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Comparative Study of the Physicochemical Properties of Seed Kernels from Five Clones of Rubber Tree (*Hevea brasiliensis*) Commonly Grown in Côte d'Ivoire

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Abstract

In addition to producing latex, rubber trees produce large quantities of seeds each year that were not being exploited in Ivory Coast. This study, conducted by the rubber tree research station of the National Agricultural Research Centre (CNRA), focuses on the physical and chemical characterisation of the seeds of five rubber tree clones commonly found in Ivory Coast. These are GT1, PB 217, IRCA 41, IRCA 230 and IRCA 331. The results revealed that the seeds have polar diameters ranging from 2.19 to 2.40 cm, equatorial diameters ranging from 2.08 to 2.27 cm, and unit masses ranging from 3.10 to 4.40 g. Depending on the clone, the kernel accounts for 56% to 60% of the weight of the whole seed. The IRCA 230 clone stands out for its maximum dimensions and high mass of 4.40 g. The kernel is rich in lipids, with contents ranging from 43.20% (GT1) to 46.99% (IRCA 230). The protein content varies from 23.17% (IRCA 230) to 25.08% (GT1). The carbohydrate and fibre content and energy value varied from 17.11% (IRCA 230) to 20.72% (IRCA 41), from 6.27% (IRCA 331) to 8.64% (PB 217) and from 567.9 kcal/100g DM (PB 217) to 592.5 kcal/100g DM (IRCA 331). Thus, according to the biochemical profile, the kernel of the IRCA 230 clone, thanks to its high oil content, can serve as a matrix for the production of vegetable oil. The kernels of the GT1 and PB 217 clones can be used to manufacture protein supplements. Energy products can be formulated from the kernel of the IRCA 331 clone. The PB 217/IRCA 41 clones are recommended for carbohydrate and fibre applications. These results thus offer prospects for economic diversification in the Ivorian rubber

industry.

Keywords

Biochemical Characterisation, Kernels, Hevea, Valorisation

1. Introduction

Côte d'Ivoire is the world's third largest producer and the largest in Africa [1], with an annual production of 1,678,000 tonnes in 2023. This success is based on the widespread use of five clones: GT1, PB 217, IRCA 41, IRCA 230 and IRCA 331, selected for their vigour, latex yield and disease resistance [2]. However, in addition to producing latex, rubber trees produce a significant amount of seeds each year. According to [3], approximately 500 kg of seeds are produced per hectare per year, of which only 10% are used in nurseries for rootstock production. The rest is lost due to a lack of utilisation. No study had yet been conducted on the physicochemical characterisation of the seeds of rubber tree clones commonly used in Côte d'Ivoire. The objective of this study is therefore to contribute to the valorisation of rubber tree seed kernels through their physicochemical characterisation in order to establish a solid database to support future valorisation strategies.

2. Materials and Methods

2.1. Plant Material

The plant material consisted of the sheaths of five (05) clones commonly used in Côte d'Ivoire (**Figure 1**). The seeds were collected from monoclonal rubber tree plots located in Toupah (south) and Prikro (centre-east), respectively in traditional and marginal rubber tree growing areas. The clones studied are:

- GT 1 (Gondang Tapen code 1)
- PB 217 (Prang Besar code 217)
- IRCA 41 (Rubber Research Institute code 41)
- IRCA 230 (Rubber Research Institute code 230)
- IRCA 231 (Rubber Research Institute code 231)

2.2. Methods

2.2.1. Sampling

The rubber tree seeds (**Figure 2(a)**) collected were dried in the sun at room temperature for 48 hours before being shelled. They were shelled in order to separate the shell from the kernel (**Figure 2(b)**). The kernels obtained were then ground and sieved through a 1 mm mesh to obtain kernel powder (**Figure 2(c)**). The kernel powder was packaged in airtight bags and labelled before laboratory analysis. The study was conducted at the Bimbresso research station.

Figure 1. Seeds from the five rubber tree clones studied.

