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Assessing the Physicochemical Properties, Thermal Stability, Anti-Inflammatory and Antioxidant Activities of *Baillonella toxisperma* Seed Butters

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Abstract

Baillonella toxisperma (Moabi) seed is a multipurpose fruit mainly used in the craft way and remains underexplored as an added value product. This study investigates the physicochemical properties of its butter to consider going beyond small-scale farming. The raw material analyzed has been extracted by using a traditional process. The physical and chemical properties of moabi butter were evaluated using official standards and established methods. Differential Scanning Calorimetry (DSC), Fourier Transfer Infrared (FTIR-ATR), and Thermogravimetry (TGA) analyses were performed to characterize thermal behavior and main chemical groups. Additionally, Gas Chromatography-Mass Spectrometry (GC/MS) was used to identify and quantify fatty acid compounds. Antioxidant and anti-inflammatory activities were also evaluated. The results show that kernel seeds yielded 30.0% butter. The refractive index was 1.464 and butter remains solid at room temperature. The density and specific gravity values were 0.91 mg/mL and 0.92 g/cm^3, respectively. The acid and peroxide values were 38.76 mg KOH/g and 6.30 meq O_2/kg. The iodine value was 16.26 (mg I_2/100 g butter) while saponification index and unsaponifiable matters were 200.5 (mg KOH/g) and 1.52%, respectively. GC/MS revealed the major fatty acids as oleic acid (53.6%), stearic acid (32.5%), and palmitic acid (10.8%), with minor fatty acids as linoleic (2.5%) and arachidic

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(0.6%) acids. FTIR results showed several bands indicating the presence of fatty compounds. TGA indicated that this butter is stable until 200˚C and fully degraded at 550˚C. DSC displayed the glass transition of moabi butter between −10˚C and −7˚C, with a melting point at 55˚C. This butter exhibited an anti-inflammatory activity at 79.95 mg/mL and an antioxidant activity at 4.94 mg/mL. The study demonstrated that moabi seed butter is an important product with interesting physicochemical properties. This butter demonstrated its potential for both human consumption and industrial applications.

Keywords

Moabi, Butter, Physicochemical Properties, Biological Activities, Thermal Analysis

1. Introduction

Gabon has a rich biodiversity with a wide variety of ecosystems and species. The species are predominantly plants, both woody and non-woody as well as wildlife, many of which are endemic [1]. Belgian authors have studied the fat content of several plant species from Central Africa, most of which are relatively common in Gabon. This is particularly true for the fatty seeds from certain Gabonese forest species, such as *Irvingia gabonensis*, *Pentaclethra macrophylla* and *Baillonella toxisperma* [2] [3]. The oils from these species are well known to local populations and are widely exploited because of their important role in food, pharmacopeia, and cosmetics. However, non-conventional vegetable oils derived from forest plants are less known, while palm oil, groundnut oil, and olive oil dominate Africa's oleaginous sector due to their research and compliance with *Codex Alimentarius* standards.

Baillonella-toxisperma Pierre (moabi), an endemic plant species of the Central African tropical rainforest belongs to the *Sapotaceae* family [1] [3]. Due to its continental abundance in areas close to the African Atlantic coastal zone, Debroux [4] described it as a coastal species of oceanic climates. Moabi is a highly sought-after species on the international timber market, and its illegal exploitation poses a real risk to the survival of the species and its indigenous people. Indeed, this species is sacred and mythical to these people, and it is estimated that 90% of the trees have already been cut down since the 1960s. According to the report on the assessment of forest resources in Gabon in 2020 [5], the moabi wood reserves was estimated at 5 to 11 million m^3. Annual production between 1994 and 1996 was around 51,100 m^3. Between the years 2007 and 2009, the volume of logs harvested almost halved, from 9144 m^3 to 5199 m^3. The non-timber forest products (NTFPs) derived from moabi are bark and butter. From the dried, roasted and pressed kernels, the forest dwellers produce a whitish-to-beige fat highly prized by local communities [3] [6]. Obtained "vegetable butter" is generally used for food, family, commercial, cosmetic, and pharmacopeia [7] [8].

Due to their chemical composition, vegetable oils are increasingly popular

among consumers and they offer several health benefits [9]. One of the main aspects of an oil's quality is its composition and oxidative stability because, once extracted, it undergoes various changes during storage or use. The potential toxicity of some oxidative degradation compounds of unsaturated fatty acids is also suspected [10] [11]. Furthermore, oxidation leads to the appearance of undesirable smells and compounds, hence reducing oil quality for consumption [12].

The aim of this study is to characterize the quality of Moabi butter obtained by a traditional route in Gabon. The physicochemical characteristics and the biological activities, including anti-inflammatory and antioxidant properties were performed in this study. With the advent of the concept of bioeconomy, it is important to know the quality of this type of natural product in order to introduce them into a global world market for biosourced products.

