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Article

Extraction and Physicochemical Composition of *Irvingia gabonensis* Almond Oil: A Potential Healthy Source of Lauric-Myristic Oil

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Abstract: *Irvingia gabonensis* is a non-timber forest product, whose fruit contains an edible fat-rich kernel. This fat can be used not only in human food but also as a source of raw materials in the cosmetic, pharmaceutical and nutraceutical industries. This work aimed to provide a physicochemical description of components present in the almonds and butter of *I. gabonensis*. Oil was extracted by soxhlet and hot-pressing from almonds. Cryo-MEB analyses allowed the observation of oleosomes in which the triglycerides of almonds are located. The triglyceride profile and the fatty acids profile of the butter were determined by gas chromatography, and a statistical analysis was performed. The thermal properties of oil were analyzed by thermogravimetric analysis. The results revealed that oil bodies have sizes ranging from 30 to 60 µm. With a 63.8 ± 0.2% fat content, *I. gabonensis* is composed of 98.4% triglycerides. The hot-pressing yield is 47.9%. The main triglycerides are essentially made up of lauric (38.5 ± 0.1%) and myristic (51.9 ± 0.2%) acids. Thermogravimetric analysis showed that the butter melted at 43.4 °C and decomposed at 415.2 °C. These results show that *I. gabonensis* butter may be proposed as a good source of lauric acid for food and nutrition.

Keywords: *I. gabonensis*; hot-pressing; MEB analysis; TGA analysis; oleosomes; triglyceride; lauric and myristic acids; lauric-myristic oils

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1. Introduction

Lauric oils are sought-after compounds because of their resistance to rancidity and high melting point. Unlike other oils, lauric oils are commonly used for both food and non-food applications [1,2]. Regarding food applications, lauric oils (coconut oil or palm kernel oil) are used in shallow frying, cocoa butter substitution, margarine and spread formulations, ice cream, non-dairy whipping cream, and filled milk. The use of lauric oils in the formulation of margarine is related to their rapid melting properties [3]. In addition, lauric oils are a source of medium-chain fatty acids, which are more rapidly absorbed, eliminated from the blood, and metabolized than long-chain fatty acids. With a low content of unsaturated fatty acids, lauric oils resist oxidation. In the human diet, the contribution of myristic acid would allow the regulation of many cellular mechanisms due to its ability to acylate proteins. Moreover, it has a short life duration in the cell because it is beta-oxidized and/or elongated in palmitic acid [4,5]. Palm kernel and copra are the main plant sources of the production of this category of oil [6]. The *Irvingiaceae* family represents an opportunity to provide these two fatty acids. There are seven species of *Irvingia*, including *I. excelsa*, *I. gabonensis*, *I. grandifolia*, *I. Malayana*, *I. robur*, *I. smithii*, and *I. wombulu* [6]. The fruits

and seeds are cheap sources of protein, vitamins, minerals, carbohydrates, oil, etc. The mesocarp or pulp of the *I. gabonensis* fruit is consumed locally as a fresh fruit, and the juice is used to make jam and jelly. The pulp of the *I. gabonensis* fruit is an important source of vitamin C and beta-carotene. *I. gabonensis* has been found to contain elemental micronutrients, and a hypolipidemic effect of the fruit juice on sodium fluoride-induced dyslipidemia in rats has been observed [7]. *Irvingia gabonensis* fruit juice has some renal and hepato-protective potential, which may be due to the presence of secondary plant metabolites such as flavonoids, tannins, and alkaloids. The fruit is also rich in calcium and magnesium [8].

Irvingia gabonensis (Aubry Lecomte ex O'Rorke Baill, 1884) is a tree up to 40 m high found in humid and warm forests of central and western Africa. The almond (kernels or seeds) of *I. gabonensis* (Figure 1) is very oleaginous and is used as a condiment and thickener in cooking [9,10].

Figure 1. *Irvingia gabonensis* almonds.

Regarding food security and the local population nutrition and health in the tropics, *I. gabonensis* was identified as a priority wild fruit tree species for domestication [11]. The almonds of *Irvingia gabonensis* are thus recognized as a non-timber forest product (NTFP) whose domestication has several economic, socio-economic, environmental, and nutritional interests. NTFPs are defined as products of biological origin (fauna and flora) other than wood that comes from natural or artificial forests or agroforestry systems [12]. Economically, the market for *I. gabonensis* almonds is estimated at $50 million in sales. Marketing is currently regional, between countries including Nigeria, Benin, Gabon, and Cameroon. Moreover, *I. gabonensis* almonds are traded internationally from Africa to the United Kingdom and the United States. However, the market remains limited, and hence its inclusion in the program dedicated to the valorization of NTFPs is pertinent. The almonds of *I. gabonensis* present potential for socio-economic development for local communities in the central and western African regions. From a social point of view, the informal sale of NTFPs generates income for many households that is used to supply necessities and to send children to school.

Irvingiaceae family has a high fat content (more than 55%). Almonds have a highly saturated oil. The triglycerides are essentially rich in lauric and myristic acids. In their study, Silou et al. showed that the triglycerides representative of the *smithii*, *wombulu*, and *gabonensis* species are LLL, MMM, LLM, and LMM [13], with L and M representing lauric and myristic acids, respectively. Based on the triglyceride composition of the fat, *Irvingia* species were reported as having low complex fats [13]. Loumouamou et al. [14] and Silou et al. [15] obtained a triglyceride profile for *I. smithii* and *I. wombulu* (Table 1).

Table 1. Triglyceride profile of *I. gabonensis*, *I. smithii* and *I. wombulu*.

