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Research Article

A Comparative Study of the Physicochemical Properties of Oils Extracted from Common Species of the Niger Delta *Raphia* Palm Fruits and *Elaeis guineensis*

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Abstract

Elaeis guineensis oils (palm oil and palm kernel oil) are versatile ingredients widely used in food applications as well as in the industrial production of biofuels and other oleochemicals. Global demand for *Elaeis guineensis* oils is increasing and has surpassed other vegetable oils. In many nations such as Nigeria, the demand outweighs the supply. Consequently, the prices of the oils have been relatively high and there is high demand for land for the cultivation of the palms. However, *Elaeis guineensis cultivation* has been noted for several environmental, climatic and social challenges. Based on these reasons, concerted efforts are being made to search for a promising feedstock that can either be used in conjunction with or as an alternative to *Elaeis guineensis* oils. In this study, oils were extracted from the mesocarp of common species of the Niger Delta *Raphia* palm fruits (*Raphia farinifera*, *Raphia hookeri* and *Raphia vinifera*) as wells as the mesocarp and kernel of *Elaeis guineensis* fruits. The potentials of using each of the *Raphia* palm oils as an alternative to *Elaeis guineensis* oils were evaluated based on standard physiochemical properties obtained using standard analytical techniques. The study showed that oils extracted from common species of the Niger Delta *Raphia* palm fruits and are very similar to *Elaeis guineensis* oils in many aspects. However, most of the physiochemical properties results showed that oils extracted from common species of the Niger Delta *Raphia* palm fruits are more suited as replacement to *Elaeis guineensis* oils in the production of biofuels and other oleochemicals than for food or edibility purposes.

Keywords

Elaeis guineensis, *Raphia* Palm Fruits, Oils, Niger Delta, Physiochemical Properties, Biofuels, Oleochemicals, Food

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1. Introduction

Plant oils have been very useful to mankind from time immemorial. Plant oils are renewable natural resource providing food and necessary nutritional resources for human health as well as bio-fuels and high valued chemical feedstock and products for human usage [1-4].

Plant oils consumption has increased drastically over the years [5-8]. A significant fraction of the global oil production and consumptions comprises palm oil, soybean oil, rapeseed oil, sunflower seed oil, palm kernel oil, peanut oil, corn oil, cottonseed oil, coconut oil and olive oil (Figure 1). Among these, the palm oil (PO) and palm kernel oil (PKO) are unique and significant [9-11].

Palm oil and palm kernel oil are vegetable oil products from the oil palm tree (*Elaeis guineensis)*. Palm oil is obtained from the mesocarp of oil palm fruits, while the palm kernel oil is extracted from the kernel of the oil palm fruits. *Elaeis guineensis* is a palm species popularly called African oil palm [10, 12-15]. Oil palms originated from tropical rain forest of Africa [10, 15], from where it spread to South-East Asia and Latin America (Figure 2a). However, South-East Asia are the highest producer of *Elaeis guineensis* oil (Table 1). In Nigeria, *Elaeis guineensis* is predominantly found in Niger Delta and neighbouring South-East and South West zones [9, 16-18]. The following are the highest *Elaeis guineensis* oil producing states in Nigeria: Edo State, Delta State, Ondo State, Osun State, Cross Rivers, Rivers State, Akwa Ibom, Imo State [19]. Other states where the oil is produced in Nigeria include; Anambra State, Ebonyi State, Abia State, Ekiti State, Oyo State, Ogun State, Enugu, Kogi State, Taraba State among others.

Global demand for *Elaeis guineensis* oils is increasing fast and has surpassed other vegetable oils (Figure 1) and in Nigeria (Figure 3), the demand outweighs the supply [20-22]. Palm Oil, Palm Kernel Oil and their fractions are versatile ingredients widely used in the food applications as well as in the industrial production of biofuels and other oleochemicals [7, 8, 23-27].

The demand for *Elaeis guineensis* oils for food and industrial applications will continue to increase due to increase in world's population and the increase in global demand for environmentally friendly products (biofuels and oleochemicals) as well as the increase in prices of fossil fuels and petrochemicals [28, 30]. Biofuel and oleochemicals are increasingly being used as substitutes to petro fuels and petrochemical respectively because they renewable, sustainable, eco-friendly and non-toxic with high biodegradability [3, 23, 31-33]. *Elaeis guineensis* -based oleochemicals also have wide range of applications [34, 35].

Although *Elaeis guineensis* oils are the world's most efficiently produced vegetable oils, their prices (Figure 4) have been relatively high due to high demand [36-38]. The prices and the rapid growth in the worldwide demand for *Elaeis guineensis* oils has led to increase in the demand for more land for the cultivation of palm. This has raised considerable global concerns because *Elaeis guineensis* cultivation has been associated with negative impacts [39-43] that include the following:

a) Environmental risks (Deforestation, Biodiversity Loss, Release of Greenhouse Gases, Transboundary Haze, Soil Impoverishment etc.).
b) Climate Risks (clearing and burning of lands for *Elaeis guineensis plantations* increases carbon footprint, which in turn results to increasing global temperatures and rising sea levels),
c) Social Risks (Land Grabbing, conflicts, Harassment and displacement of Indigenous peoples, Loss of access to forest provisioning services such as food and medicine, social unrest etc.)