2. Materials and Methods

2.1. Materials

2.1.1. Raw Material

Kernels collection

Moabi kernel seeds were harvested in the southeast of Gabon in August 2022 by native people from Ngounie's region from a 70 years old tree. The seeds were transported by car to Libreville (600 km) and stored in a fridge.

2.1.2. Chemicals

Methanol (MeOH for HPLC, Fisher Scientific), pyridine (99% extra pure, Thermo Scientific Chemicals), BSTFA + 1% TMCS (99%, for GC derivatization, LiChropur, Merck Chemicals), cyclohexane (HPLC grade, 99% min Thermo Scientific Chemicals), potassium hydroxide (reagent grade, ≥98%, Merck Chemicals), were used for analyses.

2.2. Methods

2.2.1. Butter Production

Moabi butter was extracted from the kernel seeds by using a traditional protocol described in **Figure 1**. 1000 g of kernels were used for each extraction. The extraction yield was calculated by the formula:

$$Y1 = \frac{M1}{M2} \times 100 \quad (1)$$

where $M1$: is the kernel weight and $M2$: is the mass of butter.

The rate determined the performance of the artisanal method:

$$Y1 = \frac{Y1}{Y2} \times 100 \quad (2)$$

where $Y1$: Yield of the artisanal method and $Y2$: Yield of the Soxhlet method.

The butter extraction, collected moabi seeds were crushed, and the almonds were removed. Then, the almonds were ground, followed by paste and malaxation-pressing steps, before filtration and storage (−20˚C) for further analysis.

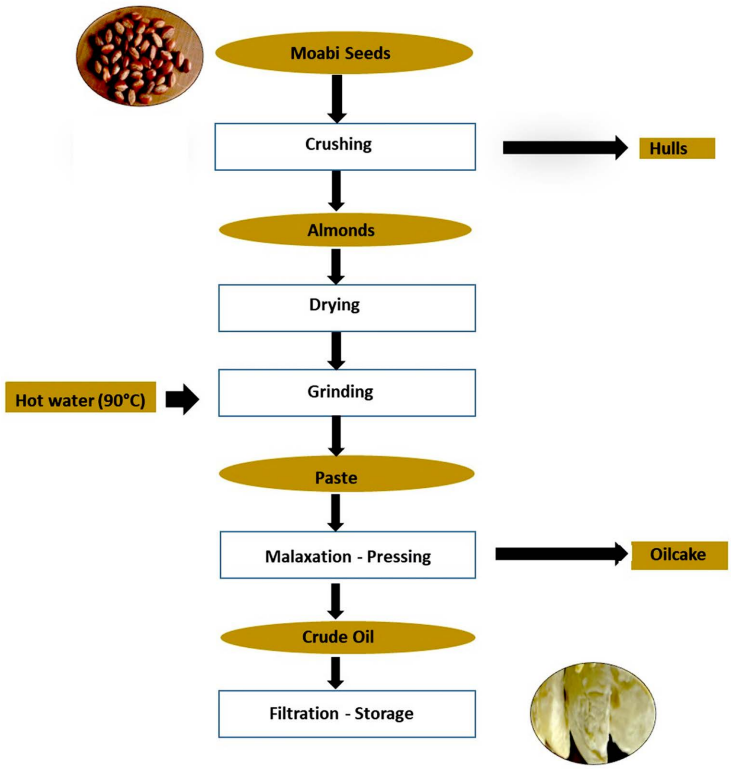

Figure 1. Artisanal process steps of moabi butter extraction.

2.2.2. Physicochemical Parameters

Physical and chemical analyses of the butter samples, including density, refractive index, specific gravity, acid value, iodine index, and peroxide value) had been done by using AFNOR (F) standards (2000). The quantities of saponifiable and unsaponifiable compounds were obtained by following the international standards ISO 3657: 2020 (F) and ISO 3596: 2000 (F), respectively [13]. Before each analysis, the butter is heated to a liquid state.

(1) *Refractive index*

A Refractometer is the instrument used to measure refractive index (RI). The refractive index of moabi's butter was measured using a precision Abbe refractometer, having a measuring range of refractive index of 1300 - 1700 with the accuracy ± 0.0002 at 25˚C.

(2) *Specific gravity*

The specific gravity of the butter was determined gravimetrically by employing the weight ratio of the butter to the equivalent amount of distilled water according to the following formula:

$$Specific\ gravity = \frac{W2}{W1} \tag{3}$$

where $W2$ and $W1$ are the weights of butter and equivalent amount of water respectively.

3) *FT-IR-ATR spectroscopy analysis*

Infrared spectra were analyzed with an FT/IR-ATR-4700 infrared spectrometer

(Jasco, Japan) equipped with an attenuated total reflectance device. Scans were done with a resolution of 4 cm^{-1} within a wavenumber range of 600 - 4000 cm^{-1}. For each sample, 32 scans were recorded, and graphics correspond to the average of those scans with an in-built correction for the baseline and the ATR crystal.

