

Evaluation of the mineral and physicochemical characteristics of plant salts produced and consumed in rural areas of western Côte d'Ivoire

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Abstract

Salts made from palmaceae (palm and coconut) and plantain peels are the main plant salts produced and consumed in West of Côte d'Ivoire. However, their physicochemical characteristics, which may justify their use in the diet of people on low-sodium diets, are not known. The present study aimed to identify and localize plant salts presenting the best physicochemical characteristics for domestic but also industrial food use. Thus, the pH, particle size, level of insoluble matter and mineral composition of the three salts were studied. The study shows that these salts are alkaline products: their pH is between 10.9 and 11.33. Those produced from palmaceae branches have at least 75% of particles less than 0.25 mm in size, while salt from plantain peels is mainly composed of lumps larger than 10 mm. In addition, palm salts are very water soluble. They contain less than 1% of insoluble matter while plantain peel salt contains 67.37%. Salts made from palmaceae branches are therefore more easily used as seasoning. However, the 3 plant salts studied have sodium/potassium ratios lower than 0.1. On this basis, they could all easily contribute to improving the diet of people following low-sodium diets and reducing the prevalence of metabolic diseases linked to high sodium chloride consumption.

Keywords: Food Risk; Metabolic Diseases; Special Diet; Salt-Free Diet; Sodium/Potassium Ratio

1. Introduction

Salts extracted from plants, commonly called “potash”, are obtained by crystallization of mineral salts from plants [1]. According to [2], most populations far from the seas have been producing and consuming it for centuries. These salts of organic origin were important elements of the diet and pharmacopoeia for many populations in sub-Saharan Africa [3]. However, these salty products have lost their importance so much so that very little study has been devoted to them. Consequently, data relating to plant salts still remains very sketchy [2,4]. Nowadays, the prevalence of diseases linked to a very high consumption of sodium (provided by table salt) is very high. This sparks interest in any alternative salt that contains less sodium. Thus, several molecules, mixtures of molecules and spices have been tested as salt substituents in numerous food matrices. However, these solutions have very often been considered too expensive and, above all, less natural than sodium chloride (NaCl). This is the case for mixtures containing potassium chloride (KCl) [5,6]. In order to advancing research in this area, this work contributes to increasing knowledge around plant salts produced and still consumed in Côte d'Ivoire. The scientific approach consists of demonstrating that these additives have beneficial characteristics and properties for domestic consumption, but also to being potentially usable in industrial food production. The study focused on the particle size configuration, physicochemical characteristics and

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mineral composition of salts made from palmaceae (palm and coconut) produced in the West of Côte d'Ivoire and salt made from plantain peels, commonly sold in markets. This work aims to serve as a basis for a real promotion of plant salts as additives to replace sodium chloride in domestic and industrial food production. He would also like to offer an alternative to severe low-salt diets, which are unbearable and often imposed in cases of pathologies such as high blood pressure.

2. Material and methods

2.1. Material

Three type of plant salts were the subject of this study. Salts from palm and coconut branches produced in three administrative regions (*Tonkpi, Guemon* and *Cavally*) in western Côte d'Ivoire by the *Dan* and *We* peoples (Figures 1 and 3) and salt from plantain peels produced by *Malinke* people (Figures 2 and 3). These plant salts were produced under the same conditions, according to the diagrams describe by [7] (Figure 3).



