (AOCS, 1998): Free fatty acids are estimated by titrating with potassium hydroxide (KOH) using phenolphthalein as an indicator. The acid value is the amount in mg of KOH required to neutralize the free fatty acids present in one gram of the sample. It is expressed as oleic acid equivalent (octadec-9-enoic acid). Dissolve 0.2 g of sample in 10 mL of neutral solvent (95% ethanol) in a 250 mL conical flask. Then add 3–4 drops of phenolphthalein indicator and mix by shaking. Titrate the contents with a potassium hydroxide solution (KOH, 0.5 M) until a pink color is obtained that persists for fifteen seconds (Eq. 12).

$$Acid\ Value = \frac{56.11 \times 0.5 \times (V_S - V_b) \times F}{mass\ (g)} \tag{12}$$

V_s: Titration volume of the sample (mL); V_b: Titration volume of the blank (mL); mass: Weight of the fat in the volume of extract used (g); F: Factor of the 0.5N KOH solution ($F = 10/V_f$, where V_f is the volume of 0.5N KOH required to neutralize 10 mL of 0.5N H_2SO_4); 56.11: Molecular weight of KOH; 0.5: Normality of KOH.

5.6. Data Analysis

The collected data will be analyzed descriptively so that all differences and variants of our study can be globally highlighted. Survey data will be entered into an Excel spreadsheet, which will allow for proportion calculations and charts. The Statistical Package for the Social Sciences (SPSS) software will be our primary analysis tool, allowing us to represent the data statistically and generate the diagrams necessary for a better expression of our results.

Quantitative data will be analyzed using SPSS Statistics version 20 software. A descriptive analysis will allow us to describe the various socio-professional characteristics, the cultural origins of the family heads, and their incomes. This analysis will also describe the distribution of household Gnetum consumption scores, the diversity scores of culinary techniques, and the frequencies and proportions of NTFP consumption. Results regarding quantitative variables will be presented as frequency, mean, standard deviation, minimum and maximum, median, and a graphical representation. Analyses involving qualitative variables will be presented as frequency, percentage, and a graphical representation (FAO, 2024; WHO, 2023b).

Statistical comparisons were performed using analysis of variance (ANOVA) followed by pairwise comparisons, with a significance threshold set at 5%. The laboratory work consisted of physicochemical analyses of fresh Gnetum africanum leaves and prepared Gnetum-based recipes, with replicate measurements for each preparation.

5.7. Expected Results

The results should allow us to identify the factors that condition the consumption of NWFPs, particularly Gnetum; these could include socio-professional factors and dietary habits. Furthermore, preparation techniques could have an impact on the quality or even the content of proteins and minerals contained in this plant; from there, it will be possible to better determine the technique(s) that best preserve nutrients and thereby contribute to the population's well-being (Mialoundama, 1993; Ukom et al., 2023; Tekwe et al., 2003). Finally, we will have also determined the place of NWFPs in Gabonese gastronomy through the analysis of the results of surveys conducted in the most populated city in Gabon, namely Libreville (FAO, 2024; Mialoundama, 1993).

5.8. Research Ethics

This study was conducted in compliance with the ethical principles applicable to research involving human subjects. Respondents' participation was voluntary and based on free and informed consent after being informed about the objectives of the study. The anonymity and confidentiality of the collected Macronutriments data were guaranteed, and the gathered information was used exclusively for scientific purposes. No intervention capable of harming the participants was carried out, in accordance with the principles of respect for persons, beneficence, and justice.

6. Results

Table 5 shows the macronutrients present in the preparations. Values are expressed as mean standard deviation; DM is Dry Matter; MF is Fresh Matter, and g is grams.

Table 5. Macronutrients

Indications	**Ashes** (g/100g DM)	**Lipids** (g/100g DM)	**DM** (g/100g DM)	**TE** (g/100g DM)	**Fiber** (g/100g DM)	**Proteins** (g/100g DM)	**Carbohydrate** (g/100g DM)
Fresh chopped Nkumu (control)	1.38 ± 0.01	1.61 ± 0.42	32.41 ± 0.53	67.59 ± 0.53	10.08 ± 0.72	6.91 ± 0.20	12.59 ± 0.13
Nkumu in water	1.70 ± 0.89	43.27 ± 1.76	28.12 ± 1.67	71.88 ± 1.67	7.56 ± 0.73	32.73 ± 0.07	0.00 ± 0.00
Nkumu with peanut paste	0.052 ± 0.001	35.94 ± 3.97	26.30 ± 1.33	73.70 ±1.33	7.68 ± 0.26	44.12 ± 0.95	0.00 ± 0.00
Nkumu in palm oil or Nyembouè	3.87 ± 0.46	78.91 ± 1.32	58.41 ± 0.90	41.59 ± 0.90	1.93 ± 0.46	13.58 ± 0.05	0.00 ± 0.00
Nkumu O'fula	9.50 ± 0.25	42.10 ± 4.28	35.17 ± 0.91	64.83 ± 0.91	10.37 ± 0.50	19.61 ± 0.49	0.00 ± 0.00

Table 6 shows the minerals present in the preparations. Values expressed as mean standard deviation; DM: Dry Matter; mg: milligram; g: gram; P: Phosphorus; Mg: Magnesium; Fe: Iron; Na: Sodium; K: Potassium; Ca: Calcium; Cu: Copper; Zn: Zinc, and Mn: Manganese.

Table 6. Minerals

Indications	**Fresh chopped Nkumu (control)**	**Nkumu in water**	**Nkumu with peanut paste**	**Nkumu in palm oil or Nyembouè**	**Nkumu O'fula**
Mg (mg/100g DM)	131.06 ± 0.61	58.13 ± 0.49	107.59 ± 0.46	11.03 ± 0.03	64.19 ± 0.48
P (mg/100g DM)	86.32 ± 0.12	432.14 ± 0.27	86.76 ± 0.26	148.09 ± 0.17	395.56 ± 0.63
Fe (mg/100g DM)	6.42 ± 0.08	4.46 ± 0.06	5.4 ± 0.02	0.46 ± 0.04	2.98 ± 0.04
Na (mg/100g DM)	149.11 ± 0.87	1480.85 ± 0.64	1464.54 ± 0.58	715.9 ± 3.68	1842.52 ± 0.54
K (mg/100g DM)	1268.36 ± 0.12	452.56 ± 0.42	928.73 ± 0.23	278.38 ± 0.20	2851.56 ± 0.46
Ca (mg/100g DM)	902.29 ± 0.22	338.23 ± 0.29	318.69 ± 0.47	154.85 ± 0.07	1375.67 ± 0.32
Cu (mg/100g DM)	0.27 ± 0.01	0.41 ± 0.01	0.22 ± 0.01	0.09 ± 0.01	0.23 ± 0.01
Zn (mg/100g DM)	1.63 ± 0.01	2.87 ± 0.01	2.16 ± 0.002	0.70 ± 0.02	1.85 ± 0.01
Mn (mg/100g DM)	13.45 ± 0.04	6.68 ± 0.01	4.48 ± 0.12	2.38 ± 0.11	8.18 ± 0.04

Table 7 shows pH and acidity of the preparations. Values and expressed as mean standard deviation; pH: Potential of hydrogen; mg: milligram, and g: gram.