4) *Thermogravimetry analysis* (*TGA*)

TGA was used to measure moabi butter's degradation as a temperature function. This measurement was performed by using the Pyris™ 1 TGA (PerkinElmer) on a 4 - 8 mg moabi butter sample in a platinum crucible. The temperature increase was programmed from 30 to 750˚C to a heating rate of 10˚C/min in two conditions: nitrogen and oxygen (20 mL/min).

5) *Differential scanning calorimetry analysis* (*DSC*)

The DSC 8500 instrument used was equipped with a rapid cooling system. Individual samples were weighed (3 - 5 mg) in standard aluminum pans (PerkinElmer instrument), and data acquisitions were carried out using the Pyris[1] data program (PerkinElmer). Samples were first scanned under nitrogen from −30˚C to 130˚C to a heating rate of 10˚C/min. Then, an isotherm was applied at 130˚C for 3 min, followed by a cooling step at the rate of 10˚C/min from 130˚C to −30˚C. An isotherm was applied at −30˚C for 3 min. Then, samples were scanned again between −30 and 130˚C at a heating rate of 10˚C/min. Each experiment was repeated three times.

6) *Acid value*

Ethanol was boiled with water bath for a few minutes to remove dissolved gases. Then it was neutralized with a few drops of phenolphthalein and 10 mL of KOH (0.1 N) until a pale pink color appeared. Add 2 - 3 g of butter and 50 mL of neutralized ethanol into a 250 mL conical flask and 50 mL. The mixture was then brought to a boil and the hot solution was titrated with KOH solution until the pink color disappears. The acid value was calculated as shown in the following Equation (4):

$$\text{Acid value (mg KOH/g)} = \frac{V \cdot N \cdot 56.1}{W} \tag{4}$$

where, V is the titrated value (mL), N is the normality of KOH = 0.1 N and 56.1 = the molar mass of KOH and W is the mass of sample.

7) *Peroxide value*

Two grams of butter sample were weighted into a 500 mL conical flask and 10 mL of chloroform were added to dissolve the sample. This was followed by the addition of 15 mL of acetic acid and 1 mL of freshly prepared saturated potassium iodide solution. The flask was immediately closed, stirred for about 1 minute, and kept at room temperature away from light for exactly 5minutes. About 75 mL of distilled water and 3 mL of starch poison were added to the content of the flask and then shaken vigorously. Few drops of starch solution were added as an indicator. The liberated iodine was titrated against 0.01 N sodium thiosulphate solution. The same procedure was applied for the blank and the peroxide value expressed in mg O_2/Kg of sample was calculated as following:

$$\text{Peroxide value (mg } O_2\text{/Kg)} = \frac{(V1 - V0) \cdot T \cdot 1000}{W} \tag{5}$$

where, $V0$ is the volume of the sodium thiosulphate solution used for the blank test, $V1$ is the volume of the sodium thiosulphate solution used for the sample, T is the normality of the sodium thiosulphate used, and W is the mass of the test sample in grams.

8) *Iodine value*

The mass of 0.2 g of butter and 150 mL of chloroform were mixed in 250 mL glass stopper bottle. Then, 25 mL of Wij's solution was then added and the whole solution was kept in the dark for 1 hour. Twenty mL of 10% potassium iodide, 150 mL of water and 2 mL of starch poison at 0.5% were added in the sample solution. Finally, the resulting mixture was then titrated with sodium thiosulphate solution at 0.1 N using starch as indicator just before the endpoint. A blank determination was performed alongside the butter samples.

Iodine value was calculated as following:

$$\text{Iodine value} = \frac{(V2 - V1) \cdot N \cdot 12.69}{W} \tag{6}$$

where, $V2$ = titer value for blank, $V1$ = titer value for sample and 1.269 = Concentration conversion coefficient and W is weight of sample (g).

9) *Saponification index and unsaponification matters were determined by the following formula:*

$$I_S = (v_0 - v_1) * c * 56.1 / m \tag{7}$$

With: v_0 is the volume of HCL solution used for titration during the blank test, v_1 is the volume of HCL solution used for titration during the sample test, c is the HCL concentration (0.5 M), and m the sample mass (2 g).

$$I_{US} = 100 * (m_1 - m_2 - m_3) / m_0 \tag{8}$$

With: m_0 is the initial mass of the sample, m_1 is the dry mass of the unsaponifiable value obtained, m_2 is the dry mass of the blank test, and m_3 is the dry mass of free fatty acids probably present and is equal to $v \times c$; where v is the volume of KOH/EtOH in mL and c the concentration at 1 M.