Figure 1 Plant salt extracted from: A-palm branches (*Elaeis guineensis*); B-coconut branches (*Cocos nucifera*)



Figure 2 Salt lumps made from plantain peels

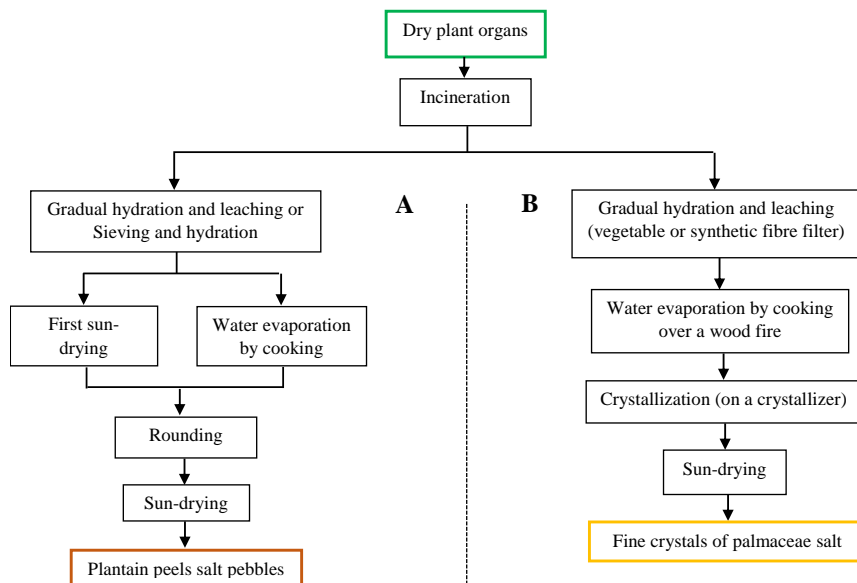


Figure 3 Artisanal production of plant salts from: A- plantain peels and B- palmaceae banches[7]

2.2. Analysis methods

2.2.1. pH

The pH of the plant salt samples were determined by direct measurement. Thus, to 10 g of vegetable salt were added 100 mL of distilled water, previously heated to 60°C. The infusion was stirred for one min, then filtered. The supernatant (25 mL) was subjected to analysis using the electronic pH meter which had been previously calibrated with buffer solutions of pH 7 and 10 [8].

2.2.2. Particle distribution

The particle size distribution of each plant salt was determined by the sieving method used by [9]. Seven sieves with mesh diameters between 63 and 1000 μm ($\Phi 63 = 0.063$ mm; $\Phi 125 = 0.125$ mm; $\Phi 200 = 0.2$ mm; $\Phi 250 = 0.25$ mm; $\Phi 500 = 0.5$ mm; $\Phi 630 = 0.63$ mm; $\Phi 1000 = 1$ mm) (AFNOR NFX11-504 standard) were used. The percentage of refusals (quantity of particles retained) from each sieve made it possible to construct particle size curves. On these plots, from the cumulative amount, the first (Q25), second (Q50) and third (Q75) quartiles were determined. Q25, Q50 and Q75 indicate the mesh sizes for which the sieve would correspond to 25%, 50% and 75% of the total mass.

2.2.3. Insoluble materials rate

The rate of insoluble materials (IMC) was determined by weighing the materials retained by a filter after solubilisation of 10 g of salt in 200 ml of distilled water according to ISO 2479 - 1972 [10].

$$IMC = [(M_e - M_s) / P_e] \times 100$$

With:

Ms: mass of the filter before use (g)

Me: mass of the filter after use (g)

Pe: test sample (g)

IMC: Insoluble matter content (%).

2.2.4. Mineral rate

The analysis of the plant salts was carried out using a FEG (Field Emission Gun) scanning electron microscope (SEM). The salt sample was reduced to ash by incineration in a muffle furnace at 550 ± 15 °C for 12 hours, before being placed on a slide. The slide was fixed on a pad and placed in the SEM chamber for digestion and reading. The values were given as a percentage of the mineral relative to the quantity of salt analysed.

$$TM = \frac{\% C \times \% M \times 1000}{DM}$$

With:

TM: mass of the element relative to the mass of the dry matter expressed in mg/kg DM

% C: ash rate in salt

% M: rate of mineral element in percentage of ash

DM: dry matter of salt

2.3. Statistical analysis

The one-way analysis of variance (ANOVA 1) using the type of salt and the region as explanatory variables was carried out using the JMP® Version 18.0.1, 2024 software. The Tukey test allowed the comparison of averages at the 5%

threshold. PCA made it possible to study salts and visualize the correlations between their physicochemical characteristics. Ward's hierarchical classification made it possible to group them into classes.

