Physicochemical and organoleptic characteristics of syrup and raw sugars obtained from oil palm (*Elaeis guineensis*) sap

.

ABSTRACT

|  |
| --- |
| **Aims** The oil palm (*Elaeis guineensis*) sap despite its biochemical and nutritional potential, has not been sufficiently exploited. To value the sap commonly called "palm wine", this study aimed to assess the possibility of its transformation into sugar.  **Study design:**  **Place and Duration of Study:** Sample: Department of Food Biochemistry and Technology, Université NANGUI Abrogoua, between February and September 2024.  **Methodology:** Fresh palm wine collected with a wine processor in palm plantation, underwent thermal evaporation (120° C to 60° C) to obtain syrup and steamed sugar and freeze-drying to obtain freeze-dried sugar. Then, physicochemical and sensory analysis were carried out.  **Results:** Results showed that sugar yield varied from 8.93 ± 0.12% (freeze-dried sugar) to 18.68 ± 0.34% (syrup). The moisture content of syrup (26.84 ± 2.46%) was the highest while that of freeze-dried sugar (18.91 ± 1.87%) was the lowest. The pH of freeze-dried sugar (3.78 ± 0.01) was the lowest while its titratable acidity (89.67 ± 0.88 meq /100 g) was the highest. Total sugars (38.50 ± 4.02% g/100 g), Brix (95.70 ± 0.30), lipids (21.37 ± 0.70%) and energy values (487.44 ± 5.27 Kcal) were lower in freeze-dried sugar unlike steamed sugar whose values were the highest respectively 45.97 ± 1.74 g/100 g; 96.90 ± 0.30; 33.98 ± 0.11% and 550.12 ± 2.25 Kcal. Chromatographic analysis of sugars revealed several simple sugars including fructose with greatest quantities. These amounts were 32.48 ± 0.23 g/100 g (syrup), 33.53 ± 0.02 g/100 g (steamed sugar) and 37.61 ± 0.01 g/100 g (freeze-dried sugar). The sensory profile of sugars showed that syrup and steamed sugar had honeyed flavor while freeze-dried sugar had a sour aftertaste.  **Conclusion:** Hypoglycemic sugar can be produced with palm wine with high fructose content. Further study should be done to stabilize palm sugars and popularize production. |

*Keywords: Oil palm, palm wine, sugars, physicochemical characteristics, quantitative sensory profile, Côte d’Ivoire*

1. INTRODUCTION

Oil palm or Guinea palm (*Elaeis guineensis* Jacq.) is a species of monocotyledonous plant of the Arecaceae family. It is widely cultivated for its fruits and seeds rich in oil for food and industrial use. It is a crop limited to the intertropical zone, which has been developed recently and whose production is very concentrated in Asia (**Baron, 2014**). The oil palm sector began to develop in Côte d'Ivoire during the colonial period, in the 1910s (**Jannot, 2010**). Today, Côte d'Ivoire is the second largest African producer of palms with 1,800,000 t per year (**Niamketchi *et al*., 2024**). It occupies this position just after Nigeria, with which it ensures most of the 4% of the world market share supplied by Africa (**Palmafrique, 2013**). According to statistics published by the Interprofessional Association of the Oil Palm Sector, Côte d'Ivoire has 75,000 ha of industrial oil palm plantations and 155,000 ha of village plantations. The sector generates 220,000 direct jobs, feeds more than two million people and represents 1.5% of the Gross Domestic Product (**Amangoua, 2020**). Oil palm is a well-developed cash crop in the southern forest zone (Aboisso, Dabou, Fresco, Grand-Lahou, Divo, Sikensi), in the east and west of Côte d'Ivoire (**Yao and Kamagaté, 2010**). However, it is mainly cultivated to produce oil from the pulp of the seeds and the palm kernel. Thus, two main oils come from the oil palm (red palm oil and white palm kernel oil). Besides oils, another resource derived from the oil palm is palm sap commonly called "Palm Wine". Palm wine is a natural drink sweetened at harvest and alcoholic after spontaneous fermentation. It is a traditional alcoholic drink widely consumed in several African countries (**Kouchade *et al*., 2017**), in South America and Asia which has little food value or unknown nutritional aspects (**Nwaiwu and Itumoh 2017**). Palm wine was originally considered as a drink for the poor but is currently canned and bottled for the international market (**Nwaiwu and Itumoh 2017**). Indeed, palm wine has so far been the subject of very little agro-industrial exploitation although it has been consumed for centuries in West Africa and Southeast Asia for its medicinal and ritual properties (**Agora africaine, 2022**). Research has shown that Palm wine contains a significant quantity of fermentable sugars, amino acids, vitamins and minerals (**Onyeukwu *et al*., 2024**). It also contains phenolic compounds, tannins and organic acids. However, its chemical composition may vary depending on the palm variety, harvest season and fermentation process (**Salhi and Gounina, 2019**).