Table 7. pH and acidity

Indications	pH	Acidity (mg/g)
Fresh chopped Nkumu (control)	5.036 ± 0.06	0.00 ± 0.00
Nkumu in water	6.37 ± 0.01	10.47 ± 1.02
Nkumu with peanut paste	6.08 ± 0.01	17.1 ± 1.06
Nkumu in palm oil or Nyembouè	5.59 ± 0.01	33.29 ± 2.67
Nkumu O'fula	7.60 ± 0.02	42.24 ± 2.36

Table 8 shows the pairwise comparisons, with respect to the macronutrient ashes.

Table 8. Pairwise comparison, with respect to macronutrient ashes

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b]	
						Lower bound	Upper bound
Ashes	Fresh chopped Nkumu	Nkumu in water	-.332	.378	1.000	-1.686	1.023
		Nkumu with peanut paste	1.317	.378	.059	-.037	2.671
		Nkumu in palm oil or Nyembouè	-2.497*	.378	.001	-3.851	-1.143
		Nkumu O'fula	-8.133*	.378	.000	-9.488	-6.779
	Nkumu in water	Fresh chopped Nkumu	.332	.378	1.000	-1.023	1.686
		Nkumu with peanut paste	1.649*	.378	.014	.294	3.003
		Nkumu in palm oil or Nyembouè	-2.165*	.378	.002	-3.520	-.811
		Nkumu O'fula	-7.802*	.378	.000	-9.156	-6.447
	Nkumu with peanut paste	Fresh chopped Nkumu	-1.317	.378	.059	-2.671	.037
		Nkumu in water	-1.649*	.378	.014	-3.003	-.294
		Nkumu in palm oil or Nyembouè	-3.814*	.378	.000	-5.168	-2.459
		Nkumu O'fula	-9.450*	.378	.000	10.804	-8.096
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	2.497*	.378	.001	1.143	3.851
		Nkumu in water	2.165*	.378	.002	.811	3.520
		Nkumu with peanut paste	3.814*	.378	.000	2.459	5.168
		Nkumu O'fula	-5.636*	.378	.000	-6.991	-4.282
	Nkumu O'fula	Fresh chopped Nkumu	8.133*	.378	.000	6.779	9.488
		Nkumu in water	7.802*	.378	.000	6.447	9.156
		Nkumu with peanut paste	9.450*	.378	.000	8.096	10.804
		Nkumu in palm oil or Nyembouè	5.636*	.378	.000	4.282	6.991

Table 9 shows the pairwise comparisons, with respect to the macronutrient lipids.

Table 9. Pairwise comparison, with respect to macronutrient lipids

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b] Lower bound	Upper bound
Lipids	Fresh chopped Nkumu	Nkumu in water	-41.661*	2.284	.000	-49.842	-33.481
		Nkumu with peanut paste	-34.333*	2.284	.000	-42.513	-26.153
		Nkumu in palm oil or Nyemboué	-77.302*	2.284	.000	-85.482	-69.121
		Nkumu O'fula	-40.493*	2.284	.000	-48.674	-32.313
	Nkumu in water	Fresh chopped Nkumu	41.661*	2.284	.000	33.481	49.842
		Nkumu with peanut paste	7.328	2.284	.094	-.852	15.509
		Nkumu in palm oil or Nyemboué	-35.640*	2.284	.000	-43.821	-27.460
		Nkumu O'fula	1.168	2.284	1.000	-7.012	9.348
	Nkumu with peanut paste	Fresh chopped Nkumu	34.333*	2.284	.000	26.153	42.513
		Nkumu in water	-7.328	2.284	.094	-15.509	.852
		Nkumu in palm oil or Nyemboué	-42.969*	2.284	.000	-51.149	-34.788
		Nkumu O'fula	-6.160	2.284	.224	-14.341	2.020
	Nkumu in palm oil or Nyemboué	Fresh chopped Nkumu	77.302*	2.284	.000	69.121	85.482
		Nkumu in water	35.640*	2.284	.000	27.460	43.821
		Nkumu with peanut paste	42.969*	2.284	.000	34.788	51.149
		Nkumu O'fula	36.808*	2.284	.000	28.628	44.989
	Nkumu O'fula	Fresh chopped Nkumu	40.493*	2.284	.000	32.313	48.674
		Nkumu in water	-1.168	2.284	1.000	-9.348	7.012
		Nkumu with peanut paste	6.160	2.284	.224	-2.020	14.341
		Nkumu in palm oil or Nyemboué	-36.808*	2.284	.000	-44.989	-28.628

Table 10 shows the pairwise comparisons, with respect to the macronutrient MS.

Table 10. Pairwise comparison, with respect to macronutrient MS

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b] Lower bound	Upper bound
MS	Fresh chopped Nkumu	Nkumu in water	4.294*	.929	.009	.968	7.621
		Nkumu with peanut paste	6.114*	.929	.001	2.787	9.441
		Nkumu in palm oil or Nyemboué	-25.998*	.929	.000	-29.325	-22.671
		Nkumu O'fula	-2.755	.929	.141	-6.082	.572
		Fresh chopped Nkumu	-4.294*	.929	.009	-7.621	-.968