3. Results et discussions

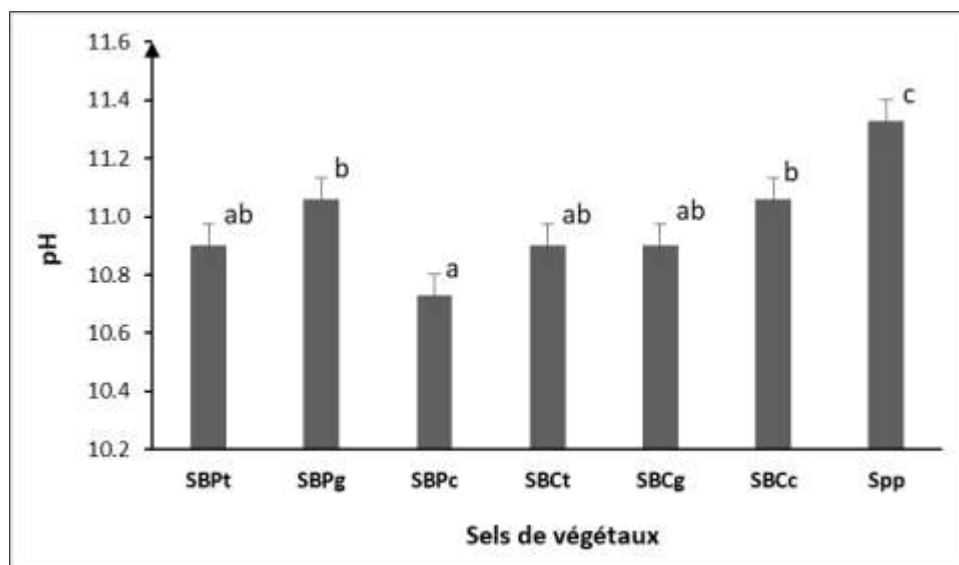
3.1. Physicochemical characteristics and mineral content of plant salts

3.1.1. Physicochemical characteristics

Three physicochemical parameters of plant salts were determined. These are pH, particle size and level of insoluble matter.

pH

The pH of the plant salts studied – between 10.7 and 11.1 – clearly reflects their alkalinity (Figure 4). This characteristic is inherent in plant incineration products. Indeed, the oxidation process promotes the formation of carbonates and hydroxides with alkaline pH [11]. These results are almost identical to those of [12] who obtained values between 10.8 and 11.1 for plant salts found on the markets of Mali. Moreover, these alkaline pH also justify the use of plant salts in softening meats. Indeed, after slaughter, the pH of the muscle goes from its physiological value (pH between 7.0 and 7.2) to a value close to 5.3 - 5.8 [13,14]. This post-mortem acidification of muscle tissue reduces the solubility of contractile proteins. In a basic environment, the pH of the muscle increases and the tenderness process is accelerated [15,13].