In the context of searching for new sources of sugar that would improve the health of populations, several studies have focused on the production of sugars from natural sources other than sugar cane and beet. Thus, studies have focused on the production of sugar from the sap of the inflorescence of coconut tree and coconut water (**Akpro *et al*., 2018**) and palms of *Borasus species flabelliffer* and *Fouenix syvestrix* (**Sarkar *et al*., 2023**). In Côte d'Ivoire, mature oil palms with low oil yield are felled for traditional palm wine production or for liqueur production (**Koffi *et al*., 2019**). However, the sap from the oil palm contains a good quantity of sugars that could be exploited in sugar production. So, to value the palm sap, this study aims to assess the possibility of its transformation into sugar.

2. material and methods

**2.1. Material**

The plant material used for this study is the sap of oil palm “palm wine” (Figure 1) harvested freshly after felling the tree.



Figure 1: Photograph of oil palm wine (*Elaeis guineensis* Jacq.) in a glass

**2.2 Methods**

**2.2.1** **Collection of palm wine samples**

Fresh palm sap (10 L) was collected from a palm wine producer in the commune of Songon in southern Côte d'Ivoire. The first wine produced was sampled early in the morning to avoid collecting fermented samples. The wine collected in plastic jugs was transported in a cooler containing ice (dry ice) to slow down fermentation and avoid any change in quality.

**2.2.1** **Production of palm wine sugars**

***2.2.1.1*** ***Production of steamed sugar***

Raw sugar from palm wine was extracted by evaporation from fresh palm sap, using a hot plate (TRIOMPH, France) equipped with a temperature, heat and time regulator. The palm wine was heated at different temperatures. Thus, one liter (l L) of sap was heated in a pan in three evaporations (phases). First, the palm wine underwent a first evaporation at 120 °C for 45 min. Then, a second at 80 °C for 20 min and finally a third evaporation at 60 °C for 15 min. The first and second phases were followed by sudden cooling punctuated by mixing for 10 min before the next one. The product obtained which is the cooked mass was cooled at room temperature then destemmed from the pan, crumbled before moving on to the third phase to obtain steamed sugar (**Apkro *et al*., 2018**).

***2.2.1.2*** ***Production of palm syrup***

Palm sap syrup was obtained by single-phase evaporation for 60 min. Evaporation was carried out at decreasing temperatures without heat interruption with regular differences of 20 °C (from 120 °C to 60 °C). So, 1 L of the sap was heated to 120 °C for 30 min. The temperature was then reduced to 100 °C for 10 min, then to 80 °C for 10 min and finally to 60 °C for 10 min. Throughout the preparation, the liquid was continuously mixed to accelerate the production of the syrup and avoid possible caking. At the end of the heating, the syrup was cooled on the bench to room temperature before being packaged in plastic bottles (**Apkro *et al*., 2018**).

***2.2.1.3*** ***Production of* freeze-dried sugar**

freeze-dried sugar was obtained by freeze-drying. Indeed, 1 L of palm wine was divided into freeze-drying flasks and placed in a freezer at -80 °C for 24 h. After freezing, the flasks containing the frozen palm wine were connected to the freeze-dryer (BIOBASE BIODUSTRY, SHANDONG, bk-FD 101). The frozen palm wine underwent vacuum sublimation to directly give freeze-dried sugar after 18 h of dehydration (**Apkro *et al*., 2018**).

