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3 **Development of a Method to produce Granulated**
4 **Sugar from the Inflorescences Sap of Coconut**
5 **(*Cocos Nucifera L.*) in Ivory Coast: Case of Hybrid**
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14 **SUMMARY**
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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 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 massecoite, 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.

2.1.1 Sap extraction equipment

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

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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

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2.2 METHODS

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2.2.1 Sampling

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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.

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2.2.2 Transformation of sap into crystalline sugar

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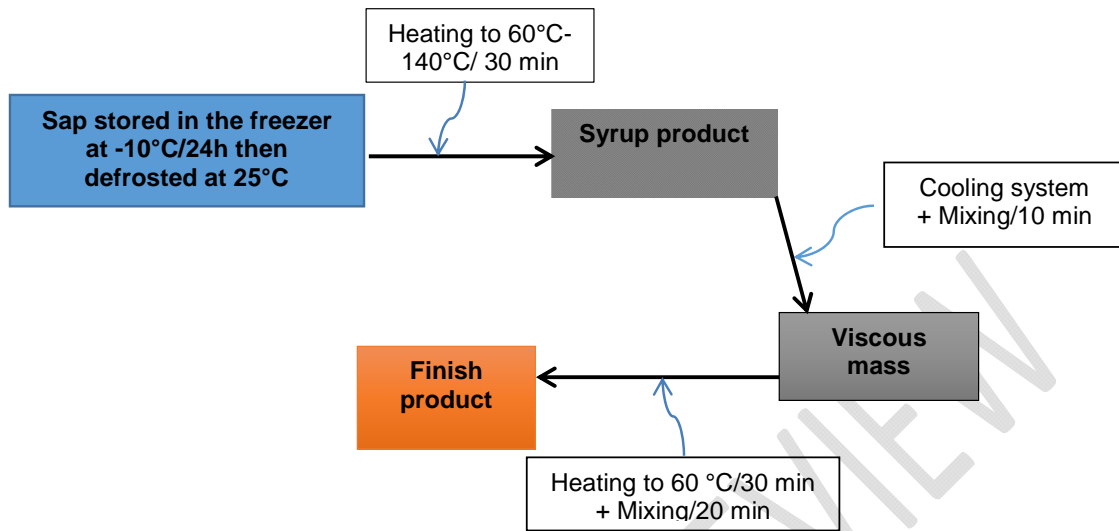
The transformation of sap into derived products was carried out by thermal spraying of the raw material. The experiments were performed on an electric hot plate (TRIOMPH) equipped with a temperature and time regulator. Heating the sap also required a frying pan and stainless-steel spatulas. A pH meter, 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.

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

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103 The first process was carried out with the sap produced and stored for 24 hours in a freezer at a
104 temperature of -10°C. After defrosting, the sap was vaporized at temperatures increasing from 60°C to
105 140°C. Then the resulting syrup was mixed, vaporized and re-mixed (Figure 1).

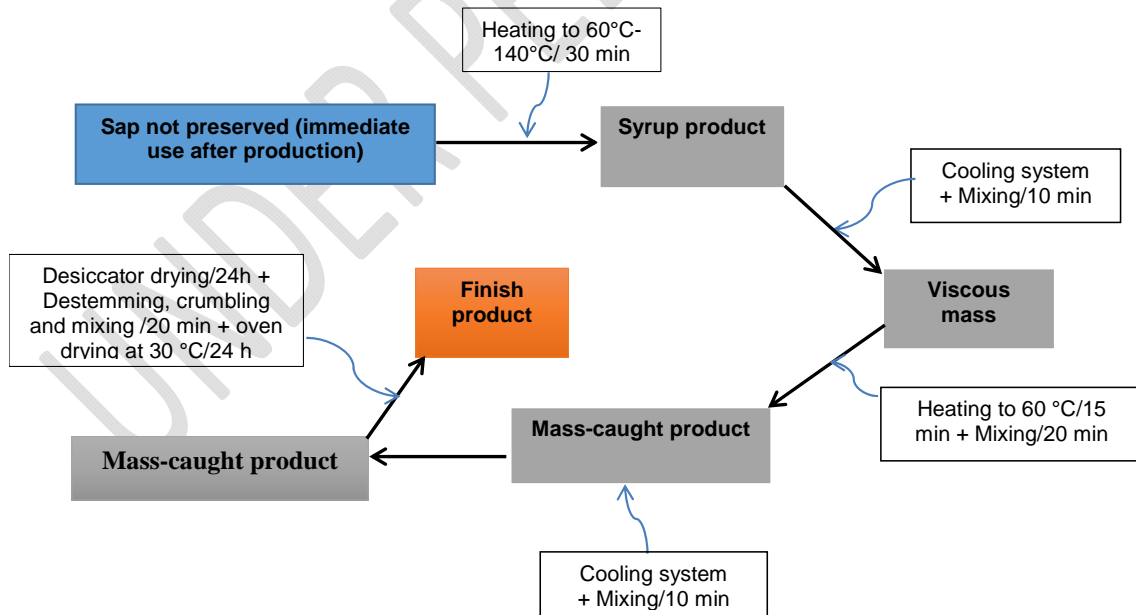
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Figure 1: Coconut sugar production diagram: from sap to syrup