Species	Triglyceride Profile	Reference
I. smithii	LLM > LMM > LLL > MMM	[14]
	LLL > MMM > LLM > LMM	[13]
I. wombulu	LLL > MMM > LLM > LMM	[13]
	LLM > LMM > LLL > MMM	[15]
I. gabonensis	LLL > MMM > LLM > LMM	[13]
	LMM > LLM > MMM > LLL	[15]

L: lauric acid; M: myristic acid.

The variability in triglyceride composition between the species can be explained by the specific fatty acid composition within each species. The following variable contents of lauric acid C12:0 and myristic acid C14:0 can be found: C12 > C14, C12 < C14 et C12 ≈ C14.

Previous studies have reported contrasting fatty acid compositions. Indeed, *I. gabonensis* has been shown to present low lauric acid content and high myristic acid, whereas for *I. wombulu* and *I. smithii* species, the lauric acid content is higher than myristic acid [11,13]. In the case of *I. smithii*, lauric and myristic acid contents are very similar [14]. Etong et al. obtained higher lauric acid content than myristic acid for *I. gabonensis* species [16]. Sonwai et al. obtained lauric acid contents higher than myristic acid for the less-used species *I. malayana* [17,18].

The *Irvingiaceae* family, represented by its different species, is an important source of saturated fatty acids and is rich in lauric and myristic acids (Table 2). The main vegetable sources of production of this category of oil are palm, through palm kernel oil, and coconut. In this category of lauric oil, *I. gabonensis* is distinguished by its richness in C14:0 and C12:0. Myristic acid is produced at 1.8 million tons or 1.6% of production per year of the main fatty acids. The development program for the domestication of Irvingiaceae in several countries of central and western Africa will help increase the production of its butter. Therefore, the production of myristic and lauric fatty acids should be increased.

Table 2. Fatty acid profile of *Irvingiaceae* species butter.

Fatty Acids (%)	C10:0	C12:0	C14:0	C16:0	C18:0	C18:n1−9	C18:2n−6	Refs.
Ig	1.34	**39.37**	**50.92**	4.97	0.73	1.82	0.49	[3]
Ig		**27.63**	**61.68**	7.49	0.81	2.12	0.27	[19]
Ig		**39.40**	**20.50**	10.30	11.40	6.90	6.40	[16]
Is	3.67	**51.85**	**33.84**	3.78	0.44	3.18	0.51	[14]
Is	2.23	**42.74**	**41.63**	5.77	0.61	4.35	0.70	[14]
Iw	2.05	**48.54**	**43.43**	3.37	0.59	1.71	0.31	[15]
Im		**46.91**	**40.28**	3.18	1.62	2.26	0.01	[17,18]

Ig: *I. gabonensis*; Is: *I. smithii*; Iw: *I. wombulu*; Im: *I. malayana*.

Nevertheless, there is no characterization of the internal structure of the almond concerning its lipid composition, nor information on the degradation temperature of butter justifying its applications. Therefore, this study aims to provide new physico-chemical knowledge on the almond and butter of *I. gabonensis* by microscopic observation of the almond and thermogravimetric analysis of the butter in addition to its physico-chemical composition.

2. Materials and Methods

2.1. Plant Material and Reagents

Irvingia gabonensis kernels were purchased at the Mont-Bouet market in Libreville, Gabon, during three periods of 2017. Each sample constitutes a replicate. Moreover, extractions were carried out in triplicate. The reagents and standards used for analytical quality were provided by Sigma-Aldrich (Saint Quentin Fallavier, France). Nihydrin and buffers were purchased from Biochrom Ltd. (Cambridge, UK).

2.2. Proximate Composition of Almonds

The moisture content of the almonds was determined by the AOAC method (1990). The ash content was achieved by calcining the samples up to constant weight in a furnace at 550 °C for four hours. The protein content of the almonds was determined by the Kjeldahl method according to the French standard NF V 18—100 using an automatic Kjeltec 8400. The protein content was calculated using 6.25 as the conversion factor for residual nitrogen to protein.

The amino acid composition of almonds was determined by Moore and Stein's method [20]. Analysis was performed by ion exchange chromatography. The apparatus used is a Biochrom 20 + amino-acid analyzer (Biochrom Ltd., Cambridge, UK) equipped with a 200 mm× 4.6 mm column + pre-column system containing sodium-based ion-exchange resins. Before analysis, the almonds were hydrolyzed with 6 N hydrochloric acid in an oven at 103 °C for 24 h. The pH of the hydrolysates was adjusted to 2.2 by a 3 N sodium hydroxide solution, and the total volume was increased to 10 mL using a buffer solution with a pH of 2.2. The samples were filtered at 0.45 µm and then analyzed. The separation of amino acids in the column was performed through elution with different pH buffers at specific temperatures. Amino acids reacted with nihydrin in the reaction loop of the chromatograph before being detected at a wavelength of 570 nm, except proline, which is detected at 440 nm.

2.3. Microscopic Cryo-MEB Analysis

The observations in Cryo scanning microscopy were performed within the GENOTOUL platform at CMEAB. The device used was an SEM Quanta 250 FEG FEI with a Cryo preparation module Quorum PP3000T. The preparation method for cooling the sample was a high-pressure Cryo-fixation by a LEICA EM ICE device. This method allowed the water to freeze immediately in the solid state while minimizing sample modifications. The latter was then fractured with a mini-scalpel (cryo-fracture) and metalized before being observed.