***2.2.1.4*** ***Sugar extraction yield***

The palm wine sugar production yield was determined by calculation according to formula 1 below described by **Almohammed, (2017)**:

**(1)**

R: Yield (%)

Mf: Mass (g) of sugar produced

Mi: Mass (g) of palm wine used

**2.2.2 Physicochemical characterization of the sugars produced**

Moisture content, dry matter and ash content of samples were determined according to the method described by **Fontana and Brady (2020)**. Titratable acidity, pH and lipid content were determined according to **AOAC (2002)**. The total soluble solids (TSS) content or Brix was determined using a refractometer (DIGIT-032, Brussels, Belgium) with automatic temperature correction of 20°C (**Apkro *et al*., 2018**). The total sugar content (**Dubois *et al.,* 1956)**, the reducing sugar content (**Bernfeld, 1955**), protein content (**Lowry *et al*., 1951**) and crude fibre content (**Wolff, 1968**) were also determined. **FAO (1998)** method based on difference calculation (Formula 2) was adopted to determine the total carbohydrate content. The energy value was determined according to the method described by **Atwater and Rosa (1899)** through mathematical formula 3. The main carbohydrate constituents of the different sugars were determined using high-performance liquid chromatography (HPLC) Equipped with a DX600 device (Dionex Corp Sunnyvale, CA) and a Dionex ED50 pulsed amperometric detector (PAD).

**(2)**

**(3)**

TC: Total carbohydrates

EV: Energy value

DM: Dry matter

**2.2.3 Sensory analysis of palm sugars**

***2.2.3.1 Composition of the panel***

The sensory evaluation of the different sugars was carried out with a panel of 25 tasters composed of 15 male and 10 female students from the Université Nangui ABROGOUA (Abidjan, Côte d’Ivoire) whose ages varied between 19 and 30 years. The tasters were recruited based on their experience in sensory analysis, their availability and willingness to participate in the study. The organoleptic descriptors considered were the sweetness, the honeyed flavor and the sour aftertaste of the samples of sugars produced.

***2.2.3.2 Carrying out the test***

The descriptive test adopted in this work was the quantitative sensory profile. The test was conducted in one session with 25 qualified tasters. The palm sugar samples were evaluated in comparison with reference samples of glucose and sucrose. All samples (palm sugars, glucose and sucrose) were coded and presented simultaneously to the tasters. The intensity of the descriptors was determined on an unstructured linear scale with an origin (0) and an end (100). A scale is provided for each descriptor, and the taster was asked to taste the samples and mark vertical lines on the scale indicating the positions of the samples relative to their intensity (**Actia, 2014**). Between two tastings, the taster rinses his mouth with water.

**2.2.4 Statistical analysis**

All data obtained from this study were entered into Excel. Then the STATISTICA 7.1 software was used for statistical processing. An analysis of variance (ANOVA) was carried out to compare the different variables. When a significant difference was observed between variables, ANOVA was completed by multiple comparisons (post ANOVA test) by performing the Duncan test with an error threshold of 0.05. For the sensory profile, ANOVA was completed by a principal component analysis (**Actia, 2014**).

3. results and discussion

**3.1 Results**

**3.1.1** **Physicochemical characterization of the sugars produced**

***3.1.1.1 Sugar yields***

The sugar yield obtained according to the production methods is presented in Figure 2. It emerges that syrup was the production method with the highest yield with 18.68%. Steaming and freeze-drying gave statistically identical yields (9.46%) and (8.93%).

