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Vitamin and Osidic Composition of Table Sugars from the Inflorescences Sap of 03 Coconut Cultivars (*Cocos nucifera* L.) in Ivory Coast

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Abstract

In order to revalorize the nucicultural sector in Ivory Coast, initiatives have been taken to diversify the uses of coconut through the production of sugar from its inflorescences. Four water-soluble vitamins have been determined in the crystalline sugar of coconuts. These are vitamins C, B_1, B_2 and B_6. On the other hand, no vitamin was identified in cane sugars. Vitamin C is the most abundant in coconut sugar. The oses contained in coconut sugar are saccharose, glucose and fructose. Sucrose is the main constituent of coconut crystal sugar. Thanks to their sweetening power close to saccharose, the coconut sugars produced can be used as sweetening ingredients in pastries, confectionery, drinks and culinary preparations. Their richness in vitamin C makes them a food that can stimulate the body's natural and immune defences.

Keywords

Coconut Sugar, Vitamins, Oses

1. Introduction

The coconut palm (*Cocos nucifera* L.) is a tropical oilseed plant native to some coastal countries of the Pacific and Indo-Atlantic ocean basins [1]. It is called tree of life, thanks to its multiple uses [2] [3]. Studies on the processing and valorization of the different parts of the coconut tree have mostly been carried out in Asian countries.

Most of the work carried out in technology in Côte d'Ivoire focuses on nuts.

Indeed, copra represents the most important form of coconut palm valorization in Côte d'Ivoire. It is mainly used to produce oil. However, the fall in the market value of coconut oil, due to competition from other oilseeds, has led to a massive abandonment of the nucicultural sector.

To enhance its value, initiatives have been taken in Côte d'Ivoire to introduce the technique of producing coconut sap from the inflorescences. This successful technique has led to the need to produce and determine the characteristics of the crystalline sugar from this sap. Konan's results [4] on the nutritional properties of coconut sap from coconut palms grown in Côte d'Ivoire indicate that, with a 16% carbohydrate content, it is almost as rich as sugar cane juice.

Thus, Okoma *et al.* [5] undertook the dehydration and crystallization of this for the production of coconut sugar. The physico-chemical characterization of coconut sugar, in comparison with brown and white cane sugar, revealed that the energy value of coconut sugars is lower than that of cane sugars. No fibers and fats were found in cane sugars, while traces were found in crystalline sugars from coconut trees [5]. Coconut sap sugars are an important source of total polyphenols.

For a complete characterization of crystalline sugars from the most cultivated varieties of coconut palms in Ivory Coast, this study aims to characterize their nutritional properties. Specifically, the aim is to determine their vitamin characteristics and the chromatographic profile of their oses.

2. Hardware

Biological Material

The biological material consisted of crystalline sugars from the sap of the inflorescences of 03 coconut cultivars. These were the improved hybrids PB113$^+$, PB121$^+$ and GOA variety. The white and red sugars of cane were taken as controls.

3. Methods

3.1. Extraction of Sap from Coconut Tree Inflorescences and Its Transformation into Table Sugar

The sap was extracted from the grade 8 spathe using the Konan [4] method. The spathe of rank 8 corresponds to the unopened spathe above the newly opened spathe. Once identified, it was first ligated and firmly attached to an underlying palm. It was then gradually tilted for a week to bring its tip to a lower elevation than the peduncle, forming an obtuse angle with the coconut trunk. When the spathe is sufficiently inclined, a section about 15 - 20 cm from its apical part is made to allow the sap to flow.

The remaining part of the spathe must then be introduced into a plastic container, through a circular opening made expressly for this purpose, the diameter of which depends on the diameter of the spathe for collecting the sap. The collection containers were previously sanitized with water heated to 100˚C in a boiling bath and replaced after each collection.

The sugars were obtained using the modified Okoma *et al.*, method [5]. One liter of freshly collected sap was boiled on a hot plate for 45 minutes at 60˚C - 120˚C to obtain a syrup. The syrup was then cold-mixed with a spatula to aerate it and initiate crystallization. Finally, the coconut sugar crystals were destemmed, crushed and dried at room temperature (25˚C) for 24 hours.

The use of freshly collected sap is necessary because without preservatives, even frozen, the use of sap results in the formation of a gelled mass that does not crystallize.