	Nkumu in water	Nkumu with peanut paste	1.820	.929	.786	-1.507	5.146
		Nkumu in palm oil or Nyemboué	-30.292*	.929	.000	-33.619	-26.966
		Nkumu O'fula	-7.049*	.929	.000	-10.376	-3.723
	Nkumu with peanut paste	Fresh chopped Nkumu	-6.114*	.929	.001	-9.441	-2.787
		Nkumu in water	-1.820	.929	.786	-5.146	1.507
		Nkumu in palm oil or Nyemboué	-32.112*	.929	.000	-35.439	-28.785
		Nkumu O'fula	-8.869*	.929	.000	-12.196	-5.542
	Nkumu in palm oil or Nyemboué	Fresh chopped Nkumu	25.998*	.929	.000	22.671	29.325
		Nkumu in water	30.292*	.929	.000	26.966	33.619
		Nkumu with peanut paste	32.112*	.929	.000	28.785	35.439
		Nkumu O'fula	23.243*	.929	.000	19.916	26.570
	Nkumu O'fula	Fresh chopped Nkumu	2.755	.929	.141	-.572	6.082
		Nkumu in water	7.049*	.929	.000	3.723	10.376
		Nkumu with peanut paste	8.869*	.929	.000	5.542	12.196
		Nkumu in palm oil or Nyemboué	-23.243*	.929	.000	-26.570	-19.916

Table 11 shows the pairwise comparisons, with respect to the macronutrient TE.

Table 11. Pairwise comparison, with respect to macronutrient TE

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b]	
						Lower bound	Upper bound
TE	Fresh chopped Nkumu	Nkumu in water	-4.294*	.929	.009	-7.621	-.968
		Nkumu with peanut paste	-6.114*	.929	.001	-9.441	-2.787
		Nkumu in palm oil or Nyemboué	25.998*	.929	.000	22.671	29.325
		Nkumu O'fula	2.755	.929	.141	-.572	6.082
	Nkumu in water	Fresh chopped Nkumu	4.294*	.929	.009	.968	7.621
		Nkumu with peanut paste	-1.820	.929	.786	-5.146	1.507
		Nkumu in palm oil or Nyemboué	30.292*	.929	.000	26.966	33.619
		Nkumu O'fula	7.049*	.929	.000	3.723	10.376
	Nkumu with peanut paste	Fresh chopped Nkumu	6.114*	.929	.001	2.787	9.441
		Nkumu in water	1.820	.929	.786	-1.507	5.146
		Nkumu in palm oil or Nyemboué	32.112*	.929	.000	28.785	35.439
		Nkumu O'fula	8.869*	.929	.000	5.542	12.196
	Nkumu in palm oil or Nyemboué	Fresh chopped Nkumu	-25.998*	.929	.000	-29.325	-22.671
		Nkumu in water	-30.292*	.929	.000	-33.619	-26.966
		Nkumu with peanut paste	-32.112*	.929	.000	-35.439	-28.785

		Nkumu O'fula	-23.243*	.929	.000	-26.570	-19.916
	Nkumu O'fula	Fresh chopped Nkumu	-2.755	.929	.141	-6.082	.572
		Nkumu in water	-7.049*	.929	.000	-10.376	-3.723
		Nkumu with peanut paste	-8.869*	.929	.000	-12.196	-5.542
		Nkumu in palm oil or Nyembouè	23.243*	.929	.000	19.916	26.570

Table 12 shows the pairwise comparisons, with respect to the macronutrient fiber.

Table 12. Pairwise comparison, with respect to macronutrient fiber

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.b	95% confidence interval of the difference b	
						Lower bound	Upper bound
Fiber	Fresh chopped Nkumu	Nkumu in water	2.515*	.458	.003	.876	4.154
		Nkumu with peanut paste	2.392*	.458	.004	.753	4.031
		Nkumu in palm oil or Nyembouè	8.144*	.458	.000	6.505	9.783
		Nkumu O'fula	-.300	.458	1.000	-1.939	1.339
	Nkumu in water	Fresh chopped Nkumu	-2.515*	.458	.003	-4.154	-.876
		Nkumu with peanut paste	-.122	.458	1.000	-1.761	1.517
		Nkumu in palm oil or Nyembouè	5.629*	.458	.000	3.990	7.268
		Nkumu O'fula	-2.815*	.458	.001	-4.454	-1.176
	Nkumu with peanut paste	Fresh chopped Nkumu	-2.392*	.458	.004	-4.031	-.753
		Nkumu in water	.122	.458	1.000	-1.517	1.761
		Nkumu in palm oil or Nyembouè	5.752*	.458	.000	4.113	7.391
		Nkumu O'fula	-2.692*	.458	.002	-4.331	-1.053
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	-8.144*	.458	.000	-9.783	-6.505
		Nkumu in water	-5.629*	.458	.000	-7.268	-3.990
		Nkumu with peanut paste	-5.752*	.458	.000	-7.391	-4.113
		Nkumu O'fula	-8.444*	.458	.000	-10.083	-6.805
	Nkumu O'fula	Fresh chopped Nkumu	.300	.458	1.000	-1.339	1.939
		Nkumu in water	2.815*	.458	.001	1.176	4.454
		Nkumu with peanut paste	2.692*	.458	.002	1.053	4.331
		Nkumu in palm oil or Nyembouè	8.444*	.458	.000	6.805	10.083

Table 13 shows the pairwise comparisons, with respect to the macronutrient proteins.

Table 13. Pairwise comparison, with respect to macronutrient proteins

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b]	
						Lower bound	Upper bound
Proteins	Fresh chopped Nkumu	Nkumu in water	-25.823*	.399	.000	-27.253	-24.393
		Nkumu with peanut paste	-37.207*	.399	.000	-38.637	-35.777
		Nkumu in palm oil or Nyembouè	-6.670*	.399	.000	-8.100	-5.240
		Nkumu O'fula	-12.700*	.399	.000	-14.130	-11.270
	Nkumu in water	Fresh chopped Nkumu	25.823*	.399	.000	24.393	27.253
		Nkumu with peanut paste	-11.383*	.399	.000	-12.813	-9.953
		Nkumu in palm oil or Nyembouè	19.153*	.399	.000	17.723	20.583
		Nkumu O'fula	13.123*	.399	.000	11.693	14.553
	Nkumu with peanut paste	Fresh chopped Nkumu	37.207*	.399	.000	35.777	38.637
		Nkumu in water	11.383*	.399	.000	9.953	12.813
		Nkumu in palm oil or Nyembouè	30.537*	.399	.000	29.107	31.967
		Nkumu O'fula	24.507*	.399	.000	23.077	25.937
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	6.670*	.399	.000	5.240	8.100
		Nkumu in water	-19.153*	.399	.000	-20.583	-17.723
		Nkumu with peanut paste	-30.537*	.399	.000	-31.967	-29.107
		Nkumu O'fula	-6.030*	.399	.000	-7.460	-4.600
	Nkumu O'fula	Fresh chopped Nkumu	12.700*	.399	.000	11.270	14.130
		Nkumu in water	-13.123*	.399	.000	-14.553	-11.693
		Nkumu with peanut paste	-24.507*	.399	.000	-25.937	-23.077
		Nkumu in palm oil or Nyembouè	6.030*	.399	.000	4.600	7.460

Table 14 shows the pairwise comparisons, with respect to the macronutrient carbohydrate.