Figure 2: Sugar yield according to production methods

***3.1.1.2 Physicochemical composition of the sugars produced***

The physicochemical composition of sugars is presented in Table I. The dry matter contents of the different samples were relatively high, varying between 77.31 ± 1.85% (steamed sugar) and 81.09 ± 1.87% (freeze-dried sugar). The dry matter, ash and total sugar contents of the sugars produced were not significantly different at the 5% threshold. These sugars had a pH between 3.78 ± 0.01 (freeze-dried sugar) and 4.02 ± 0.04 (syrup) and a titratable acidity between 89.67 ± 0.88 meq /100 g (freeze-dried sugar) and 63.00 ± 0.58 meq /100 g (steamed sugar) with significant differences. The Brix vary from one sample to another and were significantly different. Sugars were rich in lipids (21.37 ± 0.70% to 33.98 ± 0.11%) with contents that were as different from each other. The total carbohydrate contents were between 60.15 ± 0.43% and 73.46 ± 0.26% with steamed sugar and syrup having the lowest contents. The energy value of freeze-sugar and syrup were statistically identical with values of 487.44 ± 5.27 Kcal and 506.33 ± 0.16 Kcal respectively compared to steamed sugar which has the highest energy value (550.12 ± 2.25 Kcal).

Table I: Physicochemical compounds of the sugars produced

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Samples** | **DM** | **Humidity** | **Ash** | **TC** | **Fibers** | **Lipids** | **TA** | **pH** | **Brix** | **RS** | **TS** | **Protein** | **Energy** |
| Unit | (%) | | | | | | (meq/100g) |  | (°B) | (g/100g) | | | (Kcal) |
| Freeze-dried sugar | 81.09 ± 1.87a | 18.91 ± 1.87b | 3.45 ± 0.25a | 73.46 ± 0.26a | 1.41 ± 0.20a | 21.37 ± 0.70c | 89.67 ± 0.88a | 3.78 ± 0.01b | 95.70 ± 0.30b | 34.66 ± 1.61a | 38.50 ± 4.02a | 0.31 ± 0.01c | 487.44 ± 5.27b |
| Syrup | 73.83 ± 3.13a | 26.84 ± 2.46a | 4.01 ± 0.05a | 69.54 ± 0.13b | 0.70 ± 0.06b | 25.03 ± 0.04b | 64.00 ± 0.58b | 4.02 ± 0.04a | 87.00 ± 0.30c | 19.17 ± 1.73b | 42.23 ± 6.00a | 0.71 ± 0.01b | 506.33 ± 0.18b |
| Steamed sugar | 77.31 ± 1.85a | 22.69± 1.85ab | 4.40 ± 0.45a | 60.15 ± 0.43c | 0.55 ± 0.03b | 33.98 ± 0.11a | 63.00 ± 0.58b | 3.92 ± 0.04a | 96.90 ± 0.30a | 22.83 ± 0.98b | 45.97 ± 1.74a | 0.92 ± 0.01a | 550.12 ± 2.25a |

Values in the same column with the same letter are not significantly different at the 5% threshold.

**DM:** Dry matter; **TC**: Total carbohydrates; **TA**: Titratable acidity; **RS**: Reducing sugars; **TS**: Total sugars

***3.1.1.3 Nature of sugars identified by HPLC***

The sugars identified were sucrose, fructose, glucose, maltose, xylose, galactose and lactose. The results show that freeze-dried sugar obtained the highest contents of these sugars compared to steamed sugars and syrup (p < 0.05). Also, fructose (32.48 ± 0.23 g/100 g to 37.61 ± 0.01 g/100 g) and glucose (25.94 ± 0.05 g/100 g to 28.08 ± 0.02 g/100 g) were the predominant sugars in the samples followed by xylose (11.06 ± 0.20 g/100 g to 17.97 ± 0.11 g/100 g). Lactose was the sugar with the lowest quantity in the samples with contents ranging from 0.33 ± 0.01 g/100 g to 0.47 ± 0.01 g/100 g. Furthermore, the contents of these sugars are different from one sample to another except for maltose for which steamed sugar and syrup have approximately the same content (Table II).

Table II: Composition in simple sugars (g/100g) of palm wine sugars

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Samples** | **Sucrose** | **Fructose** | **Glucose** | **Maltose** | **Xylose** | **Galactose** | **Lactose** |
| Freeze-dried sugar | 6.61 ± 0.01a | 37.61 ± 0.01a | 28.08 ± 0.02a | 9.04 ± 0.35a | 17.97 ± 0.11a | 1.45 ± 0.00a | 0.47 ± 0.01a |
| Steamed sugar | 5.50 ± 0.01c | 33.53 ± 0.02b | 26.88 ± 0.12b | 5.65 ± 0.13b | 12.85 ± 0.20b | 1.17 ± 0.00b | 0.33 ± 0.01c |
| Syrup | 5.94 ± 0.11b | 32.48 ± 0.23c | 25.94 ± 0.05c | 6.41 ± 0.11b | 11.06 ± 0.20c | 1.12 ± 0.00c | 0.37 ± 0.01b |

Values in the same column with the same letter are not significantly different at the 5% threshold.

