Physicochemical and rheological characterizations of *Cocos nucifera* L. and *Elaeis guineensis* Jacq. (Arecaceae) oils for black hair shampoo formulation

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ABSTRACT

Black hair suffers from a lipid deficiency, either on the surface with a decrease in sebaceous secretion or in depth with a lack of covalent bonds between the lipids and the cuticular cells. The result is a porous cuticle, a dull, rough hair that is difficult to untangle and breaks easily. The aim of this study was to evaluate properties of oils extracted from *Cocos nucifera* and *Elaeis guineensis* intended for the formulation of shampoos for black hair. Physicochemical and rheological analyses were carried out. Both oils showed a refractive index of 1.45 and melting points of 28 °C and 30 °C for coconut oil and palm kernel oil, respectively. The relative densities, moisture contents, saponification indexes, peroxide values, unsaponifiable matter contents, para-anisidine values were relatively similar while iodine and acid values were different. Both oils are rich in lauric, oleic and linoleic acids. These oils exhibited a Newtonian behavior and a dominant elastic nature after their melting temperature in the study conditions. They could constitute active ingredients for the formulation of shampoo for black hair in view of their different characteristics.
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Keywords: Physico-chemical analyses, rheological parameters, *Cocos nucifera* oil, *Elaeis guineensis* oil.

INTRODUCTION

Alopecia is a disorder that affects the hair follicle. It is defined by a scarcity or total hair loss. The latter can be diffuse or respect a certain topography. There are two main types of alopecia depending on the severity of the damage to the hair follicle: alopecia caused by permanent destruction of the hair follicle (scarring alopecia) and alopecia induced by transitory inhibition of the hair cycle (non-scarring alopecia) (Bernard, 2003), our main focus. In this second case, hair loss is initially reversible, and is likely to remain so if the patient is treated early.

Traumatic non-scarring alopecia is frequently found in women of African origin.

This includes hairdressing habits such as the use of too aggressive cosmetics, for their hair already dry, brittle, difficult to untangle and breaks easily (Yebga, 2015). In view of this observation, filmogenic cosmetic formulations that will sheath the hair and make styling easier are recommended. Oiling active ingredients to combat this hair dryness will also be of interest to black hair. Vegetable oils such as coconut and palm kernel oils have presented these advantages. Depending on the percentage and type of fatty acids they contain, the hair will benefit from their repairing or foam-forming effect (Yebga, 2015). Coconut (*C. nucifera*) and palm kernel (*E. guineensis*) vegetable oils, belonging to the family Arecaceae, have a similar application due to their similar chemical composition. Particularly lauric acid, the main fatty acid of these oils, has a low molecular weight that helps it to penetrate more easily into the hair cortex. This property is the source of its nutritive, film-forming and repairing effects (Keis et al., 2005).

Shampoo is a cosmetic product commonly used by women with African hair (Yebga, 2015) because they make the hair very soft and easy to manipulate. The formulation of shampoos based on these vegetable oils could reduce friction between the hair shafts, minimize frizz, and improve detangling and combing of black hair by combining the advantages of both shampoo and vegetable oils. These shampoos must take into account the particularities of black hair, as there are specific formulations linked to this type of hair (Yebga, 2015). The present work was devoted to the physicochemical and rheological characterizations of oils extracted from *C. nucifera* and *E. guineensis* intended for black hair shampoo formulation.

MATERIALS AND METHODS
Plant material

Coconut and palm kernel vegetable oils were obtained from a network of local cooperatives (RET-PACI) at Abidjan - Côte d'Ivoire. The cooperatives collected palm kernel seeds and coconut fruit from March to April 2018 and from the southern region of Côte d'Ivoire.

This network uses the cold press as a method of oil extraction. The coconut and palm kernel oils obtained were therefore virgin oils.

Determination of organoleptic characteristics

The organoleptic characteristics of coconut and palm kernel oils were assessed in accordance with Gharby's method (2012). Indeed, the color of the oils was assessed visually. The odor was determined by smelling the oil and the touch feeling was determined according to the appearance of the oils.

Determination of the fatty acid composition by GC-MS

The treatment of the oils consisted of transesterification, a chemical process in which a vegetable oil is mixed with methanol in the presence of sodium hydroxide to obtain fatty acid methyl esters (FAMEs). The FAMEs formed is recovered by liquid-liquid extraction by adding an excess of n-hexane to the methanolic mixture and then vigorously stirring the whole. The n-hexane fraction above the mixture saturates. It is therefore taken completely and analyzed through GC-MS. The hexane extraction process was followed by GC-MS analysis. This analysis was performed on a Perkin Elmer device, model Clarus 680GC 600C MS equipped with a Restek Rtx-5ms column 60 m in length, with an inside diameter of 0.25 mm and a film thickness of the stationary phase of 0.25 μm. Helium was used as the carrier gas at a fixed rate of 1 ml / min. The oven temperature was programmed at 100 °C for 4 minutes, then a gradient of 3 °C / min was applied up to 250 °C. This last temperature was maintained for 11 minutes for a total analysis time of 65 minutes. The temperature of the injector was set at 250 °C. The injection was performed in split mode with a ratio of 1:50. The mass spectrometer was set in the electron impact mode with an ionization source temperature of 250 °C, electron energy of 70 eV, a scan rate of 200 scans / min, and a scan range of 70 and 600 m / z. After each GC-MS