10) *Analysis of fatty acid profile in Gas chromatographic*

30 mg of sample were placed in a centrifuge tube, then 6 mL of cyclohexane and 12 mL 2 M KOH methanolic solution were added. The tube was vortexed for 2 min at room temperature and then centrifuged at 4000 rpm for 10 min (Tamb). 1.5 mL of the organic phase was collected, filtered into a vial, and injected into the chromatography apparatus. Analysis was performed in triplicates.

Analyses were done with a Perkin Elmer Clarus 590 chromatograph equipped with a capillary column and coupled to a Perkin Elmer Clarus SQ8S mass spectrometer. The detector is equipped with a 70eV electron impact ionization source. Analytical conditions were set up as follow:

- Injector: injection volume: 2 µL, injection flow rate: 1 mL/min, carrier gas: helium, injector temperature: 250˚C.
- Column: Elite-5MS length: 30 m, diameter: 250 µm, film thickness: 0.25 µm
- Furnace: Initial temperature 160˚C maintained for 10 min, then ramp from 160

to 190˚C (3˚C/min), isothermal for 5 min, then ramp from 190 to 232˚C (7˚C/min), and finally isothermal for 14 min.

- Mass spectrometer: transfer line: 200˚C, source temperature: 180˚C.

11) *Antioxidant activity determination*

The antioxidant activity of the moabi butter sample was tested according to the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay. The analysis was performed according to Huang *et al.* [14]. 2.5 mL of oil solution of various concentrations (0, 0.3875, 0.75, 1.5, and 3 mg/mL) prepared in methanol was added into 1.0 mL of methanolic solution of DPPH (0.3 mM) and kept in the dark at room temperature for 30 minutes. Ascorbic acid (Vitamin C) and Quercetin were used as control. The freshly prepared solutions of DPPH at a concentration of 10^{-4} M (4 mL) were added to the sample weight of 2 ± 0.1 mg. This mixture was vortexed for 20 s, and absorbance was measured at 517 nm in the UV-visible spectrophotometer (Model GENESIS 10) and then kept at room temperature. After incubation for 30 min, the decreases in absorbance at 517 nm were monitored for this sample. The radical scavenging activity was estimated from the difference in the absorbance of the methanolic DPPH solution with and without sample (control). The percent inhibition was calculated from the following equation:

$$\text{Inhibition } (\%) = \frac{A0 - A}{A0} \times 100 \tag{9}$$

where $A0$ is the absorbance of the control, and A is the absorbance of the samples.

12) *Anti-inflammatory activity*

In vitro anti-inflammatory activity of the moabi butter was measured according to the protein denaturation inhibition method described by Chandra *et al.* [15] with slight modifications. The reaction medium consisted of 0.1 mL of albumin and 1.4 mL of PBS (phosphate buffered saline/Tampon phosphate saline) as an initial concentration of 1 mg/mL, at pH 6.4. This concentration was then diluted with concentrations ranging from 1000 µg/mL to 66.7 µg/mL. The extract was replaced with an equal volume of distilled water in the control.

Once prepared, the reaction mixture was incubated at 37˚C for 20 minutes and then heated at 70˚C for 5 minutes. After cooling, the absorbances were measured at 660 nm. The percentage of inhibition was calculated using the following formula [16]:

$$\% = \frac{DO\,extract}{DO\,control} \times 100 \tag{10}$$

3. Results

3.1. Oil Extraction

The method used to extract butter in moabi seed displayed a yield of 30% (**Table 1**) based on the artisanal process currently used in Gabon.

3.2. Physicochemical Characteristics

The refractive index, specific gravity, and relative density obtained in this study

were: 1.464, 0.92, and 0.91, respectively (Table 2) for the analyzed samples. Whereas its iodine value was 16.26 (mg I/100g), saponification index: 200.5 (mg KOH/100g), Acid value: 38.76 (mg KOH/100g), peroxide: 6.6 (meq O_2/Kg) value and unsaponifiable matters: 1.52% (Table 2).

Table 1. Oil extraction rate for moabi butter.

Procedure	Extraction yield (%)
Soxhlet*	50.5
Artisanal	30.0
Artisanal/Soxhlet	59.4
*Loumouamou *et al.* (2012) [18]	

Table 2. Physico-chemical parameters of moabi butter.

Parameter	Average values
Refractometry index (20˚C)	1.464 ± 0.000
Specific gravity 20˚C (g/cm^3)	0.92 ± 0.001
Acid value (mg KOH/g)	38.76 ± 0.32
Iodine value (mg I/100g)	16.26 ± 1.59
Peroxide value (meq O_2/kg)	6.30 ± 0.23
Saponification index (mg KOH/g)	200.5 ± 6.82
Unsaponifiable matters (%)	1.52 ± 0.05

3.3. FTIR

FTIR is commonly used to evaluate oil quality parameters such as oxidation, nitration, water content, and soot content [17]. Figure 2 shows the obtained butter FTIR spectrum in absorption range of 4000 and 500 cm^{-1}.