***3.1.1.4 Intensity of sensory descriptors of different sugars***

Table III presents the intensity of the descriptors studied for each sample. Thus, on a scale of 0 to 100, syrup and steamed sugar with intensities 45.97 ± 4.34 and 40.11 ± 4.57 respectively were the sweetest. Freeze-dried sugar had the lowest sweetness intensity (26.35 ± 3.93). Regarding flavor, syrup (56.87 ± 4.41) and steamed sugar (55.45 ± 4.87) obtained the highest intensities. Finally, freeze-dried sugar obtained the strongest intensity of aftertaste (60.81 ± 5.12).

Principal component analysis (PCA) shows that syrup and steamed sugar were better characterized by their sweetness and flavor while freeze-dried sugar is marked by its sour aftertaste (Figure 3).

Table III: Intensity of descriptors of sugar samples

|  |  |  |  |
| --- | --- | --- | --- |
| **Samples** | **Sweetness** | **Honeyed flavor** | **Sour aftertaste** |
| Syrup | 45.97 ± 4.34**a** | 56.87 ± 4.41**a** | 42.67 ± 4.69**b** |
| Steamed sugar | 40.11 ± 4.57**a** | 55.45 ± 4.87**a** | 51.19 ± 4.87**ab** |
| Freeze-dried sugar | 26.35 ± 3.92**b** | 39.39 ± 5.77**b** | 60.81 ± 5.12**a** |

Values in the same column with the same letter are not significantly different at the 5% threshold.

Figure 3: Characterization of sugars according to their sensory descriptors

**3.2 Discussion**

**3.2.1 Physicochemical composition of sugars**

The processing of oil palm (*Elaeis guineensis*) wine led to the extraction of three types of sugars. Two thermal evaporation processes, one continuous for the syrup and the other discontinuous for the steamed sugar, and freeze-drying for the freeze-dried sugar. The sugar yield of these processes showed variations of the order of 8.93 to 18.68% (i.e. 93 g/L and 180 g/L). These yields are higher than those obtained by **Apkro *et al*., 2018** in their study of sugar production with coconut water which were from 55.90 g/L to 66.18 g/L. The observed differences would be attributable to the variability of the sugar composition which is a function of the raw material used to produce sugars. Indeed, according to **Salhi and Gounina (2019)**, the dry matter content of date palm sap varies from 8.09% to 15.72% while **Kodjo *et al*. (2022)** showed that of coconut water is between 5.63% and 7.68%. Of the three types of palm wine sugars, freeze-dried sugar appeared to be the most acidic with a pH of 3.78 ± 0.01. This acidity could be explained by the duration of freeze-dried sugar (5 days). Due to the time taken to obtain this sugar, the fermentation process already initiated spontaneously could lead to organic acids or alcohols (**Solomon *et al*., 2006**) and modified the taste (**Zennoune, 2022**). On the other hand, the rapid production of steamed sugar and syrup by thermal evaporation would justify the low acidity noted. The lowest pH value recorded with freeze-dried sugar agrees with its high titratable acidity (89.67 ± 0.88 meq /100g) because it has been shown that pH and titratable acidity are inversely proportional (**Konan *et al*., 2016**). It emerges from this work that the titratable acidity values of palm wine sugars are generally high (63.00 ± 0.58 - 89.67 ± 0.88 meq /100g). Thus, these sugars produced would be beneficial for the diabetic consumer. Indeed, according to **Apkro *et al*. (2018)**, high acidity of sugars helps to lower their glycemic index by inhibiting certain enzymes responsible for the digestion of starch and other carbohydrates. Furthermore, the study showed that freeze-dried sugar has the highest levels of reducing sugars (34.66 ± 1.61 g/100g) and the lowest levels of total sugars (38.50 ± 4.02 g/100g). Looking at the biochemical composition of the palm wine sugars produced, it appears that the lipid and protein contents of the steamed sugar and syrup are higher. These high contents could be attributed to the heat treatments undergone. **Vautier *et al*. (2010)** agreed by reporting that heat treatments for cooking sugars lead to an increase in protein, lipid and ash contents. This explains their high energy values compared to freeze-dried sugar. Similarly, the ash contents of steamed sugar and syrup are the highest with respective values of 4.40 ± 0.45% and 4.01 ± 0.05. These ash values are higher than those found by **Bergeret (1985)** which is 3.4% for unfermented sap of the oil palm. The high ash content in sugars obtained by thermal evaporation compared to freeze-drying could be explained by the effect of heat which constitutes a mineralization factor by destruction of organic matter and the exposure of the various minerals which are easily measured (**Apkro *et al*., 2018**).