3.2. Sampling

The study covered three campaigns during the year 2017, January, June and December. Per campaign, 03 batches of coconut crystal sugar were produced and two batches of sugars (brown and white) of cane were sampled. Nine lots of coconut crystal sugar were produced in total and six lots of cane sugars were analyzed. The nutritional parameters were repeated three times and the analyses were performed on each of the batches.

3.3. Dosing of Vitamins

Four water-soluble vitamins were quantified in the coconut sugar samples. These are L-ascorbic acid (vitamin C), thiamine (vitamin B_1), riboflavin (vitamin B_2) and pyridoxine (vitamin B_6). The choice of these vitamins was guided by the vitamin profile of the sap of the inflorescences of cultivars studied by Okoma, [6]. The assay was performed by high performance liquid chromatography (HPLC).

For vitamin extraction, ten (10) g of each sugar sample was placed in 100 mL vials. The test samples were then dissolved with 80 mL of methanol in the ultrasonic tank before being cooled to room temperature. The cooled mixtures were then made up with 100 mL of the same solvent and filtered through Wattman paper. Finally, the filtrates were diluted by half with the mobile phase composed of pure methanol (98%, MERCK, ratio with water 30/70 thus 45.4/54.6), orthophosphoric acid (H_3PO_4; 0.62% Methanol), acetonitrile (0.78% Methanol) and 2 N acetic acid (5 mL). For the determination of vitamins, the injection of the mobile phase containing the sugar filtrates into the HPLC column allowed elution. An external vitamin standard (standard) was formed from L-ascorbic acid (vit. C, 98.9%), thiamine hydrochloride (vit. B_1, 100%) and pyridoxine (vit. B_6, 99.9%) and riboflavin (vit. B_2, 99.7%) obtained from SIGMA CHEMICALS Co.

Different quantities of these vitamins were weighed and then dissolved in methanol. Then an aliquot volume was taken from it and made up to 100 mL with the mobile phase, thus obtaining different concentrations of vitamins (standard).

Thus, each vitamin presented in the external standard has a concentration that is higher than the limit value of its quantification. The injection and elution of the vitamins contained in this standard made it possible to evaluate a drift coefficient and to correct the raw results before calculating the contents of the four water-soluble vitamins evaluated in each crystal sugar sample. Finally, the samples were analyzed in duplicate and the average obtained expressed in mg vitamin /100mg sugar.

3.4. Chromatographic Profile of the Oses

The qualitative and quantitative identification of the soluble oses contained in our crystalline sugar samples studied was carried out using a High Performance Liquid Chromatography (WATERS Alliance E2598), equipped with a 5 µm and 250 × 4 mm alkylamine column and a refractometric detector. The crystalline sugar samples were diluted 1/10. Then, the whole was homogenized and filtered.

Ten (10) µL of the solution filtered on a microporous membrane (0.45 µm diameter) was injected into the column for bone elution. The mobile phase consisted of an isocratic eluent composed of acetonitrile/water (80/20, v/v) and injected at a flow rate of 1 mL/min. A synthetic standard mixture composed of the eluted pure sugars obtained from SIGMA CHEMICALS Co. resulted in an average recovery efficiency of 98.14% (Table IV). These are fructose (7.8 g/L), glucose (12 g/L), sucrose (13 g/L) and mannose (5.6 g/L) with purity greater than 99.5%; 99.8%; 99.7% and 99.2% respectively.

3.5. Sweetness Index

The sweetness index or sweetening power is used to assess the ability of a substance to sweeten a food. It is the ability of this substance to stimulate the sensation of sweetness.

The sweetness index of the sugars studied was obtained from the different sugar contents obtained by chromatography according to the **Prades** formula, [7].

$$\mathrm{SI}(\%) = 1 * \mathrm{TSac} + 1.7 * \mathrm{Tag} + 0.8 * \mathrm{TGluc} + 0.3 * \mathrm{TMan}$$

TSac: sucrose content; **TFruc:** fructose content; **TGluc:** glucose content; **TMan:** mannose content.

3.6. Statistical Analysis of the Data

The statistical analysis consisted in making a descriptive analysis of the vitamins and oses contained in coconut sugar. This concerned the determination of the minimum, the maximum, the coefficient of variation of the quantitative parameters and the frequency of the modalities of the different qualitative parameters. Then, the comparative analysis of the three cultivars was carried out using the single criterion analysis of variance (ANOVA 1). Indeed, this ANOVA test is preceded by the MANOVA (Multiple Analysis of Variance) in order to verify if the variables taken together make it possible to highlight the existence of a significant difference between the cultivars based on the parameters analyzed. The ANOVA 1 test was followed by the post-ANOVA test of the smallest significant difference (ppds).