The aforementioned reasons justify the current efforts at searching for promising feedstock that can be used either in conjunction with or as an alternative to *Elaeis guineensis* oils.

The Niger Delta region of Nigeria, in which oil palms can be found, comprises hundreds of plant species belonging to several families [44], some which contains oils [45-47]. Among these families is the Arecaceae or palmae (the palm family) to which the oil palm or *Elaeis guineensis belong* [10]. Other palms found in the Niger Delta include *Cocos nucifera* [48]; *Nypa Jruticans* [49-51]; *Phoenix reclinata* [52]; *Raphia* palm Beauv [53-59] and *Rattans* [60].

The *Raphia* (Raffia) palm is one the most diversified and unique members of the Arecaceae family found in tropical Africa [57, 61, 62]. Unlike the *Elaeis guineensis* which comprises three varieties, *Raphia* palm comprises over 20 identified species spread over tropical Africa region and Madagascar [53, 54, 62] with one species (*R. taedigera*) also occurring in Central and South America (Figure 2b). *Raphia* palms can grow up to 16 metres (52 ft) tall. They are known for their compound pinnate leaves, which are the longest in the plant kingdom. The plants are hapaxanth (monocarpic) and monoecious [44, 54, 63].

While *Elaeis guineensis* are predominant in the better drained areas of the Niger Delta, the *Raphia* palms are ubiquitous in the Niger Delta swamps [16, 17, 55, 57]. The diverse species *Raphia* palms present in the Niger Delta include *Raphia Africana*, *Raphia farinifera*, *Raphia hookeri*, *Raphia longiflora*, *Raphia mannii*, *Raphia* mambillensis, *Raphia palma-pinus*, *Raphia* regalis, *Raphia taedigera* and *Raphia Vinifera* [53-59].

Raphia palms are economically and culturally important. Similar to *Elaeis guineensis*, every part of *the Raphia p*alm is valuable [54, 62, 64-67]. However, unlike *Elaeis guineensis* whose fruits and seed oils are highly utilized, *Raphia* palm fruits are often neglected even though they contain oils, with most of their fruits falling into the swamps and creeks as wastes. The loss of *Raphia* palm biomass especially the fruits is due its monocarpic nature, which often make the domestication of the plant and harnessing of its biomass unattractive [44]. Nevertheless, *Raphia* palms are easily and naturally propagated, and can spread very fast. They also produce abundant fruits during their lifespan. It is therefore, imperative to harness oils from these neglected fruits and evaluate their potential for food and industrial applications especially in the production of biofuels and oleochemicals.

In the field of oils study, the knowledge of the physico-chemical properties and the content of the oils are vital for determining the value of the oils as well as their production and utilization [68, 69]. Thus, in this study, the potentials of oil extracted from common species of the Niger Delta *Raphia* palm fruits as alternative to *Elaeis guineensis* (palm oil and palm kernel oil) were evaluated based on their physiochemical properties and oil contents.

