

Effect of Coconut Water and Pellicle Testa on the Nutritional Quality of Coconut Milk

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Received May 26, 2024; Revised June 28, 2024; Accepted July 04, 2024

Abstract The fruit of the *Cocos nucifera* L. tree is the main agricultural product of coastal farmers in Côte d'Ivoire, where coprah is the only way to valorise the kernel, which has little economic value. However, processing the kernel into vegetable milk could diversify the use of the kernel, help improve farmers' incomes and provide people with a nutritious drink as an alternative to animal milk. Therefore, the aim of this study is to produce and evaluate the nutritional properties of coconut kernel milks. ANOVA results indicate a significant effect ($p < 0.05$) of testa and coconut water on the physicochemical, proximate and mineral composition of milks. Milk F0 without addition of water has more fat (21.59%) and energy (240.50 kcal/100 mL). Milk F3 with coconut water and testa has more ash (4.44%), carbohydrates (7.98%), protein (4.01%), milk solids non-fat (10.01%), total sugars (63.05%). The minerals (mg/100 mL) such as potassium (5252.50), calcium (283.74), magnesium (203.50), sodium (94.63), phosphorus (89.75) and sulfur (285.45) is also high in F3. In conclusion, the addition of coconut water and testa increases the nutritional value of coconut milk, making it an interesting natural electrolyte drink and an innovative way to diversify coconut products in Côte d'Ivoire.

Keywords: *Cocos nucifera*, kernel, milk, testa, coconut water, Nutritive

Cite This Article: Kouadio Marcellin Konan, Soro Pégnonsienrè Lacina, Koné Fankroma Martial Thierry, Doubi Bi Tra Serges, and Konan Konan Jean Louis, "Effect of Coconut Water and Pellicle Testa on the Nutritional Quality of Coconut Milk." *American Journal of Food Science and Technology*, vol. 12, no. 3 (2024): 96-102. doi: 10.12691/ajfst-12-3-3.

1. Introduction

In Côte d'Ivoire, coconut farming covers approximately 50,000 hectares of land, including several industrial plantations and numerous small private farms. More than 20,000 families living in coastal areas depend mainly on coconut farming, which plays a crucial role in their social and economic life [1]. For decades, copra has been the primary processing method for coconut kernels, as it enables the production of copra oil. This oil is widely used as a cosmetic ingredient. Copra oil is the main way for Ivorian farmers to add value to their coconut kernels. However, demand for coconut copra oil, which accounts for only about 2% of the global oil market, is declining due to the rise of other oilseeds [2]. Coconut farming has become unprofitable and farmers are abandoning it. This has contributed to poverty in coconut-producing areas of Côte d'Ivoire. In recent decades, the production of and demand for fresh coconuts and derived food products has increased significantly, making the industry a major

contributor to the economies of major producing countries [3]. The production of coconut milk from the kernel is an important way of exploiting the coconut. According to [4], the market is experiencing an annual growth rate of 17.6%. The global coconut milk market is forecast to grow from USD 873.8 million in 2019 to USD 1673.2 million in 2025, driven by increasing market demand. Global coconut milk production has increased from 188,801 million tonnes in 2013 to 343,178 million tonnes in 2018, with an average growth rate of 12.69% [5]. The production of coconut milk from fresh kernels has the potential to diversify coconut products in Côte d'Ivoire, which could increase farmers' incomes and contribute to food security. In addition, the consumption of plant-based milk substitutes is growing rapidly worldwide due to their positive impact on human health [6,7]. Coconut milk is a valuable addition to plant-based dairy drinks. It helps compensate for nutritional deficiencies in the human diet [8]. Therefore, the aim of this study was to develop a coconut kernel milk drink and evaluate its nutritional value in order to propose a novel approach to diversify coconut kernel products in Côte d'Ivoire.

2. Material and Methods

2.1. Materials

Fresh mature coconuts of the local hybrid PB121⁺ were harvested from healthy, mature, asymptomatic palms, all of the same age and under similar management practices at the Marc Delorme Coconut Research Station in southern Côte d'Ivoire.

