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Research Article

FROM COCONUT FIBER (*Cocos nucifera* L.) TO EDIBLE SALT: PHYSICOCHEMICAL ANALYSIS OF AN INNOVATIVE PRODUCT

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ABSTRACT. Coconut fiber (*Cocos nucifera*) is an abundant, inexpensive agricultural by-product with high potential for value-added processing. However, it is undervalued. In this context, the aim of this study is to determine the physicochemical characteristics of an edible salt obtained from the ash of this fiber. To do this, coconut fiber from the West Africa Tall (WAT) cultivar, immature with gelatinous almonds (N_{IGA}) and mature with hard almonds (N_{MHA}), was used. The fiber was incinerated to produce ash, which was washed, filtered and boiled to obtain salt crystals that were dried and then analysed. The yield, particle size, colour distance, pH and ash and mineral content were the parameters evaluated. It appears that the yield of N_{IGA} salt is around 1.89%, while that of N_{MHA} is 1.51%. These salts consist mainly of fine grains with a diameter of less than 500 µm. N_{MHA} salt has a darker orange colour than N_{IGA} salt. N_{IGA} and N_{MHA} salts have an alkaline pH (N_{IGA}: 12.59; N_{MHA}: 12.43). They are very rich in chloride (N_{IGA}: 14,755.35 mg/100g DM; N_{MHA}: 13,810.29 mg/100g DM), and potassium (N_{IGA}: 16,700.35 mg/100g DM; N_{MHA}: 15,950.71 mg/100g DM). They contain smaller amounts of sodium (N_{IGA}: 1,220.32 mg/100g DM; N_{MHA}: 1153.48 mg/100g DM) and phosphorus (N_{IGA}: 1427.65 mg/100g DM; N_{MHA}: 1361.19 mg/100g DM). Calcium content (N_{IGA}: 441.893 mg/100g DM; N_{MHA}: 410.584 mg/100g DM), magnesium (N_{IGA}: 252.73 mg/100g DM; N_{MHA}: 224.893 mg/100g DM), iron (N_{IGA}: 208.89 mg/100g DM; N_{MHA}: 180.89 mg/100g DM) and iodine (N_{IGA}: 44.45 mg/100g DM; N_{MHA}: 40.12 mg/100g DM) are low. Salts derived from immature and mature coconut fiber of the WAT cultivar are rich in potassium and low in sodium. They could be used as an alternative to table salt.

Keywords: *West Africa Tall (WAT) cultivar, Vegetable salt, Maturity stages, Physicochemical parameters*

INTRODUCTION

Natural salt, also known as table salt, is a crystalline product composed mainly of sodium chloride (NaCl). It is extracted either from the sea, underground rock salt deposits or natural brines [1]. It is used in the chemical industry to manufacture cleaning products, polymers, paper and textiles [2], but mainly in cooking [3]. For decades, salt has been considered the universal condiment. It is used to enhance flavour or add saltiness to dishes, or even to act as a food preservative. Salt plays an important physiological role in humans. It is crucial in maintaining the water balance between the inside and outside of cells. It is involved in the intestinal absorption of chlorine, amino acids, glucose and water and in their reabsorption by the kidneys [4]. However, most adults consume too much sodium, averaging 4,310 mg/day (or 10.78 g/day of salt), which is more than twice the maximum recommended intake [5]. High sodium intake (> 2 grams/day, equivalent to 5 grams of salt per day) and insufficient potassium intake (less than 3.5 grams per day) lead to high blood pressure and an increased risk of heart disease and stroke [6]. Increased dietary sodium intake has also been linked to an increased risk of stomach cancer, kidney disease and bone demineralisation [7]. Faced with the problems associated with excessive NaCl consumption, many people are becoming increasingly interested in consuming salts

extracted from plants. This is the case for salts based on rice fiber and palm branches, which are rich in potassium and low in sodium [8]. These salts also contain minerals that are essential for humans, such as sulphur, silicon, phosphorus, calcium, iron, copper and magnesium. Their Na/K ratios are less than 1, unlike table salt, which is well above 1 [8]. Pharmacological properties such as hepatoprotective, anti-inflammatory, antioxidant, hypolipidaemic, diuretic, hypoglycaemic, and hypotensive actions are attributed to them [9]. The multiple pharmacological properties of coconut fiber justify the present study, which aims to evaluate the physicochemical characteristics of an edible salt made from this raw material, with a view to its valorisation and safe use.