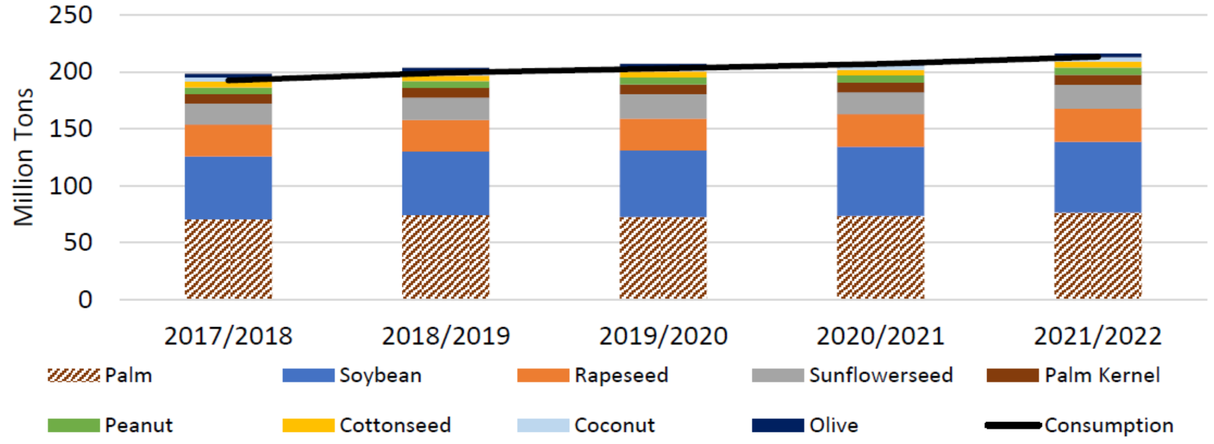

Figure 1. *Global vegetable oil production and consumption [8].*

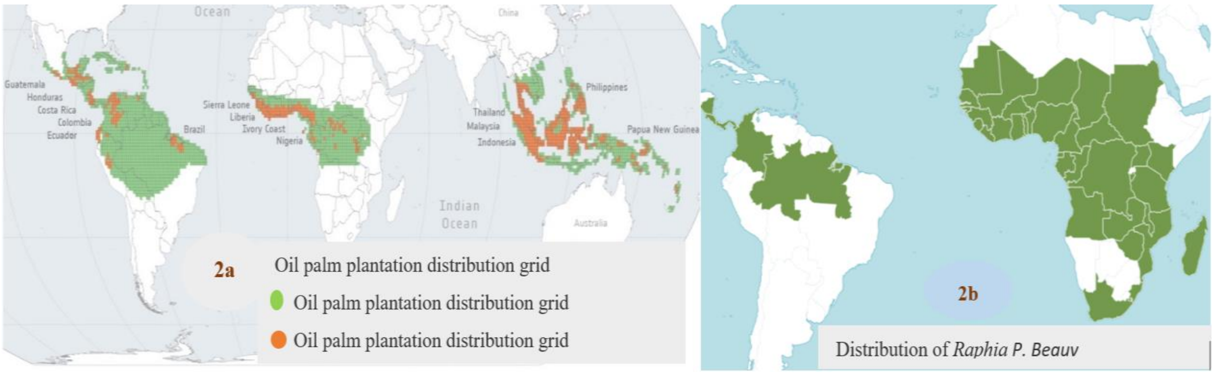

Figure 2. *Elaeis guineensis and Raphia Palm Distributions [43, 59].*

Table 1. *Major Oil Palm Producing Countries [70].*

RANK	1	2	3	4	5	6	7	8	9	10
Country	Indonesia	Malaysia	Thailand	Colombia	Nigeria	Guatemala	Papua New Guinea	Ecuador	Honduras	Brazil
Oil Production (1000 MT)	40,500	20,500	2,900	1,530	970	740	630	610	580	525

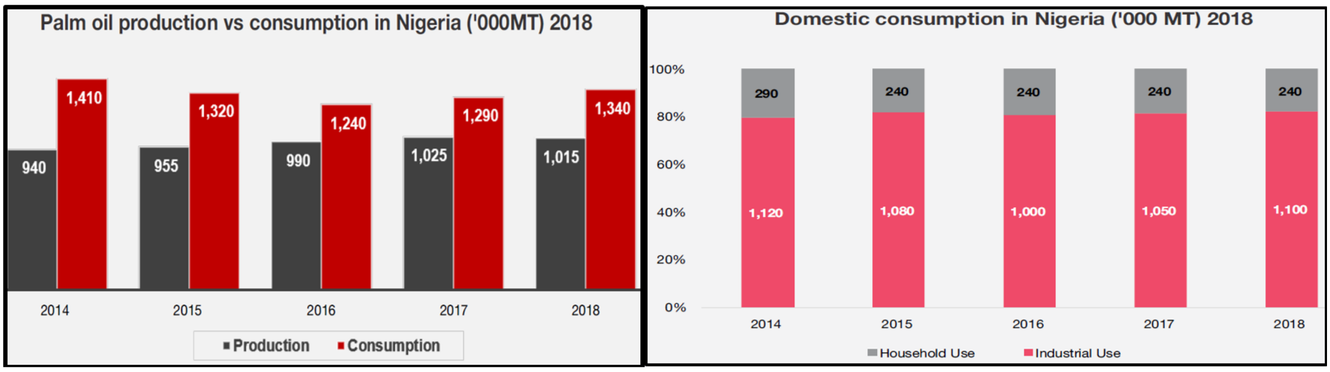

Figure 3. *Palm oil production versus consumption in Nigeria [20].*

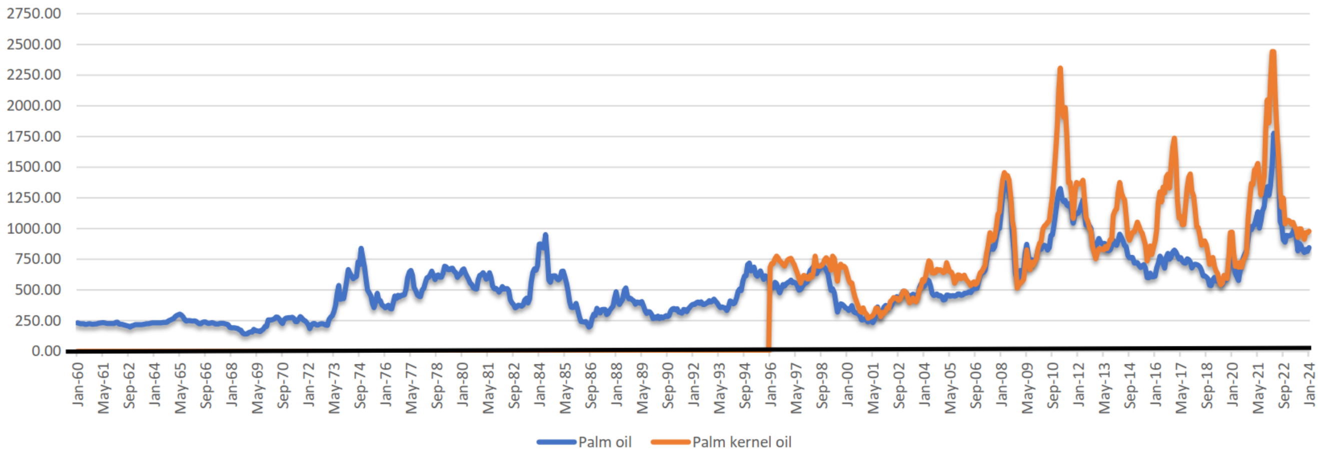

Figure 4. *Elaeis guineensis oils prices ($/MT) Adapted from World Bank World Bank Commodity Price Data [38].*