analysis, the identified fatty acids were quantified and the recovery rate was deduced from the initial mass of oil taken. The calculated recovery rate was approximately 80%. This test was triplicated in order to optimize the recovery of FAME. Values are expressed as relative percentage of total fatty acids with the mean ± standard deviation.

Biochemical characterization
Moisture content
The OHAUS MB35 Infrared Moisture Analyzer was used to evaluate the moisture content in the oils. Three tests have been conducted.

Saponification, iodine, acid, peroxide, para-anisidine and unsaponifiable matter content indexes
The French standards NF ISO 661-1980, NF ISO 3961, NF EN ISO 660, NF T 60-220, NF EN ISO 6885 and NF T 60-205 (Association Française de Normalisation, 1984) were used to determine the saponification, iodine, acid, peroxide, para-anisidine and unsaponifiable matter contents respectively. The results are the mean values obtained from each test repeated three times.

Physical characterization
Density
The density was determined by the ratio of the density of oil to water at 40 °C (Codex Alimentarius Commission, 2019). This test was triplicated for relevant analysis.

Refractive index
The refractive index was determined according to the French standard NF ISO 6320 (Association Française de Normalisation, 1984). The refractive index was determined at 40 °C using a thermostatically controlled Abbe refractometer. This test was repeated three times.

Differential Scanning Calorimetry (DSC)
Differential scanning calorimetry of coconut and palm kernel oils was measured by DSC 1 Mettler Toledo over a temperature range of -50 to 70 °C at 2 °C min^{-1} under a nitrogen atmosphere (20 mL min^{-1}). We weighed 3-4 mg of each oil into a hermetically

sealed aluminum dish. An empty, sealed aluminum dish was used as a reference. The sample was heated to 25 °C and cooled to -50 °C at 5 °C min^{-1}, then kept isothermal at -50 °C for 1 min before being heated to 70 °C at 5 °C min^{-1}. The melt profiles of the samples were produced by the STAR software. The data were integrated on the basis of this software in the TA tab. The melting start and end temperatures as well as the melting enthalpies were determined based on the values of the melting curves. The enthalpy of fusion (DH) was calculated on the basis of the peak areas integrated on the melting zones. The analysis was triplicated.

Determination of rheological characteristics of oils
Viscosity
The rheological properties were determined using a Thermo Haake Viscometer with a cone-plane geometry and MV/DIN mobile. Measurements were made at 25, 30, 35 and 40 °C and the temperature was controlled by a thermostatic bath coupled to the rheometer.

For process control and data logging, the Rheowin Job Manager Pro software was used. The rheograms were obtained by varying the shear rate from 0 to 300 s^{-1} for 60 seconds. All measurements were performed three times, using a new sample each time, and the average value of the repetitions was used to calculate the rheological parameters. Modelling was performed using the Newton and Ostwald-de Waele models. The equations corresponding to these models are as follows:

Newton: $\tau = \mu \gamma$ (1)

Ostwald-de Waele: $\tau = K \gamma^n$ (2)

Where: τ = shear stress (Pa); γ = shear velocity (s^{-1}); n = flow index; K = consistency index ($Pa.s^n$); μ = viscosity (Pa. s)

Elastic G' and viscous G'' modules
Rheological studies were conducted to determine the flow properties, melting temperatures and viscoelastic properties of butters.
The rheological measurements were performed on the KINEXUS rotational rheometer

MALVERN INSTRUMENTS connected to rSpace data processing software, using a 20 mm plane cone geometry, 2° truncations, with a 1 mm Gap and equipped with a cover to cover the exposed surface of the samples to prevent drying. The butter samples were analyzed over a temperature range of 10 °C to 50 °C with a heating rate set at 5 °C per minute, under 1% deformation and at a frequency of 1 Hz. Measurements in oscillatory mode were performed to determine the moduli G' (elastic) and G'' (viscous) according to temperature. G'' describes the viscous character where the energy is dissipated during the cycle. G' reflects the solid component or elastic behavior. The higher the G' value, the more dominant the elastic character and conversely, the higher the G'' value, the more dominant the viscous properties. The evolution curves of these moduli according to temperature made it possible to assess the viscoelastic character as well as the melting temperature of the studied butters. All the measurements were repeated three times.

RESULTS

Determination of organoleptic characteristics

The palm kernel oil extracted from the seeds of *Elaeis guineensis* (Arecaceae) was a liquid or waxy consistency depending on the temperature, yellowish with a palm odor.