2.4. Oil Extraction by Soxhlet and Hot-Pressing

The oil content of the kernels was determined by the standard Soxhlet method (AFNOR NF EN ISO 659, 1998). Fifty-seven grams of kernels were crushed and grounded into a very fine powder using a bladed grinder. The resulting powder was then placed in the Soxhlet, and cyclohexane was used as the extraction solvent. The reaction was performed at 50 °C for 7 h. After extraction, the solvent was removed using a rotary evaporator. The results were expressed as a percentage based on the dry matter of the seed powder.

The hot pressing of the kernels was carried out using a single screw press (Komet, Germany) with a length of 18 cm, a diameter of 12 mm, and a flow rate of 1 kg/h. The kernels had been previously crushed to reduce their size. The screwcover was heated with a heating sleeve. Different pressing experiments were carried out. A 7 mm nozzle and a distance of 0.5 cm between the end of the screw and nozzle were used. The temperatures of the heating ring, screw head, oil outlet, and cake were 40, 90–120, 60, and 70 °C, respectively. The cake obtained from the pressing of the kernels was also pressed a second time to optimize the extraction of the oil. After pressing, the oil obtained, which was solid at room temperature, was liquefied at 50 °C in an oven and then centrifuged at 10,000× *g* at 30 °C for 10 min to remove impurities.

2.5. Determination of the Fatty Acids Profile

The fatty acids profile was determined by gas chromatography. The analysis method consists of the methylation of fatty acids using trimethylsulfonium hydroxide at 0.2 M in methanol (TMSH) (standard NF EN ISO 12966-3, 2016). A 15 mg sample of oil was solubilized in 1 mL of TBME (*ter*-butyl methyl ether). Next, 100 µL of this solution was sampled, and 50 µL of TMSH was added. The resulting fatty acid methyl esters were analyzed by gas chromatography. The apparatus used is a Varian 3900 chromatograph equipped with a CP-Select CB for FAME fused silica WCOT capillary column

(50 m, 0.25 mm internal diameter and 0.25 μm film thickness, injection split 1:100). During the analysis, which lasted 55 min, 1 μL of the sample was eluted by helium, used as the carrier gas, at a rate of 1.2 mL/min. The oven temperature was 185 °C for 40 min, then increased by 15 °C/min to 250 °C, and 250 °C for 10.68 min. The flame ionization detector (FID) detector and injector had a temperature of 250 °C. Identification mix 37 (supelco) [21].

2.6. Determination of the Triglyceride Profile of the Butter

The triglyceride profile of the oil was determined by gas chromatography coupled with a flame ionization detector (FID). The compounds were identified by comparing retention times with reference standards (myristic acid, monomyristine, dimyristine, and trimyristine), and quantification was performed by internal calibration. Samples were silylated using MSHFBA (*N*-methyl-*N*-trimethylsilyl-heptafluorobutyramide) as a reagent. One hundred microliters of an internal standard solution (heptadecane at 10 mg/mL in cyclohexane) was added to ten milligrams of oil. This mixture was completed with 10 mL of cyclohexane. In an insert, 160 μL of the previous solution was added to 40 μL of silylated reagent (MSHFBA). The analysis was performed using an Rtx-5 (Restek) column (15 m, 0.32 mm internal diameter, and 0.25 μm film thickness). The injection volume was 1 μL and the carrier gas, helium, was at a pressure of 15 psi at the column head. The temperature on the column was 55 °C for 0.5 min, then increased by 200 °C/min up to 340 °C, and finally was kept at 340 °C for 40 min. The oven temperature was 55 °C for 0.5 min, then increased by 45 °C/min to 80 °C, 10 °C/min to 360 °C, and 360 °C for 16 min. The temperature of the detector was 365 °C.

2.7. Thermogravimetric Analysis (TGA)

The thermogravimetric analysis was performed using an SDT Q600 thermogravimetric analyzer (TA instrument) under a nitrogen atmosphere at a flow rate of 100 mL/min in a temperature range of 25 °C to 500 °C with a ramp of 10 °C/min.

2.8. Statistical Analysis

All samples were analyzed in performed triplicate, and the results are expressed as averages ± SD.

3. Results and Discussion

3.1. Microscopic Characterization of I. gabonensis Almonds

The images obtained by cryo-MEB observation of *I. gabonensis* almonds allowed the detection of oil bodies called oleosomes (Figure 2). Oleosomes or oil bodies are plant cell organelles that serve as storage structures for lipids, primarily triglycerides. These are the most abundant storage structures for vegetable oil. In this section, we observed and determined the size of the oleosomes of *I. gabonensis* almonds. Figure 2a,b show an overview of the almond fracture. The latter would be mainly composed of oleosomes. Figure 2c,d show the enlargement of these cells. According to the literature, the almond is composed of more than 60% oil [3,10,19,22–24]. This suggests that the fragments observed are oleosomes. These oil bodies' sizes ranged from 30 to 60 μm. Oleosomes consist of a core of hydrophobic neutral lipids, surrounded by a monolayer of phospholipids, itself stabilized by particular proteins called oleosins. These proteins play a major role in the formation and stability of oleosomes and consequently in their resistance to lipid extraction. The oleosins would determine in particular the size of the oleosomes, which in turn conditions their functional properties.