2. Materials and Methods

2.1. Materials

The materials used in the study comprised:

Raphia palm fruits (*farinifera*, *hookeri* and *vinifera* species) and oil palm fruits (Dura and Tenera varieties).

Laboratory reagents: Distilled water, n-hexane 98%, Potassium hydroxide pellet (BDH, 95%), carbon tetrachloride, Potassium iodide (M&B, 95%), Wijs solution, Iodine monochloride, Acetic Acid (BDH), sodium thiosulphate ($Na_2S_2O_3$- BDH, 95%), Hydrochloric acid (BDH, 95%), Phenolphthalein, Ethanol (BDH, 95%).

Apparatus, Equipment and Accessories: Soxhlet apparatus, Desiccator, Pycnometer, Brookfield viscometer, Stanhope-Seta Point Apparatus, Lovibond Tintometer F Model, Cleveland Open Cup Apparatus, Hanna pH meter, Abbe refractometer, Rancimat apparatus, Crucibles, Portable Electronic Balance (Ohaus - 30253019 Scout Pro), Thermometer, Rotary evaporator (Rikakikai, Tokyo), Pyrex laboratory glass wares.

2.2. Methods

2.2.1. Sourcing of Materials

Raphia palm fruits (*farinifera*, *hookeri* and *vinifera* species) and oil palm fruits (Dura and Tenera varieties) were sourced from Emu communities (Emu Unor, Emu Ebeoma, Emu Obodoeti, Emu Ebendo, Emu Iyasele) and Aradhe community in Ndokwa West and Isoko North local government areas of Delta state respectively. The fruits were identified by Taxonomists in Biological science Department of Igbinedion University, Okada.

All reagents (analytical grades) and apparatus used were provided by Chemical Engineering Laboratory of the Igbinedion University, Okada.)

2.2.2. Extraction of Oils

Solvent oil extraction method was used due to its inherent advantages such as high oil yield, low residual oil rate, high quality oil, low labor intensity, ease of reproducibility and repeatability etc. [2, 71, 72]. More so, solvent extraction has been successfully used extract to oil from palm pressed oil fibres and palm oil mill effluent [37, 73-77].

Thus, oils were extracted from the pulverized mesocarp of the *Raphia* palm and oil palm fruits as well as pulverized palm kernel previously dried following the procedures described by Igbafe *et al*., (2020); Azuokwu *et al*., (2020); Azuokwu and Eiroboyi Itohan, (2021) and Yerima *et al*., (2022) [72, 76, 78-80].

2.2.3. Determination of Oil Yields

The percentage of the oil yields were determined using equation 1:

$$Yield(\%) = \left(\frac{Weight\ of\ oil\ Extracted}{Weight\ of\ Sample\ Used\ for\ Extraction}\right) \times 100 \quad (1)$$

2.2.4. Determination of Physical Properties

(i). Determination of Colour and Odour

The colour of the oil samples was determined by visual inspection aided by colour charts and Lovibond tintometer in accordance to AOCS Official methods Cc 13b – 45 standard procedures [81].

The odour was determined by smell organ (Olfactory) [80].

(ii). Determination of Specific Gravity

The specific gravity of each oil was determined using pycnometric method. A 50 ml pycnometer was used in line with ASTM D891-09 standard following the procedures as described ISEDC, (2017) [82]. The Specific gravity calculated using equation 2:

$$Specific\ Gravity = \frac{W_3 - W_1}{W_2 - W_1} \quad (2)$$

Where: W_1 = weight of empty pycnometer bottle, W_2 = weight of pycnometer bottle + distilled water; W_3 = weight of pycnometer bottle + oil

(iii). pH Determination

The pH of the oil samples was determined by Hanna pH meter and beaker [31]. 40cm^3 of the different oil samples were poured into different beakers, then, the Hanna pH meter electrode was immersed into the oil containing beakers to measure their respective pH levels.

(iv). Determination of Viscosity

The dynamic (absolute) viscosities of the oil samples were determined by Brookfield viscometer in line with ASTM D2983 following with the procedure as discussed by Rafiu et al., (2022) [83]. The dynamic (absolute) viscosities were converted to kinematic viscosities using equation 3:

$$\upsilon = \frac{\mu}{\rho} \quad (3)$$

Where ν = kinematic viscosity; μ = absolute or dynamic viscosity and ρ = density

(v). Determination of Cloud Point, Pour Point and Slip Melting Point

In this study, the ASTM-D2500 and ASTM D97 were adapted with some modifications to determine the Cloud Point and Pour point respectively using Stanhope-Seta point apparatus [14, 84, 85].