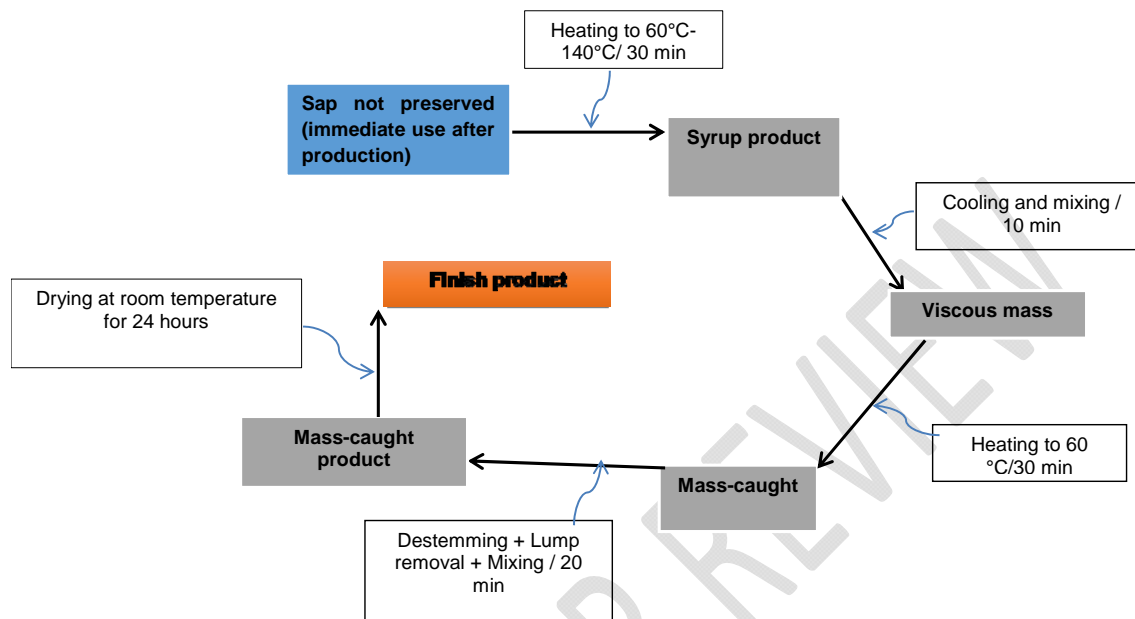
In the 2nd process, the sap was used as soon as it was produced, without intermediate preservation, but maintaining the main stages of the first process. However, the duration of the 2nd vaporization was reduced by half and the massecuite was dried at 30°C in an oven (Figure 2).



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Figure 2: Production diagram of crystalline coconut sugar by method 2

121 In the 3rd process, the^{2nd} vaporization was maintained at 30°C and the resulting massecuite was
 122 destemmed, crumbled to begin crystallization, kneaded and dried at room temperature for 24 hours
 123 (Figure 3).
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125 **Figure 3: Production diagram of crystalline coconut sugar by method 3**

126 **2.2.3. Evaluation of physicochemical parameters related to coconut sugar production**

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

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

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$$\text{Yield (\%)} = \text{Mass of the derivative} * 100 / \text{Mass of sap}$$

133 **2.2.4. Data processing**

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

136 **3. RESULTS AND DISCUSSION**

137 **3.1. RESULTS**

138 **3.1.1. FIRST PROCESS FOR TRANSFORMING SAP INTO COCONUT SUGAR**

139 In the first process, the sap has a pH of 6.5, a total solids content of 14% and a whitish coloring after
 140 24 hours storage (**Table 2**). After the first vaporization, the syrup obtained has brown color and has a
 141 total solids content more than 30%, the maximum value reported by the refractometer used. The^{2nd}
 142 vaporization led to **more** viscous, dark brown syrup. Its mixing results in a slight jelly setting (**Figure 4**).
 143 However, no crystallization is observed after the application of this process.

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162 **Figure 4:** Gelled syrup obtained by method 1
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166 **3.1.2. SECOND PROCESS FOR TRANSFORMING SAP INTO COCONUT SUGAR**

167 Freshly collected, without prior preservation, coconut sap, has a pH of 7.2, an ochre color and a total
168 soluble solids content of 14.8% (**Table 2**). At the end of the 1st vaporization, the syrup obtained is red
169 ochre in color, viscous texture with also more than 30% total soluble solids. After mixing and cooling
170 the masseccute with a desiccator, a small amount of crystal formation is observed in a gel cluster
171 (**Figure 5**). This gel setting is permanent after drying at 30°C in an oven for 24 hours.
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178 **Figure 5:** Gelled sugar heaps obtained by method 2
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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 (Figure 6).



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Figure 6: Coconut sugar crystals obtained from process 3

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

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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

218 coconut trees could have an estimated coconut sugar production of between 16,000 kg and 19,200 kg
219 per year (Table 3).