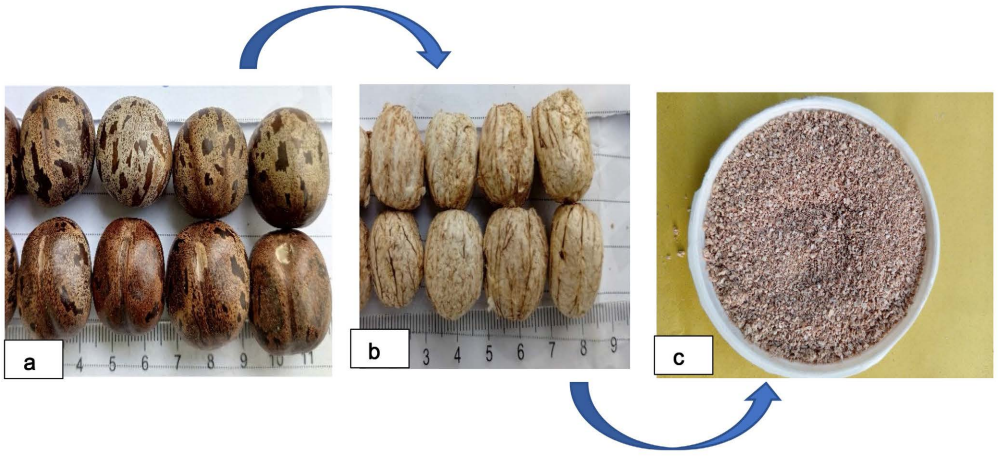

Figure 2. (a) seeds, (b) kernels and (c) rubber tree kernel powder.

2.2.2. Determination of Agro-Morphological Parameters

The polar and equatorial diameters of rubber tree seeds per clone were determined using a small distance measuring instrument called an electronic display calliper

with a range of 0 to 150 mm and an accuracy of 0.03 mm. The mass of whole seeds, shells and kernels was determined per clone using a precision balance accurate to 0.01 g (OHAUS, model: PA2102C).

2.2.3. Determination of Physicochemical Parameters

The pH of the almond powders was determined using the AOAC method [4], with an electronic pH meter. Titratable acidity (in meq/100 g) was determined using the colorimetric method described in French standard NF V05-101 [5]. Titration was carried out with sodium hydroxide (NaOH at N1 = 0.1 N) after first adding 2 to 3 drops of phenolphthalein. The method used to determine the dry matter content was that proposed by AOAC [6], by deduction of the moisture content. The principle is based on the loss of mass of the sample in an oven (MEMMERT 854 SCHWABACH, Germany) at 105˚C for 24 hours until a constant mass is obtained. The loss of mass was determined by weighing on a precision balance (OHAUS, model: PA2102C). The ash content was estimated using the AOAC method [7]. This method involves eliminating all organic compounds contained in the rubber tree seed samples by incineration at 550˚C for 12 hours in a muffle furnace (NABERTHERM GmbH). The total soluble sugars and reducing sugars were measured using the Dubois [8] and Bernfeld [9] methods, respectively. Fibre was measured using the Wolff method [10]. Lipids were measured using the Soxhlet extraction method [11]. Proteins were determined using the KJELDHAL method (AOAC, [4]). The total carbohydrate content, expressed as a percentage of dry matter, was calculated by difference using the formula proposed by FAO [12] (2010). The energy value (EV) of foods comes from the three macronutrients (protein, carbohydrates and lipids). It was calculated by multiplying the average values of carbohydrates, lipids and proteins by the Atwater factors of 4, 9 and 4 respectively, and then adding the values obtained. It is expressed in kilocalories (kcal) [13].

2.2.4. Statistical Analysis

The tests were carried out in three trials. One-way analysis of variance (ANOVA) was performed using XLSTAT software (2019) on all the results obtained in order to determine whether there were any significant differences between the different values obtained. The different means were compared using Duncan's test at a 5% probability threshold. The correlation test was performed to determine the relationship between the physicochemical compounds. Principal component analysis (PCA) and ascending hierarchical classification (AHC) were performed to classify the five clones according to their physicochemical parameters.