Table 14. Pairwise comparison, with respect to macronutrient carbohydrate

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b] Lower bound	Upper bound
Carbohydrates	Fresh chopped Nkumu	Nkumu in water	12.585*	.049	.000	12.412	12.759
		Nkumu with peanut paste	12.585*	.049	.000	12.412	12.759
		Nkumu in palm oil or Nyembouè	12.585*	.049	.000	12.412	12.759
		Nkumu O'fula	12.585*	.049	.000	12.412	12.759
	Nkumu in water	Fresh chopped Nkumu	-12.585*	.049	.000	-12.759	-12.412
		Nkumu with peanut paste	.000	.049	1.000	-.174	.174
		Nkumu in palm oil or Nyembouè	1,97E-28	.049	1.000	-.174	.174
		Nkumu O'fula	1,05E-12	.049	1.000	-.174	.174
	Nkumu with peanut paste	Fresh chopped Nkumu	-12.585*	.049	.000	-12.759	-12.412
		Nkumu in water	.000	.049	1.000	-.174	.174
		Nkumu in palm oil or Nyembouè	1,97E-28	.049	1.000	-.174	.174
		Nkumu O'fula	1,05E-12	.049	1.000	-.174	.174
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	-12.585*	.049	.000	-12.759	-12.412
		Nkumu in water	-1,97E-28	.049	1.000	-.174	.174
		Nkumu with peanut paste	-1,97E-28	.049	1.000	-.174	.174
		Nkumu O'fula	1,05E-12	.049	1.000	-.174	.174
	Nkumu O'fula	Fresh chopped Nkumu	-12.585*	.049	.000	-12.759	-12.412
		Nkumu in water	-1,05E-12	.049	1.000	-.174	.174
		Nkumu with peanut paste	-1,05E-12	.049	1.000	-.174	.174
		Nkumu in palm oil or Nyembouè	-1,05E-12	.049	1.000	-.174	.174

Table 15 shows the pairwise comparisons, with respect to the mineral Mg.

Table 15. Pairwise comparison, with respect to the mineral Mg

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b] Lower bound	Upper bound
Mg (mg/100g DM)	Fresh chopped Nkumu	Nkumu in water	72.930*	.375	.000	71.587	74.273
		Nkumu with peanut paste	23.470*	.375	.000	22.127	24.813
		Nkumu in palm oil or Nyembouè	120.030*	.375	.000	118.687	121.373
		Nkumu O'fula	66.873*	.375	.000	65.530	68.217

	Nkumu in water	Fresh chopped Nkumu	-72.930*	.375	.000	-74.273	-71.587
		Nkumu with peanut paste	-49.460*	.375	.000	-50.803	-48.117
		Nkumu in palm oil or Nyembouè	47.100*	.375	.000	45.757	48.443
		Nkumu O'fula	-6.057*	.375	.000	-7.400	-4.713
	Nkumu with peanut paste	Fresh chopped Nkumu	-23.470*	.375	.000	-24.813	-22.127
		Nkumu in water	49.460*	.375	.000	48.117	50.803
		Nkumu in palm oil or Nyembouè	96.560*	.375	.000	95.217	97.903
		Nkumu O'fula	43.403*	.375	.000	42.060	44.747
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	-120.030*	.375	.000	121.373	118.687
		Nkumu in water	-47.100*	.375	.000	-48.443	-45.757
		Nkumu with peanut paste	-96.560*	.375	.000	-97.903	-95.217
		Nkumu O'fula	-53.157*	.375	.000	-54.500	-51.813
	Nkumu O'fula	Fresh chopped Nkumu	-66.873*	.375	.000	-68.217	-65.530
		Nkumu in water	6.057*	.375	.000	4.713	7.400
		Nkumu with peanut paste	-43.403*	.375	.000	-44.747	-42.060
		Nkumu in palm oil or Nyembouè	53.157*	.375	.000	51.813	54.500

Table 16 shows the pairwise comparisons, with respect to the mineral P.

Table 16. Pairwise comparison, with respect to mineral P

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b]	
						Lower bound	Upper bound
P (mg/100g DM)	Fresh chopped Nkumu	Nkumu in water	-345.820*	.278	.000	346.817	344.823
		Nkumu with peanut paste	-.437	.278	1.000	-1.433	.560
		Nkumu in palm oil or Nyembouè	-61.930*	.278	.000	-62.927	-60.933
		Nkumu O'fula	-309.237*	.278	.000	310.233	308.240
	Nkumu in water	Fresh chopped Nkumu	345.820*	.278	.000	344.823	346.817
		Nkumu with peanut paste	345.383*	.278	.000	344.387	346.380
		Nkumu in palm oil or Nyembouè	283.890*	.278	.000	282.893	284.887
		Nkumu O'fula	36.583*	.278	.000	35.587	37.580

	Nkumu with peanut paste	Fresh chopped Nkumu	.437	.278	1.000	-.560	1.433
		Nkumu in water	-345.383*	.278	.000	346.380	344.387
		Nkumu in palm oil or Nyembouè	-61.493*	.278	.000	-62.490	-60.497
		Nkumu O'fula	-308.800*	.278	.000	309.797	307.803
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	61.930*	.278	.000	60.933	62.927
		Nkumu in water	-283.890*	.278	.000	284.887	282.893
		Nkumu with peanut paste	61.493*	.278	.000	60.497	62.490
		Nkumu O'fula	-247.307*	.278	.000	248.303	246.310
	Nkumu O'fula	Fresh chopped Nkumu	309.237*	.278	.000	308.240	310.233
		Nkumu in water	-36.583*	.278	.000	-37.580	-35.587
		Nkumu with peanut paste	308.800*	.278	.000	307.803	309.797
		Nkumu in palm oil or Nyembouè	247.307*	.278	.000	246.310	248.303

Table 17 shows the pairwise comparisons, with respect to the mineral Fe.