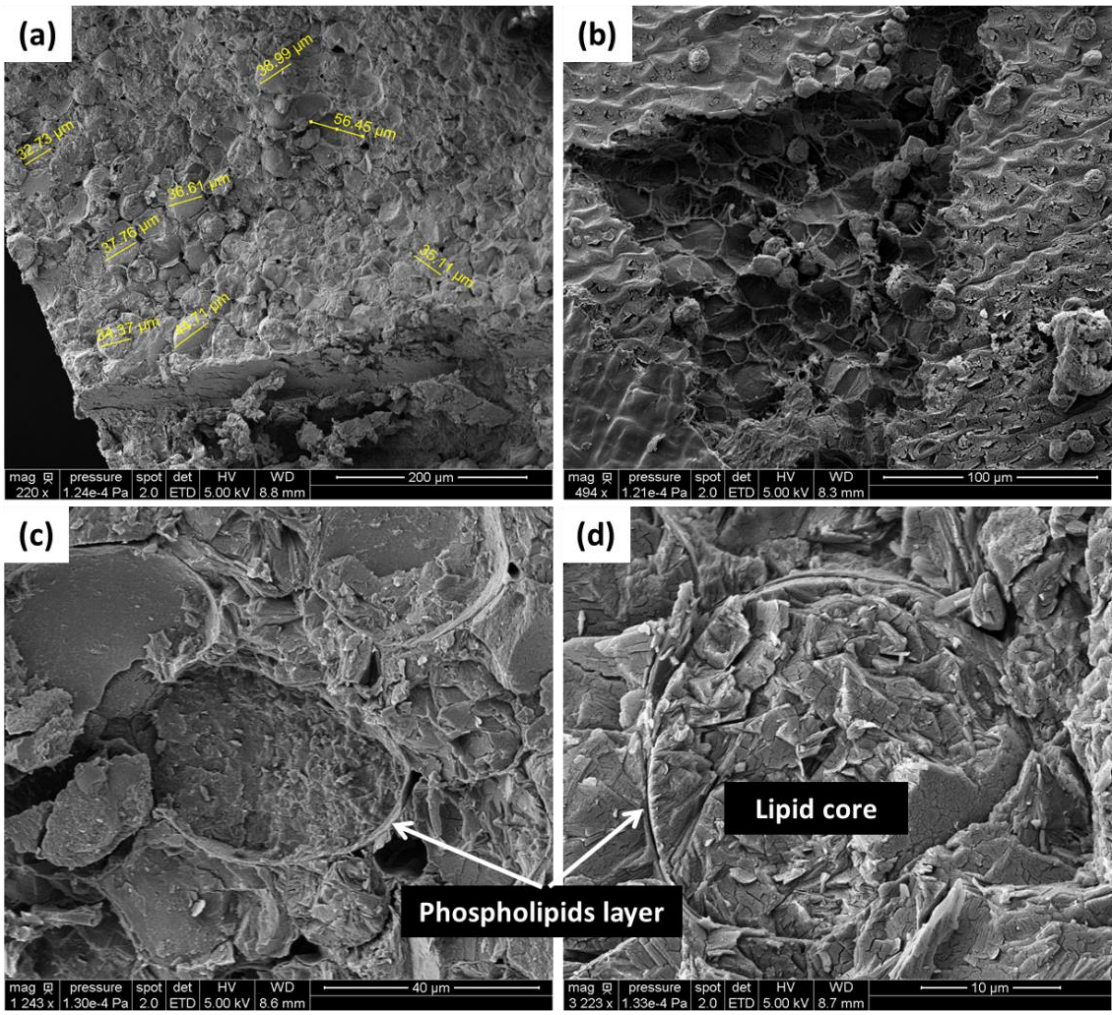

Figure 2. Ultrastructure of the almonds of *I. gabonensis* seen in electronic microscopy at a pression of 1.33×10^{-4} to 1.21×10^{-4} Pa. (**a**,**b**): Fracture of the almond showing the oleosomes of different sizes. (**c**,**d**): Enlargement of the oleosomes showing the lipid core and the membrane.

Oil bodies of common mature seeds such as olive, rapeseed, mustard, cotton, flax, maize, peanut, and sesame had an average diameter between 0.5 and 2.0 µm [25,26]. These larger sizes are generally observed in the mesocarp of fruits. These are larger than those of the seeds. For example, the oleosomes of palm seeds had a size ranging from 4 to 26 µm, while for the mesocarp, the sizes were between 4 and 32 µm. It has also been observed that the difference in size can be related to variety. In the case of avocado, for instance, oleosomes of 41.5 µm were obtained for the Hass variety and 11.9 µm for the americana variety [27]. In future studies, it would be interesting to study the size of the oleosomes of *I. gabonensis* and correlate them with the variety, butter yield, and even the triglyceride composition.

The microscopic observation of the almonds of *I. gabonensis* highlights the size and the morphology of oil bodies inside the almonds.

3.2. Composition of I. gabonensis Almonds

Irvingia gabonensis almonds contained 63.8 ± 0.2% fat, 19.9 ± 0.1% carbohydrates, 13.0 ± 0.2% protein, 2.3 ± 0.0% ash, and 1.1 ± 0.0% moisture. These values show that *I. gabonensis* is an oleoproteaginous almond, an important source of oil, carbohydrates, and protein. The results of the amino acid profile (Table 3) show that the almond of *I. gabonensis* is a source of glutamic acid (19.93%), aspartic acid (10.05%), and arginine (9.05%). It is also a good source of essential amino acids: leucine (8.54%), valine (5.24%), isoleucine (5.20%), and lysine (5.10%). The other amino acids have values between 1.89% and 5.45%.

Irvingia gabonensis almond presents an appreciable amount of protein and may contribute by a small or significant amount to the supply of essential amino acids in the diet.

Table 3. The composition in amino acids of the proteins of *I. gabonensis* almonds.