MATERIALS AND METHODS

Material

The plant material consisted of coconut fiber (Fig. 1) of the West Africa Tall (WAT) cultivar harvested from a coconut plantation in Jacqueville, Côte d'Ivoire. The work was carried out with immature coconuts with gelatinous almonds and mature coconuts with hard almonds.



Fig. 1. *Coconut fiber of the West Africa Tall (WAT) cultivar*

Methods

Sampling

Five coconut trees were randomly selected. From each coconut tree, five fruits (coconuts) were harvested at different stages of maturity: immature gelatinous almond (IGA) and medium-mature hard almond (MHA), for a total of 50 fruits. The choice of cultivar is justified by the fact that WAT is the popular local cultivar in rural areas in Côte d'Ivoire.

Sample preparation

The coconuts were harvested in May 2023 and then hulled in the laboratory. These fibers were dried for three (3) days in an oven at 50°C. After drying, the fibers were ground using a branded mixer (Silver Crest) to obtain a powder to facilitate incineration. The powder thus obtained was placed in a calcination oven at a temperature of 800°C for 6 hours. A sample of 100 g of this ash was washed with one (1) liter of distilled water according to the method described by Koriko et al. [10]. The mixture was stirred regularly

for 3 days before being filtered through a 0.1 mm sieve. The filtrate thus obtained was brought to a boil on a hot plate for 6 h. The salts obtained were then placed in an oven at 45°C for 72 hours and then stored in jars for subsequent analyses.

Determination of ash content and salt yield

Ash determination was carried out according to the AOAC method [11]. The yield (R) of salt in relation to ash was obtained by taking the ratio of the mass of salt obtained to the mass of ash after incineration, multiplied by 100 (Eqn. 1).

$$R_{\text{ash}}(\%) = \frac{m_{\text{salt}}}{m_{\text{ash}}} \times 100$$

Eqn. 1

The salt yield in relation to the fiber was obtained by calculating the ratio of the mass of salt obtained to the mass of fiber used, multiplied by 100 (Eqn. 2).

$$R_{\text{fiber}}(\%) = \frac{m_{\text{salt}}}{m_{\text{fiber}}} \times 100$$

Eqn. 2

Determination of the physicochemical parameters of vegetable salt

Grain size of salts (granulometry)

The particle size distributions of WAT coconut fiber salts were studied by dry sieving of 100 g of salt following the method of Dossou et al. [12]. The percentage of rejects (quantity of particles retained) of each sieve was calculated relative to the test sample (Pe) (Eqn. 3).

$$\text{Rejects (\%)} = \frac{\text{Retained mass (g)}}{\text{Pe (g)}} \times 100$$

Eqn. 3

where Pe is the test sample.

Determination of color

Measurement of the color of salts in immature and mature coconut fiber was carried out using a CR-10 Plus colorimeter series no. 10049339 (Konica Minolta, Inc., Japan) using the L* a* b* color system defined by the International Commission on Illumination [13]. The color difference was calculated by the classical CIE76 method (ΔE*ab, Eqn. 4) and interpreted according to the following perception thresholds:

$$\Delta E = \sqrt{(L^*_{\text{MHA}} - L^*_{\text{IGA}})^2 + (a^*_{\text{MHA}} - a^*_{\text{IGA}})^2 + (b^*_{\text{MHA}} - b^*_{\text{IGA}})^2}$$

Eqn. 4

- $\Delta E < 1 \rightarrow$ imperceptible
- $1 \leq \Delta E \leq 3 \rightarrow$ perceptible only to a trained eye
- $\Delta E > 3 \rightarrow$ perceptible by the majority of consumers

where L* is brightness; a* is the green (−) to red (+) axis; b* is the blue (−) to yellow (+) axis; C* is saturation (chroma); h is the hue angle; N_{MHA} denotes mature coconuts with hard almonds and N_{IGA} immature coconuts with gelatinous almonds.

Determination of pH and water content of salts

The determination of the pH values of the salts was carried out using a digital pH meter (HANNA HI2211, Romania) according to the AFNOR method [14]. As for the determination of the water content, it was done according to the AOAC method [11].