The slip melting points were determined by open-tube capillary-slip method as described by FSSAI, (2021) [86].

(vi). Determination of Flash, Fire and Smoke Points

The flash points, fire points and smoke points of the oil samples were determined using Cleveland Open Cup Apparatus, Thermometer and Splinter sticks. The flash and fire points were determined following the ASTM D92 standard [84, 87]; while the smoke points were in line with in line with the AOCS method 9a-48 [88].

(vii). Determination of Moisture Content

The moisture contents were determined following AOAC 984.20 procedures (Moisture Loss on Drying) [83, 86, 89]. An empty dish was weighed and recorded. 10g of oil was added to the empty dish. The weight of the dish with the oil contents were measured are recorded. The dish with the oil contents were kept in an oven for an hour and maintained at a temperature of 105°C and reweighed after cooling in a desiccator. This process continued until a constant weight is reached. The moisture content percentage was calculated using equation 4:

$$Moisture\ Content\ (\%) = \left(\frac{W_2 - W_3}{W_2 - W_1}\right) \times 100 \quad (4)$$

Where W_1 = weight of empty dish, W_2 = weight of dish + oil before drying in the oven and W_3= weight of dish + oil after drying in the oven.

(viii). Determination of Refractive Index

The refractive indices of the oil samples were determined at room temperature, using Abbe refractometer (LEICA MARK II) in accordance to ASTM D1218 standard. Following the procedures described by FSSAI, (2021); Rubalya et al., (2016); and Rafiu et al., (2022) [83, 86, 90].

2.2.5. Determination of Chemical Properties

(i). Determination of Acid Values and Free Fatty Acids

The acid values and free fatty acid composition of the oils were determined by titration in line with AOCS 5a-40; AOAC Official Method 940.28; ASTM D 5555-95, and ASTM D664 standard procedures as outlined by Dimberu and Belete, (2011); Rubalya et al., (2016); Rafiu et al., (2022) [83, 90, 91]. The acid value was calculated using Equation 5.

$$Acid\ Value\ (mgKOH/g) = \frac{V \times C \times 56.1}{m} \quad (5)$$

Where: V = Average Volume of potassium hydroxide required for titration in ml.; C = concentration of KOH solution = 0.1N in this case and m = mass of oil used in grams.

Free Fatty Acid (FFA) value: The FFA in was evaluated using the Equation 6.

$$\%\ Free\ Fatty\ Acid\ = \frac{Acid\ Value}{2} \quad (6)$$

(ii). Determination of Iodine Value

The Iodine values of the oil samples were determined by titrimetry based on Wijs method and in accordance to ASTM D5554 [90], AOAC 993.20 [92] and ASTM D5768 standard procedures as outlined by Rubalya et al., (2016); Bong et al., (2020); Rafiu et al., (2022) [14, 83, 90].

The iodine value was calculated as follows:

$$IV\ (gI_2/100g\ oil) = \frac{(B-S) \times N \times 12.691}{Weight\ of\ Sapmple} \quad (7)$$

Where: IV = Iodine Value, B = titration of blank, S = titration of sample, and N = normality of $Na_2S_2O_3$ solution.

(iii). Determination of Peroxide Value

The peroxide values of the oil samples were determined by titrimetry based on the Association of Analytical Chemists AOAC 965.33 [92] and AOCS Cd 8b-90 (97) [83, 85] standard procedures. The peroxide values of each oil sample were calculated as follows:

$$Peroxide\ Value = \frac{1000 \times (S-B) \times N}{W} \quad (8)$$

Where: S = Volume of sodium thiosulfate solution in millilitre used for samples; B = Volume of sodium thiosulfate solution in millilitre used for blank; N = Normality of sodium thiosulfate solution and W = Weight of oil sample in gram.

(iv). Determination of Saponification and Ester Values

The saponification values of the oil samples were determined based on ASTM D 5558 – 95 standards [93], as outlined by Rubalya et al., (2016) and Rafiu et al., (2022) [83, 90].

The saponification value was then calculated using equation 9.

$$Saponification\ Value\ (SV) = \frac{5.61 \times (B-S)C}{m} \quad (9)$$

Where: B =Volume of HCl required by blank, S = Volume of HCl required by sample; C = Concentration of HCl (0.5N); 5.61– Molar mass of KOH and m= Mass of sample.

Ester value: The ester value was calculated as the difference between the saponification value and the acid value [46].

$$Ester\ Value = Saponification\ Value - Acid\ Value \quad (10)$$

(v). Determination of Unsaponifiable Matter

The unsaponifiable matter contents of the oil samples were determined based on AOCS method Ca 6b-53/ AOCS Method Ca 6a-40 [88] as described by Japir et al., (2017) and Elisa et al., (2021) [94, 95].