Amino Acids	Content (%)
Aspartic acid	10.05 ± 0.33
Threonine	3.93 ± 0.12
Serine	5.45 ± 0.01
Glutamic acid	19.93 ± 1.02
Glycine	5.20 ± 0.01
Alanine	4.72 ± 0.01
Cysteine	1.89 ± 0.26
Valine	5.24 ± 0.08
Methionine	2.70 ± 1.63
Isoleucine	5.20 ± 0.53
Leucine	8.54 ± 0.75
Tyrosine	2.58 ± 0.24
Phenylalanine	3.54 ± 0.33
Lysine	5.10 ± 0.12
Histidine	2.52 ± 0.24
Proline	4.40 ± 0.41
Arginine	9.05 ± 0.54
Tryptophan	ND [1]

[1] ND: Not determined.

3.3. Extraction Yield of I. gabonensis Oil

The oil content in *I. gabonensis* almonds determined by the Soxhlet method was 63.8%. These results corroborate the values from the literature with an oil content of up to 75.5% [3,10,19,22–24]. The fat content in the almonds of these varieties is higher than that of almonds from the fruits of tropical oilseeds such as cocoa (50.0–52.0%) and moabi, *Baillonella toxisperma,* (50.5%) [13].

The hot-pressing yield was 47.9%. This represents 75.03% of the total oil content of the almond. Matos et al. obtained an extraction yield of 34.5%. In this study, the seeds are previously heated to 110 °C in an autoclave and then hot pressed under a pressure of 1 bar [3]. Ogunsina et al. [28] obtained an extraction yield of 36.6% by hot pressing using a hydraulic press. The pressing method used in this study is a new process for obtaining *I. gabonensis* butter by hot pressing. Indeed, the hopper is equipped with an agitator, and a heating band can be used to heat the press cylinder. Once introduced into the hopper, the seeds are conveyed into the compression screw. They are crushed and heated in a light way. The oil is released at the end of the process. This method is an easy way to implement this process with a good extraction yield and can be adapted for food processes.

3.4. Triglyceride Profile of I. gabonensis by Statistical Analysis

The results obtained for the triglyceride profile show that oil is 98.4% triglycerides. Based on the fatty acid composition, the predominant triglycerides present in *I. gabonensis* oil were determined. Thus, the main triglycerides were MLM, LML, MMM, MLP, and LLL, with respective mass contents of 31.0%, 23.0%, 13.9%, 6.3%, and 5.7%. Mass grades between 5 and 1% are attributed to MPM, LPL, MLO, and MLD (Figure 3), where D, L, M, P, and O represent dodecanoic, lauric, myristic, palmitic, and oleic acids, respectively. The results of this statistical study can be compared with the analytical results reported by Yamoneka et al. [22] and Silou et al. [15], who reported an order of preponderance of MLM, LML, MMM, LLL. The triglyceride profile of *I. gabonensis* oil allows it to be classified as a low-complexity fat [13]. Myristic acid was most abundant in the triglycerides of *I. gabonensis* oil. Myristic acid is generally present in dairy matter and is also found in vegetable oils such as copra and palm kernel. According to recent studies, the intake of myristic acid via the diet could help regulate many cellular mechanisms. It is mainly beta-oxidized and/or

elongated in palmitic acid and therefore has a short life duration in the cell. Myristic acid can acylate proteins. This induces a structural and functional role in regulating biological activity [3,4]. *Irvingia gabonensis* is an available source of functional myristic acid provided by food for biological processes.

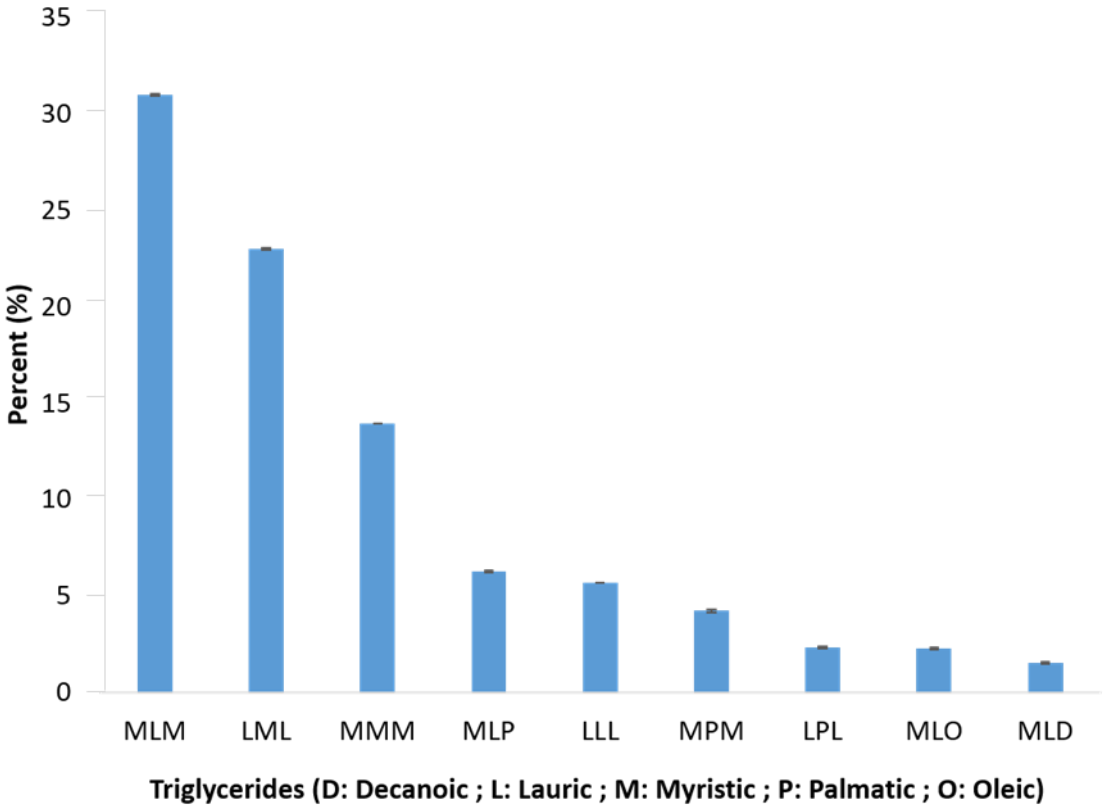

Figure 3. Triglycerides composition observed in almonds of *I. gabonensis*.