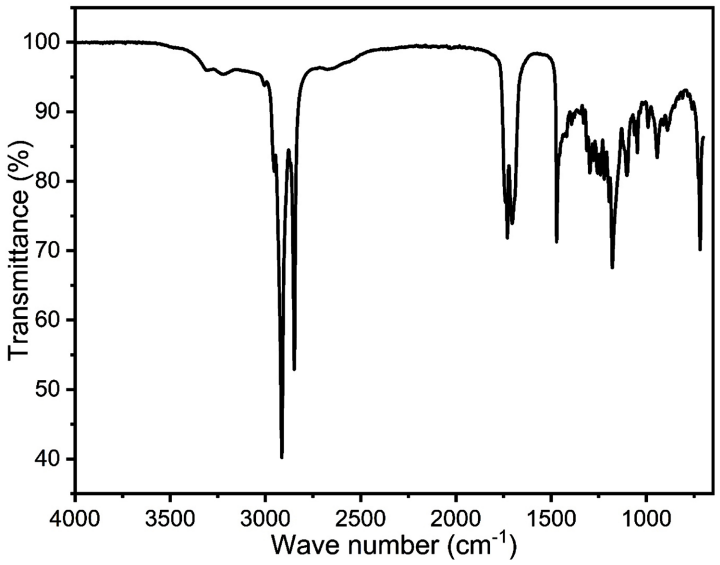

Figure 2. FTIR spectrum of moabi butter.

3.4. Fatty Acid Composition

Identifying fatty acid methyl esters was done by directly comparing the retention time and fragmentation pattern of each separated compound with the mass-spectra lipid library (Archive of Mass Spectra, NIST). The quantification was based on peak area integration. The results are illustrated and listed in Table 3, and Figure 3 and Figure 4.

Table 3. Fatty acid composition (% in total area of initial concentration) of moabi butter from GC/MS.

Fatty acid	Retention time (min)	Rate (%)
Saturated		
Palmitic C16:0	19.85 - 20.01	10.791 ± 0.239
Stearic C18:0	29.61 - 29.7	32.502 ± 1.164
Arachidic C20:0	35.95 - 36.02	0.584 ± 0.032
Monounsaturated		
Oleic C18:1	28.62 - 28.73	53.591 ± 1.748
Polyunsaturated		
Linoleic C18:3	28.24 - 28.33	2.532 ± 0.079

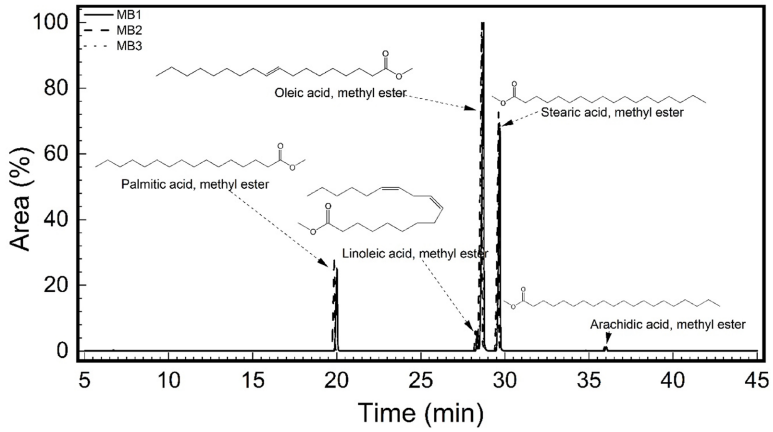

Figure 3. GC-MS chromatograms of peak area as a function of time (triplicates, *MB*1, *MB*2 *and MB*3). *MB*: moabi butter sample.

3.5. Biological Activities

In this study, both anti-inflammatory and antioxidant activities of moabi butter were characterized. The antioxidant activity is related to the content of natural compounds, such as tocopherols and diterpenes, that are concentrated in the UM fraction. Table 4 shows the values of IC_{50} for anti-inflammatory and antioxidant activities.

3.6. Thermal Characterization

A fast-thermal investigation of the raw material and results are shown in Figure 5.

