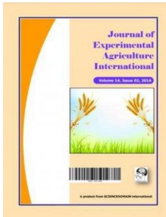

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Development of a Method to Produce Granulated Sugar from the Inflorescences Sap of Coconut (*Cocos nucifera L.*) in Ivory Coast: Case of Hybrid PB113+

J. Okoma. D. Muriel[1*], Konan. K. Jean-Louis[1], R. Assa. Rebecca[2] and Konan. N. Ysidor[3]

[1]Marc Delorme Research Station for Coconut, National Centre of Agronomic Research (CNRA), Abidjan, Côte d'Ivoire.
[2]Laboratory of Biochemistry and Food Sciences, UFR Biosciences, University Felix Houphouët Boigny, Abidjan, Côte d'Ivoire.
[3]Pélefero Gon Coulibaly University (UPGC, Korhogo), Côte d'Ivoire.

Authors' contributions

All authors have read and approved the final manuscript. Authors JODM, RAR and KKJL designed and wrote the study protocol. Author JODM conducted the documentary research, conducted the laboratory analyses, the 1st draft and revised the manuscript. Author KNY participated in the elaboration of the 1st draft, the statistical analysis and provided a major contribution in the elaboration of the final document. Authors KKJL and RAR took part in the interpretation of the results. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To develop a method for transforming inflorescences sap of coconut into crystalline sugar, with a view to diversifying coconut exploitation in Côte d'Ivoire.
Study Design: The sap was extracted from inflorescences of row 8 of PB113 hybrid and harvested 03 times a day (07h, 12h and 17h). Three processes for transforming sap into crystalline sugar have

**Corresponding author: E-mail: muriel.okoma@gmail.com;*

been gradually tested, taking into account the quality of the sap, the temperature-treatment time combination and the physical constraints applied to the sap.

Place and Duration of Studies: Marc Delorme Station for Coconut Research at the National Centre for Agricultural Research, between May 2015 and July 2016.

Methodology: Six coconuts was selected from those that showed no evidence of a history of disease or pest attack. Then, in their leaf corona, the unopened inflorescences, rank 8, were used for sap extraction [12]. On each coconut tree, the sap was collected in a plastic container previously sanitized with water heated to 100°C in a boiling bath and was collected 03 times a day (07h, 12h and 17h). The collected samples were placed in an isothermal cooler before being sent to the laboratory for processing. The transformation of sap into derived products was carried out by thermal spraying of the raw material. The experiments were performed on an electric hot plate (TRIOMPH) equipped with a temperature and time regulator. Heating the sap also required a frying pan and stainless-steel spatulas. A pH meter, a 0.01 electronic precision balance (METTLER BD 202, made in USA) and a refractometer were also used to measure physico-chemical parameters of the sap before and during its transformation. Three (3) processes were tested in this study for the transformation of inflorescences sap into coconut sugar. In each process, variable time-temperature heating combinations were used.

Results: Both first one's processes tested did not produce sugar crystals. Their deficiencies were improved in the 3rd process which resulted in the clear crystallization of the sap. With this process, a first vaporization of the sap was carried out with gradually increasing temperatures up to 140°C for 30 min giving a fairly firm coconut syrup. The syrup was sprayed for a second time at 60°C for 30 minutes to obtain a massecuite, which was then destemmed, crumbled and dried at ambient temperature to provide crystalline coconut sugar. This sugar comes in the form of crystals of irregular grain size with a red coloring, similar to brown cane sugar. The results reveal that the production of 1 kg of crystalline coconut sugar requires the treatment of 6.25 L of coconut inflorescences sap.

Conclusion: The extension of the method of production of crystalline coconut sugar must be encouraged and represents an important support for the development of coconut sap in Côte d'Ivoire. However, further studies must be carried out to determine the biochemical characteristics of the coconut sugar produced.

Keywords: Coconut sap; inflorescence; production parameters; sugar; Ivory Coast.