Determination of the mineral composition of salts

Mineral determination was carried out by air-acetylene flame atomic absorption spectrophotometer (SAA 20 type VARIAN). The wavelengths of the minerals potassium, magnesium, sodium and calcium are respectively 765.5 nm, 286 nm, 589 nm, 422.71 nm [15]. Iodine (I) determination was performed by titrimetry with sodium thiosulfate solution (0.002N). Chloride ion (Cl^-) was determined by the argentometric method using standard $AgNO_3$ solution as titer and potassium chromate as indicator [16].

Determination of the Na/K ratio

The determination of the sodium to potassium ratio was obtained by dividing the sodium content by the potassium content for the different salts produced.

Statistical analysis

All experiments in this study were carried out in triplicate, and the results are presented as mean ± standard deviation. Statistical analyses were performed by one-way analysis of variance (ANOVA), followed by Tukey's multiple comparison test at the 5% significance level, using XLSTAT software (version 2016). This approach made it possible to compare the physicochemical parameters of the salts evaluated between two stages of maturity of coconut fibers (N_{IGA} and N_{MHA}).

RESULTS AND DISCUSSION

Ash content and salt yield

Table 1 shows the ash contents and salt yields of immature (N_{IGA}) and mature (N_{MHA}) coconut fibers. The ash content of immature nut fibers is 4.75%, while that of mature nut fibers is 6.91%. The salts obtained are shown in Fig. 2.



Fig. 2. *Coconut fiber salt from immature nuts with gelatinous almonds (N_{IGA}, left) and mature nuts with hard almonds (N_{MHA}, right)*

The salt yield of immature nuts relative to ash is 86.17% and 1.89% relative to fiber. That of mature nuts relative to ash is 68.17% and 1.51% relative to fiber. Thus, the salt

yield relative to ash and fiber of immature coconuts is higher than the salt yield relative to ash and fiber of mature coconuts.

Table 1. *Ash content and salt yield of immature and mature coconut fibers*

Maturity stage	Ash (%)	Salt yield (%)	
		Relative to ash	Relative to fiber
N_{IGA}	4.75	86.17	1.89
N_{MHA}	6.91	68.17	1.51

N_{IGA}: Immature coconuts with gelatinous almonds; N_{MHA}: Mature coconuts with hard almonds

The ash content of immature coconut fibers of the West Africa Tall cultivar with gelatinous almonds (4.7%) is lower than that of mature coconut fibers with hard almonds (6.9%). The low ash content of immature fibers can be explained by the physicochemical characteristics specific to these immature fibers. Indeed, young fibers contain a lot of water (80–85%) and a low content of inorganic mineral residue [17]. Despite a lower ash content, immature fibers give a higher salt yield (1.89%) than mature fibers (1.51%). This can be explained by the fact that the coconut is still in the active growth phase and the fiber contains more dissolved mineral salts (Na^+, K^+, Cl^-, Ca^{2+}, Mg^{2+}, etc.) transferred from the coconut palm to support the maturation of the endosperm (coconut pulp and water). Also, the presence of soft and less lignified fibers promotes better incineration and release of salts, while the fibers of more lignified, drier mature nuts have the available salts partly transferred to the pulp or fixed in the fiber, which reduces the yield [18]. Taking into account the salt yield of the palm branches obtained by Koriko et al. [10], which is 1.24%, coconut fibers are a better source of salt. Salts obtained from both immature and mature coconuts are heterogeneous salts.

Physicochemical characteristics of coconut salt

Grain size distribution of coconut salts

Fig. 3 shows the particle size histogram of salts from N_{IGA} and N_{MHA} coconut fibers. For salts produced from N_{IGA} nuts, 15.54% of salt has a diameter less than 750 µm, 22.88% has a diameter less than 500 µm, 42.07% has a diameter less than 250 µm and 16.82% has a diameter less than 100 µm. For salts produced from N_{MHA} nuts, 29.89% of salt has a diameter less than 750 µm, 22.58% has a diameter less than 500 µm, 30.68% has a diameter less than 250 µm and 11.83% has a diameter less than 100 µm. The majority of grains of these salts have a dimension less than 500 µm (81.77% for N_{IGA} nuts and 65.10% for N_{MHA} nuts).