All the statistical tests were performed with XLSTAT version 7.5.3 and Statistica 7.1.

4. Results

4.1. Vitamin Composition of the Coconut Crystalline Sugars Studied

Four water-soluble vitamins were determined in the crystalline sugars of the coconut trees studied (Table 1). These are vitamins C, B_1, B_2 and B_6. On the other hand, no vitamin was identified in the red and white sugars of cane.

Vitamin C is more abundant in coconut sugars than other vitamins. It is statistically higher in PB113$^+$ (26.42 ± 0.99 mg/100g). The lowest vitamin C content is recorded in sugar from GOA, 7.02 ± 0.93 mg/100g. The sugar from PB121$^+$ (14.04 ± 0.4 mg/100g) has the highest vitamin $_{B1}$ content, while the sugar from PB113$^+$ contains 13.55 ± 0.21 mg/100g.

Regarding vitamin B_6, the sugar of the PB121$^+$ hybrid (10.3 ± 0.11 mg/100g) contains proportions that are statistically higher than that of PB113$^+$ (8.15 ± 0.12 mg/100g), which in turn remains high compared to GOA (5.32 ± 0.14 mg/100g).

In addition, all the sugars studied contain very little vitamin B_2. Its contents are between 0.15 ± 0.02 (PB121$^+$ mg/100g) and 0.19 ± 0.01 (PB113$^+$ mg/100g).

4.2. Chromatographic Profile of the Oses and Sweetness Index of the Sugars Studied

Chromatographic analysis of the oses contained in coconut crystal sugar reveals the presence of sucrose, glucose and fructose (Table 2). Their contents are unevenly distributed within each cultivar. Sucrose is the constituent that was mainly dosed in the crystalline sugar of the coconut trees studied without, however, differentiating them. In fact, its contents in the crystalline sugar of the PB121$^+$ (75.26 ± 2.01 g/100g) and PB113$^+$ (76.69 ± 2.12 g/100g) hybrids and the GOA cultivar (75.1 ± 1.80 g/100g) are statistically identical. However, they are statistically lower than those of the sugarcane sugars which are more provided.

White cane sugar contains exclusively sucrose with a high content of 99.02 ± 2.15 g/100g while its brown counterpart contains less statistically (96.4 ± 2.24 g/100g).

Fructose is the second ose dosed in coconut sugar in small proportions compared to sucrose. Its sugar content of PB121$^+$ (7.5 ± 1.24 g/100g) and GOA (7.25 ± 1.87 g/100g) is statistically identical and higher than that of PB113+ (6 ± 0.98 g/100g). Fructose is very low in brown sugar (0.28 ± 0.09 g/100g) and does not exist in white cane sugar. However, statistical analysis does not reveal any difference between cultivars for this ose.

On the other hand, among the three oses contained in coconut crystal sugar, the proportions of glucose are statistically lower and vary from 2.61 ± 0.40 to 2.86 ± 0.36 g/100g. Brown and white cane sugars do not contain fructose.

Table 1. Water-soluble vitamin contents of the crystalline sugars studied.

	Water-soluble vitamins (mg/100g)					
Designations	Vitamin C	Vitamin B_1	Vitamin B_2	Vitamin B_6	F	P intra
PB121⁺	15.16 ± 0.18^{Ba}	14.04 ± 0.4^{Ab}	0.15 ± 0.02^{Bd}	10.3 ± 0.11^{Ac}	436.78	**<0.001**
PB113⁺	26.42 ± 0.99^{Aa}	13.55 ± 0.21^{Bb}	0.19 ± 0.01^{Ad}	8.15 ± 0.12^{Bc}	350.09	**<0.001**
GOA	7.02 ± 0.93^{Cb}	11.94 ± 0.11^{Ca}	0.16 ± 0.0^{Bd}	5.32 ± 0.14^{Cc}	301.25	**<0.001**
Wit B	0.00 ± 0.0^{D}	0.00 ± 0.0^{D}	0.00 ± 0.0^{C}	0.00 ± 0.0^{D}	-	-
Wit R	0.00 ± 0.0^{D}	0.00 ± 0.0^{D}	0.00 ± 0.0^{C}	0.00 ± 0.0^{D}	-	-
F	226.01	48.03	158.87	94.56		
P inter	**<0.001**	**<0.001**	**<0.001**	**<0.001**		

For each character, the values with the same capital letter in each column are statistically identical. For each row, the values with the same lowercase letter, in each row, are statistically identical. **F:** value of the statistical test; **P inter:** value of the probability of the statistical test between cultivars; **P intra:** value of the probability of the statistical test within cultivars; **Wit B:** Sugar control Sugar cane white; **Wit R:** Sugar control Sugar cane red; **PB121⁺:** improved PB121 hybrid; **PB113⁺:** improved PB113 hybrid; **GOA:** cultivar Grand Ouest Africain.