2.2. Coconut Milk Wet Extraction Process

Firstly, approximately 1500 grams of coconut kernels without the brown pellicle were obtained from 5 nuts, with an average mass of 300 grams of kernel per nut. The coconut kernels were cut into small pieces, washed with deionized water, bleached at 55°C for 5 minutes and ground. Plain coconut milk F0 and three milk

formulations (F1 to F3) were prepared. Following milling, plain milk F0 involved grinding only the fresh mature kernels without adding water and brown pellicle (testa). Formulation F1 was made by grinding the kernels with the addition of coconut water at a ratio of 1:2. Formulation F2 was made by grinding the kernels with the addition of brown pellicle (testa) in a ratio of 1:0.25. Formulation F3 was made by grinding the kernels with the addition of coconut water and its brown pellicle (testa) in a ratio of 1:2:0.25. Each process was repeated three times. The obtained milks F0, F1, F2, F3 were pasteurised by heating it at 69°C (155°F) for 30 minutes, following Food and Drug Administration recommendations [9]. After pasteurisation, each milk formulation was poured into a glass container, sealed, and refrigerated for further analysis. Please refer to the flow chart for the steps involved in processing coconut milk (Figure 1).

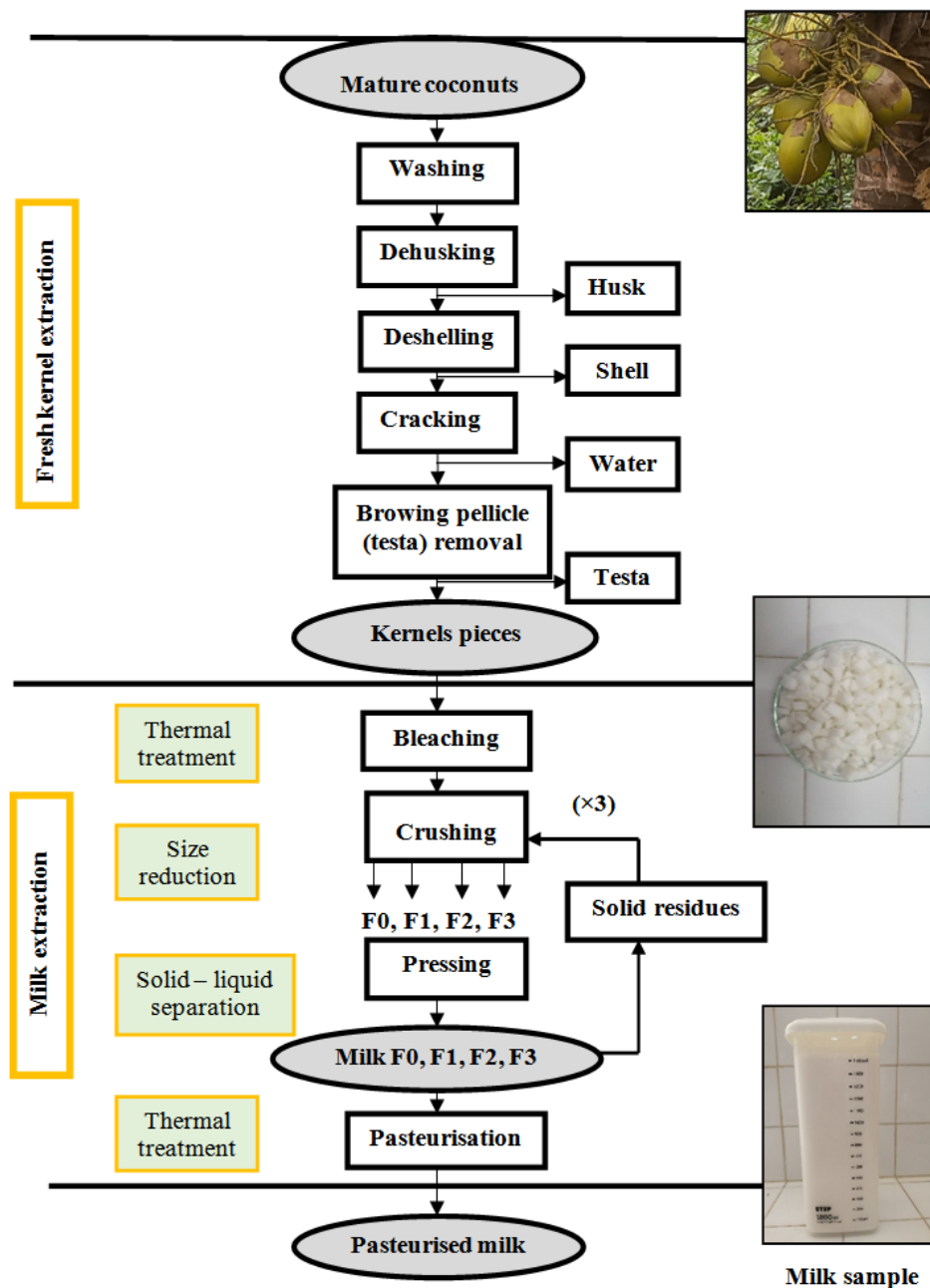


Figure 1. Flow chart of the processing steps for coconut milk formulations

2.3. Nutritive Analysis

The analysis of coconut milk followed AOAC procedures [10]. The percentage yield extraction was calculated using the method of [7]. The pH was measured with a calibrated pH meter, and the total soluble solids were determined using a portable digital refractometer (ATAGO, PAL-1). The titratable acidity of the beverages was determined by titration with 0.1 M NaOH and phenolphthalein indicator. The percentage of lactic acid was used to express the titratable acidity, while the sweetness was determined by the ratio of soluble solids to acidity, following the method described by [11]. The density of the coconut milk was determined using a picnometer bottle. Colour parameters were determined according to the International Commission on Illumination (CIE) system using a calibrated colorimeter ($L^* = 95.9$, $a^* = 1.1$ and $b^* = 0.3$) from Konica Minolta