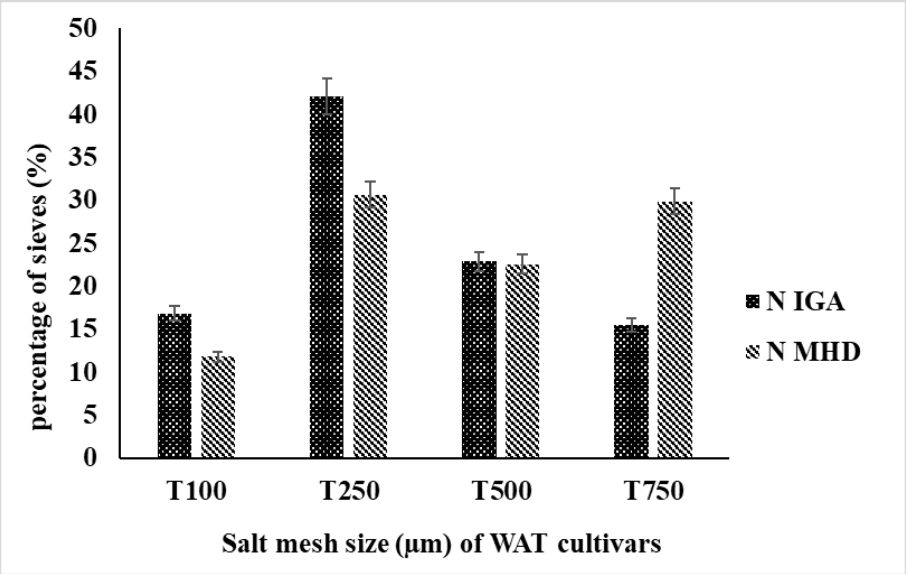


Fig. 3. *Histogram of particle size distribution of N_{IGA} and N_{MHA} coconut salts*

Their particle size configuration is different. Salt extracted from immature coconuts with gelatinous almonds consists mainly of fine particles, with 81.5% of grains smaller than 500 µm and only 8.5% are larger than 500 µm. This predominance of fine particles brings this salt closer to conventional food powders with a particle size between 80 and 500 µm [19]. This fineness promotes rapid and homogeneous dissolution of this salt. This salt could therefore be used in culinary preparations requiring uniform incorporation of salt, giving them a homogeneous texture when consumed. On the other hand, salt from mature coconuts with hard almonds has 65.1% of grains smaller than 500 µm and 35.9% greater than 500 µm. The presence of a significant proportion of grains greater than 500 µm reveals a coarser fraction which can influence the sensory perception of salt, particularly in terms of intensity and duration of the salty taste [20]. These salts will therefore have a double advantage, that of the solubility and homogeneity of a fine salt, as well as the sensory effect and texture of a coarser salt that provides a more intense but shorter-lasting salinity when tasted. This heterogeneity in grain size gives both types of salt a dual functionality: solubility and sensory effect for both functional and gastronomic applications [20].

Colorimetric analysis of immature and mature coconut fiber salts

The data set presented in Table 2 includes the colorimetric parameters of chromaticity (C^*), hue angle (h) as well as the green-red (a^*) and blue-yellow (b^*) components, in relation to lightness (L*). The salt of immature coconuts is characterized by a slightly red (a^* N_{IGA} = +8.6) and moderate yellow (b^* N_{IGA} = +15.9) coloration. This color is moderately saturated (C^* N_{IGA} = 18.1) with an average brightness (L^* N_{IGA} = 45.8) neither very light nor very dark with a slightly orange tint (h N_{IGA} = 61.7). The salt from mature coconuts is characterized by a redder color (a^* N_{MHA} = +10.7 > a^* N_{IGA} = +8.6) and a yellower color (b^* N_{MHA} = +19.1 > b^* N_{IGA} = +15.9) and more saturated (C^*N_{MHA} = 22 > C^*N_{IGA} = 18.1). This salt is darker (L^*N_{MHA} = 43.0) with a hue that also tends towards orange (h N_{MHA} = 60.6). Depending on the value of ΔE (4.7), the color difference between salt from immature coconuts and that from mature coconuts is visible to the naked eye. Salt from mature coconuts is more orange, darker, and more colorful than salt from immature coconuts.