Table 2. Content of oses constituents and sweetness index of the crystalline sugars studied.

	oses (g/100g)					
Designations	**Sucrose**	**Glucose**	**Fructose**	**IS (%)**	**F**	***P intra***
PB121⁺	75.26 ± 2.01^{Ca}	2.61 ± 0.40^{Ac}	7.5 ± 1.24^{Ab}	90.10 ± 2.4^{C}	311.54	**<0.001**
PB113⁺	76.69 ± 2.12^{Ca}	2.86 ± 0.36^{Ac}	6 ± 0.98^{Bb}	89.18 ± 2.02^{C}	322.87	**<0.001**
GOA	75.1 ± 1.80^{Ca}	2.72 ± 0.24^{Ac}	7.25 ± 1.87^{Ab}	89.60 ± 1.79^{C}	285.64	**<0.001**
Wit B	99.02 ± 2.15^{Aa}	0	0	99.02 ± 0.81^{A}	401.33	**<0.001**
Wit R	96.4 ± 2.24^{Ba}	0	0.28 ± 0.09^{Cb}	96.88 ± 1.24^{B}	357.89	**<0.001**
F	24.92	41.377	102.83			
P *intra*	**<0.001**	**<0.001**	**<0.001**			

For each character, the values with the same capital letter in each column are statistically identical. row, the values with the same lowercase letter, in each row, are statistically identical. **F:** value of the statistical test; **P inter:** value of the probability of the statistical test between cultivars; **P intra:** value of the probability of the statistical test within cultivars; **IS:** sweetness index; **Wit B:** Sugar control Sugar cane white; **Wit R:** Sugar control Sugar cane red; **PB121⁺:** improved PB121 hybrid; **PB113⁺:** improved PB113 hybrid; **GOA:** cultivar Grand Ouest Africain.

The sweetness index of white (99.02% ± 0.81%) and cane red (96.88% ± 1.24%) sugars is higher than that of PB121⁺ (90.10% ± 2.4%), GOA (89.60% ± 1.79%) and PB113⁺ (89.18% ± 2.02%) (Table 2).

5. Discussion

Four water-soluble vitamins were dosed into the coconut crystal sugar. The most concentrated in the sugar of the coconut varieties studied are ascorbic acid (vitamin C), pyridoxine (vitamin B_6) and thiamine (vitamin B_1). Vitamin B_2 is present in small proportions.

The PB113$^+$ hybrid provides sugars that are richer in vitamin C than the other two cultivars. Vitamin C is synthesized from glucose or other simple precursors and is used as a preservative in the food industry [8]. It is found in relatively high concentrations in animal and plant tissues compared to other water-soluble vitamins. Human plasma contains about 10 mg per liter.

It participates in the synthesis of collagen and red blood cells. It is an anti-tumor, anti-scorbutic and anti-mutagen. In addition, vitamin C stimulates the body's natural and immune defenses [9]. Vitamin C levels are higher than those measured in palm sugar, *i.e.* 6.62 mg/100g [10]. Coconut palm sap is reported to contain more vitamin C than palm sap, as reported by Ghosh *et al.* [11].

No vitamins were dosed in the cane control sugars. This difference could be due to the type of plant material studied and the cooking techniques applied. Indeed, Asghar *et al.* [12] reported that sugar cane juice contains very few water-soluble vitamins compared to coconut sap. In addition, the refining process would have a depressing effect on the vitamin composition of sugarcane sugars. Moreover, vitamins B_1 and B_6 are found in higher proportions in PB121$^+$. Although present in small amounts, vitamin B_2 is mostly present in the GOA cultivar.

However, all the vitamin contents recorded in sugars are lower than those measured in the sap of the same plant material by Okoma [6]. Indeed, on the same plant material, the author indicated that the sap of PB113$^+$ contained 43 mg/100ml; 27 mg/100mL; 2 mg/100mL and 19.1 mg/100mL for vitamins C, B_1, B_2 and B_6, respectively.