CR400 in Germany. Moisture content was determined in a hot air circulating oven. Total fat was determined by n-hexane extraction in a Soxhlet extractor. Protein ($N \times 6.25$) was determined using the Kjeldahl method. Available carbohydrate was determined by difference. The total and reducing sugars were determined respectively using two methods: [12] with phenol and concentrated sulphuric acid, and [13] with 3,5-dinitrosalicylic acid (DNS). The non-reducing sugar content was obtained by subtracting the reducing sugars from the total sugar content. Multiplying the non-reducing sugar content by a factor of 0.95 gives the sucrose content in mg/100 mL. The non-reducing sugar content was determined by subtracting the reducing sugar from total sugar. The milk solids non-fat (MSNF) content was estimated by subtracting the total lipid content from the milk solids content. Energy was estimated in kcal/100 mL by multiplying the percentages of crude protein, crude lipid, and carbohydrate by the recommended factors (2.44, 8.37, and 3.57 respectively) proposed by [14]. The mineral content of each coconut milk sample was estimated by ashing 10g of the milk at 550°C in a muffle furnace (Pyrolabo, France). The resulting ash was then boiled with 10 mL of 20% hydrochloric acid in a beaker and filtered into a 100 mL standard flask, which was then filled with deionised water up to the mark. The mineral profile was determined using inductively coupled plasma mass spectrometry (ICP-MS, Thermo Scientific) [15].

2.4. Statistical Analysis

All experiments in this study were performed in triplicate and results are expressed as mean $\pm$ standard deviation. Data were statistically analysed by one-way analysis of variance (ANOVA) using Tukey's test of XLSAT statistical software.

3. Results and Discussion

The composition of coconut milk varies depending on several factors, including the maturity, variety, age, and growing environment of the coconut, as well as cultural practices and extraction process conditions. The amount of water added and the temperature used for extraction can also affect the composition [8]. This study employed coconut water and brown pellicle (testa) in the kernel milk extraction process due to their nutritional, mineral, and phytochemical qualities [16,17,18,19].