3. Results

3.1. Agro-Morphological Parameters

The agro-morphological parameters of the seeds of the five clones studied are shown in Table 1. A significant difference was observed between the five clones at the 5% threshold. Seed weights ranged from 3.10 to 4.40 g, with the highest

value observed in clone IRCA 230. In terms of polar and equatorial diameter, clone IRCA 230 had the highest values: 2.40 cm for polar diameter and 2.27 cm for equatorial diameter. The same applies to the ratio, with values close to 60% for all five clones. However, the IRCA 230 clone had the highest values, with 60% for the percentage and 2.67 g for the kernel weight.

Table 1. Agro-morphological parameters of seeds from five rubber tree clones.

Rubber tree clones	Polar diameter (cm)	Equatorial diameter (cm)	Seed mass (g)	Almond mass (g)	Hull mass (g)	Ratio (%)	
						Almond	Shell
GT1	2.38 ± 0.76^{a}	2.11 ± 0.87^{c}	3.89 ± 0.17^{bc}	2.18 ± 0.22^{bc}	1.50 ± 0.11^{b}	59 ± 2^{b}	41 ± 2^{a}
PB 217	2.40 ± 0.55^{a}	2.18 ± 0.75^{b}	4.02 ± 0.23^{b}	2.33 ± 0.18^{b}	1.69 ± 0.09^{a}	58 ± 2^{b}	42 ± 2^{a}
IRCA 41	2.19 ± 0.67^{c}	2.08 ± 0.57^{c}	3.10 ± 0.36^{d}	1.80 ± 0.24^{d}	1.30 ± 0.12^{c}	58 ± 1^{b}	42 ± 1^{a}
IRCA 230	2.40 ± 0.46^{a}	2.27 ± 0.37^{a}	4.40 ± 0.35^{a}	2.67 ± 0.22^{a}	1.73 ± 0.19^{a}	60 ± 3^{a}	40 ± 3^{b}
IRCA 331	2.33 ± 0.76^{b}	2.16 ± 0.97^{b}	3.68 ± 0.59^{c}	2.15 ± 0.38^{c}	1.54 ± 0.23^{b}	58 ± 1^{b}	42 ± 1^{a}
P	0.010	0.071	0.018	0.024	0.047	0.420	0.420
F	5.94	3.02	4.98	4.50	3.57	1.07	1.07

The means ± standard deviation assigned different letters at the level of each parameter in each column are significantly different at $p < 0.05$ according to Duncan's test.

3.2. Physicochemical Parameters

The almonds from the seeds of the five clones showed statistically different levels (Table 2).

The titratable acidity of the five clones ranged from 1.23 to 2.54 meq·g/100g, with clone IRCA 331 having the highest value (2.54 meq·g/100g). In terms of dry matter content, all clones had values relatively greater than or equal to 90%, except for clone IRCA 331, which had the lowest content at 88.53%. For lipid content, the values obtained ranged from 43.16% to 46.99%; with no significant difference between clones PB217 and IRCA331. Protein content ranged from 23.17% to 25.08%, with clone PB217 (25.08%) having the highest content. In terms of total carbohydrate content, the analysis revealed a significant difference, with contents ranging from 17.11% to 20.68%. The lowest values, below 20%, were obtained with clones IRCA 230 (17.11%) and GT1 (17.75%). For fibre, the values obtained ranged from 6.27% to 8.55%. Clones IRCA 331 and PB 217 had values below 7%, and the other three clones had values close to 8%. Statistical analysis revealed a significant difference at the 5% threshold between the different clones in terms of total and reducing sugar content. Total sugar content ranged from 27.10 to 115 mg/100g and reducing sugar content from 5 to 17.67 mg/100g. The IRCA 331 clone had the highest values for both total sugars (75 mg/100g) and reducing sugars (16.67 mg/100g). The energy value of the almonds from the five rubber tree clones was 588.85, 567.90, 568.80, 586.84, and 592.49 kcal/100g DM for clones GT1, PB217, IRCA 41, IRCA 230, and IRCA 331, respectively. The highest energy value was obtained with the IRCA 331 clone, followed by the GT1 clone, and the

lowest content was found in the PB217 clone.

Table 2. Physicochemical characteristics of the kernel of five rubber tree clones.