**3.2.2 Simple sugars identified samples**

The chromatographic analysis confirmed highest level of freeze-dried sugar in reducing sugars revealing its high levels in fructose (37.61 ± 0.01 g/100g), glucose (28.08 ± 0.02 g/100g), maltose (9.04 ± 0.35 g/100 g), xylose (17.97 ± 0.11 g/100 g), galactose (1.45 ± 0.00 g/100 g) and lactose (0.47 ± 0.01 g/100 g) compared to the other two sugars. This richness of freeze-dried sugar in reducing sugars would be due to the freeze-drying process. According to **Naknean *et al*. (2015)**, freeze-drying retains a good number of reducing sugars compared to steamed sugar and syrup which lose them by caramelization under the effect of heat. The reducing sugar contents of the sugar produced from palm wine are higher than those of refined cane sugar obtained by **Srikaeo *et al*. (2019)** with values of 0.23 g/100 g for glucose and 2.06 g/100 g for fructose. These low reducing sugar contents in refined sugar would be due to the chemical refining process that removes the reducing sugar as mentioned by **Srikaeo *et al*. (2019)**. In contrast, the low total sugar content of freeze-dried sugar could be due to fermentation by microorganisms at the beginning of freeze-drying. This hypothesis is corroborated by the results of **Solomon *et al*. (2006)** who showed that in contaminated sugar, microorganisms can convert sucrose into glucose and fructose (invert sugar).

**3.2.3 Sensory descriptors sugars**

Sensory analysis of sugars produced from palm wine showed a lower sweetening power or sweetness than the glucose and sucrose references. Thus, all palm wine sugars had a lower sweetness intensity (26.35 ± 3.92 to 45.97 ± 4.34). However, of the three test sugars studied, steamed sugar (40.11 ± 4.57) and syrup (45.97 ± 4.34) had a higher sweetness intensity while freeze-dried sugar had the highest sour aftertaste intensity. Albeit freeze-dried sugar contained the highest content in sugar, its sweetness taste was not perceived by tasters. Thus, the high acidity level of freeze-dried sugar decreased its sweetness (**Pelletier *et al*., 2004; Symoneaux *et al*., 2015**).

4. Conclusion

This study shows the effectiveness of the production of sugar from oil palm with interesting yields. These sugars present good biochemical characteristics. The higher content of fructose in these sugars suggests that they could be hypoglycemic. Thus, this study offers a way to valorize oil palm.

Disclaimer (Artificial intelligence)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

References

Actia, (2014). Evaluation sensorielle : Guide de bonne pratique, 2ème Edition revue et augmentée. *Actia*, 82 p.

Agora africaine, (2022). Le vin de palme serait le vin le plus séculaire d’Afrique. https://www.agoraafricaine.info/2022/07/18/le-vin-de-palme-serait-le-vin-le-plus-seculaire-dafrique/.

Akpro, L. A., Konan, K; J. L., Gbogouri, G. A., Konan, B. R., & Yao S. D. (2018). Physicochemical coconut water assessment and the microbiological quality of its sugar extracted from five coconut ecotypes at the Marc Delorme station, Côte d'Ivoire. *International Journal of Applied Biology and Pharmaceutical Technology*, 1(9): 24-31. http://dx.doi.org/10.21276/ijabpt

Almohammed, F. (2017). Application des électrotechnologies pour une valorisation optimisée de la betterave à sucre dans un concept de bioraffinerie. Thèse de doctorat de l’Université de Technologie de Compiègne, France, 213 pp.