(vi). Determination of Ash Content

The ash content of the oil samples was determined following ASTM D 482 method described by Rafiu et al., (2022) [83]. Equation 11 was then used to calculate the ash contents.

$$Ash\ Content\ (\%) = \left(\frac{W_3 - W_1}{W_2 - W_1}\right) \times 100 \quad (11)$$

Where: W_1 = weight of empty crucibles; W_2 = weight of empty crucible + sample and W_3 = weight of crucible + ashes sample.

(vii). Determination of Oxidative Stability

The oxidative stability of the oils was determined by the Rancimat apparatus in accordance to EN-14112, AOCS Cd 12b-92 and ASTM D 6751 specifications.

The tests were carried out using 3g of oil sample at 120 ℃ and 20 L/h of air flow following the procedures described by Thomas *et al.*, (2011); Magdalena *et al.*, (2018) [96, 97]. The oil stability was expressed in terms of induction period (IP) in hours.

2.2.6. Determination of Other Fuel Properties of the Oils

(i). Determination of Cetane Number

The cetane numbers of the oil samples were calculated using equation 12 [98-100].

$$Cetane\ Number\ = 46.3 + \frac{5458}{SV} - 0.225 \times IV \quad (12)$$

Where: SV = Saponification of oil sample, IV = Iodine Value of oil sample.

(ii). Determination of Heat of Combustion

The heat of combustion of the oil samples were calculated using equation 13 [101].

$$Heat\ of\ combustion\ (cal/g) = 11380\ - IV - 9.15 \times SV \quad (13)$$

Where: SV = Saponification of oil sample, IV = Iodine Value of oil sample.

(iii). Higher Heating Value

The high heating value (HHV) of the oil samples were calculated using equation 14 [100, 102].

$$HHV\ (MJ/Kg) = 49.43 - 0.041 \times SV - 0.015 \times IV \quad (14)$$

Where: SV = Saponification of oil sample, IV = Iodine Value of oil sample.

2.2.7. Determination of Tastes

Physical methods were used to determine the tastes of oils after determining the pH and the toxicity levels of the oils through other chemical analysis.

3. Results and Discussion

The oil yields and physicochemical properties of oils extracted from common species of the Niger Delta *Raphia* Palm Fruits and *Elaeis guineensis* are shown in Table 2. The results are mean of three independent experiments.

3.1. Oil Yield

The oil extraction yields were 44.5% for the *Raphia vinifera*, 45.2% for the *Raphia farinifera* and 45.8% for the *Raphia hookeri* (Table 2). These oil extraction yields are comparable to those of *Elaeis guineensis* oils of 46.8% and 43.2% for palm oil and palm kernel oil respectively.

These percentage oil yields are higher than those of plants found in the Niger Delta notably *Azadirachta indica* seed oil of 38% [103]; *Chrysophyllum albidum* seed oil of 30.6% [78]; *Jatroha* curcas seed oil of 42.5% [104]; Hevea *brasiliensis* (Rubber) seed oil of 43% [105]; Lagenaria *siceraria* seed oil of 35% [106]; *Nicotiana tabacum* seed oil of 32.1% [80]; *Ricinus communis* seed oil of 42% [103]. These results showed that just like the *Elaeis guineensis*, the common species of the Niger Delta *Raphia* Palm fruits are prolific in oil.

3.2. Physical Properties

3.2.1. pH

The results of this study (Table 2) showed that the pH values of oils extracted from common species of the Niger Delta *Raphia* palm fruits are between 5.86 - 6.22 compared to *Elaeis guineensis* oils of 6.88 and 6.42 for palm oil and palm kernel oil respectively. Thus, *Raphia* oils are slightly acidic than *Elaeis guineensis* oils. Vegetable oil that is suitable for cooking is typically neutral in pH and falls between 6.9 and 6.7 [107]. pH is an important factor during transesterification in biodiesel production as low pH value during the reaction affect the catalyst.

3.2.2. Colour

Oils extracted from common species of the Niger Delta *Raphia* are reddish, while palm oil and palm kernel oil are -orange-red and light brownish yellow respectively. These are in line with the Lovibond values. Palm oil is naturally reddish because of high beta-carotene content [18].

3.2.3. Tastes and Odours

Vegetable oils used in a recipe, while cooking, or during frying are characterized by neutral / pleasant/ faint taste, odour and flavor. Oils used as industrial feedstock should also be characterized by neutral / pleasant/ faint odour and flavor.

Oil extracted from common species of the Niger Delta *Raphia* palm fruits are bitter to taste with mild odour (Table 2). On the other hand, the palm oil is characterized by faint smell and pleasant tastes while the palm kernel oil had distinctly nutty/ herbaceous taste and odour. Due to their bitter tastes, the *Raphia* palm fruits oils are not as suitable as *Elaeis guineensis* oils in a recipe.

3.2.4. Specific Gravity/Density

Density is one of the parameters that have a great impact on the combustion efficiency of diesel engines [31, 108]. Density also has profound impact on the design of pipes, its accessories and associated equipment; pressure losses are directly proportional to density [31, 108, 109, 110].