Table 2. *Color parameters of immature and mature coconut fiber salts*

Maturity stage	L*	a*	b*	C*	h	ΔE
N_{IGA}	45.8 ± 1.1^{a}	8.6 ± 0.1^{b}	15.9 ± 0.2^{b}	18.1 ± 0.2^{b}	61.7 ± 0.1^{a}	4.7
N_{MHA}	43.0 ± 0.9^{b}	10.7 ± 0.1^{a}	19.1 ± 0.4^{a}	22.0 ± 0.5^{a}	60.6 ± 0.3^{b}	

In each column, mean values followed by different letters (a, b) are significantly different ($P < 0.05$) according to Tukey's test. N_{IGA}: Immature coconuts with gelatinous almonds; N_{MHA}: Mature coconuts with hard almonds

Salts from mature nuts with hard almonds have a slightly orange tint and are darker than salts from immature coconut fibers with gelatinous almonds, which have a lighter orange color. These colors would probably be linked to differences in mineral composition. The lighter, slightly orange tint of salt extracted from immature coconut fibers with gelatinous almonds would be linked to a still incomplete mineralization and a low content of oxidized phenolic compounds. Indeed, according to Karseno et al. [21], young coconut fibers contain fewer phenolic compounds than mature fibers. Conversely, the more intense orange coloration of salt from mature nuts could be explained by the accumulation of polyphenols and the high concentration of mineral elements such as iron, manganese and silica. Thus, during incineration, silica can interact with metal oxides (Fe, Mn), forming colored silicates responsible for reddish to brown-yellow shades [22]. The color variation, sufficiently perceptible, could influence the perception of consumers, who often associate white salt with purity and quality.

pH, water content and dry matter of immature and mature coconut fiber salts

Table 3 presents the pH values, water contents, dry matter of salts from immature and mature coconut fibers. The pH (12.59) and water content (3.06%) of salts from immature coconuts N_{IGA} are statistically higher than those from mature coconuts (pH: 12.43; water content: 2.45%). However, the dry matter of salts from immature nuts (96.93%) is lower than that from mature nuts (97.54%).

Table 3. *pH, water content and dry matter of immature and mature coconut fiber salts*

Maturity stage	pH	Water (%)	Dry matter (%)
N_{IGA}	12.59 ± 0.01^{a}	3.06 ± 0.00^{a}	96.93 ± 0.00^{b}
N_{MHA}	12.43 ± 0.01^{b}	2.45 ± 0.00^{b}	97.54 ± 0.01^{a}

In each column, mean values followed by different letters (a, b) are significantly different ($P < 0.05$) according to Tukey's test. N_{IGA}: Immature coconuts with gelatinous almonds; N_{MHA}: Mature coconuts with hard almonds

The salts of immature coconut fibers with gelatinous almonds, as well as those of mature nuts with hard almonds, have pH values of around 12, which reflect their alkalinity. This alkalinity is due to the effective presence of minerals such as calcium, magnesium, potassium and sodium in the salts studied. Also, the oxidation process promotes the formation of carbonates and hydroxides with an alkaline pH [23]. This is also the case for salts from coconut branches, which have an alkaline pH of 10.9 [24]. Salts from immature coconut fibers with gelatinous almonds contain more water (3.06%) than those from mature coconut fibers with hard almonds (2.45%). The higher presence of hygroscopic ions such as calcium, magnesium, potassium, iron and sodium in salts from young nuts could explain their high water content. These molecules attract and retain atmospheric water [25]. However, the contents are well below the limit (4%) set by the

ECOSTAND standard [26], guaranteeing good stability and suitability for extended storage.

Calcium, magnesium and phosphorus content

Table 4 shows the contents of calcium (Ca), magnesium (Mg) and phosphorus (P). Generally, the contents of Ca (441.893 mg/100g DM), Mg (252.73 mg/100g DM) and P (1427.65 mg/100g DM) are higher in immature coconut fiber salts unlike those of mature coconut fiber salts which are respectively 410.584, 224.893 and 1361.19 mg/100g DM.