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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

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3.2. DISCUSSION

231 Three processes to produce crystalline sugar from coconut inflorescence sap were tested in this study.
232 The first experiment was carried out with coconut sap stored at -15°C in the freezer for 24 hours
233 before processing. This method did not produce crystals, and the syrup obtained was not very viscous.
234 This result could result from various biochemical modifications produced in the sap during its
235 conservation. Indeed, as soon as it is produced, coconut sap contains mainly sucrose (9.4% to
236 12.24%) but also fructose and glucose residues that can be directly used by fermentative
237 microorganisms [16]. Even if the sap has been stored cold, the presence of these reducing sugars
238 could have been amplified by these ferments, the presence of which is otherwise spontaneous; the
239 sucrose molecules being easily hydrolyzed into reducing sugars (glucose and fructose) under
240 enzymatic action. In addition, fructose is a carbohydrate with a low crystallization index. It is also the
241 reducing sugar whose microbial use comes second only to that of glucose. Thus, an accumulation of
242 fructose in the sap increases the fructose/glucose ratio, which could be unfavorable to the production
243 of crystalline coconut sugar. The importance of the fructose/glucose ratio in the crystallization of
244 carbohydrate fluids such as honey has been highlighted by Dailly [17]. This author reveals that, the
245 crystallization of carbohydrate fluids such as the crystallization of honey is fast for an F/G ratio < 1.05;
246 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
247 ratio in the case of coconut sap syrup above which crystallization would be residual or even non-
248 existent. In addition, the presence of these reducing sugars in the preserved coconut sap is
249 detrimental to the quality of coconut sugar: They are at the origin of defects due to enzymatic browning
250 reactions during their reactions with proteins or Maillard reactions. In fact, the agri-food industry
251 applies the Maillard reaction to many food processing processes in order to provide consumers with
252 the desired flavors and colors [18]. However, depending on the conditions used, the Maillard reaction
253 may lead to the parallel formation of undesirable colors, flavors or flavors following rancidity or
254 browning. Such a phenomenon could also justify the crystallization defects and the brown aspect of
255 the syrup made from coconut sap used after conservation for 24 hours.
256 Processes 2 and 3 allowed the crystallization of coconut sap syrup, confirming that this phenomenon
257 occurs when few reducing sugars contained in the initial raw material are present. This is all the more
258 appropriate as some Asian coconut sugar producers systematically pasteurize the sap before further
259 processing. In the 2nd processing process, the sap was used as soon as it was produced by the
260 coconut inflorescence, without prior conservation. The vaporization temperature of the sap was also
261 modified: it gradually increased from 60°C to 100°C, unlike the 1st process in which it was
262 systematically fixed at 100°C. This modification was made to avoid molecular component alterations
263 following the sudden heat treatment of the sap. After the syrup was dehydrated in 15 minutes, a gelled
264 mass of sugar crystals was obtained. This could result from insufficient dehydration of the syrup in 15
265 minutes. Based on this assumption, the dehydration time of the syrup was extended in the 3rd process.
266 During this last process, the second vaporization was carried out at 60°C for 30 min and allowed the

267 massequite to form. Thus, as a result of extensive dehydration, the sugar molecules aggregate more
268 strongly to transform into a dry massequite. In comparison with the cane sugar production process, a
269 similarity is observed in our tests. Indeed, at 55°C and at reduced pressure the cane syrup is
270 transformed into a massequite containing sugar crystals. At the end of this process, the destemming of
271 the relatively dry massequite was carried out, followed by crumbling to separate the sugar crystals.
272 This phase is different from the cane sugar manufacturing process where the massequite is mixed
273 before being turbinéd several times in centrifuges to separate the crystals from the molasses [19].
274 The yield of 14.25% is an indicator of the profitability of exploiting coconut inflorescences in favor of
275 coconut sugar production. Indeed, projections show that this yield could allow the production of 100 to
276 120 kg of sugar/coconut/year or even an annual production of 1.6 T to 1.9 T of coconut sugar per ha
277 of coconut plantation planted with the hybrid variety PB113+, one of the most popular ecotypes of
278 coconut trees. These forecasts are therefore related to the type of coconut tree used. But the climatic
279 and soil conditions on which the general development of the coconut tree depends must also be
280 considered. Nevertheless, the control of the parameters of transformation of the coconut tree's
281 inflorescence sap into crystalline sugar is an important aspect to be consider.
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283 4. CONCLUSION

284 After testing 03 processes, it appears that crystallization requires a sap that has been exposed to little
285 fermentation and contains few reducing sugars, case of process three. Using this appropriated
286 process, from 6.25 L of sap, it comes out 1 kg of crystallized sugar. The experiment shows that 1
287 inflorescence of the coconut provides 62 L of sap and 10 kg of sugar. Considering 1 tree or coconut
288 palm and per year, production of sap is variable from 620 to 744 L which are enough to get 100 to 120
289 kg of sugar. Per ha, coconut farmer can get 99 200 to 119 040 L and it comes out equivalent of 16,000
290 to 19, 200 kg crystallized sugar. The popularization of this method could represent an important
291 support for the valorization of coconut sap in Côte d'Ivoire.
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296 CONSENT (IF APPLICABLE)

297 Not concerned
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300 ETHICAL APPROVAL (IF APPLICABLE)

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