The specific gravity values were 0.886 for the raffia *vinifera*, 0.890 for the raffia *farinifera* and 0.893 for the raffia *hookeri* (Table 2). These values are close to those of *Elaeis guineensis* oils of 0.899 and 0.912 for palm oil and palm kernel oil respectively. Thus, the *Raphia* palm fruits oils have almost the same energy content per unit volume as those of *Elaeis guineensis* oils. In addition, specific gravity and density of the oils are within tolerable limits for optimal injection and complete combustion in engines. High-density can cause pumping and transportation problems; and can also lead to incomplete combustion and particulate matter emissions [31]. The specific gravity values are also within the NAFDAC (2019) [111], limits of 0.891 – 0.899 for palm oil.

Table 2. Oil Yields and Physicochemical properties of oils extracted from common species of the Niger Delta Raphia Palm Fruits and Elaeis guineensis.

Parameters	*Raphia* Fruits Oils			*Elaeis guineensis*	
	Farinifera	*Hookeri*	*Vinifera*	Palm oil	Palm kernel oil
Yield (%)	45.2	45.8	44.5	46.8	43.2
pH	5.86	6.05	6.22	6.88	6.42
Colour	Red (50R 20Y)	Red (50R 20Y)	Red (50R 20Y)	Orange-Red (50R 50Y)	Light Brownish Yellow (8R 60Y)
Odour	Mild	Mild	Mild	Faint	Nutty
Taste	Mildly bitter	Slightly bitter	bitter	Pleasant	Nutty
Specific gravity	0.890	0.893	0.886	0.899	0.912
Kinematics Viscosity at 40℃ (cSt)	34.1	34.4	33.7	39.8	32.9
Cloud point (℃)	25.8	25.6	25.2	26	24
Pour point (℃)	19.5	19.4	19.1	19.8	18
Slip Melting point (℃)	30.3	30.0	29.4	31	28
Smoke Point (℃)	210	215	207	228	191
Flash point (℃)	288	292	286	301	249
Fire point (℃)	305	310	303	320	288
Moisture Content (%)	0.20	0.21	0.24	0.19	0.18
Refractive Index	1.452	1.454	1.451	1.450	1.449
Acid number (mgKOH/g)	7.14	6.52	6.08	4.36	3.58
Free Fatty Acid (%)	3.57	3.26	3.04	2.18	1.79
Peroxide Value (mEqO_2/Kg)	9.02	8.36	6.84	5.96	4.38
Iodine value (I_2g/100g)	58.6	54.1	52.3	50.8	20.6
Saponification Value (mgKOH/g)	212.8	210.2	216.4	202.9	247.8
Ester Value (mgKOH/g)	205.66	203.68	210.32	198.54	244.22
Unsaponifiable Matter (%)	0.31	0.24	0.46	0.53	0.78
Oxidative stability (hours)	10.3	10.5	11.0	11.6	13.1
Cetane Number	58.76	60.09	59.75	61.77	63.69
Heat of Combustion (cal/g)	9374.28	9402.57	9347.64	9472.67	9092.03
HHV(MJ/Kg)	39.83	40.00	39.77	40.35	38.96
Ash Content (%)	1.05	1.01	1.09	1.68	2.01

R = Red, Y = Yellow

3.2.5. Viscosity

Viscosity is one of the one the most important physico-chemical properties vegetable oil [72, 108, 109, 110, 112]. Viscosity is a measure of the resistance offered by a fluid to flow [72, 109]. It has a great impact on the combustion efficiency of diesel engines. [31, 108]. It also has tremendous impact on the design of pipes, its accessories and associated equipment [31, 108, 109, 110]. In addition, viscosity is a parameter that determines lubrication efficiencies of oils and their application of lubricants [72, 109]. Higher viscosity leads to poor fuel atomization, low quality of fuel injection and spray processes [113, 114] and high-pressure losses [72, 109] but in some cases higher lubricating effectiveness [109, 115].

The kinematics viscosity of the oils extracted from common species of the Niger Delta *Raphia* palm fruits were 33.7 cSt for *Raphia vinifera*, 34.1 cSt for *Raphia farinifera* and 34.4 cSt for the *Raphia hookeri*. These values are comparable to those of *Elaeis guineensis* oils of 34.9 cSt and 32.9 cSt for palm oil and palm kernel oil respectively. The viscosity exhibited by these oils showed that it will easy to pump and inject them into the engines.

3.2.6. Cloud, Pour and Slip Melting Points

The temperature at which oil begins to be cloudy or hazy as it is slowly cooled is known as the cloud point, and the temperature at which it stops flowing or pouring is known as the pour point. The cloud and pour points show if an oil is suitable for use in cold temperatures, the lower the cloud and pour point the better the oil. The cloud points of oils extracted from common species of the Niger Delta *Raphia* palm fruits were 25.2 ℃ for the *Raphia vinifera*, 25.6 ℃ for the *Raphia hookeri* and 25.8 ℃ for the *Raphia farinifera*. These are slightly lower than the cloud points of palm oil (26 ℃) and slightly higher than that of palm kernel oil (24 ℃). The pour points of oils extracted from common species of the Niger Delta *Raphia* palm fruits were 19.1 ℃ for the *Raphia vinifera*, 19.4 ℃ for the *Raphia hookeri* and 19.5 ℃ for the *Raphia farinifera*. These are slightly lower than the pour points of palm oil (19.8 ℃) and slightly higher than that of palm kernel oil (18 ℃).