The coconut oil extracted from the fruit of *Cocos nucifera* L. (Arecaceae) is of a liquid or waxy consistency depending on the temperature, whitish, with a fragrant odor.

Determination of the fatty acid composition by GC-MS

The coconut oil is of the saturated type (90.20 ± 0.25% saturated fatty acids). It's composed mainly of lauric (45.60 ± 0.35%), myristic (18.96 ± 0.01%), palmitic (9.27 ± 0.12%), oleic (7.92 ± 0.18%), stearic (2.84 ± 0.06%) and linoleic (1.78% ± 0.06%) acids (Table 1).

Palm kernel oil is also of the saturated type (82.08 ± 0.02% of saturated fatty acids), composed of lauric (46.63 ± 0.01%), myristic

(16.26 ± 0.02%), oleic (15.40 ± 0.02%), palmitic (8.48 ± 0.01%), stearic (2.89 ± 0.00%) and linoleic (2.30 ± 0.01%) acids (Table 1).

Biochemical characterization

The palm kernel and coconut oils were of good quality criteria because their moisture contents and their acid, peroxide and anisidine values respected the standards (Table 2).

Physical characterization

The densities and refractive index of both oils were comparable but the onset melting temperature and the peak melting temperatures were different (Table 3).

Determination of the rheological characteristics of butters
Viscosity

The oils showed a linear behavior during flow (Figure 1) showing their Newtonian character, also highlighted by the values of the flow index (n) close to 1, provided by the Rheowin Job Manager Pro software and listed in Table 4 (Silva et al., 2015).

The viscosity of these vegetable oils is inversely proportional to temperature up to 40 °C with a higher viscosity of palm kernel oil at all temperatures (Ollivier et al., 2015) (Figure 2).

Elastic G' and viscous G'' modulus

Figure 3 illustrates the elastic (G') and viscous (G'') behavior of both oils as a function of temperature. There was the predominance of the viscous character of coconut oil over the elastic character up to 24 °C (melting temperature of the oil); above this melting temperature, a dominant elastic character after their melting temperature was observed. For palm kernel oil, the viscous character predominated up to 33 °C (above its melting temperature 30 °C) and after 33 °C, palm kernel oil showed the same behavior as coconut oil. These oils showed a dominant viscous character until their melting temperature but after an elastic behavior of both oils was predominant.

Table 1: The coconut and palm kernel oil fatty acids composition by GC-MS (%).

Fatty acids	Coconut oil	Palm Kernel oil
Caprylic acid 8:0	7.70 ± 0.05	3.95 ± 0.00
Capric acid 10:0	5.77 ± 0.04	3.59 ± 0.00
Lauric acid 12:0	**45.60 ± 0.35**	**46.63 ± 0.01**
Myristic acid 14:0	18.96 ± 0.01	16.26 ± 0.02
Palmitic acid 16:0	9.27 ± 0.12	8.48 ± 0.01
Stearic acid 18:0	2.84 ± 0.06	2.89 ± 0.00
Oleic acid cis 18:1n-9	**7.92 ± 0.18**	**15.40 ± 0.02**
Oleic acid trans 18:1n-7	0.11 ± 0.00	0.13 ± 0.00
Linoleic acid 18:2n-6	**1.78 ± 0.06**	**2.30 ± 0.01**
Arachidic acid 20:0	0.07 ± 0.00	0.13 ± 0.00
Gadoleic acid 20:1n-9		0.10 ± 0.01
Behenic acid 22:0		0.07 ± 0.00
Lignoceric acid 24:0		0.08 ± 0.00
SFA	**90.20 ± 0.25**	**82.08 ± 0.02**
MUFA	**8.03 ± 0.18**	**15.62 ± 0.03**
PUFA	**1.78 ± 0.06**	**2.30 ± 0.01**
UFA	**9.81 ± 0.24**	**17.92 ± 0.04**

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acid; UFA: unsaturated fatty acids. Les valeurs représentent la moyenne ± écart type, n=3. This Table shows the fatty acid composition of coconut and palm kernel oils obtained by GC-MS analysis.

Table 2: Moisture, indexes and unsaponifiables of palm kernel and coconut vegetable oils.

Vegetable oils	Palm kernel oil	Coconut oil
Moisture content (%)	0.1 ± 0.1	0.1 ± 0.1
Saponification Index (mg of KOH/g of oil)	275 ± 21	287 ± 14
Iodine Index (g of I$_2$/100 g of oil)	16 ± 03	8 ± 03
Acid Index (mg of KOH/g of oil)	06 ± 01	03 ± 01
Peroxide Index (meq of O$_2$/kg)	05 ± 02	03 ± 02
Para anisidine Index	10 ± 02	07 ± 03
Unsaponifiable matter content (%)	0.4 ± 0.3	0.2 ± 0.1

Les valeurs représentent la moyenne ± écart type, n=3. This Table includes the different results of the biochemical characterization carried out on these oils, including moisture content, indexes and unsaponifiables.