3.5. Fatty Acid Profile of I. gabonensis in Butter

Gas chromatography results (Table 4) showed that butter consisted of five saturated fatty acids representing 97.6 ± 0.1% of the total saturated fatty acids. Myristic acid (C14:0) and lauric acid (C12:0) were the most abundant with 51.9 ± 0.2 and 38.5 ± 0.1%, respectively. *Irvingia gabonensis* oil may be regarded as myristic-lauric butter because myristic acid was the most abundant fatty acid, followed by lauric acid. *Irvingia gabonensis* oil falls into the category of a butter rich in fatty acids C12:0 and C14:0 with copra (C12:0 to 44.75%).

Table 4. Fatty acid profile of *I. gabonensis* oil.

Fatty Acids	Length of Carbon Chain	% Relative Mass
Decanoic	C10:0	1.29 ± 0.03
Lauric	C12:0	38.48 ± 0.09
Myristic	C14:0	51.87 ± 0.18
Palmitic	C16:0	5.25 ± 0.01
Stearic	C18:0	0.73 ± 0.02
Oleic	C18:n1−9	1.89 ± 0.04
Linoleic	C18:2n−6	0.57 ± 0.01
SFA [1]		**97.60 ± 0.05**
MUFA [2]		1.89 ± 0.04
PUFA [3]		0.57 ± 0.01
SFA/MUFA		51.64

[1] SFA: Saturated fatty acid; [2] MUFA: Monounsaturated fatty acids; [3] PUFA: Polyunsaturated fatty acids.

3.6. Thermogravimetric and Melting Point Analyses of *I. gabonensis* Butter

Thermogravimetric analysis is a simple and suitable method to study the decomposition patterns of a sample. Figure 4 shows melting point of 43 °C, which very high for an oil and is directly related to the fatty acid composition of the oil, which is rich in C12:0 an C14:0 fatty acids. *I. gabonensis* oil could be valorized in the food industry to control the texture of products in the manufacture of spreads and in the substitution of cocoa oil [29,30]. The second point is that the mass loss of the sample is complete (100%) at a temperature of 415.2 °C. This high temperature reveals that *I. gabonensis* oil is very stable and would be suitable for use as a stable frying oil or for use in high-temperature cooking applications. The need for lauric oil covers technical applications as well, thanks to its advantages, which include nice color, good odor, and high chemical stability without risk to oxidation reactions due to the near absence of unsaturated and polyunsaturated fatty acids. TGA analysis thus made it to determine the degradation temperature of *I. gabonensis* oil.

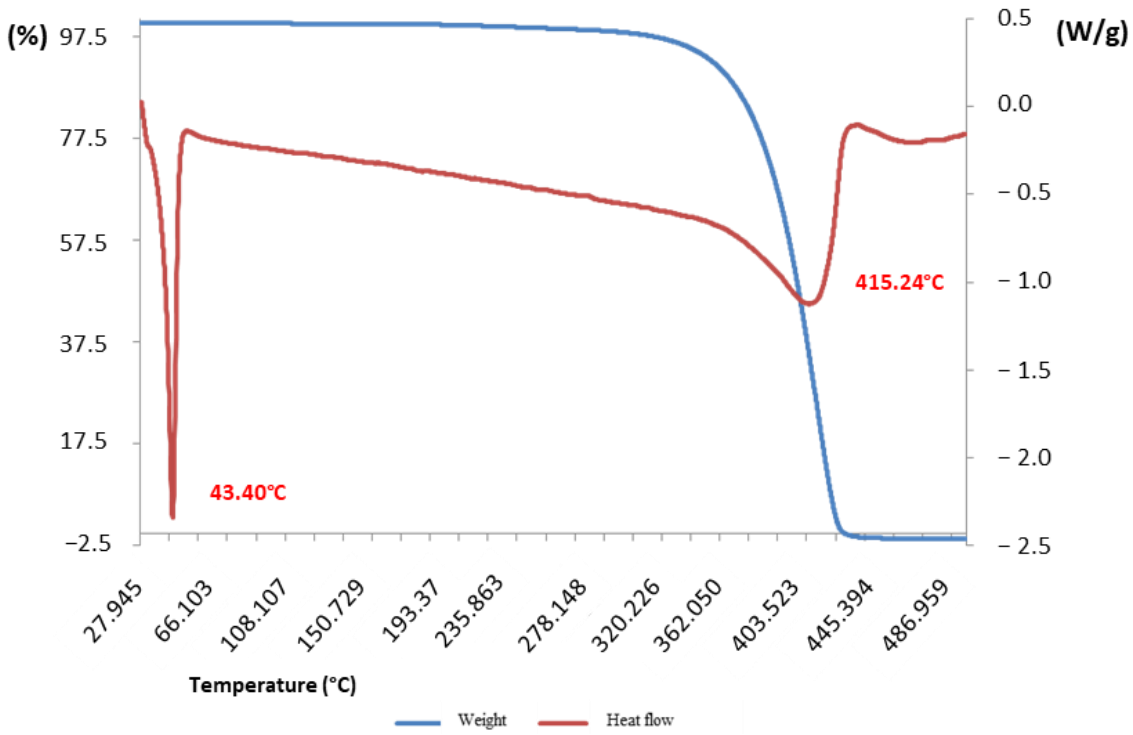

Figure 4. Thermogram obtained by TGA analysis of *I. gabonensis* butter.