Physicochemical parameters	Rubber tree clones						
	GT1	PB217	IRCA 41	IRCA 230	IRCA 331	P	F
pH	6.04 ± 0.00^{d}	6.31 ± 0.01^{a}	5.98 ± 0.00^{e}	6.20 ± 0.01^{b}	6.08 ± 0.01^{c}	<0.0001	1611.80
Titratable acidity (meq·g/100g)	1.23 ± 0.03^{e}	1.55 ± 0.07^{c}	1.88 ± 0.33^{b}	1.41 ± 0.03^{d}	2.54 ± 0.03^{a}	<0.0001	532.86
Dry matter (%)	90.92 ± 0.05^{b}	90.65 ± 0.08^{c}	90.41 ± 0.15^{d}	92.32 ± 0.11^{a}	88.53 ± 0.07^{e}	<0.0001	590.28
Lipids (%)	46.39 ± 0.05^{b}	43.61 ± 0.07^{c}	43.16 ± 0.11^{d}	46.99 ± 0.09^{a}	46.45 ± 0.08^{b}	<0.0001	1488.48
Proteins (%)	25.08 ± 0.10^{a}	23.17 ± 0.07^{d}	24.37 ± 0.03^{b}	23.86 ± 0.06^{c}	23.26 ± 0.04^{d}	<0.0001	459.50
Total carbohydrates (%)	17.75 ± 0.19^{b}	20.68 ± 0.46^{a}	20.72 ± 0.21^{a}	17.11 ± 0.06^{c}	2036 ± 0.17^{a}	<0.0001	141.61
Fibres (%)	7.38 ± 0.22^{c}	8.64 ± 0.37^{a}	8.17 ± 0.16^{b}	8.55 ± 0.12^{ab}	6.27 ± 0.14^{d}	<0.0001	59.82
Ash (%)	3.40 ± 0.14^{c}	3.89 ± 0.07^{a}	3.57 ± 0.09^{bc}	3.48 ± 0.09^{bc}	3.67 ± 0.10^{b}	0.001	10.73
Total sugars (mg/100g)	27.10 ± 0.17^{d}	41.33 ± 0.58^{c}	73.00 ± 0.00^{b}	69.00 ± 0.00^{b}	75.00 ±5.00^{a}	<0.0001	676.64
Reducing sugars (mg/100g)	5.00 ± 0.00^{d}	7.33 ± 0.58^{c}	11.67 ± 1.53^{b}	11.00 ± 0.00^{b}	17.67 ± 1.15^{a}	<0.0001	87.42
Energy value (kcal/100g DM)	588.85 ± 0.55^{b}	567.90 ± 1.60^{d}	568.80 ± 1.38^{d}	586.84 ± 0.70^{c}	592.49 ± 0.89^{a}	<0.0001	341.14

The means ± standard deviation assigned different letters at the level of each parameter in each column are significantly different at $p < 0.05$ according to Duncan's test.

3.3. The correlation Matrix

Table 3 shows the various relationships between the physicochemical parameters. It appears that the total sugar content is positively and very strongly correlated with the reducing sugar content (r = 1.00) and titratable acidity (r = 0.91). Titratable acidity is positively and strongly correlated with total sugar content (r = 0.91). However, moisture is positively and moderately correlated with titratable acidity (r=0.87) and total carbohydrate content (r = 0.70), but negatively correlated with fibre content (r = −0.80). Dry matter is negatively correlated with titratable acidity (r = −0.87) and total carbohydrate content (r = −0.70) and is positively correlated with moisture (r = 1.00). Similarly, dry matter is positively correlated with fibre content (r = 0.80). Ash content is positively correlated with carbohydrate content (r = 0.76). Energy value is positively correlated with lipid content (r = 0.95). Ash content is negatively correlated with protein content (r = −0.83).