Table 3: Densities, refractive indexes, melting enthalpies and temperatures of palm kernel and coconut vegetable oils.
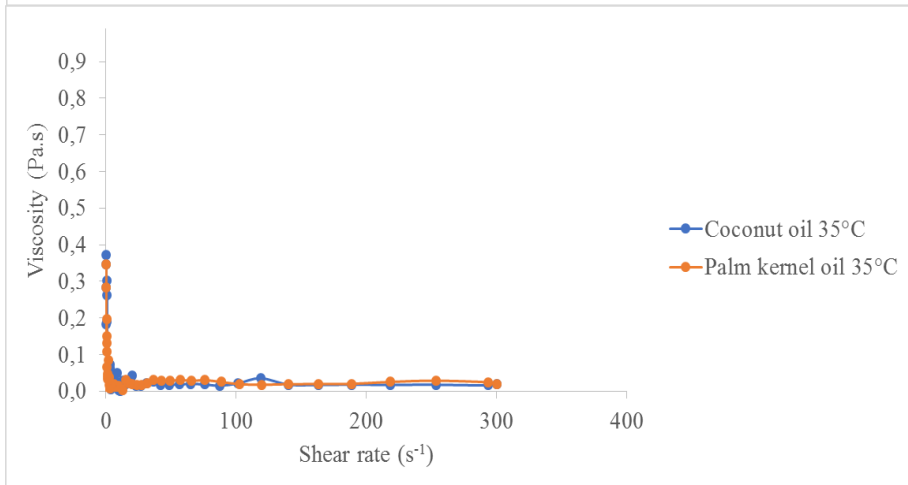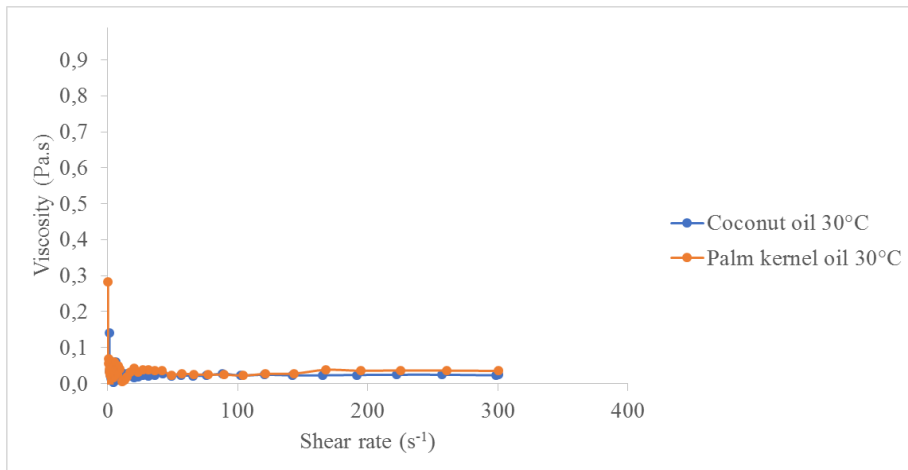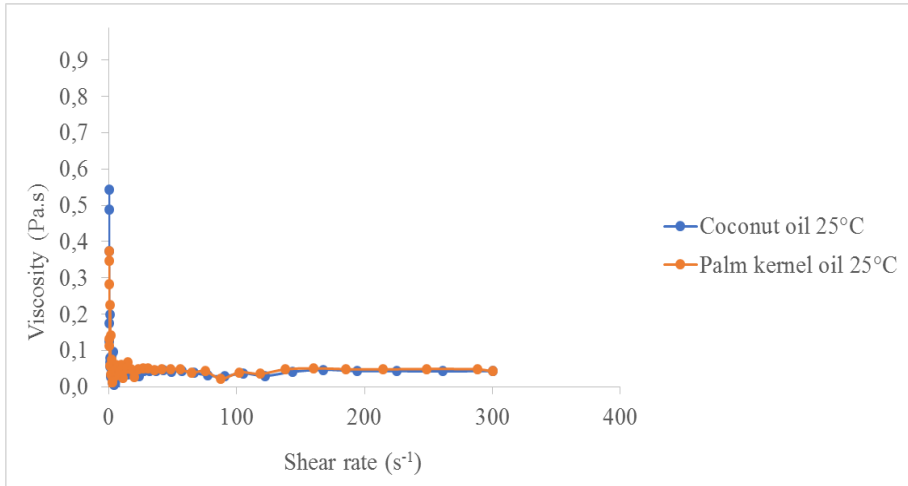
	Palm kernel oil	Coconut oil
Density (40°C)	0.87 ± 0.03	0.89 ± 0.03
Refractive index (40°C)	1.45 ± 0.00	1.45 ± 0.00
Onset melting temperature (°C)	28.13 ± 0.17	11.62 ± 1.32
Peak melting temperature (°C)	29.78 ± 0.17	24.07 ± 0.57

Les valeurs représentent la moyenne ± écart type, n=3. This Table summarizes the densities, refractive indexes, melting enthalpies and temperatures of palm kernel and coconut vegetable oils.