4. Conclusions

In this study, *I. gabonensis* almond was chosen for its lipid bioavailability. *Irvingia gabonensis* kernel is an important source of tropical vegetable oil (64%) consisting mainly of triglycerides. The analysis of the morphology of the almonds revealed the presence of oil bodies or oleosomes with sizes from 30 to 60 µm in which the triglycerides would be found. *Irvingia gabonensis* proteins are a source of essential amino acids that play various roles in the body. Hot pressing of *I. gabonensis* resulted in the extraction of 48% of oil in relation to the mass of the seed, which represents 75% of the total oil content. Oil is mainly composed of triglycerides MLM, LML, and MMM, with percentages of 31%, 23%, and 14%, respectively. These triglycerides are mainly composed of myristic (51%) and lauric (38%) fatty acid chains. There are myristic–lauric oils and lauric–myristic oils. The oil is solid at room temperature, and its melting point is 44 °C. The degradation temperature of 415 °C reveals its recoverable thermal stability in applications requiring high temperatures. The lauric and myristic acids, with a medium chain length, distinguish them from other vegetable oils and give them a proven technical comparative advantage in of human foods and non-food items (the soap industry, surfactants and fatty acids, and methyl esters).

I. gabonensis oil can thus be used for the manufacture of margarine and cooking butters because of its thermal stability but also because of the non-degradation of fatty acids due to the absence of unsaturated and polyunsaturated fatty acids. The findings obtained in the present study are preliminary results due to the limited seeds used and should be ascertained by examining numerous samples from different origins and cultivated under various environmental conditions. *Irvingia gabonensis* is one of these little-known and underused crops that can meet the high demand for lauric oil in food.

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References

1. Matos, L.; Nzikou, J.M.; Matouba, E.; Pandzou-Yembe, V.N.; Guembot Mapepoulou, T.; Linder, M.; Desobry, S. Studies of *Irvingia gabonensis* Seed Kernels: Oil Technological Applications. *Pak. J. Nutr.* **2009**, *8*, 151–157. [CrossRef]
2. Barreca, S.; La Bella, S.; Maggio, A.; Licata, M.; Buscemi, S.; Leto, C.; Pace, A.; Tuttolomondo, T. Flavouring Extra-Virgin Olive Oil with Aromatic and Medicinal Plants Essential Oils Stabilizes Oleic Acid Composition during Photo-Oxidative Stress. *Agriculture* **2021**, *11*, 266. [CrossRef]
3. Beauchamp, E.; Rioux, V.; Legrand, P. Acide Myristique: Nouvelles Fonctions de Régulation et de Signalisation. *Med. Sci.* **2009**, *25*, 57–63. [CrossRef] [PubMed]
4. Rioux, V. Fatty Acid Acylation of Proteins: Specific Roles for Palmitic, Myristic and Caprylic Acids. *OCL* **2016**, *23*, D304. [CrossRef]
5. Gunstone, F.D.; Harwood, J.L. Occurrence and Characterization of Oils and Fats. In *Lipid Handbook*, 3rd ed.; CRC Press: Boca Raton, FL, USA, 2007; pp. 37–141. ISBN 978-1-4200-0967-5.
6. Silou, T.; Biyoko, S.; Heron, S.; Tchapla, A.; Maloumbi, M.G. Caractéristiques Pysico-Chimiques et Potentialités Technologiques Des Amandes de *Irvingia gabonensis*. *Riv. Ital. Sostanze Gr.* **2004**, *81*, 49–57.
7. Emejulu, A.A.; Alisi, C.S.; Asiwe, E.S.; Iheanacho, K.M.; Onwuliri, V.A. Hypolipidemic Effect of *Irvingia gabonensis* Fruits Juice on Sodium Fluoride Induced Dyslipidemia in Rats. *Afr. J. Biochem. Res.* **2014**, *8*, 151–157. [CrossRef]
8. Emejulu, A.A.; Alisi, C.S.; Asiwe, E.S.; Nwaogu, L.A.; Igwe, C.U.; Onwuliri, V.A. Renal and Hepato-Protective Effect of *Irvingia gabonensis* Juice on Sodium Fluoride-Induced Toxicity in Wistar Rats. *J. Clin. Toxicol.* **2015**, *6*, 1000296. [CrossRef]
9. Sahoré, A.D.; Koffi, L.B.; Kouamé, A.M. Technical Sheet of *Irvingia gabonensis* Seeds Preparation in Ivory Coast. *Am. J. Food Technol.* **2013**, *1*, 42–44. [CrossRef]
10. Leakey, R.R.B.; Greenwell, P.; Hall, M.N.; Atangana, A.R.; Usoro, C.; Anegbeh, P.O.; Fondoun, J.-M.; Tchoundjeu, Z. Domestication of *Irvingia gabonensis*: 4. Tree-to-Tree Variation in Food-Thickening Properties and in Fat and Protein Contents of Dika Nut. *Food Chem.* **2005**, *90*, 365–378. [CrossRef]
11. FAO. Domestication and Commercialization of Non-Timber Forest Products in Agroforestry Systems. In Proceedings of the International Conference on Domestication and Commercialization of Non-Timber Forest Products in Agroforestry Systems, Nairobi, Kenya, 19–26 February 1996.
12. CBFP. *The Forests of the Congo Basin: A Preliminary Assessment*; Maryland University Press: Baltimore, MD, USA, 2005; p. 33.
13. Silou, T. Corps gras non conventionnels du Bassin du Congo: Caractérisation, biodiversité et qualité. *OCL* **2014**, *21*, D209. [CrossRef]
14. Loumouamou, B.W.; Gomoufatan, J.P.M.; Silou, T.; Nzikou, J.M.; Mbaya Gindo, G.V.; Figueredo, G.; Chalard, J.P. Extraction and Chemical Composition of Seed Kernel Oil from *Irvingia Smithii* of Congo Basin. *Adv. J. Food Sci. Technol.* **2013**, *5*, 506–513. [CrossRef]
15. Silou, T.; Loumouamou, B.W.; Nsikabaka, S.; Kinkela, T.; Nzikou, M.; Chalard, P.; Figueredo, G. Contribution to the Varietal Delimitation of *Irvingia Gabonensis* and *Irvingia wombulu* Chemical Composition Variability of Fats Extracted from Kernels. *J. Food Technol.* **2011**, *9*, 36–42. [CrossRef]