3.4. Ascending Hierarchical Classification (AHC)

Ascending hierarchical classification (AHC) based on Ward's logarithm enabled the creation of a dendrogram (Figure 3) and the characteristics of each group. This figure highlights three groups from the five clones. Group 1, consisting of PB217 and GT1, corresponds to the clones previously identified in Table 2 as having the highest fibre and protein levels. Group 2, including IRCA230 and IRCA 41, shows intermediate acidity and sugar levels associated with relatively high dry matter. The third group, represented by IRCA 331 alone, is distinguished by its

high total and reducing sugar contents and titratable acidity but low fibre and dry matter contents.

Table 3. Correlation matrix between the physicochemical parameters of the nuts of the five rubber tree clones.

Variables	pH	RS	TS	TA	CF	TC	M	DM	AC	Lp	Pr	EV
pH	1.00											
Reducing sugars (%RS)	−0.23	1.00										
Total sugars (%TS)	−0.25	**1.00**	1.00									
Titratable acidity (TA)	−0.28	**0.92**	**0.91**	1.00								
Crude fibre (CF)	0.51	−0.55	−0.56	−0.67	1.0							
Total carbohydrates (TC)	−0.03	0.36	0.35	0.63	−0.13	1.00						
Moisture (M)	−0.33	0.61	0.61	**0.87**	**−0.80**	**0.70**	1.00					
Dry matter (DM)	0.33	−0.61	−0.61	**−0.87**	**0.80**	**−0.70**	**−1.00**	1.00				
Ash content (AC)	0.63	0.15	0.13	0.34	0.17	**0.76**	0.37	−0.37	1.00			
Lipids (Lp)	−0.03	0.17	0.19	−0.04	−0.45	**−0.76**	−0.12	0.12	−0.57	1.00		
Proteins (Pr)	−0.65	−0.54	−0.52	−0.54	0.01	−0.50	−0.35	0.35	**−0.83**	0.12	1.00	
Energy Value (EV)	−0.24	0.31	0.32	0.17	−0.69	−0.59	0.15	−0.15	−0.56	**0.95**	0.14	1.00

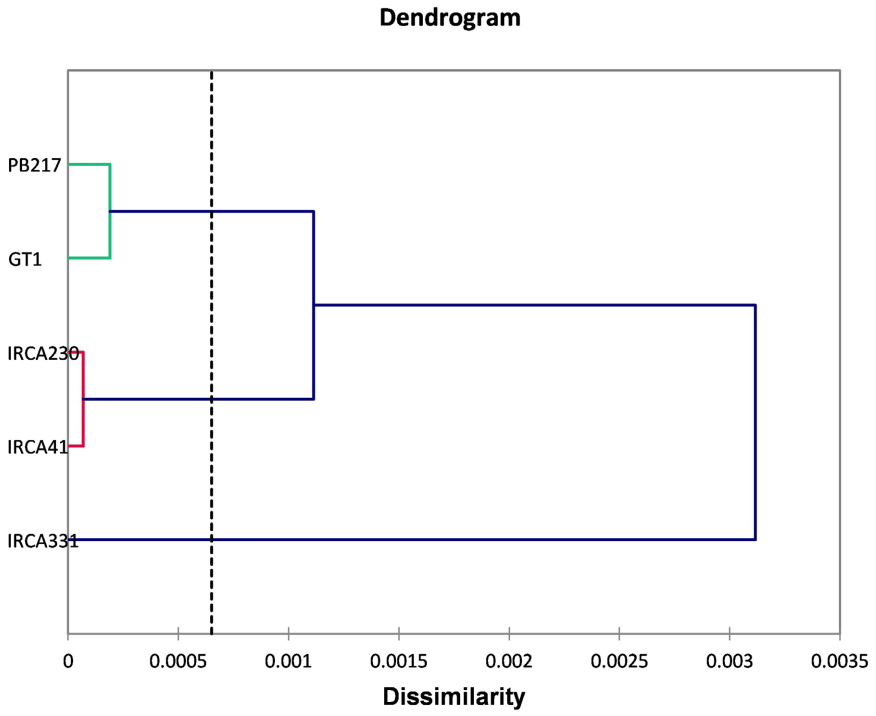

Figure 3. Ascending hierarchical classification of the five rubber tree clones.