Table 4: Rheological parameters of vegetable oils, experimental data from rheological models.

T°C	Oils	Models				
		Newton $\tau = \mu\ \gamma$		**Ostwald-de Waele** $\tau = K\ \gamma^n$		
		μ (mPa.s)	R^2	K	n	R^2
	Palm kernel 1	24	0.99	0.012	1.109	0.99
40 °C	Palm kernel 2	25	0.95	0,019	1.045	0.99
	Coconut 1	23	0.98	0.009	1.175	0.99
	Coconut 2	23	0.98	0.023	0.990	0.99
	Palm kernel 1	28	0.99	0.015	1.114	0.99
	Palm kernel 2	33	0.99	0.030	1.019	0.99
35 °C	Coconut 1	25	0.98	0.028	1.215	0.99
	Coconut 2	28	0.98	0.045	0.913	0.99
	Palm kernel 1	34	0.99	0.023	1.076	0.99
	Palm kernel 2	44	0.98	0.021	1.136	0.99
30 °C	Coconut 1	31	0.99	0.020	1.085	0.99
	Coconut 2	34	0.98	0.030	1.023	0.99
	Palm kernel 1	40	0.99	0.026	1.084	0.99
25 °C	Palm kernel 2	56	0.98	0.045	1.042	0.99
	Coconut 1	37	0.99	0.035	1.011	0.99
	Coconut 2	52	0.98	0.033	1.084	0.99
20 °C	Coconut 1	61	0.99	0.043	1.066	0.99
	Coconut 2	59	0.99	0.041	1.009	0.99

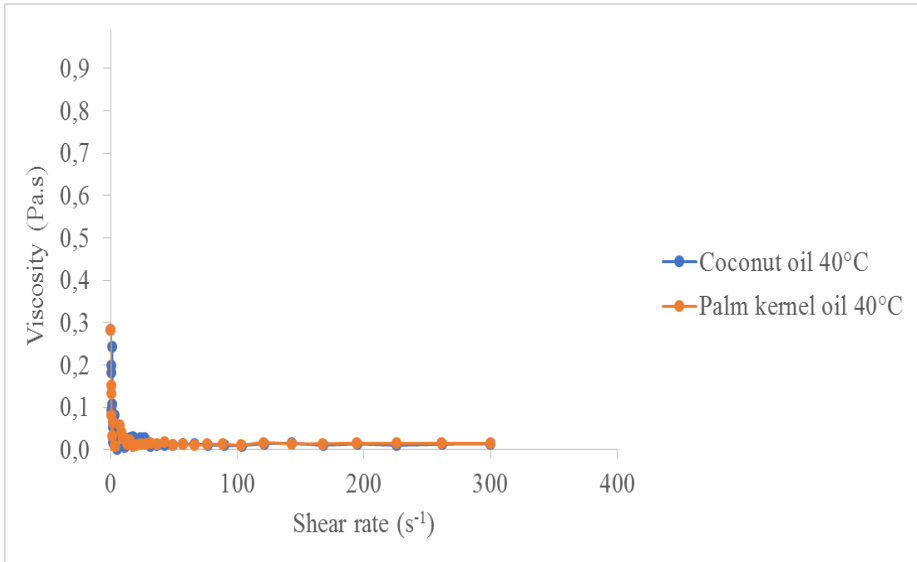Les valeurs représentent la moyenne ± écart type, n=3.

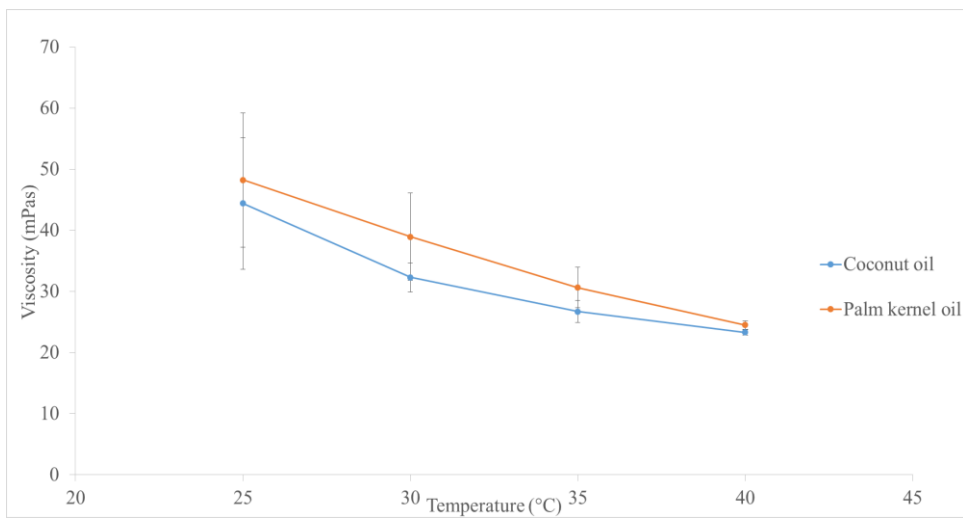**Figure 1:** Viscosity of palm kernel and coconut oils depending on shear rate at 25, 30, 35 and 40°C.