3.1. Physicochemical Composition

The physicochemical properties of the coconut milk drink formulations (F0 to F3) are tabulated in Table 1. The results show that the milk formulation had a significant effect ($p < 0.05$) on all the physicochemical properties. This could be explained by the testa and coconut water added to the formulations. The range of milk yield (m/m) from the kernel was 52.96% to 59.31%. The yields of the milk formulations containing coconut water (F1 and F3) were higher. Water added to the grinding process helps to break down the kernel more easily, increasing the amount of milk in the finished product. In fact, adding water to the extraction process causes the particles to grind more intensely, resulting in a higher yield [20]. Previously, [7] reported 53.33% to 61.67% of coconut milk yield. The coconut milk F0 had a milky consistency with L^* (brightness) = 93.27, a^* (redness) = 0.25, and b^* (yellowness) = 3.14. According to [21], the high L^* value of coconut milk indicates that it has a milky white colour, which may affect consumer acceptability. [22] reported that the lightness of coconut milk is higher as the fat content increases. This is because fat can increase the scattering and reflection of light. Contrary to F0 and F1 milk, F2 and F3 milk samples with testa have a low lightness index value (L^*) due to pigments in the brown pellicle (testa).

Table 1. Physicochemical properties of processed drink milks

Parameters	F0	F1	F2	F3
Yield (%)	52.96 $\pm$ 0.78 ^b	57.26 $\pm$ 0.65 ^a	53.78 $\pm$ 0.71 ^b	59.31 $\pm$ 0.68 ^a
pH	6.21 $\pm$ 0.19 ^a	6.12 $\pm$ 0.20 ^a	5.87 $\pm$ 0.08 ^a	5.35 $\pm$ 0.13 ^b
TA (%)	0.35 $\pm$ 0.02 ^b	0.38 $\pm$ 0.02 ^b	0.36 $\pm$ 0.04 ^b	0.44 $\pm$ 0.03 ^a
Sweetness	19.65 $\pm$ 0.57 ^{bc}	21.80 $\pm$ 0.54 ^a	18.76 $\pm$ 0.25 ^c	20.69 $\pm$ 1.09 ^{ab}
TSS	7.02 $\pm$ 0.32 ^b	8.54 $\pm$ 0.23 ^a	7.38 $\pm$ 0.27 ^b	8.19 $\pm$ 0.18 ^a
Density	0.987 $\pm$ 0.02 ^b	1.091 $\pm$ 0.05 ^a	0.991 $\pm$ 0.00 ^b	1.088 $\pm$ 0.01 ^a
L^*	93.27 $\pm$ 0.78 ^a	90.57 $\pm$ 0.81 ^b	87.02 $\pm$ 1.67 ^c	83.43 $\pm$ 1.79 ^d
a^*	0.25 $\pm$ 0.01 ^d	0.45 $\pm$ 0.09 ^c	1.24 $\pm$ 0.04 ^b	1.62 $\pm$ 0.06 ^a
b^*	3.14 $\pm$ 0.10 ^b	3.54 $\pm$ 0.18 ^b	9.46 $\pm$ 0.29 ^a	8.15 $\pm$ 0.48 ^a

F: Milk formulation, F0 = kernel, F1 = kernel + water, F2 = kernel + coconut testa, F3 = kernel + testa + coconut water. Values are expressed as Mean $\pm$ Standard deviation. Mean values in the same line with different superscript letters were significantly different ($p < 0.05$).