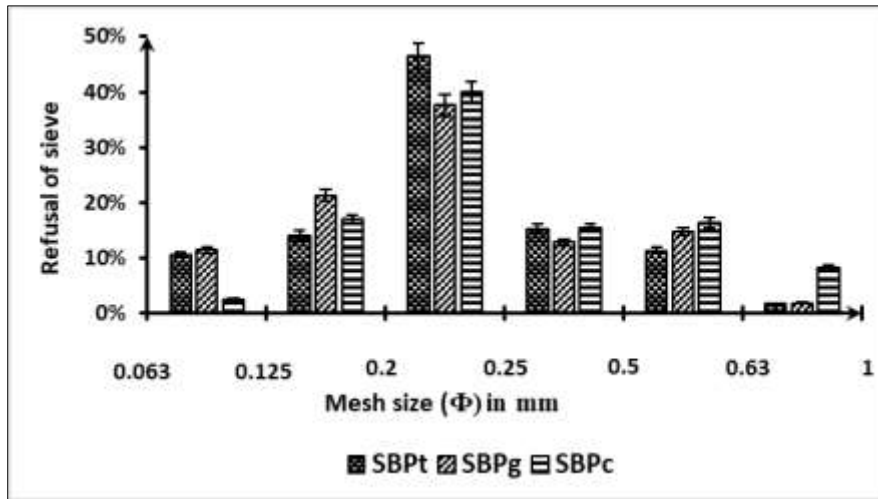
SBPt: salt made from palm branches produced in Tonkpi; SBPg: salt made from palm branches produced in Guémon; SBPc: salt made from palm branches produced in Cavally; SBCT: salt made from coconut branches produced in Tonkpi; SBCg: salt made from coconut branches produced in Guémon; SBCc: salt made from coconut branches produced in Cavally; SPP: salt made from plantain peels

Figure 4 pH values of the plant salts

Particle size distribution of plant salts

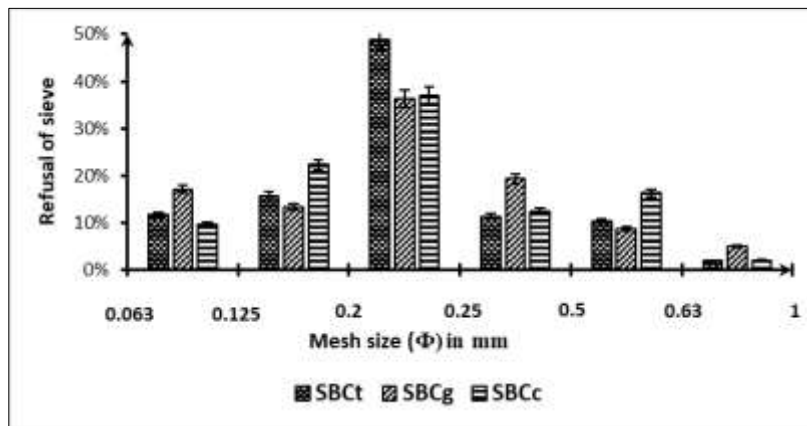
The particle size configuration of the plant salts produced in the *Tonkpi*, *Guémon* and *Cavally* regions can facilitate their use as a seasoning product. Indeed, the particle size is a fundamental characteristic for any additive used in kitchen. It is directly related to the phenomena of physical exchange and reactivity: water migration, drying and solubilisation [16]. About palmaceae's salts, whatever the region and whatever the studied plant salt, the size of most grains are between 0.2 mm and 0.25 mm ($200 \mu\text{m} < \Phi < 250 \mu\text{m}$) (Figures 5 and 6).

The mesh parameters, corresponding to Q25, Q50 and Q75, indicate that the palmaceae salts are made up of 75% of grains with diameters less than or equal to 0.25 mm (Table I). This characteristic is therefore likely to facilitate their use as seasoning additive in domestic and industrial food production. Palmaceae salts are finer than fine table salt, the grain size of which is between 0.3 and 1.0 mm in size [10]. Conversely, plantain peel salt, which has lumps larger than 10 mm, is difficult to use as a seasoning product.