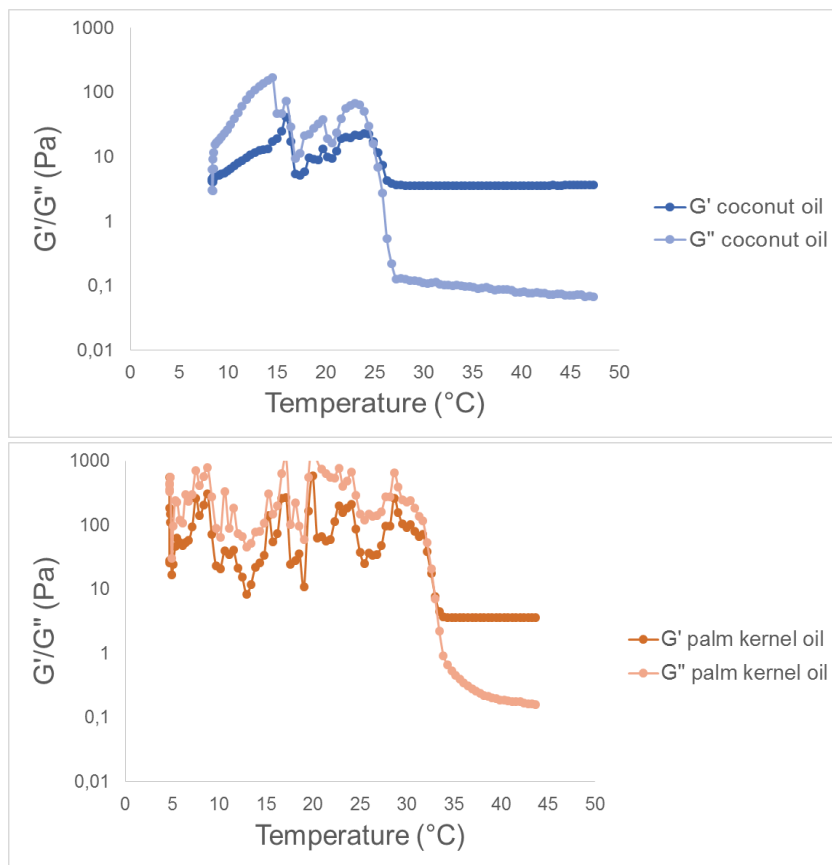**Figure 2:** Viscosity of palm kernel and coconut oils according to temperature.

Figure 3: Modulus G' and G" of palm kernel and coconut oil according to temperature.

DISCUSSION

It is important in the development of a formulation to ensure the quality of the raw materials used. The organoleptic and physicochemical characteristics are indicators of their quality. Thus, in this work, the study of the organoleptic characteristics of these oils was carried out and compared with previous studies. Rakotomalala (2008) had found a white or slightly yellowish-white color of the palm kernel oil. This result was in agreement with ours. This yellow color of palm kernel oil could be due to the presence of carotene (carotenoids) (Nessa et al., 2004). Coralie (2015) had described a virgin coconut oil to be white-ivory color identical to the one in this present study. The coconut oil is liquid at a temperature above 24 °C but because of its high saturated fatty acid triglyceride content, it becomes a waxy whitish mass below 24 °C. This is why it is called coconut oil in tropical countries and coconut butter in more temperate areas (Coralie, 2015). This fact could explain the fluid character of palm kernel and coconut oils observed in Abidjan (Côte d'Ivoire) but waxy in Dijon (France). Based on this result, in the shampoo formulation, a preliminary heating step will be necessary if the oil is solidified.

The composition of fatty acids content of both oils was carried out by GC-MS analysis. The carbon chain of palm kernel oil (C24) was longer than that of coconut oil (C20). Pantazari and Ahmad (2004) showed

that the main fatty acids of palm kernel oil were lauric acid (48%), myristic acid (16%) and oleic acid (15%) in accordance with our study. Deffan et al. (2012) also found these same major fatty acids in their study concerning determination of the fatty acid composition of coconut oil. We obtained a similar fatty acid composition in both oils (Table 1). Palm kernel oil is comparable to coconut oil due to its composition (Pantazari and Ahmad, 2004).