Table 17. Pairwise comparison, with respect to mineral Fe

Dependent variable	**(I) Sample**	**(J) Sample**	**Difference of means (I-J)**	**Standard error**	**Sig.[b]**	**95% confidence interval of the difference [b]**	
						Lower bound	**Upper bound**
Fe (mg/100g DM)	Fresh chopped Nkumu	Nkumu in water	1.963*	.041	.000	1.817	2.110
		Nkumu with peanut paste	1.037*	.041	.000	.890	1.183
		Nkumu in palm oil or Nyembouè	5.963*	.041	.000	5.817	6.110
		Nkumu O'fula	3.440*	.041	.000	3.294	3.586
	Nkumu in water	Fresh chopped Nkumu	-1.963*	.041	.000	-2.110	-1.817
		Nkumu with peanut paste	-.927*	.041	.000	-1.073	-.780
		Nkumu in palm oil or Nyembouè	4.000*	.041	.000	3.854	4.146
		Nkumu O'fula	1.477*	.041	.000	1.330	1.623
	Nkumu with peanut paste	Fresh chopped Nkumu	-1.037*	.041	.000	-1.183	-.890
		Nkumu in water	.927*	.041	.000	.780	1.073
		Nkumu in palm oil or Nyembouè	4.927*	.041	.000	4.780	5.073
		Nkumu O'fula	2.403*	.041	.000	2.257	2.550
		Fresh chopped Nkumu	-5.963*	.041	.000	-6.110	-5.817

	Nkumu in palm oil or Nyembouè	Nkumu in water	-4.000*	.041	.000	-4.146	-3.854
		Nkumu with peanut paste	-4.927*	.041	.000	-5.073	-4.780
		Nkumu O'fula	-2.523*	.041	.000	-2.670	-2.377
	Nkumu O'fula	Fresh chopped Nkumu	-3.440*	.041	.000	-3.586	-3.294
		Nkumu in water	-1.477*	.041	.000	-1.623	-1.330
		Nkumu with peanut paste	-2.403*	.041	.000	-2.550	-2.257
		Nkumu in palm oil or Nyembouè	2.523*	.041	.000	2.377	2.670

Table 18 shows the pairwise comparisons, with respect to the mineral Na.

Table 18. Pairwise comparison, with respect to mineral Na

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.b	95% confidence interval of the difference b	
						Lower bound	Upper bound
Na (mg/100g DM)	Fresh chopped Nkumu	Nkumu in water	-1331.737*	1.430	.000	1336.85	1326.61
		Nkumu with peanut paste	-1315.430*	1.430	.000	1320.55	1310.30
		Nkumu in palm oil or Nyembouè	-566.790*	1.430	.000	571.912	561.668
		Nkumu O'fula	-1693.413*	1.430	.000	1698.53	1688.29
	Nkumu in water	Fresh chopped Nkumu	1331.737*	1.430	.000	1326.61	1336.85
		Nkumu with peanut paste	16.307*	1.430	.000	11.184	21.429
		Nkumu in palm oil or Nyembouè	764.947*	1.430	.000	759.824	770.069
		Nkumu O'fula	-361.677*	1.430	.000	366.799	356.554
	Nkumu with peanut paste	Fresh chopped Nkumu	1315.430*	1.430	.000	1310.30	1320.55
		Nkumu in water	-16.307*	1.430	.000	-21.429	-11.184
		Nkumu in palm oil or Nyembouè	748.640*	1.430	.000	743.518	753.762
		Nkumu O'fula	-377.983*	1.430	.000	383.106	372.861
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	566.790*	1.430	.000	561.668	571.912
		Nkumu in water	-764.947*	1.430	.000	770.069	759.824
		Nkumu with peanut paste	-748.640*	1.430	.000	753.762	743.518
		Nkumu O'fula	-1126.623*	1.430	.000	1131.74	1121.50
	Nkumu O'fula	Fresh chopped Nkumu	1693.413*	1.430	.000	1688.29	1698.53
		Nkumu in water	361.677*	1.430	.000	356.554	366.799
		Nkumu with peanut paste	377.983*	1.430	.000	372.861	383.106
		Nkumu in palm oil or Nyembouè	1126.623*	1.430	.000	1121.50	1131.74

Table 19 shows the pairwise comparisons, with respect to the mineral K.

Table 19. Pairwise comparison, with respect to mineral K

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.b	95% confidence interval of the difference b	
						Lower bound	Upper bound
K (mg/100g DM)	Fresh chopped Nkumu	Nkumu in water	815.800*	.256	.000	814.882	816.718
		Nkumu with peanut paste	339.633*	.256	.000	338.715	340.551
		Nkumu in palm oil or Nyembouè	989.987*	.256	.000	989.069	990.905
		Nkumu O'fula	-1583.200*	.256	.000	1584.11	1582.28
	Nkumu in water	Fresh chopped Nkumu	-815.800*	.256	.000	816.718	814.882
		Nkumu with peanut paste	-476.167*	.256	.000	477.085	475.249
		Nkumu in palm oil or Nyembouè	174.187*	.256	.000	173.269	175.105
		Nkumu O'fula	-2399.000*	.256	.000	2399.91	2398.08
	Nkumu with peanut paste	Fresh chopped Nkumu	-339.633*	.256	.000	-340.51	338.715
		Nkumu in water	476.167*	.256	.000	475.249	477.085
		Nkumu in palm oil or Nyembouè	650.353*	.256	.000	649.435	651.271
		Nkumu O'fula	-1922.833*	.256	.000	1923.75	1921.91
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	-989.987*	.256	.000	990.905	989.069
		Nkumu in water	-174.187*	.256	.000	175.105	173.269
		Nkumu with peanut paste	-650.353*	.256	.000	651.271	649.435
		Nkumu O'fula	-2573.187*	.256	.000	2574.10	2572.26
	Nkumu O'fula	Fresh chopped Nkumu	1583.200*	.256	.000	1582.28	1584.11
		Nkumu in water	2399.000*	.256	.000	2398.08	2399.91
		Nkumu with peanut paste	1922.833*	.256	.000	1921.91	1923.75
		Nkumu in palm oil or Nyembouè	2573.187*	.256	.000	2572.26	2574.10

Table 20 shows the pairwise comparisons, with respect to the mineral Ca.