SBPt: salt made from palm branches produced in Tonkpi; SBPg: salt made from palm branches produced in Guémon; SBPc: salt made from palm branches produced in Cavally

Figure 5 Palm branches salt particle size distribution



SBCT: salt made from coconut branches produced in Tonkpi; SBCg: salt made from coconut branches produced in Guémon; SBCc: salt made from coconut branches produced in Cavally

Figure 6 Coconut branches salt particle size distribution

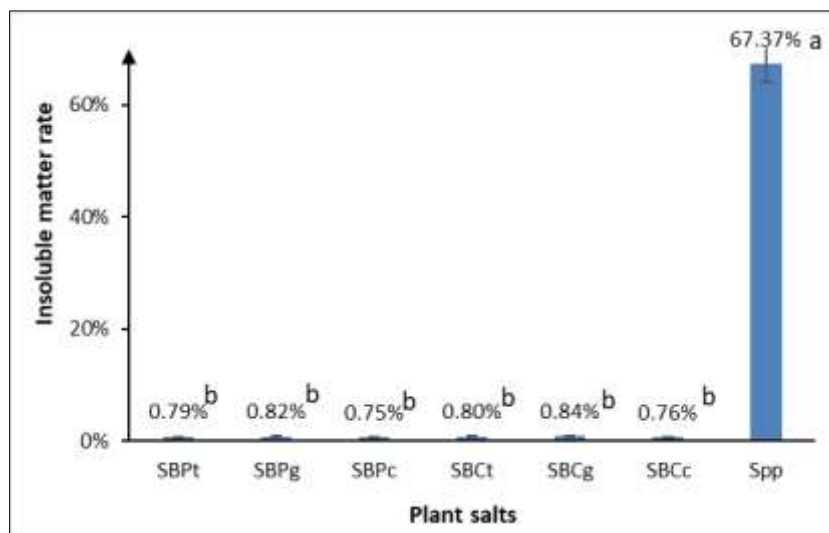
Table 1 Sieve mesh settings for first, second and third quartiles

	SBPt	SBPg	SBPc	SBCT	SBCg	SBCc
$\Phi_{Q_{25}}$ (mm)	0.125	0.058	0.165	0.11	0.067	0.053
$\Phi_{Q_{50}}$ (mm)	0.19	0.19	0.19	0.19	0.19	0.19
$\Phi_{Q_{75}}$ (mm)	0.21	0.22	0.25	0.2	0.22	0.22

SBPt: salt made from palm branches produced in Tonkpi; SBPg: salt made from palm branches produced in Guémon; SBPc: salt made from palm branches produced in Cavally; SBCT: salt made from coconut branches produced in Tonkpi; SBCg: salt made from coconut branches produced in Guémon; SBCc: salt made from coconut branches produced in Cavally

nut branches produced in Guémon; SBCc: salt made from coconut branches produced in Cavally; $\Phi_{Q_{25}}$: mesh size for sieve equal to 25% of the test portion ; $\Phi_{Q_{50}}$: mesh size for sieve equal to 50 % of the test portion ; $\Phi_{Q_{75}}$: mesh size for sieve equal to 75% of the test portion

3.2. Insoluble matter level in plant salts



SBPt: salt made from palm branches produced in Tonkpi; **SBPg:** salt made from palm branches produced in Guémon; **SBPc:** salt made from palm branches produced in Cavally; **SBCt:** salt made from coconut branches produced in Tonkpi; **SBCg:** salt made from coconut branches produced in Guémon; **SBCc:** salt made from coconut branches produced in Cavally; **SPP:** salt made from plantain peels

Figure 7 Insoluble matter levels in plant salts

In terms of purity, the “plant salts” produced from palmaceae branches presented less than 1% of insoluble materials while the salt from banana peels contained 67.37% (Figure 7). Palm salts, unlike plantain peel salt, are therefore very water-soluble products. The absence of organic matter would represent an advantage if these products were to be iodized [17]. However, the palmaceae salts insoluble matter levels are higher than the Senegalese standard, NS 03-0017, set at 0.3% for table salt (NaCl) [10].

3.3. Mineral content

Plant salts present significant mineral diversity. According to their concentration in the studied salts, they were classified into two categories: major and minor minerals.