Lauric acid, the main fatty acid identified in these two oils has a good affinity to hair proteins, because it is polar like keratin, the protein that makes up hair (Ruetsch et al., 2001). Due to its low molecular weight (< 1000 Da), lauric acid would be able to penetrate the hair cuticle, as well as the cortex.

Moreover, essential fatty acids (oleic and linoleic acids) were found in these oils. Linoleic acid is believed to induce hair growth in the scalp and eyebrows (Prager et al., 2002). It is an inhibitor of 5-alpha reductase (Goldberg and Lenzy, 2010), the hormone that converts circulating testosterone in the hair follicle into the active metabolite dihydrotestosterone (DHT), which is responsible for the disruption of the anagen phase (Yebga, 2015). Some experts showed that oleic acid (omega 9) increase the brightness and partial repair of damages caused by external agents such as hair straighteners. This acid makes hair grow faster. The presence of these acids could therefore be favorable in hair care (Miquelino, 2017).

After the determination of the chemical composition in fatty acids, other biochemical parameters of these oils were evaluated among others moisture content, indexes and unsaponifiables.

Moisture content is very little in both oils (0.1%) (Table 2). Coralie (2015) had obtained moisture content less than 0.1% for virgin coconut oil. For palm kernel oil, Udeh and Obibuzor (2017) reported a moisture content value of 0.51%. Our results are relatively similar to those of Coralie (2015) for coconut oil but significantly lower than those of Udeh and Obibuzor (2017) for palm kernel oil. This relatively low moisture content of the oils could be explained by a good drying method of the mill and a cold press method of extraction of these oils.

The saponification indexes were 275 mg KOH/g for palm kernel oil and 287 mg KOH/g for coconut oil (Table 2). The results of the saponification indexes of the two oils were different from those of the codex alimentarius (2019): 230 - 254 mg KOH/g for palm kernel oil and 248 - 265 mg KOH/g for coconut oil. The high saponification indexes of oils would thus testify to the length of their carbon chain of fatty acids. The higher is the saponification number, the richer in fatty acids with short length of carbon chain is the oil. This was observed in both oils and would be the reason why they are mostly used in soap making and as raw material in the production of many surfactants (Marina et al., 2009). These oils could constitute the oily phase of shampoo formulations and thus promote their stability by this characteristic.

The iodine index determines the degree of unsaturation of fatty acids. The iodine value was 16 g I_2/100 g for palm kernel oil (Table 2) while Udeh and Obibuzor (2017) reported an iodine value of 60.80 g I_2/100 g. The iodine value of 08 g I_2/100 g was found in our study for coconut oil, identical to that of Marina et al. (2009). The iodine values of both oils were in accordance with those of the codex alimentarius (2019): 14 - 21 g I_2/100 g for palm kernel oil and 6.3 - 10.6 g I_2/100 g for coconut oil. These values are lower than those of unsaturated sunflower oil (128.0 g I_2/100 g) (Bachheti et al., 2012), thus indicating the low content of unsaturated fatty acids in the different oils, which is more indicative of their saturated character. These results confirmed the refractive index results of these oils which showed the presence of saturated molecules in the majority.

The acid number indicated the level of deterioration and spoilage of the oils (Abiodun et al., 2014). The acid indexes were 06 for palm kernel oil and 03 for coconut oil respectively (Table 2), while the standard set by the codex alimentarius is 4 mg KOH/g for cold-pressed oils except for crude palm kernel oil. Our results are in agreement with those of the codex alimentarius because our oils were extracted by using the cold pressing method.

The peroxide index has shown the concentration of peroxides formed during the early stages of lipid oxidation, a quality criterion of the oil that also indicates its stability (Ni et al., 2015). The peroxide value was 05 meq O_2/kg for palm kernel oil (Table 2), slightly higher than that of Udeh and Obibuzor (2017) who reported 4.26 meq O_2/kg. The peroxide value of coconut oil was 03 meq O_2/kg (Table 2), higher than that of virgin coconut oil which was 0.27 meq O_2/kg in the work of Marina et al. (2009) and smaller than that of *Averrohoa carambola* seed oil which was 16 meq O_2/kg in the study of Samuel et al. (2016). The codex alimentarius value for unrefined vegetable oils is 15 meq O_2/kg. The peroxide value characterizes the ability of an oil to oxidize and thus become rancid. The peroxide values of the oils were low, indicating the primary oxidative stability of these oils (Marina et al., 2009). It is important to combine the measurement of the peroxide value and the para-anisidine value for a true assessment of the oxidation state of the oil.

The determination of the para-anisidine index has been a reliable indicator of the rancidity of fats (Van et al., 2004). There is no normal value indicated in the Codex alimentarius unlike the peroxide value. For some authors, oil should have a para-anisidine value of less than 10 (Marina et al., 2009). This index has not unit. The oils studied presented para-anisidine indexes that met the standard. They were 10 for palm kernel oil and 07 for coconut oil respectively (Table 2). It thus

appears that our oils are of good quality but the value of the para-anisidine index of the palm kernel oil, very close to the normal value, must call our attention to the beginning of a slight secondary oxidation. The storage conditions of these oils should be reviewed as they were kept at room temperature and in the light.