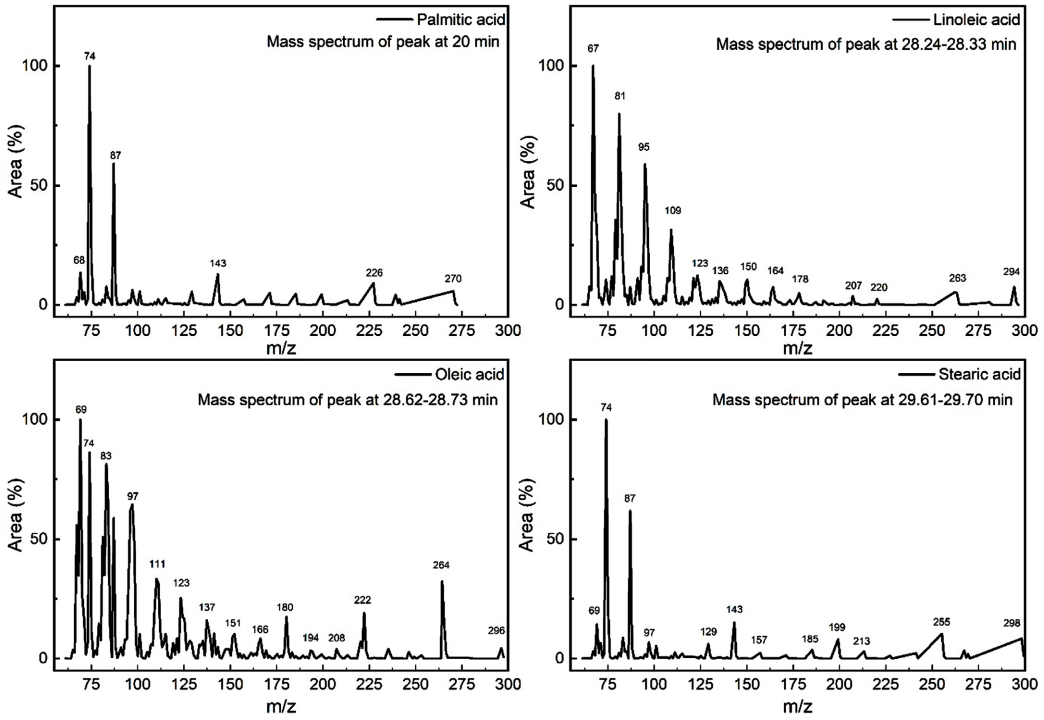

Figure 4. Mass spectrum profile of the main fatty acids-methyl ester form. Palmitic acid, methyl ester; Linoleic acid, methyl ester; Oleic acid, methyl ester and Stearic acid, methyl ester.

Table 4. Anti-inflammatory and antioxidant activities of moabi butter.

Activity	Inhibition activity as a function of concentration	R^2	IC_{50} (mg/mL)
Anti-inflammatory	y = 0.3108x + 25.15	0.99	79.95
Antioxidant	y = 0.3216x + 51.88	0.935	4.97

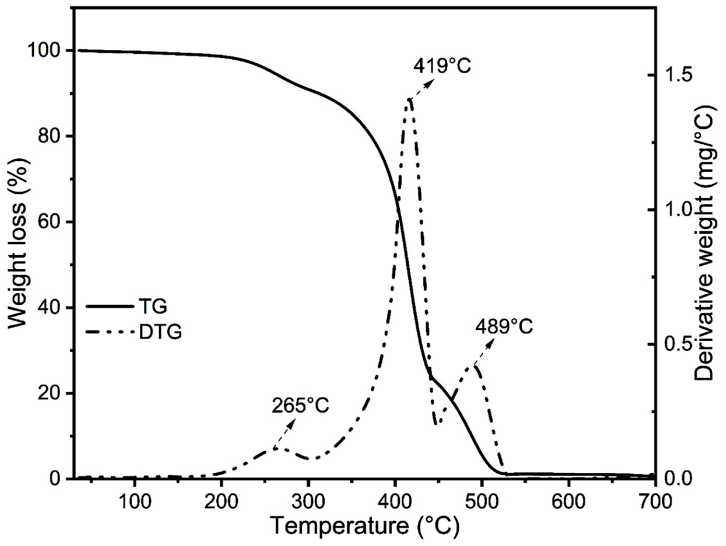

Figure 5. TG and DTG curves of moabi butter, from 30˚C to 750˚C under nitrogen atmosphere (20 ml/min).

4. Discussion

4.1. Extraction and Conventional Characterization

The moabi butter production yield with Soxhlet is higher than the artisanal production obtained by the operators of the NGO *Gabon Boutique* (**Table 1**). Nevertheless, this comparison suggests that a simple technique adapted to communities can be implemented to optimize production and provide a genuine source of income. According to the Soxhlet method, the yield should be around 50.5% [18]. However, the artisanal method performed an extraction yield of 30%. This study showed that the extraction method used has an oil yield of 59.6% of the lipids available. A yield of 30% is relatively low compared with those of [19] on moabi butter in the Cameroon region (East and South), who found yields ranged from 38.2 to 54.6%, with a mean value of 42.8%. This difference may be due to the process used by *Gabon Boutique* operators, who do not roast the raw material during extraction. In another study, non-conventional oilseeds, such as *Hibiscus sabdariffa* or *Griffonia simplicifolia*, presented yields of 13% and 28.40% [20]-[22]. These values are lower than those obtained in this study. In contrast, *Irvingia gabonensis* oil (Odika) has a higher yield at 34% [2] [23]-[25] while the specific gravity is 0.92 and is comparable to those obtained on the others [21]; which revealed a 0.911 kg/dm^3 density of *Griffonia simplicifolia*.