1. INTRODUCTION

Coconut (*Cocos nucifera* L.) is a perennial crop found in coastal countries in tropical regions [1]. Its surface area covers about 12 million hectares worldwide, with the largest plantations located in South-East Asian countries such as Indonesia, the Philippines and India, which together have more than 7 million hectares, or more than 75% of the world's coconut plantation [2,3]. This plant represents an important source of income for many people in rural areas in these countries. In Côte d'Ivoire, coconut is cultivated on 50,000 ha, mainly in the coastal part of the country. In this country, fruit has so far been the main form of coconut cultivation, while all parts of the plant can be exploited for multiple purposes [4]. Fruits commonly known as coconuts are consumed as refreshing in their immature state for the appreciable organoleptic qualities of their water [5,6]. But when they are mature, their albumen is generally dried, called copra in this case, in order to be used to extract coconut oil useful in the food, pharmaceutical and especially cosmetic industries [7,8,9]. However, other vegetable oils that are often more appreciated are present on the oilseed market, which has a negative impact on the commercial value of coconut oil. In addition, Asian countries facing the same copra crisis have invested in other ways to promote coconut production. In this diversification, the production of coconut sap from inflorescences has met with great success with the coconut sector. Indeed, coconut sap is produced with young inflorescences, to the detriment of nut production. Like the sap from other palms trees, coconut sap is often consumed directly by the population and is highly appreciated for its nutritional properties. However, the greatest valuations of coconut sap concern its transformation into syrup, sugar [10-11]. Indeed, syrup and coconut sugar are among the carbohydrate foods that have a low glycemic index of less than 50 [12]. The good nutritional and dietary characteristics of coconut sap derivatives ensure that they have a good market value. Thus, coconut sap represents a real added value for the valorization of this plant: it does not provide significant income to producers while remaining in line with the promotion of sustainable agriculture. In Côte d'Ivoire, the production and valorization of coconut sap has not yet been popularized. This is why, since 2011, studies have been initiated to exploit the sap of the most widespread cultivars in the Ivorian coconut grove. Initial work assessed the production potential and nutritional characteristics of the sap of these varieties. The results show that the PB113+ hybrid provides the largest volume of sap for a longer operating life than the other three cultivars (62 liters produced in 47 days) [13]. Several studies indicate that the coconuts inflorescences sap is a generally neutral substance (pH 6.97 to 7.32) and liquid very rich in carbohydrates, with a content of 10-15%, mainly sucrose [14], a level close to that of sugar cane. This high sucrose content is thus favorable to the valorization of coconut sap into crystalline sugar, as in other coconut-producing countries. In addition, sensory tests have revealed that the sap of the PB113+ hybrid is more appreciated by consumers, with an acceptance rate of 92.86%, than that from other coconut cultivars [15]. Transforming the sap of this coconut hybrid into coconut sugar could thus have good market characteristics and provide good added value to the coconut tree. The aim of this work is to contribute to the development of a method for transforming coconut inflorescence sap into crystalline sugar, with a view to diversifying the exploitation of coconut palms in Côte d'Ivoire.

2. EQUIPMENT AND METHODS

2.1 Equipment

2.1.1 Experimental site

The biological material consisted of coconut inflorescences sap from the row 8 to hybrid PB113+. The coconut palms were selected on plot 081 to Marc Delorme Research Station for coconut of National Centre of Agronomic Research (CNRA), Côte d'Ivoire. This station is in Port-Bouët, in the Abidjan district, and has a strong leadership in coconut research.

2.1.2 Sap extraction equipment

The equipment for extracting coconut sap was made up of various field tools taking into account access to the coconut inflorescences to be treated, the collection of the sap and its transfer to the treatment site (Table 1).