The unsaponifiable matter contents recorded with both oils are 0.4% and 0.2% for palm kernel oil and coconut oil respectively (Table 2). This result (0.2%) differs from that of Coralie (2015), who obtained an unsaponifiable matter content of 0.5% for virgin coconut oil. The unsaponifiable matter content of both oils was approximately comparable.

Furthermore, to the evaluation of the biochemical parameters, the determination of the physical characteristics has been performed. The densities of both oils were similar (Table 3).

The density of coconut oil obtained was relatively in agreement with those of Coralie (2015) who obtained a relative density of 0.90 at 40 °C for virgin coconut oil in his study. The density results of the two oils were also similar to those of the codex alimentarius: 0.90 - 0.91 for palm kernel oil and 0.91 - 0.92 for coconut oil. These results were in agreement with our results.

These two oils have the same refractive index (1.45) (Table 3). The refractive index obtained for coconut oil was in accordance with the work of Coralie (2015) who also obtained 1.45. The refractive indexes of the two oils were also similar to those of the codex alimentarius which was 1.45 for both oils. This result was different to studies of Novidzro et al. (2019) and Opoku-Boahen et al. (2013) who found respectively a value of 1.47 for the refractive index of *Griffonia simplicifolia* seeds oil and *Citrullus colocynthis* seeds oil. The refractive index varies according to the degree of unsaturation and the length of the carbon chain of fatty acids

in the sample (Nehdi et al., 2012). The higher is the refractive index, the more are unsaturated molecules.

Also, there was a later onset melting temperature of palm kernel oil, then an endothermic peak at 30 °C for palm kernel oil and 24 °C for coconut oil respectively (Table 3).

Besides to the evaluation of the physicochemical characteristics, the analysis of the rheological parameters of these oils has been achieved. The Newton and Ostwald-de Waele models have been used for the rheological evaluation of oil extracts (Table 4) because they are suitable for representing the rheological behavior of vegetable oils (Silva et al., 2015).

For most fats, the viscosity is between 50 and 80 mPa-s at 20 °C according to Ollivier et al. (2015). This result is in agreement with our work as coconut oil had a viscosity of 60 mPa-s at 20 °C. The viscosity of palm kernel oil could not be measured at 20 °C as it had already solidified. Below this temperature, heating the palm kernel oil would be recommended to keep it fluid for shampoo formulation.

In addition, the rheograms obtained (Figure 1) supported the previous results. A Newtonian behavior of these oils during a shear rate of 10 s^{-1} to 300 s^{-1} at all temperatures (25, 30, 35 and 40 °C) was demonstrated. The data obtained are consistent with the studies described in the literature (Franco and Nguyen, 2011). When the relationship is linear, the fluid is Newtonian and the viscosity is constant regardless of the rate of stress applied. This observation was made for these oils. It would suggest that the increase in shear during shampoo formulation has no influence on viscosity of the shampoo because oils have higher influence on the rheological behavior of emulsions (Akhtar et al., 2009).

Rheology studies have also shown the predominance of the viscous character of coconut oil over the elastic character up to 24 °C (melting temperature of the oil); above this melting temperature, a dominant elastic character after their melting temperature was observed (Figure 3). For palm kernel oil, the viscous character predominated up to 33 °C (above its melting temperature 30 °C) and after 33 °C, palm kernel oil showed the same behavior as coconut oil. These oils showed a dominant viscous character until their melting temperature but after an elastic behavior of both oils was predominant (Figure 3).

Conclusion

During this study, physicochemical and rheological characteristics of palm kernel and coconut oils have been studied. It was found that the oils studied presented good quality criteria as the acid, peroxide and para-anisidine indices met the standards.

In addition, they had a high saponification index giving them interesting surface-active properties for shampoo formulations.

The presence of lauric acid in the oily extracts was revealed, suggesting a good affinity of these oils to hair proteins, which are able to penetrate the cuticle and cortex of the hair, due to their low molecular weight (< 1000 Da).

Moreover, linoleic acid has been identified, which is believed to promote hair growth in the scalp and eyebrows.

The oily extracts showed a viscous or elastic character depending on the temperature with a dominant elastic character after their melting temperature.

In conclusion, palm kernel and coconut oils could be used as anti-alopecia active ingredients due to their richness in lauric, oleic and linoleic acids, in shampoo formulations because they have high saponification indices giving them foaming capacity.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

ANT-K and KCN-G designed the study; ANT-K, MKK and SAAA-A-G performed all the experiments; LCAK, ILD, AN and KRDN-C analyzed the data; JAL, PAK and ANT-K wrote the paper with input from all authors.

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