The pH of freshly produced coconut milk ranged from 5.35 to 6.21, while the titratable acidity ranged from 0.35 to 0.44 lactic acid. The slightly acidic pH of F2 and F3 milk could be due to the organic acid present in the pellicle testa. These values are similar to those reported by [21] who measured a pH of 6.39 and by [23] who found a titratable acidity range of 0.28 to 0.44. The formulations' acidity did not cause sensory rejection, which is a positive attribute. This is because the food and beverage sector prefers foods that are more resistant to the growth of pathogenic bacteria, which can cause gastrointestinal issues [24,25]. Total soluble solids (TSS) is a measure of the amount of soluble solids in a substance, including its total sugar content and a small amount of soluble proteins, amino acids, vitamins, pigments, phenolics, minerals and other organic components [26,27]. The coconut milk formulations had a range of TSS from 7.02 to 8.54 °Brix. Formulations F1 and F3, which contained coconut water, had higher TSS values. This suggests that the higher TSS of the coconut milk drink was caused by the addition of coconut water. Our results were higher than the cashew milk (3.00) studied by [28], and lower than the soy milk (11.68) reported by [29]. However, [27] had found a higher TSS value of 18.51 °Brix for coconut milk. Foods with a sweetness index higher than 19 are considered sweet according to [30]. The sweetness indices of coconut milk (18.76 – 21.80) provide a reasonable estimate of the sweetness of the milk, which influences the consumer's perception of its organoleptic qualities [31]. The study showed that coconut milk samples F0 and F2 had a lower density than F1 and F3. This is because fat, which is less dense than water, is present in higher amounts in milk samples with more fat.

3.2. Proximate Composition

The proximate composition and energy value of the coconut milk drink formulations (F0 to F3) are shown in Table 2. The proximate parameters of coconut milk were significantly improved ($p < 0.05$) with the incorporation of coconut water and testa, according to the ANOVA results. The moisture content of the coconut milk samples ranged from 66.95 to 68.83%. The significant difference in the moisture content of these formulations is due to the addition of water during the process. The high amount of water in the produced milk samples was predictable as coconut milk is a liquid food consisting mainly of water, making it susceptible to microbial contamination. To prevent milk spoilage, it is necessary to keep the produced milk cold due to its high-water content. Previous reports by researchers on the moisture content of coconut milk ranged from 61.07 to 90.33% [21,27,32,33,34]. A high-water ratio during aqueous extraction of coconut milk can increase the concentration of water-soluble phytochemicals found in the kernel. However, this process also increases the aqueous phase of the milk, which is an oil-in-water emulsion. The ash contents of formulated coconut milk samples were all high, ranging from 1.15% to 4.44% with a significant difference ($p < 0.05$). Compared to the value recorded from the commercial reference sample vitamilk (1.26%) [35], our formulated coconut milks are rich in minerals. Others authors [27,34,36] reported lower ash content in cow's milk (0.65%) and tiger

nut milk (1.49%). The high ash content in F3 coconut milk is due to the incorporation of testa and coconut water during milk preparation, which are rich in minerals. Additionally, the coconut water added contributes to the mineral washout from the kernels. Previous studies have shown that the testa (brown pellicle) surrounding the coconut kernel is a rich source of minerals [16,37]. Additionally, [38] found that mature coconut water is mineral-rich. Incorporating coconut water and testa could therefore increase the mineral content of coconut milk, making it an interesting natural electrolyte drink. All of the formulated coconut milk samples have a considerable protein content, ranging from 3.41% to 4.01% with a significant difference ($p < 0.05$). The high protein content in milk formulation F3 could be due to the water, which contributes to more protein solubilisation and testa which is also an important source of proteins [16,37]. The findings here are high compared to the values (2.06 - 3.50) reported by [21,32] for coconut. Also, the protein content of these coconut milk samples were similar to that of cow's milk (3.48 - 4%) found by authors [36,39,40]. These results demonstrate that the addition of coconut water and testa increases the protein content of the milk. In contrast to the claim made by [34] that the protein content of coconut milk varies between 2.14 and 2.97%, our results show otherwise. In addition, [41] suggest that the balance and composition of amino acids in plant milks are more important than their protein content. There were significant differences in the amount of available sugars from 5.72 to 7.98%, total soluble sugars from 37.53 to 63.05%, reducing sugars from 11.60 to 27.84% and sucrose from 24.33 to 34.88% between the formulated coconut milk drinks. Formulations F1 and F3 containing coconut water have higher levels of carbohydrates, total soluble sugars and sucrose. This may be due to the addition of coconut water, which already contains a significant amount of soluble carbohydrates, resulting in an accumulation of total sugars in the extracted milk. According to [42], mature coconut water has a remarkable soluble sugar content. Patil et al reported low levels of carbohydrates in coconut milk (4.21%) [21]. The sucrose content found here is high, which is in line with previous reports that sucrose is the most abundant sugar in coconut milk [8,43]. The lipid and energy content of our coconut milk samples ranged from 18.96 to 21.66% and 216.75 to 240.50 kcal/100 mL respectively. The energy value found here is lower than that reported for coconut milk (332.20 - 603.37) [27,33]. Differences in the composition of plant milks may explain the variation in energy values. Some nuts, such as coconut, are high in fat. This makes them energy dense foods [44]. The energy value of coconut milk is determined by its main component, lipids. milks F0 and F2, which have a high lipid content, also have a higher energy value. Coconut formulations with higher water content have lower fat content after aqueous extraction. This is due to the immiscibility of water and oil. The fat content found here was lower than that reported by [21,32] (30.34 - 38.00%).