2.2 Methods

2.2.1 Sampling

Six coconuts were selected from those that showed no evidence of a history of disease or pest attacks. Then, in their leaf corona, the unopened inflorescences, rank 8, were used to extract sap [13]. On each coconut tree, the sap was collected in a plastic container previously sanitized with water heated to 100°C in a boiling bath and was collected 03 times a day (07h, 12h and 17h). The collected samples were placed in an isothermal cooler before being sent to the laboratory for processing.

Table 1. Coconut sap extraction equipment

Materials	Use
Scale	Access to the leaf crown
Kniffe	Cut the spathe
Yarn roll	Tie the inflorescences
Cans	Harvesting, transporting and storing sap
Filter funnel	Filter the sap
Chiffon fabric	Protect the inflorescence and sap from insects during production

2.2.2 Transformation of sap into crystalline sugar

The transformation of sap into derived products was carried out by thermal spraying of the raw material. The experiments were performed on an electric hot plate (TRIOMPH) equipped with a temperature and time regulator. Heating the sap also required a frying pan and stainless-steel spatulas. A pH meter, a 0.01 electronic precision balance (METTLER BD 202, made in USA) and a refractometer were also used to measure physico-chemical parameters of the sap before and during its transformation.

Three (3) processes were tested in this study for the transformation of sap into coconut sugar. In each process, variable time-temperature heating combinations were used.

The first process was carried out with the sap produced and stored for 24 hours in a freezer at a temperature of -10°C. After defrosting, the sap

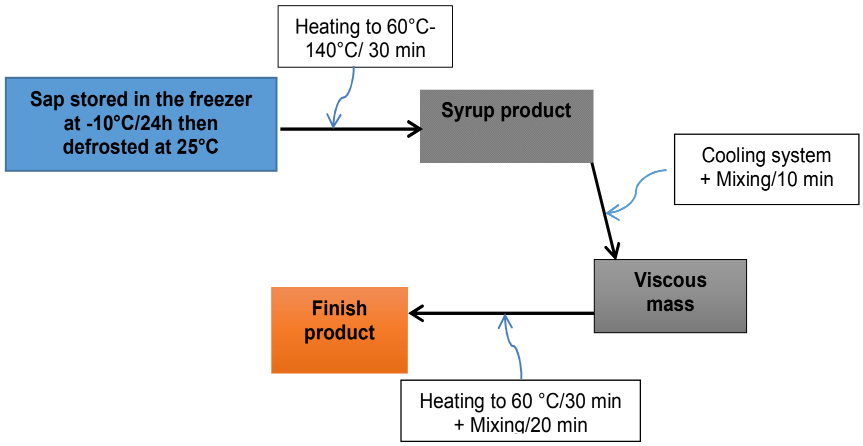

Fig. 1. Coconut sugar production diagram: from sap to syrup

was vaporized at temperatures increasing from 60°C to 140°C. Then the resulting syrup was mixed, vaporized and re-mixed (Fig. 1).

In the 2nd process, the sap was used as soon as it was produced, without intermediate preservation, but maintaining the main stages of the first process. However, the duration of the 2nd vaporization was reduced by half and the massecuite was dried at 30°C in an oven (Fig. 2).

In the 3rd process, the 2nd vaporization was maintained at 30°C and the resulting massecuite was destemmed, crumbled to begin crystallization, kneaded and dried at room temperature for 24 hours (Fig. 3).

2.2.3 Evaluation of physicochemical parameters related to coconut sugar production

The hydrogen potential (pH) of the crystalline sugar samples was evaluated using a portable pH meter from HANNA. A 0.01 precision electronic balance (METTLER BD 202, *made in USA*) and a manual refractometer (DIGIT, 032), allowed us to obtain the masses and total soluble solids contents (°Brix) of the coconut sugar samples produced respectively.