Table 20. Pairwise comparison, with respect to mineral Ca

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.b	95% confidence interval of the difference b	
						Lower bound	Upper bound
Ca (mg/100g DM)	Fresh chopped Nkumu	Nkumu in water	564.060*	.242	.000	563.195	564.925
		Nkumu with peanut paste	583.603*	.242	.000	582.738	584.469
		Nkumu in palm oil or Nyembouè	747.443*	.242	.000	746.578	748.309
		Nkumu O'fula	-473.380*	.242	.000	-474.45	472.515
		Fresh chopped Nkumu	-564.060*	.242	.000	564.925	563.195

	Nkumu in water	Nkumu with peanut paste	19.543*	.242	.000	18.678	20.409
		Nkumu in palm oil or Nyembouè	183.383*	.242	.000	182.518	184.249
		Nkumu O'fula	-1037.440*	.242	.000	1038.30	1036.57
	Nkumu with peanut paste	Fresh chopped Nkumu	-583.603*	.242	.000	-584.69	582.738
		Nkumu in water	-19.543*	.242	.000	-20.409	-18.678
		Nkumu in palm oil or Nyembouè	163.840*	.242	.000	162.975	164.705
		Nkumu O'fula	-1056.983*	.242	.000	1057.84	1056.11
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	-747.443*	.242	.000	748.309	746.578
		Nkumu in water	-183.383*	.242	.000	184.249	182.518
		Nkumu with peanut paste	-163.840*	.242	.000	164.705	162.975
		Nkumu O'fula	-1220.823*	.242	.000	1221.68	1219.95
	Nkumu O'fula	Fresh chopped Nkumu	473.380*	.242	.000	472.515	474.245
		Nkumu in water	1037.440*	.242	.000	1036.57	1038.30
		Nkumu with peanut paste	1056.983*	.242	.000	1056.11	1057.84
		Nkumu in palm oil or Nyembouè	1220.823*	.242	.000	1219.95	1221.68

Table 21 shows the pairwise comparisons, with respect to the mineral Cu.

Table 21. Pairwise comparison, with respect to mineral Cu

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b]	
						Lower bound	Upper bound
Cu (mg/100g DM)	Fresh chopped Nkumu	Nkumu in water	-.140*	.006	.000	-.160	-.120
		Nkumu with peanut paste	.053*	.006	.000	.033	.073
		Nkumu in palm oil or Nyembouè	.180*	.006	.000	.160	.200
		Nkumu O'fula	.047*	.006	.000	.027	.067
	Nkumu in water	Fresh chopped Nkumu	.140*	.006	.000	.120	.160
		Nkumu with peanut paste	.193*	.006	.000	.173	.213
		Nkumu in palm oil or Nyembouè	.320*	.006	.000	.300	.340
		Nkumu O'fula	.187*	.006	.000	.167	.207
	Nkumu with peanut paste	Fresh chopped Nkumu	-.053*	.006	.000	-.073	-.033
		Nkumu in water	-.193*	.006	.000	-.213	-.173
		Nkumu in palm oil or Nyembouè	.127*	.006	.000	.107	.147
		Nkumu O'fula	-.007	.006	1.000	-.027	.013
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	-.180*	.006	.000	-.200	-.160
		Nkumu in water	-.320*	.006	.000	-.340	-.300
		Nkumu with peanut paste	-.127*	.006	.000	-.147	-.107

		Nkumu O'fula	-.133*	.006	.000	-.153	-.113
	Nkumu O'fula	Fresh chopped Nkumu	-.047*	.006	.000	-.067	-.027
		Nkumu in water	-.187*	.006	.000	-.207	-.167
		Nkumu with peanut paste	.007	.006	1.000	-.013	.027
		Nkumu in palm oil or Nyembouè	.133*	.006	.000	.113	.153

Table 22 shows the pairwise comparisons, with respect to the mineral Zn.

Table 22. Pairwise comparison, with respect to mineral Zn

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b]	
						Lower bound	Upper bound
Zn (mg/100g DM)	Fresh chopped Nkumu	Nkumu in water	-1.240*	.009	.000	-1.271	-1.209
		Nkumu with peanut paste	-.527*	.009	.000	-.558	-.496
		Nkumu in palm oil or Nyembouè	.927*	.009	.000	.896	.958
		Nkumu O'fula	-.220*	.009	.000	-.251	-.189
	Nkumu in water	Fresh chopped Nkumu	1.240*	.009	.000	1.209	1.271
		Nkumu with peanut paste	.713*	.009	.000	.682	.744
		Nkumu in palm oil or Nyembouè	2.167*	.009	.000	2.136	2.198
		Nkumu O'fula	1.020*	.009	.000	.989	1.051
	Nkumu with peanut paste	Fresh chopped Nkumu	.527*	.009	.000	.496	.558
		Nkumu in water	-.713*	.009	.000	-.744	-.682
		Nkumu in palm oil or Nyembouè	1.453*	.009	.000	1.422	1.484
		Nkumu O'fula	.307*	.009	.000	.276	.338
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	-.927*	.009	.000	-.958	-.896
		Nkumu in water	-2.167*	.009	.000	-2.198	-2.136
		Nkumu with peanut paste	-1.453*	.009	.000	-1.484	-1.422
		Nkumu O'fula	-1.147*	.009	.000	-1.178	-1.116
	Nkumu O'fula	Fresh chopped Nkumu	.220*	.009	.000	.189	.251
		Nkumu in water	-1.020*	.009	.000	-1.051	-.989
		Nkumu with peanut paste	-.307*	.009	.000	-.338	-.276
		Nkumu in palm oil or Nyembouè	1.147*	.009	.000	1.116	1.178

Table 23 shows the pairwise comparisons, with respect to the mineral Mn.