Table 4. *Calcium, magnesium and phosphorus composition of immature and mature coconut fiber salts (mg/100g DM)*

Maturity stage	Calcium	Magnesium	Phosphorus
N_{IGA}	441.893 ± 2.90^{a}	252.73 ± 2.17^{a}	1427.65 ± 3.95^{a}
N_{MHA}	410.584 ± 5.83^{b}	224.893 ± 2.91^{b}	1361.19 ± 5.51^{b}

In each column, mean values followed by different letters (a, b) are significantly different ($P < 0.05$) according to Tukey's test. N_{IGA}: Immature coconuts with gelatinous almonds; N_{MHA}: Mature coconuts with hard almonds

Iron, iodine and chloride content

Table 5 presents the iron (Fe), iodine (I) and chloride (Cl) contents of coconut fiber salts. Generally, the Fe (208.89 mg/100g DM), I (44.45 mg/100g DM) and Cl (14755.35 mg/100g DM) contents are higher in immature coconut fiber salts unlike those of mature coconut fiber salts which are respectively 180.89, 40.12 and 13810.29 mg/100g DM.

Table 5. *Iron, iodine and chloride composition of immature and mature coconut salts (mg/100g DM)*

Maturity stage	Iron	Iodine	Chloride
N_{IGA}	208.89 ± 1.84^{a}	44.45 ± 0.34^{a}	14755.35 ± 93.79^{a}
N_{MHA}	180.89 ± 1.21^{b}	40.12 ± 0.31^{b}	13810.29 ± 90.71^{b}

In each column, mean values followed by different letters (a, b) are significantly different ($P < 0.05$) according to Tukey's test. N_{IGA}: Immature coconuts with gelatinous almonds; N_{MHA}: Mature coconuts with hard almonds

Potassium and sodium content and Na/K ratio

Table 6 shows the potassium and sodium contents and the sodium to potassium (Na/K) ratios of the salts. The sodium (1220.32 mg/100g DM) and potassium (16700.35 mg/100g DM) contents are higher in immature coconut salts compared to mature coconut salts which are 1153.48 mg/100g DM and 15950.71 mg/100g DM respectively. The Na/K ratios of the different salts are approximately 0.07.

Table 6. *Potassium and sodium composition (mg/100g DM) and Na/K ratios of immature and mature coconut salts*

Maturity stage	Na	K	Na/K
N_{IGA}	1220.32 ± 6.10^{a}	16700.35 ± 93.79^{a}	0.073
N_{MHA}	1153.48 ± 0.60^{b}	15950.71 ± 46.89^{b}	0.072

In each column, mean values followed by different letters (a, b) are significantly different ($P < 0.05$) according to Tukey's test. N_{IGA}: Immature coconuts with gelatinous almonds; N_{MHA}: Mature coconuts with hard almonds

Thus, the substantial presence of calcium and magnesium reveals that these salts could have benefits for bone health (calcium) and muscle or nerve function (magnesium). Magnesium, for example, can have a protective effect against cardiovascular diseases, particularly by modulating calcium efflux in cases of hypercalcemia [27]. Minerals such as iodine, iron and phosphorus, although in small quantities, are very important from a nutritional point of view. Indeed, iodine is essential for thyroid function [28]. Iron would contribute to good oxygenation [29] and phosphorus to energy metabolism [30].

Chlorine and potassium are predominant in both types of salts. The high potassium content compared to sodium could give this vegetable salt hypotensive properties, a less salty taste and promote the balance between potassium and sodium. Indeed, potassium is an essential macronutrient that regulates blood pressure, thus contributing to the prevention of hypertension, a significant risk factor for cardiovascular diseases [31]. It also appears that the sodium to potassium ratio of immature and mature coconut fiber salts is less than one, as recommended by the WHO [32]. These ratios are of particular interest in the prevention of high blood pressure.

CONCLUSION

The objective of the present study was to determine the physicochemical characteristics of a salt made from *Cocos nucifera* fibers. The results showed that the salt yield of immature nut fibers with gelatinous almonds of the West Africa Tall (WAT) cultivar was higher than that of mature nut fibers with hard almonds. These salts are characterized by an alkaline pH with a low water content. The salt grains are mostly fine with dimensions less than 500 µm. The salts of mature coconut fibers are slightly orange in color, more pronounced than those of immature coconuts. These different salts contain larger amounts of potassium and chloride ions than sodium and phosphorus and small amounts of calcium, magnesium, iron and iodine. The salts produced from *Cocos nucifera* fibers would therefore be salts rich in potassium chloride (KCl) and could be used as a substitute for usual cooking salt.

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