Amangoua, E. P. (2020). Filière palmier à huile : Ça ne baigne plus pour les planteurs. Accessed online on 03/15/2023. <https://www.fratmat.info>.

AOAC (Association of Official Analytical Chemists). 2002. AOAC official methods of analysis. Arlington, Va.: AOAC Intl.

Atwater, W. O., & Rosa, E. B. (1899). Description of a new Respiration calorimeter and experiments on the conservation of energy in the human body. Washington, DC. Government printing office; 1899. US Department of Agriculture Office of Experimentation Station, Bulletin, 69 p.

Baron, V. (2014). Dynamiques de plantation et conduite technique du palmier à huile (*Elaeis sp.*) dans le bassin de production de Los Rios et du Guayas, Equateur. Mémoire de fin d'études, Ecole supérieure d'agro-économie internationale. Cergy-Pontoise: ISTOM, 88 p.

Bernfield, P. (1955). Amylase α and β methods. Enzymology I (9th edn), Colowich SP, Kaplan NO (eds). Academic Inc. New York.

Bergeret, B. (1985). Preliminary note on the study of palm wine in Cameroon. *Tropical Medicine*, 17(6): 901-904.

Dubois, M., Gilles, K., Hamilton, J., Rebers, P., & Smith, F. (1956). Colorimetric method for the determination of sugars and related substances. *Analytical Chemistry*, 280: 350-356. https://doi.org/10.1021/ac60111a017

FAO. (1998). Carbohydrates in human nutrition. Report of a Joint FAO/WHO Expert consultation. FAO Food Nutrition Paper, 66:1-140.

Fontana, A. J. J., & Brady, P. C. (2020). Measurement of Water Activity, Moisture Sorption Isotherm, and Moisture Content of Foods. Water Activity in Foods: Fundamentals and Applications, 2nd Edn; John Wiley & Sons, Inc. pp 20.

Jannot, C. (2010). Emplois, économie, environnement : le développement de la filière palmier à huile en Côte d’Ivoire. *OCL*, 17(6): 393-399 p. https://doi.org/10.1051/ocl .2010.0344

Kodjo, N. F., Akpro, L. A., Sarka, D. M., Konan, J. L., & Niamké, A. S. L. (2022). Caractéristiques physico-chimiques de l’eau de coco immature de six descendances hybrides F1 NJM x GVT hybrid progenies*. European Scientific Journal*, 18 (30), 60-72. https://doi.org/10.19044/esj.2022.v18n30p60

Koffi, F. C. R., Adou, M., & Assemand, E. (2019). Evaluation de la qualité du Koutoukou liée aux différents procédés de fabrication traditionnelle dans les grandes zones de production en Côte d’Ivoire. *Journal of Applied Biosciences* 143:14635-14648. https://www.ajol.info/index.php/jab/article/view/192274

Konan, B. R., Agnememel, A. B., Akely, P. M. T., Assa, R. R., Konan, K. J., & Amani, N. G. (2016). Variation des paramètres biochimiques de l'eau de coco (*Cocos nucifera* L.) issu de la culture *in vitro* pendant la période de stockage. *International Journal of Biological and Chemical Sciences*. 10(3): 957-965. https://doi.org/10.4314/ijbcs.v10i3.4

Kouchade, C. A., Kounouhewa, B., & Awokou, S. K. (2017). La récolte de vin de palme : procédé et effets des conditions environnementales. *OCL*, 24(5): 1-8. https://doi.org/10.1051/ocl/2017035

Lowry, O. H., Rosenbrough, N. J., Farr, A. L., & Randall, R. J. (1951). “Protein Measurement with the Folin Phenol Reagent.” *Journal of Biological Chemistry*, 193, 265-275.