3.4. Major minerals in plant salts

Potassium is the most abundant mineral in all the studied plant salts. The levels were between 21030.36 mg/kg and 31128.90 mg/kg DM, between 35 to 58% (Table II). The average sodium content varies between 901.53 mg/kg and 2223.48 mg/kg DM (9 to 11 %). Salts made from palm branches were richer in potassium and less rich in sodium than salts from coconut branches (Table II). The potassium and sodium contents of the plant salts in this study are very much lower than those obtained by [18] during work on other plant salts produced from palm and sorghum stalks, coconut and rice husk, banana trunks and cassava peels in several localities in Togo. In their study, the values oscillated respectively between 7064.02 mg/100g and 8863.20 mg/100g and between 204.02 mg/100g and 314.44 mg/100g for potassium and sodium.

The obtained Na/K ratios values were between 0.029 and 0.096 (Table II). These reports are close to those obtained by [18]. These were between 0.01 and 0.08 while [4] obtained values up to 0.15 for *Cocos nucifera* of Cayenne. The Na/K ratio varies significantly ($p < 0.05$) from one substrate to another and from one region to another. This variation could be the result of combined effects of phytochemical composition, soil quality and manufacturing processes. In all cases, these Na/K ratios clearly indicate that these salts could help improve the dietary conditions of individuals following strict low-sodium diets, such as those with hypertension. In fact, a Na/K ratio less than 1 is indicative of low sodium intake via the salt used [19]. Potassium ingested in large quantities, in addition to its vasoactive effect, can increase sodium excretion. A low salt Na/K ratio is better for the consumer's health.

Table 2 Potassium and sodium levels - Na/K ratios of plant salts

Plant salts	Minerals		
	K (mg/kg)	Na (mg/kg)	Na/K ratio
SBPt	24942.75 ± 172.43 ^b	1946.15 ± 05.91 ^a	0.078
SBPg	26580.66 ± 121.98 ^b	2202.52 ± 10.34 ^a	0.083
SBPc	27408.13 ± 125.21 ^b	1762.06 ± 09.21 ^a	0.064
SBCt	21030.36 ± 238.37 ^c	2028.69 ± 13.86 ^a	0.096
SBCg	24938.94 ± 201.61 ^b	2223.48 ± 17.66 ^a	0.089
SBCc	24972.74 ± 100.30 ^b	1841.87 ± 10.93 ^a	0.074
SPP	31128.90 ± 266.65 ^a	901.3 ± 15.18 ^b	0.029

Values assigned the same letter in the same column are not significantly different at the 5% threshold (Tukey test). **SBPt**: salt made from palm branches produced in Tonkpi; **SBPg**: salt made from palm branches produced in Guémon; **SBPc**: salt made from palm branches produced in Cavally; **SBCt**: salt made from coconut branches produced in Tonkpi; **SBCg**: salt made from coconut branches produced in Guémon; **SBCc**: salt made from coconut branches produced in Cavally; **SPP**: salt made from plantain peels

3.5. Minor minerals in plant salts

Plant salts contain calcium (77.34 – 249.94 mg/kg), phosphorus (103.94 – 310.97 mg/kg) and magnesium (69.26 – 217.14 mg/kg) (Table III). They also contain iron (424.85 – 2017.56 mg/kg) and zinc (81.28 – 461.17 mg/kg) (Table IV). The presence of these minerals is an undeniable asset from a nutritional and therapeutic point of view. Indeed, calcium and magnesium contribute to skeletal health. Magnesium can have a protective effect against cardiovascular diseases, in particular by modulating calcium efflux in cases of hyperkalaemia [20]. Zinc, like iron, helps prevent anaemia, but especially helps with healing. Zinc is also a constituent of insulin, therefore necessary for sugar metabolism. Its presence in sufficient quantities in the diet of diabetics is therefore very positive [21].