Table 23. Pairwise comparison, with respect to mineral Mn

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b]	
						Lower bound	Upper bound
Mn (mg/100g DM)	Fresh chopped Nkumu	Nkumu in water	6.770*	.062	.000	6.546	6.994
		Nkumu with peanut paste	8.907*	.062	.000	8.683	9.130
		Nkumu in palm oil or Nyembouè	11.070*	.062	.000	10.846	11.294
		Nkumu O'fula	5.267*	.062	.000	5.043	5.490
	Nkumu in water	Fresh chopped Nkumu	-6.770*	.062	.000	-6.994	-6.546
		Nkumu with peanut paste	2.137*	.062	.000	1.913	2.360
		Nkumu in palm oil or Nyembouè	4.300*	.062	.000	4.076	4.524
		Nkumu O'fula	-1.503*	.062	.000	-1.727	-1.280
	Nkumu with peanut paste	Fresh chopped Nkumu	-8.907*	.062	.000	-9.130	-8.683
		Nkumu in water	-2.137*	.062	.000	-2.360	-1.913
		Nkumu in palm oil or Nyembouè	2.163*	.062	.000	1.940	2.387
		Nkumu O'fula	-3.640*	.062	.000	-3.864	-3.416
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	-11.070*	.062	.000	-11.294	-10.846
		Nkumu in water	-4.300*	.062	.000	-4.524	-4.076
		Nkumu with peanut paste	-2.163*	.062	.000	-2.387	-1.940
		Nkumu O'fula	-5.803*	.062	.000	-6.027	-5.580
	Nkumu O'fula	Fresh chopped Nkumu	-5.267*	.062	.000	-5.490	-5.043
		Nkumu in water	1.503*	.062	.000	1.280	1.727
		Nkumu with peanut paste	3.640*	.062	.000	3.416	3.864
		Nkumu in palm oil or Nyembouè	5.803*	.062	.000	5.580	6.027

Table 24 shows the pairwise comparisons, with respect to pH.

Table 24. Pairwise comparison, with respect to pH

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b]	
						Lower bound	Upper bound
pH	Fresh chopped Nkumu	Nkumu in water	-1.337*	.022	.000	-1.416	-1.257
		Nkumu with peanut paste	-1.053*	.022	.000	-1.133	-.974
		Nkumu in palm oil or Nyembouè	-.563*	.022	.000	-.643	-.484
		Nkumu O'fula	-2.570*	.022	.000	-2.650	-2.490
		Fresh chopped Nkumu	1.337*	.022	.000	1.257	1.416

	Nkumu in water	Nkumu with peanut paste	.283*	.022	.000	.204	.363
		Nkumu in palm oil or Nyembouè	.773*	.022	.000	.694	.853
		Nkumu O'fula	-1.233*	.022	.000	-1.313	-1.154
	Nkumu with peanut paste	Fresh chopped Nkumu	1.053*	.022	.000	.974	1.133
		Nkumu in water	-.283*	.022	.000	-.363	-.204
		Nkumu in palm oil or Nyembouè	.490*	.022	.000	.410	.570
		Nkumu O'fula	-1.517*	.022	.000	-1.596	-1.437
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	.563*	.022	.000	.484	.643
		Nkumu in water	-.773*	.022	.000	-.853	-.694
		Nkumu with peanut paste	-.490*	.022	.000	-.570	-.410
		Nkumu O'fula	-2.007*	.022	.000	-2.086	-1.927
	Nkumu O'fula	Fresh chopped Nkumu	2.570*	.022	.000	2.490	2.650
		Nkumu in water	1.233*	.022	.000	1.154	1.313
		Nkumu with peanut paste	1.517*	.022	.000	1.437	1.596
		Nkumu in palm oil or Nyembouè	2.007*	.022	.000	1.927	2.086

Table 25 shows the pairwise comparisons, with respect to acidity.

Table 25. Pairwise comparison, with respect to acidity

Dependent variable	(I) Sample	(J) Sample	Difference of means (I-J)	Standard error	Sig.[b]	95% confidence interval of the difference [b]	
						Lower bound	Upper bound
Acidity (mg/g)	Fresh chopped Nkumu	Nkumu in water	-10.473*	1.408	.000	-15.516	-5.431
		Nkumu with peanut paste	-17.100*	1.408	.000	-22.142	-12.058
		Nkumu in palm oil or Nyembouè	-33.290*	1.408	.000	-38.332	-28.248
		Nkumu O'fula	-42.237*	1.408	.000	-47.279	-37.194
	Nkumu in water	Fresh chopped Nkumu	10.473*	1.408	.000	5.431	15.516
		Nkumu with peanut paste	-6.627*	1.408	.008	-11.669	-1.584
		Nkumu in palm oil or Nyembouè	-22.817*	1.408	.000	-27.859	-17.774
		Nkumu O'fula	-31.763*	1.408	.000	-36.806	-26.721
	Nkumu with peanut paste	Fresh chopped Nkumu	17.100*	1.408	.000	12.058	22.142
		Nkumu in water	6.627*	1.408	.008	1.584	11.669
		Nkumu in palm oil or Nyembouè	-16.190*	1.408	.000	-21.232	-11.148
		Nkumu O'fula	-25.137*	1.408	.000	-30.179	-20.094
	Nkumu in palm oil or Nyembouè	Fresh chopped Nkumu	33.290*	1.408	.000	28.248	38.332
		Nkumu in water	22.817*	1.408	.000	17.774	27.859
		Nkumu with peanut paste	16.190*	1.408	.000	11.148	21.232

		Nkumu O'fula	-8.947*	1.408	.001	-13.989	-3.904
	Nkumu O'fula	Fresh chopped Nkumu	42.237*	1.408	.000	37.194	47.279
		Nkumu in water	31.763*	1.408	.000	26.721	36.806
		Nkumu with peanut paste	25.137*	1.408	.000	20.094	30.179
		Nkumu in palm oil or Nyembouè	8.947*	1.408	.001	3.904	13.989

7. Discussion

The objective of this study was to evaluate the impact of different processing methods of Nkumu on its nutritional quality, specifically its macronutrient and mineral composition, as well as its physicochemical characteristics (pH and acidity). The obtained results highlight significant variations related to preparation methods, confirming that culinary practices profoundly influence the nutritional value of traditional foods (Gibson et al., 2006).

7.1. Effect of Processing Methods on Macronutrients

The results in Tables 8 to 14 show that the nutritional composition of Nkumu varies heavily depending on the cooking method. Fresh chopped Nkumu exhibits a low lipid content (1.61 g/100 g DM) and a notable proportion of carbohydrates (12.59 g/100 g DM). This is consistent with the nutritional profile generally reported for African leafy vegetables, which tend to be low in fat and relatively rich in dietary fiber (Akissoé et al., 2014; Uusiku et al., 2010), including Gnetum africanum (Ali et al., 2011).

In contrast, the enriched preparations—specifically Nkumu with peanut paste and Nkumu with palm oil—show a significant increase in lipid content (35.94 to 78.91 g/100 g DM). This increase is explained by the incorporation of fat-rich ingredients, such as peanuts and palm oil, known for their high energy density (Slavin, 2013). This confirms that traditional culinary practices deeply modify the nutritional value of staple foods.