Naknean, P., & Meenune, M. (2015). Impact de la clarification de la sève de palmier et de la méthode de transformation sur la qualité du sirop de sucre de palme (Borassus flabellifer Linn.). *Sugar Technology*, 17: 195-203.

Niamketchi, G. L., Konan, J. N., Mahyao, G. A., N’guessan, H. A., Adou, C. B., Kablan, A. B. M., & Gouai, A. (2024). Quality assessment of artisanal palm oil from smallholders in the department of Man, western region of Côte d'Ivoire. *World Journal of Advanced Research and Review*, 24(01), 846–856. <https://doi.org/10.30574/wjarr.2024.24.1.2765>.

Nwaiwu, O., & Itumoh, M. (2017). Molecular phylogeny of yeasts from palm wine and enological potentials of the drink. *Annual Research & Review in Biology*, 20(3), 1–12. https://doi.org/10.9734/ARRB/2017/37748

Onyeukwu, O. B., Diakparomre, O., Njideaka, O. T., Dibie, D. C., & Nwaiku, F. (2024). Palm Wine: A Review on Its Composition, Preservation, Health Benefits, and Market Value. *International Journal of Basic Science and Technology*, 10(1), 71-80. <https://doi.org/10.5555/PRNM1680>

Palmafrique, (2013). La filière palmier à huile dans l’économie ivoirienne. Accessed online on 03/15/2023. http://www.palmafrique.com/telechargez-le-manuel-du-planteur-de-palmier-a-huile.

Pelletier, C. A., Lawless, H. T., & Horne, J. (2004). Sweet–sour mixture suppression in older and young adults. *Food Quality and Preference*, 15(2), 105–116. https://doi.org/10.1016/S0950-3293(03)00037-5

Salhi, A. & Gounina, M. (2019). Évaluation nutritionnelle d'un produit alimentaire « Lagmi » extrait des palmiers dattiers dans des régions de Sud de Tébessa. Mémoire de Master, Université de Larbi Tébessi, Faculté des Sciences Exactes et des Sciences de la Nature et de la Vie, 116 p.

Sarkar, T., Mukherjee, M., Roy, S., & Chakraborti, R. (2023). Palm sap sugar is an unconventional source of sugar exploration for bioactive compounds and its role in functional food development. *Heliyon*, 9(2023): 1-19. https://doi.org/10.1016/j.heliyon.2023.e14788

Solomon, S., Banerji, R., Shrivastava, A. K., Singh, P., Singh I, Verma, M., et al. (2006). Post-harvest deterioration of sugar cane and chemical methods to minimize sucrose losses. *Sugar Technology*, 8(1): 74-78. https://doi.org/10.1007/BF02943746

Srikaeo, K., Sangkhiaw, J., & Likittrakulwong, W. (2019). Production and functional properties of palm sugars. *Walailak Journal of Science and Technology*, 16(11): 897-907. https://doi.org/10.48048/wjst.2019.5323

Symoneaux, R., Chollet, S., Patron, C., Bauduin, R., Le Quéré, J. M., & Baron, A. (2015). Prediction of sensory characteristics of cider according to their biochemical composition: Use of a central composite design and external validation by cider professionals. *LWT-Food Science and Technology*, 61(1), 63-69. https://doi.org/10.1016/j.lwt.2014.11.030

Vautier, A., Carlier, M., Martin, J-L., Gault, E., & Vendeuvre, J-L. (2010). Impact of cooking and core temperature on the nutritional values of pork tenderloin roast. *The technical review of the IFIP*. 33: 1-15.

Wolff, J. P. (1968). Manual of fat analysis. Azoulay ed., Paris (France), 519 p.

Yao, R. N., & Kamagaté, D. K. (2010). Oil palm (Elaeis guineensis Jacq.) production and extraction rates under marginal climatic conditions in northeastern Côte d’Ivoire. *African Agronomy*, 22 (2): 149-161. https://doi.org/10.4314/aga.v22i2.68363

Zennoune, A. (2022). Etude de l’impact couplé du procédé de congélation et des conditions d’entreposage sur la qualité des produits surgelés : Application aux matrices poreuses. Génie des procédés. Université Paris-Saclay, Français. NNT: 2022UPASB015. tel-03854395.