Although coconut milk contains more oil than other vegetable milks, its consumption does not increase the risk of obesity. This is because the fat in coconut milk is easily digested and does not accumulate in adipose tissue [45]. In addition, including coconut milk in a balanced diet does

not affect body weight and may even help with weight loss [46]. Lauric acid, the main saturated fat in coconut milk, has remarkable antiviral, antifungal, and

antibacterial properties. Studies have also shown that it promotes brain development and bone health [43,47].

Table 2. Proximate (g/100mL) and energy (kcal/100 mL) of processed drink milks

Parameters	F0	F1	F2	F3
Moisture	67.31 ± 0.81 ^{ab}	68.65 ± 0.36 ^a	66.95 ± 0.31 ^b	68.83 ± 0.59 ^a
Ash	1.15 ± 0.41 ^c	2.97 ± 0.48 ^b	3.31 ± 0.49 ^b	4.44 ± 0.22 ^a
Fat	21.59 ± 0.57 ^a	19.44 ± 0.36 ^b	21.66 ± 0.83 ^a	18.96 ± 0.95 ^b
Protein	3.41 ± 0.29 ^b	3.82 ± 0.20 ^a	3.68 ± 0.18 ^a	4.01 ± 0.11 ^a
Carbohydrates	5.72 ± 0.39 ^c	7.81 ± 0.68 ^a	6.48 ± 0.47 ^{ab}	7.98 ± 0.81 ^a
Milk SNF	7.22 ± 0.24 ^c	8.47 ± 0.33 ^b	8.89 ± 0.06 ^b	10.01 ± 0.19 ^a
Total Sugars	37.53 ± 1.08 ^d	58.44 ± 0.58 ^b	44.71 ± 0.39 ^c	63.05 ± 1.01 ^a
Red. Sugars	11.60 ± 0.55 ^d	23.87 ± 0.32 ^b	16.27 ± 0.70 ^c	28.84 ± 1.27 ^a
N. Red. Sugars	25.61 ± 0.53 ^d	33.67 ± 0.97 ^b	28.62 ± 0.55 ^c	36.71 ± 0.72 ^a
Sucrose	24.33 ± 0.50 ^d	31.99 ± 0.93 ^b	27.19 ± 0.52 ^c	34.88 ± 0.69 ^a
Energy	240.50 ± 3.81 ^a	216.75 ± 5.16 ^b	226.61 ± 4.21 ^{ab}	217.37 ± 4.09 ^b

F: Milk formulation, F0 = kernel, F1 = kernel + water, F2 = kernel + coconut testa, F3 = kernel + testa + coconut water. N. Red.: Non reducing, SNF: solids non-fat. Values are expressed as Mean ± Standard deviation. Mean values in the same line with different superscript letters were significantly different ($p < 0.05$).