- Protein Content: The high protein content observed in the peanut paste Nkumu (44.12 g/100 g DM) can be attributed to the protein contribution of legumes, particularly peanuts, which constitute a major source of plant-based protein (Asibuo et al., 2008).
- Carbohydrate Absence: Conversely, the near-absence of carbohydrates in the processed Nkumu dishes suggests either a relative dilution effect caused by the addition of other macronutrients, or possible thermal degradation or leaching during the cooking process.
- Dietary fibers: Dietary fibers remain relatively high across all preparations, particularly in Nkumu O'fula (10.37 g/100 g DM), which is highly beneficial for digestive health and the prevention of chronic diseases (Slavin, 2005; Slavin, 2013).

7.2. Variation in Mineral Composition

The results in Tables 15 to 23 reveal significant variability in mineral content depending on the culinary treatments. Fresh Nkumu stands out for its high levels of calcium (902.29 mg/100 g DM) and potassium (1268.36 mg/100 g DM), confirming that leafy vegetables serve as an excellent source of essential micronutrients (Uusiku et al., 2010).

- Potassium and Sodium Spikes: Certain preparations, particularly Nkumu O'fula, exhibit exceptionally high contents of potassium (2851.56 mg/100 g DM) and sodium (1842.52 mg/100 g DM). This increase could be explained by the addition of indigenous salt or other condiments during preparation, as well as the concentration of nutrients due to moisture reduction (Gibson et al., 2006; WHO, 2020).
- Health Concerns: The particularly high sodium content in some preparations (Nkumu in water, peanut paste Nkumu, and Nkumu O'fula) constitutes a critical point, as excessive sodium consumption is linked to an increased risk of hypertension and cardiovascular disease (WHO, 2012; WHO, 2023a).
- Iron Losses: Furthermore, the decrease of iron in the processed preparations, notably in the palm oil Nkumu (0.46 mg/100 g DM), could be related to leaching losses or to interactions with other food compounds that reduce its bioavailability (Hurrell & Egli, 2010).

7.3. Influence of pH and Acidity

The pH values (Tables 24 and 25) indicate that the different preparations vary from slightly acidic (fresh Nkumu, pH ≈ 5.0) to neutral or slightly alkaline (Nkumu O'fula, pH ≈ 7.6). These variations can be attributed to the added ingredients and the biochemical reactions induced by cooking.

The increase in acidity within the processed preparations, particularly in Nkumu O'fula (42.24 mg/g), might result from the formation of organic acids or the addition of fermented or acidic ingredients. While high acidity can improve microbiological preservation, it can also influence organoleptic properties.

7.4. Nutritional and Health Implications

Overall, the results demonstrate that:

- Culinary processing increases the energy density of foods, primarily through the addition of lipids.
- Enriched preparations (peanut, palm oil) improve protein and energy intake (Asibuo et al., 2008).
- Certain practices lead to a worrying increase in sodium levels (WHO, 2012; WHO, 2023a). · Fresh Nkumu remains the best source of essential micronutrients, offering a more balanced profile.

These observations confirm that preparation methods heavily influence—either by increasing or decreasing—the nutritional quality of traditional foods, as has been demonstrated in several studies on African leafy vegetables (Uusiku et al., 2010).
This study highlights the significant impact of processing methods on the nutritional quality of Nkumu. While some preparations, such as those based on peanut paste, improve protein and energy supply, others—particularly those rich in oil or salt—can present nutritional risks if consumed excessively (WHO, 2020).
Thus, promoting Nkumu in the diet should be accompanied by nutritional recommendations aimed at optimizing preparation methods to preserve its qualities while limiting excesses in lipids and sodium (FAO, 2024; WHO, 2023a).

8. Conclusions

The objective of this study was to evaluate the impact of different processing methods of Nkumu on its nutritional composition and physicochemical properties. The obtained results highlighted significant variations in macronutrient and mineral contents, as well as pH and acidity parameters depending on the preparation methods. Fresh chopped Nkumu presents a globally balanced nutritional profile, characterized by a low lipid content, a notable presence of carbohydrates, and an appreciable richness in essential minerals such as calcium, potassium, and iron.

It thus constitutes an interesting source of micronutrients and dietary fiber. Culinary transformations, particularly the addition of peanut paste and palm oil, lead to a significant increase in the energy density of the preparations due to their high lipid and protein content (Asibuo et al., 2008). Nkumu with peanut paste stands out for its high protein contribution, while Nkumu with palm oil represents the most energy-dense preparation. However, these enrichments are accompanied by a marked nutritional imbalance, notably a near-absence of carbohydrates. Furthermore, certain preparations—specifically Nkumu O'fula and Nkumu in water—exhibit very high sodium contents, which could pose a health risk in cases of excessive consumption (WHO, 2012; WHO, 2023a).

On the other hand, Nkumu O'fula is also characterized by a remarkable richness in potassium and calcium, highlighting its high nutritional potential. The variations observed in pH and acidity indicate that processing methods influence the physicochemical properties of the preparations, with potential implications for shelf-life, microbiological quality, and the organoleptic characteristics of the food. However, the results of this study must be interpreted considering certain limitations:

- Geographical Context: The study was carried out within a specific geographical context in Gabon, which may limit the generalization of the results to other regions where Gnetum spp. is consumed.
- Analytical Scope: The evaluation focused primarily on nutritional and physicochemical parameters, omitting microbiological analyses and sensory evaluations of the preparations, which would have provided a more comprehensive assessment of their sanitary and organoleptic quality.

In short, this study demonstrates that Nkumu processing methods play a determining role in the final nutritional quality of the dishes. While some practices improve energy and protein supply, they can also cause excesses in lipids and sodium. Consequently, it is necessary to promote balanced culinary practices aimed at preserving the nutritional qualities of Nkumu while limiting excessive intakes of fats and salt. Valuing this leafy vegetable within the diet could contribute to improving nutritional security, provided that appropriate preparation methods are adopted (FAO, 2024; WHO, 2023a).

About the limitations, this study was conducted primarily in the Estuary Province. As culinary habits may vary across the regions of Gabon, the results obtained cannot be generalized to the entire country without further studies. Certain microbiological and sensory analyses were not included.

Future studies should incorporate microbiological, sensory, and toxicological analyses of the different Nkumu preparations. It would also be relevant to evaluate the bioavailability of micronutrients and the presence of antinutritional compounds.

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