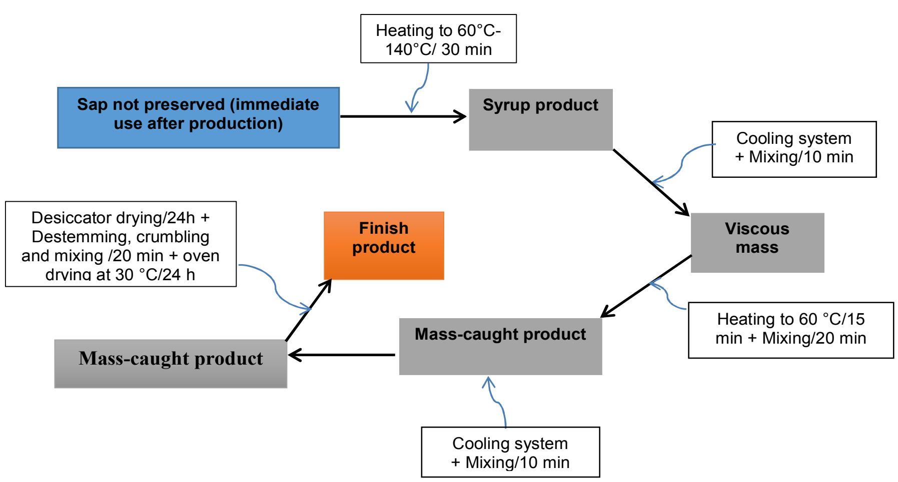

Fig. 2. Production diagram of crystalline coconut sugar by method 2

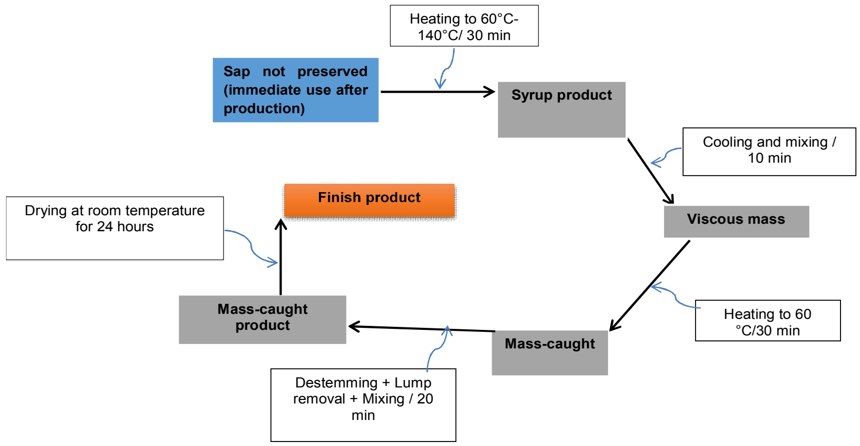

Fig. 3. Production diagram of crystalline coconut sugar by method 3

Then, the transformation yield of the sap into coconut sugar was evaluated according to the formula:

Yield (%) = Mass of the derivative * 100 / Mass of sap

2.2.4 Data processing

The collected data were entered under Excel software, and an analysis of variance (ANOVA) of the means was performed with XLSTAT software version 7.5.3.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 First process for transforming sap into coconut sugar

In the first process, the sap has a pH of 6.5, a total solids content of 14% and a whitish coloring after 24 hours storage (Table 2). After the first vaporization, the syrup obtained has brown color and has a total solids content more than 30%, the maximum value reported by the refractometer used. The 2nd vaporization led to more viscous, dark brown syrup. Its mixing results in a slight jelly setting (Fig. 4). However, no crystallization is observed after the application of this process.

3.1.2 Second process for tsransforming sap into coconut sugar

Freshly collected, without prior preservation, coconut sap, has a pH of 7.2, an ochre color and a total soluble solids content of 14.8% (Table 2). At the end of the 1st vaporization, the syrup obtained is red ochre in color, viscous texture with also more than 30% total soluble solids. After mixing and cooling the massecuite with a desiccator, a small amount of crystal formation is observed in a gel cluster (Fig. 5). This gel setting is permanent after drying at 30°C in an oven for 24 hours.