With regard to the vitamin profile of crystal sugar, there is a significant decrease of 60%; 50%; 45.5% and 52.6% respectively for the above-mentioned vitamin contents.

This could be explained by the fact that the high temperatures would degrade the water-soluble vitamins, especially vitamins C and B_1.

Indeed, vitamin C is probably the vitamin whose losses during cooking have been the most studied. The factors involved in its degradation seem to be heat and oxidation.

Its losses have mainly been studied in plants. This shows that all vegetables do not have the same sensitivity to cooking. According to Frédéric, [13] pan-cooked potatoes lose 54% of their vitamin C content, whereas peppers cooked in the same way lose only 24%.

The degree of maturity as well as the structure of a plant is two important parameters that condition the losses related to this vitamin.

Vitamin B_1 is very soluble in water and particularly unstable to heat, in neutral or alkaline medium. This vitamin is as well brought by food of animal as vegetable origin. Its losses have therefore been studied in the 2 food groups. In processed cereal products, about 50% of Vitamin B_1 is destroyed. This degradation is all the higher as the product is added with an alkalizing raising agent.

Among meat products, pork is particularly rich in Vitamin B_1 and the loss seems to be limited compared to other meats (30% for pork versus 70% for chicken [14].

Vitamin B_1 is involved in the metabolism of carbohydrates through a coenzymatic function provided by thiamine pyrophosphate (TPP). It is antinevritic and anti beriberiberic. The biological mechanism of action of vitamin B_1 also consists in the transport of free radicals.

In addition, vitamin B_6 participates in the metabolism of lipids, amino acids and the synthesis of nicotinamide (vit. B_3). It is an important antioxidant agent. Indeed, its biological role is to transport free radicals in order to participate in their evacuation. The daily intake of vitamin B6 recommended for an adult is 2.2 mg. The excess of vitamin B_6 can cause nerve damage.

Sucrose is the constituent that was mostly dosed in coconut crystal sugar in statistically identical proportions. The carbohydrate profile revealed that glucose and fructose are the main reducing sugars in coconut sugar.

They come mainly from the hydrolysis of sucrose. Indeed, Martine, [15] reported that during the coconut sugar manufacturing process, the increase in temperature accelerates the hydrolysis of sucrose into reducing sugars.

Hence, the high levels of reducing sugars obtained in the coconut sap crystalline sugar samples at high final temperatures.

This corroborates our results which show that within a given cultivar, total and reducing sugar contents increase with heat treatment.

The sweetness index (SI) of coconut sap sugars is close to that of cane. Its calculation takes into account the contents of saccharose, fructose and glucose which are the main bones of coconut sap sugar. So, it is strongly positively correlated to these three oses.

Thus, the SI of sugarcane sugars, although similar to that of coconut, remains statistically higher due to its high sucrose content.

However, the SI of coconut sap sugars, which represents their ability to stimulate the sensation of sweetness, is close to that of sucrose, which is generally taken as a reference. However, substances with a sweetening power close to 100 for the same weight can be considered as mass sweeteners [16].

Therefore, coconut sap sugars can be used in pastry, confectionery and culinary preparations as a substitute for cane sugar.

6. Conclusions

Four water-soluble vitamins (C, B_1, B_2 and B_6) were determined in the crystal sugar of coconut palms. On the other hand, no vitamin was identified in cane sugars. Vitamin C is the most abundant in coconut sugar.

The oses contained in coconut crystal sugar are sucrose, glucose and fructose. Sucrose is the main constituent of coconut crystal sugar. The sweetness index of cane sugars is close to that of coconut trees.

In view of all the above, coconut sugars are natural sweeteners rich in vitamins, especially vitamin C, unlike refined cane sugar which is essentially composed of sucrose and its red counterpart which contains very few nutrients.

Thanks to their sweetening power close to sucrose, the coconut sugars produced can be used as sweetening ingredients in pastries, confectionery, beverages and culinary preparations. Their richness in vitamin C makes them a food that can stimulate the body's natural and immune defences.

Contribution of the Authors

This work was carried out in collaboration among all authors. Authors ODMJ, ARR and KKJL designed and wrote the study protocol. Author ODMJ conducted the documentary research, conducted the laboratory analyses, the statistical analysis and the first draft and revised the manuscript. Authors KKJL and ARR took part in the interpretation of the results and provided a major contribution in the elaboration of the final document.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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