The refractive index was 1.464, similar to the values reported by Fungo *et al.* [19] and generally in the literature:1.44 to 1.48. This value is also close to the refractive indices of oils such as argan oil (1.463 - 1.472), sunflower oil (1.461 - 1.468), peanut oil (1.460 - 1.465), shea butter 1.462 - 1.465 [24] [26].

The acid value obtained in our study was 38.76 mg KOH/g of butter. This value is higher than the standard requirements for mg KOH/g oil on cold-pressed and virgin oils [26]. The work done by [19] gives acid values: 13.83 to 14.50 in the Eastern region and 14.17 to 14.87 in the Southern region of Cameroon. On other plant species, the acid value of oils is presented in very variable proportions. In 2006, Aboubacar [27] obtained an acid value of 4.2 for *Jatropha curcas*. [28] obtained 23.09 for *Griffonia simplicifolia* oil. According to [10], a low acid value indicates good-quality oil. The high acid value obtained may indicate poor oil quality and possibly be correlated with oxidation occurring during storage.

The peroxide value result was: 6.30 meq O_2 /Kg. This sample complies with the maximum 15 meq O_2/kg oil recommended by Codex Alimentarius [24] for virgin and cold-pressed oils. Compared with the values found on other moabi butter [19], which range from 2.13 to 2.69 in the South and 2.18 to 2.46 in the East of Cameroon, the peroxide value obtained in this study is higher than the latter. The same trend is observed for *I. gabonensis* oils (1.25 to 7.04 meq O_2/Kg) [2]. Consequently, the sample has not yet undergone any alteration, as their peroxide values are below 10 meq O_2/Kg [29], which characterizes most conventional oils and is generally considered to reflect an acceptable level of oxidation [30] [31]. According to Onyeike and Acheru [31] oils are rancid when the peroxide value is 20 to 40 meq O_2/kg; therefore, these two oils can be rancid probably due to their storage

conditions or self-life [29].

The iodine value obtained for our sample is 16.26. Overall, this value is well below the iodine values given by the Codex Alimentarius [24] [25] for common oils such as soybean (125 - 138), peanut (80 - 106), olive (75 - 95), castor (75 - 94) and palm oil (50.0 - 55.0). However, some of the iodine values obtained in this study corroborate the values of specific named vegetable oils. Compared with non-conventional oils such as moabi butter obtained [19] in the East (54.41 to 56.53) and South (56.89 to 57.98) zones of Cameroon, they are very low. The value of our sample is within the iodine index range of *Jatropha curcas* oil (10 - 18) [27] and close to *Griffonia simplicifolia* oil (13.38) [10] [21].

Based on the iodine value, they can be classified as drying, semi-drying, and non-drying oils. The results obtained allow moabi butter to be classified as non-siccative (II < 100), *i.e.*, edible [32] [33]. Novidzro *et al.* [21] assert that with a low iodine index, this oil can be preserved without too much risk of auto-oxidation and show that it does not contain much unsaturation [8].

The results show that the saponification index is 200 g KOH/g butter. This result could indicate the presence of fatty acids with carbon chains that are not too long, just as [34] indicated for *Citrullus colocynthis* oil (219), whose saponification value exceeds that of other vegetable oils such as olive oil (185 - 200), sunflower oil (188 - 194) and argan oil (189 - 193), as well as palm oil (190 - 209) [24]. As a result, this butter is highly suitable for use in soap-making. This index is closer to other oils than that mentioned by some authors for *Jatropha curcas* oil (194), and aiele oil (206.4) [35].

4.2. FTIR-ATR-GC/MS

In the analysis of the spectroscopic profile, it has been observed that the absence of the bands at 3009 cm^{-1} and the weak band at ~3005.7 cm^{-1} indicated a low content of linoleic acid or linoleic acyl group (**Figure 2**). The bands at 2915 cm^{-1} and 2849 cm^{-1} were assigned to the stretching vibration of aliphatic -CH from CH_2 and CH_3 groups of fatty compounds contained in moabi butter. Ester carbonyl functional group of the triglycerides (1731 cm^{-1}) and free fatty compounds shoulder (1702 cm^{-1}) were identified in this butter. The absence of C=C stretching vibration of cis-alkenes was noted, but bending in-plane vibrations of -CH from this group was identified (1396 cm^{-1}). The ester group was assigned to the band at 1195 cm^{-1}. 1297 - 1420 cm^{-1} were assigned to the bending vibration of -CH_2 or -CH_3. Furthermore, it appeared that moabi butter contains a low amount of linoleic acid (<3%) [36]. The three other main fatty compounds, namely oleic acid, palmitic acid, and stearic acid, are more predominant (>10%).