Table 3. Minerals concentration (mg/100 mL) of processed drink milks

Parameters	F0	F1	F2	F3
Potassium	4216.44 ± 204.93 ^c	4815.10 ± 106.98 ^b	5030.77 ± 50.51 ^{ab}	5252.50 ± 152.68 ^a
Calcium	196.73 ± 6.03 ^c	259.39 ± 6.53 ^b	250.73 ± 5.67 ^b	283.74 ± 5.01 ^a
Magnesium	141.34 ± 8.84 ^c	179.80 ± 1.83 ^b	173.62 ± 2.64 ^b	203.50 ± 7.23 ^a
Sulfur	160.57 ± 7.13 ^c	217.05 ± 5.45 ^b	286.89 ± 7.14 ^a	285.45 ± 4.01 ^a
Phosphorus	48.03 ± 1.70 ^d	62.08 ± 1.04 ^b	85.75 ± 0.72 ^c	89.75 ± 1.29 ^a
Sodium	45.40 ± 3.50 ^d	79.63 ± 2.32 ^c	87.30 ± 3.35 ^b	94.63 ± 2.27 ^a

F: Milk formulation, F0 = kernel, F1 = kernel + water, F2 = kernel + coconut testa, F3 = kernel + testa + coconut water. Values are expressed as Mean ± Standard deviation. Mean values in the same line with different superscript letters were significantly different ($p < 0.05$).

3.3. Mineral Concentration

Determining the mineral content of foods is crucial for various reasons. For instance, mineral concentration and type significantly affect food qualities such as taste, appearance, texture, and stability [16]. Table 3, below, provides information on the mineral concentration of the coconut milk drink formulations (F0 to F3). The study found that including coconut water and testa significantly improved ($p < 0.05$) the mineral concentrations (mg/100mL) in coconut milk. The milk formulation containing coconut milk with coconut water and testa (F3) is richer in minerals than other milk formulations. The potassium concentration in coconut milk formulations ranged from 4216.44 to 5252.50. Calcium (196.73 - 283.74), magnesium (141.34 - 203.50), sulfur (160.57 - 286.89), phosphorus (48.03 - 89.75), and sodium (45.40 - 94.63) are present in significant amounts in formulated milks. Potassium is a vital macro-mineral nutrient that regulates blood pressure, thereby aiding in the prevention of hypertension, a significant risk factor for cardiovascular disease [15]. Therefore, consuming formulated milk may reduce the risk of metabolic diseases in humans. The calcium content obtained here, which ranges from 196.73 to 283.74, aligns with several authors' findings and is greater than the values reported for coconut milk (92.50 - 244.75) and bovine milk (122 - 233) [34] [48,49,50]. As shown, coconut milk is a wholesome beverage with minerals. Based on the quantity and quality of minerals identified in coconut milk, the study's conclusions imply

that ingesting coconut milk may benefit people living in developing countries who are insufficient especially for minerals.

4. Conclusion

To date, no studies have been conducted to evaluate the nutritional properties of coconut milk drinks produced in Côte d'Ivoire. The ANOVA results indicate a significant effect ($p < 0.05$) of brown pellicle (testa) and coconut water on the physicochemical, proximate and mineral composition of coconut milk. The addition of testa and water to coconut milk increased the nutrient and mineral content. Formulated coconut milk was rich in minerals essential for the proper functioning of the human body. The incorporation of coconut water and testa increase the nutritional value of coconut milk, making it an interesting natural electrolyte drink that could be an innovative way to diversify coconut products in Côte d'Ivoire. According to this study, processing coconut kernels into milk could provide a nutritious food product with health benefits for consumers, contribute to food security in Côte d'Ivoire and improve the profitability of coconut farmers.

ACKNOWLEDGEMENTS

The authors are grateful to Marc Delorme, Director of the Coconut Research Station, and the researchers for their guidance. The authors also thank the farmers

and extension personnel from the research station for their cooperation.

Statement of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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