3.1.3 Third process for transforming sap into coconut sugar

The ^{3rd} process differs from the ^{2nd} process only in the duration of the ^{2nd} vaporization and the drying conditions of the massecuite after mixing. The massecuite destemmed, crumbled and then dried at room temperature results in a clear crystallization of the product. This produces coconut sugar granules that are ochre-yellow in color (Fig. 6).

Fig. 4. Gelled syrup obtained by method 1

3.1.4 Yield of transformation of coconut sap into crystalline sugar

Since the formation of coconut sugar crystals is only evident with the 3rd process, the production yield of coconut sugar was estimated only from this method. From 1 L of coconut sap, an average of 160 g of crystalline coconut sugar is obtained, giving an average yield of 14.29%. Considering this processing yield, the production of 1 kg of sugar requires the collection of 6.25 L of coconut sap (Table 3).

In addition, on the basis of the yield of coconut sap production and its transformation into crystalline sugar, projections can be made for large-scale exploitation of this product. Thus, from the average of 62 L of sap produced by coconut inflorescence, it is possible to obtain 10 kg of crystalline sugar. In addition, each coconut tree produces 10 to 12 inflorescences annually, which suggests a production of 100 to 120 kg of coconut sugar/coconut tree/year. In the end, 1 ha of coconut grove with 160 adult coconut trees could have an estimated coconut sugar production of between 16,000 kg and 19,200 kg per year (Table 3).

Fig. 5. Gelled sugar heaps obtained by method 2

3.2 Discussion

Three processes to produce crystalline sugar from coconut inflorescence sap were tested in this study. The first experiment was carried out with coconut sap stored at -15°C in the freezer for 24 hours before processing. This method did not produce crystals, and the syrup obtained was not very viscous. This result could result from various biochemical modifications produced in the sap during its conservation. Indeed, as soon as it is produced, coconut sap contains mainly sucrose (9.4% to 12.24%) but also fructose and glucose residues that can be directly used by fermentative microorganisms [16]. Even if the sap has been stored cold, the presence of these reducing sugars could have been amplified by these ferments, the presence of which is otherwise spontaneous; the sucrose molecules being easily hydrolyzed into reducing sugars (glucose and fructose) under enzymatic action. In addition, fructose is a carbohydrate with a low crystallization index. It is also the reducing sugar whose microbial use comes second only to that of glucose. Thus, an accumulation of fructose in the sap increases the fructose/glucose ratio, which could be unfavorable to the production of crystalline coconut sugar. The importance of the fructose/glucose ratio in the crystallization of carbohydrate fluids such as honey has been highlighted by Dailly [17]. This author reveals that, the crystallization of carbohydrate fluids such as the crystallization of honey is fast for an F/G ratio < 1.05; slow for 1.05< F/G < 1.45 and rare for F/G > 1.45. There would therefore be a limit value for the F/G ratio in the case of coconut sap syrup above which crystallization would be residual or even non-existent. In addition, the presence of these reducing sugars in the preserved coconut sap is detrimental to the quality of coconut sugar: They are at the origin of defects due to enzymatic browning reactions

Table 2. Parameters for transforming coconut sap into crystalline sugar

Parameter of sap and its transformation		Process 1	Process 2	Process 3
Sap before processing	**Sap quality**	**Stored/24 hours**	**Not kept**	
	Volume and mass of sap	1L = 1050±13 g	1 L = 1120±12 g	
	pH	6,5±0,3	7,2±0,2	
	Total soluble solids (%)	14±0,6	14,8±0,5	
	Color	Whiteish	Orange-Ochre	
Derivative product	Viscosity	Viscous good	Low Viscosity	Viscous pitch
	Appearance after processing	Slight gelation	Permanent gel + some crystals	Complete crystallization
	Product quantity (mass)	100±5 g	120±7 g	160±15 g
	Total soluble solids (%)	> 30	> 30	-
	Color	Dark brown	Ochre-yellow	Ochre-yellow