However, the presence of saturated, monosaturated, and polysaturated fatty acids in moabi butter (**Table 3**) has been checked by high-resolution gas chromatography. The moabi butter oil is similar to shea butter [37]. The oleic acid C18:1 is the major compound of the *Baillonella toxisperma* butter with 53.6%, a monosaturated fatty acid. Linoleic acid was the only one polysaturated fatty acid in the

moabi butter (C18:3) at 2.5% (Figure 3). Three saturated fatty acids were detected: palmitic acid (C16:0) (10.8%), stearic acid (C18:0) (32.5%), and arachidic acid (C20:0) (0.6%). The fatty acid profile of this butter was: % C18:1 > % C18:0 > % C16:0 > % C18:3 > % C20:0. So, both including oleic and stearic acids represent 85% of the total fatty acids. The content of saturated fatty acids (SFA) was 43.3%. The monounsaturated fatty acids (MUFA) level was 53.6%. The level of polyunsaturated fatty acids (PUFA) was 2.51%. This shows that this butter is an important source of monounsaturated fatty acids. However, an ANOVA analysis showed no significant difference in the amount of unsaturated and saturated fatty acids (*p-value* = 0.594, $F = 0.35$ *and* $F\ crit = 10.13$). The mass spectra of the main esterified acids clearly show that saturated and unsaturated have the same profiles between the same group, and at the level of each profile (Figure 4), from mass correlation from each profile, there is a repetitive values m/z: 13, 14, 30, 32 and a one-time m/z: 44; and correspond to the methylene and carboxyl groups respectively. These results are similar to those of Fungo *et al.* (2017) on moabi butter in Cameroon. According to these authors, the mean fatty acid contents were oleic (57.5%), stearic (36.3%), palmitic (4.5%), arachidic (0.5%), and linolenic (0.3%). However, the amount of palmitic acid in this study is twice as high as that of Cameroon moabi butter.

In terms of biological activities, antioxidant and anti-inflammatory activities displayed low levels (Table 4). Nevertheless, its high saponification index makes it a promising candidate for soap production and formulation of shaving creams [22] [38] or lubricants [39]. The determination of the iodine index in this study showed the presence of unsaturation and the non-siccativity of moabi oil. According to Hounkpe [22] non-siccative oils can be used effectively in cosmetics, specifically for normal and dry skin and are ideal bases for massage oils.

4.3. Thermal Stability

From the TG and DTG curves of moabi butter analyzed in inert and oxidative conditions, the thermal stability occurred in 3 steps. The first onset peak of degradation started at 191˚C and correspond to 1.23% of the total mass. At this stage, 98.77% of the initial mass was remained. This is the degradation of low molecular-weight products [39]. This first step has a maximum degradation at 262˚C and ends at 300˚C (91% of total mass remains). This reaction may indicate that the moabi butter contains low unsaturated fatty acids. Indeed, the total mass consumed in this stage represents 7.77% of the initial mass and indicates the thermal oxidative degradation of hydroperoxides and peroxides formed by oxygen and alkyl radical reactions from unsaturated fatty acids.

Continuously, the second stage of degradation started at 310˚C, reaching the maximum at 420˚C for a total decomposition at 451˚C (21% of the total mass remains). 70% of the initial mass is lost due to the degradation of the carbon chains of the fatty compounds. Decomposition of the third compound begins about 458˚C, reaching a maximum degradation at 489˚C, and is completely decomposed at 528˚C

(1% of total mass remains) and was assigned to the degradation of the carbonaceous waste oils. Based on these results, it is clear that Moabi butter is thermally stable and follows the general behaviors of thermal decomposition of vegetable oils in an oxidizing atmosphere (in two or three stages). Butter is stable up to about 200˚C and offers a wide range of uses and value-adding opportunities for art and industry. The DSC provided us with qualitative information on the shape of butter at temperatures below 100˚C. Thus, from DSC results, the melting point was around 55˚C, and the glass transition was between -10˚C and −7˚C.

5. Conclusion

This study comprehensively described the physicochemical characteristics, fatty acid composition, and antioxidant and anti-inflammatory properties of moabi butter. The research was initiated to promote the utilization of moabi butter in Gabon. The properties of the moabi butter extracted revealed that the seed kernel is a good source of butter that could be employed for industrial purposes. The butter extracted from the moabi seeds has interesting physicochemical properties, while the antioxidant and anti-inflammatory activities were modest. The high saponification value indicates its suitability for soap-making and other cosmetic uses. The low iodine value also suggests good oxidative stability, making it a durable option for long-term storage and use. The results suggest that moabi butter may be an alternative source for various industrial applications, including cosmetics and food products.

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Author Contributions

A.O: Conceptualization, conceived of the presented idea; conceived and planned the experiments, writing original draft, review, and editing; J.L.M: carried out the experiments, results analysis, A.B: Investigation, analysis, writing original draft; review and editing; J.M.: analysis and review; E.R: review and editing; S.M: methodology, investigation; C.E: project administration. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest for this investigation.

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