All the studied plant salts contained, for some, only traces of iodine and for others no iodine (Table IV). This could be explained by the quality of the soil in the area where the samples were collected. Indeed, the work carried out by [22,23] demonstrated that the mountainous western zone is one of the most affected by iodine deficiency in Côte d'Ivoire. According to these same authors, the high prevalence of endemic goitre is due to the low iodine content of soil, water and food in the Tonkpi region. Thus, to contribute to the fight against iodine deficiency, we recommended, like [18], a study of the iodization capacity of plant salts.

Table 3 Calcium, magnesium, manganese and phosphorus contents of plant salts

Plant salts	Minerals			
	Ca (mg/kg)	Mg (mg/kg)	Mn (mg/kg)	P (mg/kg)
SBPt	249.94 ± 2.05 ^a	81.56 ± 1.95 ^b	90.72 ± 1.76 ^{bc}	192.47 ± 2.35 ^{ab}
SBPg	77.34 ± 1.21 ^f	69.26 ± 0.15 ^b	214.75 ± 4.87 ^a	299.94 ± 3.05 ^a
SBPc	129.67 ± 3.31 ^d	81.56 ± 0.47 ^b	95.91 ± 0.24 ^{bc}	192.47 ± 0.81 ^{ab}
SBCt	224.37 ± 6.73 ^b	101.01 ± 2.3 ^{ba}	124.71 ± 0.7 ^{bc}	201.45 ± 1.39 ^{ab}
SBCg	87.04 ± 2.08 ^e	83.88 ± 0.21 ^b	55.73 ± 1.95 ^d	310.97 ± 4.21 ^a
SBCc	153.58 ± 0.14 ^c	88.21 ± 0.44 ^b	102.67 ± 3.31 ^{bc}	188.82 ± 2.83 ^{ab}
SPP	-	217.14 ± 6.25 ^a	41.91 ± 1.78 ^d	103.94 ± 0.93 ^b

Values assigned the same letter in the same column are not significantly different at the 5% threshold (Tukey test). **SBPt**: salt made from palm branches produced in Tonkpi; **SBPg**: salt made from palm branches produced in Guémon; **SBPc**: salt made from palm branches produced in Cavally; **SBCt**: salt made from coconut branches produced in Tonkpi; **SBCg**: salt made from coconut branches produced in Guémon; **SBCc**: salt made from coconut branches produced in Cavally; **SPP**: salt made from plantain peels

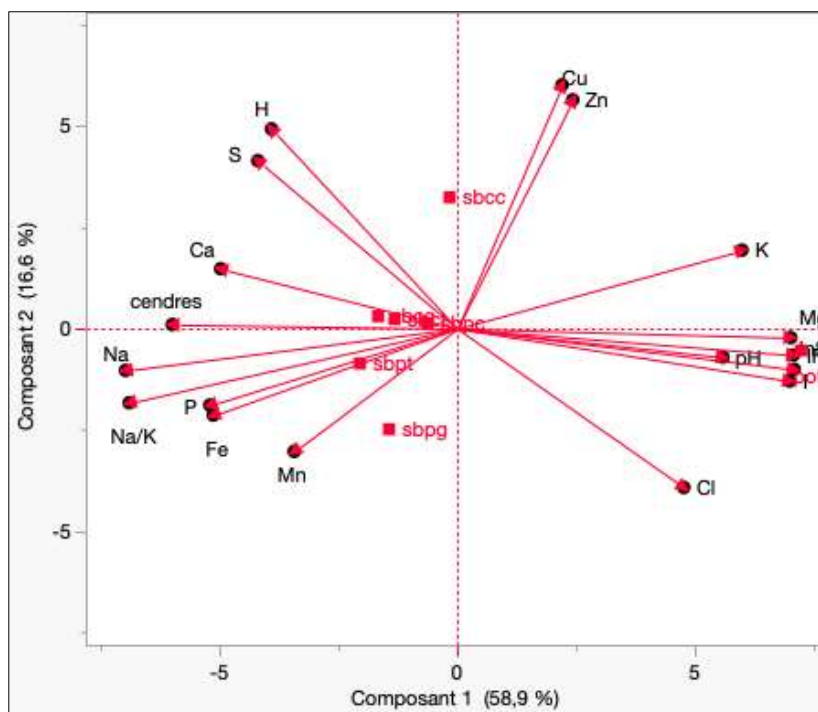
Table 4 Iron, zinc and iodine content of plant salts