4. Discussion

The physical characteristics of the different rubber tree seeds show a diversity of shapes, sizes and weights similar to those reported by [14], with values ranging

from 2 to 4 g. These differences between clones could be due to their genetic origin, genotypic variability and the effect of the environment. Indeed, clones GT1 and PB217 originate from Asia, while IRCA clones are the result of Ivorian selection [2]. The kernel accounts for between 56.04% and 60.68% of the total weight, values comparable to those observed in Cameroon (36.41% - 75.80%) [15]. This high proportion highlights the nutritional and economic potential of rubber seed kernels for commercial exploitation. The titratable acidity of the kernels is low, and the pH tends towards neutrality, probably due to the presence of organic acids such as citric acid [16].

The pH is lower than that of soybeans (6.8) and comparable to that of peanuts (6.30 - 6.48) [17]. This moderate acidity helps to limit microbial proliferation, thereby improving the stability and preservation of kernels intended for animal feed or industrial use. The moisture content observed is lower than that reported by [18] and complies with the standard recommended by the Codex Alimentarius [19] [20], promoting good preservation.

With lipid levels of around 50%, rubber tree nuts are among the richest oil-bearing products [21], comparable to peanuts (40%), cotton seeds (16% - 28%) and soybeans (28.20%) [22]. These levels are similar to those found in South African rubber tree nuts [22]. Compared with major commercial oilseeds, the lipid content of the IRCA 230 clone (46.99%) is slightly higher than that of groundnut (around 45%) and markedly greater than that of soybean (approximately 20%), confirming its strong potential for vegetable oil production. The protein content varies significantly between clones, which may be related to cultivation practices, soil nitrogen availability or fertilisation [23].

These values exceed those reported for Nigerian seeds (19.40%) and Cameroonian sunflower seeds (20.7%) [24] [25]. Crude fibre is less than 10%, indicating good digestibility. According to [26], a food containing approximately 6% fibre can be considered high in fibre. The levels observed here are higher than those of seeds grown in Nigeria (4.47% to 5.88%) [27]. Fibre plays an essential role in intestinal transit and dietary balance [28] [29]. The ash content varies from one clone to another, influenced by soil type and climate [30]. These values are comparable to those observed in melon seeds (3.30%) and peanuts (3.08%) [31] [32].

Total carbohydrates are slightly higher than those reported by [33] and comparable to [34] [35], confirming the high energy content of these nuts. The energy value (567.9 - 592.5 kcal/100g DM) exceeds that observed for Bangladeshi seeds (210.1 kcal/100g) [33] and Nigerian soybeans (469.8 kcal/100g) [21]. These results confirm that rubber tree nuts have great potential for food and industrial applications, supporting the promotion of this local resource [2] [3] [36]. Further characterisation of fatty acid and amino acid profiles will be essential to assess whether the extracted oil is suitable for food or industrial applications and to determine the nutritional quality of the proteins for feed formulation.

5. Conclusion

This study confirmed the variability of the agromorphological characteristics of

the seeds and the physicochemical characteristics of the nuts produced by five rubber tree clones commonly used in Côte d'Ivoire. In terms of morphology and mass, the IRCA 230 clone appears to be the most promising. In-depth analysis of the physicochemical parameters of the nuts reveals that each clone has a distinctive and decisive advantage. The IRCA 230 clone stands out for its high lipid content (46.99%). The GT 1 clone is rich in protein (25.08%), while IRCA 331 has the highest energy density (592 kcal/100g DM). They could therefore contribute effectively to the production of vegetable oil, the formulation of specific food supplements, or the development of concentrated energy products. Looking ahead, it would be useful to determine the fatty acid and amino acid profile of these almonds in view of their oil and protein content. This study paves the way for identifying technologies and areas of application for these rubber tree seeds.

Authors' Contributions

The contributions of each of the co-authors of this article are described as follows:

ODMJ: designing the methodology, selecting the various companies, monitoring data analysis and writing the article.

AS and KN: seed sampling, performing the various tests and data analysis.

DM and BRK: supervision and validation.

KJLK: supervision and validation.

KKJL: validation of methods and protocols, and final proofreading of the article.

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Conflicts of Interest

The authors declare that there are no conflicts of interest with respect to this article.

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