16. Etong, D.I.; Mustapha, A.O.; Taleat, A.A. Physicochemical Properties and Fatty Acid Composition of Dikanut (*Irvingia gabonensis*) Seed Oil. *Res. J. Chem. Sci.* **2014**, *4*, 70–74.
17. Sonwai, S.; Ponprachanuvut, P. Characterization of Physicochemical and Thermal Properties and Crystallization Behavior of Krabok (*Irvingia malayana*) and Rambutan Seed Fats. *J. Oleo Sci.* **2012**, *61*, 671–679. [CrossRef]
18. Sonwai, S.; Ornla-ied, P.; Aneknun, T. Lauric Fat Cocoa Butter Replacer from Krabok (*Irvingia malayana*) Seed Fat and Coconut Oil. *J. Oleo Sci.* **2015**, *64*, 357–365. [CrossRef]
19. Ogunsina, B.S.; Bhatnagar, A.; Indira, T.; Radha, C. The Proximate Composition of African Bush Mango Kernels (*Irvingia gabonensis*) and Characteristics of Its Oil. *Ife J. Sci.* **2012**, *14*, 177–183.
20. Moore, S.; Stein, W.H. Photometric Ninhydrin Method for Use in the Chromatography of Amino Acids. *J. Biol. Chem.* **1948**, *176*, 367–388. [CrossRef]
21. Amorello, D.; Orecchio, S.; Pace, A.; Barreca, S. Discrimination of almonds (*Prunus dulcis*) geographical origin by minerals and fatty acids profiling. *Nat. Prod. Res.* **2016**, *30*, 2107–2110. [CrossRef]
22. Yamoneka, J.; Malumba, P.; Blecker, C.; Gindo, M.; Richard, G.; Fauconnier, M.-L.; Lognay, G.; Danthine, S. Physicochemical Properties and Thermal Behaviour of African Wild Mango (*Irvingia gabonensis*) Seed Fat. *LWT-Food Sci. Technol.* **2015**, *64*, 989–996. [CrossRef]
23. Ifeduba, E.A.; Awachie, M.N.; Sabir, J.S.M.; Akoh, C.C. Fatty Acid Composition of *Irvingia gabonensis* and *Treculia africana* Seed Lipids and Phospholipids. *J. Am. Oil Chem. Soc.* **2013**, *90*, 517–528. [CrossRef]
24. Ogodo, A.C. Physical and Chemical Characteristics of the African Bush Mango (*Irvingia gabonensis* Var. *garbonensis*) Seed Oil. *Int. J. Adv. Eng. Manag.* **2014**, *1*, 28–31.
25. Tzen, J.; Cao, Y.; Laurent, P.; Ratnayake, C.; Huang, A. Lipids, Proteins, and Structure of Seed Oil Bodies from Diverse Species. *Plant Physiol.* **1993**, *101*, 267–276. [CrossRef] [PubMed]
26. Ross, J.H.E.; Sanchez, J.; Millan, F.; Murphy, D.J. Differential Presence of Oleosins in Oleogenic Seed and Mesocarp Tissues in Olive (*Olea europaea*) and Avocado (Persea Americana). *Plant Sci.* **1993**, *93*, 203–210. [CrossRef]
27. Sánchez-Albarrán, F.; Salgado-Garciglia, R.; Molina-Torres, J.; López-Gómez, R. Oleosome Oil Storage in the Mesocarp of Two Avocado Varieties. *J. Oleo Sci.* **2019**, *68*, 87–94. [CrossRef]
28. Ogunsina, B.S.; Olatunde, G.A.; Adeleye, O. Effect of Pre-Treatments on Mechanical Oil Expression from Dika Kernels. *Niger. Food J.* **2014**, *32*, 1–9. [CrossRef]
29. Yamoneka, J.; Malumba, P.; Lognay, G.; Béra, F.; Blecker, C.; Danthine, S. Enzymatic Inter-Esterification of Binary Blends Containing *Irvingia gabonensis* Seed Fat to Produce Cocoa Butter Substitute. *Eur. J. Lipid Sci. Technol.* **2018**, *120*, 1700423. [CrossRef]
30. Jahurul, M.H.A.; Zaidul, I.S.M.; Norulaini, N.A.N.; Sahena, F.; Jinap, S.; Azmir, J.; Sharif, K.M.; Omar, A.K.M. Cocoa Butter Fats and Possibilities of Substitution in Food Products Concerning Cocoa Varieties, Alternative Sources, Extraction Methods, Composition, and Characteristics. *J. Food Eng.* **2013**, *117*, 467–476. [CrossRef]