Table 3. Yield of transformation of sap into coconut sugar and projections on coconut sugar production

Quantity of sap	Quantity of coconut sugar	Yield
1 L = 1120±12 g	160±15 g	14,29±0,5%
Projection estimation		
Parameter	**Quantity of sap**	**Quantity of sugar**
Basis of estimation	6,25 L	1 kg
By Coconut Inflorescence (Variety PB113+) (*)	62 L	10 kg
By coconut tree (production of 10-12 inflorescences/year)	620-744 L/year	100-120 kg/year
Per hectare of coconut trees (160 coconut trees) /year	99 200-119 040 L/year	16,000-19,200 kg/year

Fig. 6. Coconut sugar crystals obtained from process 3

during their reactions with proteins or Maillard reactions. In fact, the agri-food industry applies the Maillard reaction to many food processing processes in order to provide consumers with the desired flavors and colors [18]. However, depending on the conditions used, the Maillard reaction may lead to the parallel formation of undesirable colors, flavors or flavors following rancidity or browning. Such a phenomenon could also justify the crystallization defects and the brown aspect of the syrup made from coconut sap used after conservation for 24 hours.

Processes 2 and 3 allowed the crystallization of coconut sap syrup, confirming that this phenomenon occurs when few reducing sugars contained in the initial raw material are present. This is all the more appropriate as some Asian coconut sugar producers systematically pasteurize the sap before further processing. In the 2nd processing process, the sap was used as soon as it was produced by the coconut inflorescence, without prior conservation. The vaporization temperature of the sap was also modified: it gradually increased from 60°C to 100°C, unlike the first process in which it was systematically fixed at 100°C. This modification was made to avoid molecular component alterations following the sudden heat treatment of the sap. After the syrup was dehydrated in 15 minutes, a gelled mass of sugar crystals was obtained. This could result from insufficient dehydration of the syrup in 15 minutes. Based on this assumption, the dehydration time of the syrup was extended in the 3rd process. During this last process, the second vaporization was carried out at 60°C for 30 min and allowed the massecuite to form. Thus, as a result of extensive dehydration, the sugar molecules aggregate more strongly to transform into a dry massecuite. In comparison with the cane sugar production process, a similarity is observed in our tests. Indeed, at 55°C and at reduced pressure the cane syrup is transformed into a massecuite containing sugar crystals. At the end of this process, the destemming of the relatively dry massecuite was carried out, followed by crumbling to separate the sugar crystals. This phase is different from the cane sugar manufacturing process where the massecuite is mixed before being turbined several times in centrifuges to separate the crystals from the molasses [19]. The yield of 14.25% is an indicator of the profitability of exploiting coconut inflorescences in favor of coconut sugar production. Indeed, projections show that this yield could allow the production of 100 to 120 kg of sugar/coconut/year or even an annual production of 1.6 T to 1.9 T of coconut sugar per ha of coconut plantation planted with the hybrid variety PB113+, one of the most popular ecotypes of coconut trees. These forecasts are therefore related to the type of coconut tree used. But the climatic and soil conditions on which the general development of the coconut tree depends must also be considered.

Nevertheless, the control of the parameters of transformation of the coconut tree's inflorescence sap into crystalline sugar is an important aspect to be consider.

4. CONCLUSION

After testing 03 processes, it appears that crystallization requires a sap that has been exposed to little fermentation and contains few reducing sugars, case of process three. Using this appropriated process, from 6.25 L of sap, it comes out 1 kg of crystallized sugar. The experiment shows that 1 inflorescence of the coconut provides 62 L of sap and 10 kg of sugar. Considering 1 tree or coconut palm and per year, production of sap is variable from 620 to 744 L which are enough to get 100 to 120 kg of sugar. Per ha, coconut farmer can get 99 200 to119 040 L and it comes out equivalent of 16,000 to19, 200 kg crystallized sugar. The popularization of this method could represent an important support for the valorization of coconut sap in Côte d'Ivoire.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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