Plant salts	Minerals		
	Fe (mg/kg)	Zn (mg/kg)	Iodine (mg/kg)
SBPt	2017.56 ± 12.3a	214.16 ± 7.77d	-
SBPg	1725.07 ± 18.28a	81.28 ± 2.36f	-
SBPc	424.85 ± 8.11c	381.96 ± 7/4b	-
SBCt	1808.09 ± 11.22a	210.99 ± 5.66d	-
SBCg	1713.66 ± 14.74a	149.65 ± 3.19e	-
SBCc	968.31 ± 18.12b	461.17 ± 2.96a	0.0048 ± 0.021a
SPP	369.36 ± 6.67c	313.45 ± 3.21c	0.0051 ± 0.0013a

Values assigned the same letter in the same column are not significantly different at the 5% threshold (Tukey test). **SBPt**: salt made from palm branches produced in Tonkpi; **SBPg**: salt made from palm branches produced in Guémon; **SBPc**: salt made from palm branches produced in Cavally; **SBCt**: salt made from coconut branches produced in Tonkpi; **SBCg**: salt made from coconut branches produced in Guémon; **SBCc**: salt made from coconut branches produced in Cavally; **SPP**: salt made from plantain peels

Variability of the physicochemical and mineral characteristics of salts depending on the region and the plant used

The one-way Anova revealed significant differences between the salts ($p < 0.05$) depending on the region and the plant used.



SBPt: salt made from palm branches produced in Tonkpi; **SBPg**: salt made from palm branches produced in Guémon; **SBPc**: salt made from palm branches produced in Cavally; **SBCt**: salt made from coconut branches produced in Tonkpi; **SBCg**: salt made from coconut branches produced in Guémon; **SBCc**: salt made from coconut branches produced in Cavally; **SPP**: salt made from plantain peels

Figure 8 Variability of the physicochemical characteristics depending on the region and the vegetable matter

The PCA, using Pearson correlation, represented the differences in biochemical and mineral composition of the studied plant salts. The first principal component F1, which represents approximately 60% of the total variance, opposes insoluble matter, K, Mg, pH and Cl to Ash, Ca, Na, P, Fe and Mn. Furthermore, H, S, Cu and Zn were better represented according to F2 which expresses 17% of the total variance (Figure 8).

The visualization of the plant salts in the two-dimensional space shows that Spp, associated with pH, Mg, Cl, K and insoluble matter according to F1, is opposed to SBCg and SBPt, much more associated with ashes and minerals Na, Ca, Fe, P and Mn. SBPc seemed better represented on dimension F3 (not shown). However, it should be noted the similarity between SBCc and SBPg, better represented according to F2 (Figure 8).

4. Conclusion

The plant salts produced from palmaceae branches are more easily used as seasoning because at least 75% of their particles are smaller than 0.25 mm. All the studied plant salts contain a lot of potassium. Conversely, they only contain very tiny quantities of sodium, especially those produced in Tonkpi and Cavally. The Na/K ratios of all plant salts studied are less than 0.1. On this basis, they can easily replace table salt in a strict low-sodium diet. Palmaceous salts do not present great differences in chemical and physical characteristics. The constituents are almost the same, except that the quantities vary depending on the origin of the raw material. Furthermore, Tonkpi's palm salt (SBPt) and Cavally's coconut salt (SBCc) show the best nutritional profiles on the base of their mineral compositions. Also, these plant salts are all very low in iodine. A supply of this element is therefore essential whether they should be used as food additives.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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