The slip melting point refers to the temperature at which a material transitions from a solid state to a molten or liquid state under the influence of shear stress. The slip melting points of *Raphia* palm fruit oils (29.4 ℃ for *vinifera*, 30.0 ℃, *hookeri* and 30.3 ℃ for *farinifera*) are slightly lower than that of palm oil (31 ℃) and slightly higher than that of palm kernel oil (18 ℃).

3.2.7. Flash, Fire and Smoke Points

Oil's volatility and fire resistance can be estimated using the flash and fire points. The flash points and fire points of the oils extracted from common species of the Niger Delta *Raphia* palm fruits were in the range of 286 ℃ to 292 ℃ and 303 ℃ to 310 ℃ respectively. These values are lower than the flash point and fire point of palm oil (301 ℃ and 320 ℃ respectively) but higher than that the flash point and fire point of palm kernel oil (249 ℃ and 288 ℃ respectively). This means that these oils can be transported, stored and utilized without the risks of fire incidence because they exceeded the 130 ^{o}C minimum ASTM recommended range.

The smoke points of the oils extracted from common species of the Niger Delta *Raphia* palm fruits were in the range of 207 ℃ to 215 ℃. These values are lower than the smoke point of palm oil (228 ℃) but higher than that the smoke point of palm kernel oil (191 ℃). Oils with high smoke point are used in more cooking techniques. When oil reaches its smoke point and starts to burn, it also destroys phytochemicals and healthy nutrients in the oil and the food, which makes them both more flammable and produces free radicals that are bad for your health if you consume them. Oils with low smoke point are not ideal in engines.

3.2.8. Moisture Content

High moisture contents are known to cause problem in transesterification, reduces shelf life, and may also cause corrosion in internal combustion engine [31]. Moisture (Water) and free fatty acids are always detrimental to the conventional transesterification of fats and vegetable oils for the production of biodiesel because they lead to soap formation, catalyst consumption, and decreased catalyst efficiency, all of which lead to a low conversion [116]. High moisture contents are also known to cause rancidity of edible oil thereby reduces its quality and its shelf life. For edible oil, the maximum World Health Organization (WHO) standard for moisture content is 0.2% (CODEX Alimentarius, 1999; Negash *et al.*, 2019) [117, 118].

The moisture contents of oils extracted from common species of the Niger Delta *Raphia* palm fruits (0.20-0.24%) were slightly higher than those *Elaeis guineensis* oils (palm oil 0.19% and palm kernel oil 0.18%).

3.2.9. Refractive Index

Refractive index is a key optical parameter that describes how light travels through a medium and in oil chemistry, it is used to analyze the likelihood of occurrence of rancidity in oil through oxidation [119]. The higher the refractive index, the more likely the oil deteriorates due to rancidity through oxidation. The analyses shown that the refractive indices of the *Raphia* palm fruit oils (1.451- 1.454) are slightly lower than those of the *Elaeis guineensis* oils of 1.450 and 1.449 for palm oil and palm kernel oil respectively. Thus, there is no significant difference between refractive indices of *Raphia* and *Elaeis guineensis* oils.

3.3. Chemical Properties

3.3.1. Acid Values and Free Fatty Acids

The acid value and free fatty acid are important parameters for characterizing oil for industrial applications and human nutritional use [94]. Oils with low acid value are more stable to oxidation rancidity than those with high acid values. Free fatty acids are often produced during the breakdown of triglycerides; thus, it is a relative indicator of rancidity.

For nutritional purposes, acid values of less than 0.6 mgKOH/g and free fatty acid value of less than 0.3% have been recommended by NAFDAC, and FAO/WHO [94, 111, 120-124]. Oil with very high acid value of oils is toxic to livestock [122].

For industrial applications, acid value / free fatty acids can be used to determine the amount of corrosive acid as well as oxidation products present in the oil [125]. The acid value/free fatty acid contents of oils affect biodiesel yield and purity [126, 127]. High acid values/free fatty acids and water are detrimental to the conventional transesterification of fats and oils for biodiesel production. They lead to soap formation, catalyst consumption, and decreased catalyst efficiency, leading to a low conversion [116]. More cleansing (detergency) results from a lower acid value [128].

The acid values of oils extracted from common species of the Niger Delta *Raphia* palm fruits (6.08 mgKOH/g for the *Raphia vinifera*, 6.52 mgKOH/g for the *Raphia hookeri* and 7.14 mgKOH/g for the *Raphia farinifera*) were slightly higher than those of the *Elaeis guineensis* oils (4.36 mgKOH/g and 3.58 mgKOH/g for palm oil and palm kernel oil respectively).

The free fatty acids of oils extracted from common species of the Niger Delta *Raphia* palm fruits (3.04 % for the *Raphia vinifera*, 3.26 % for the *Raphia hookeri* and 3.57 % for the *Raphia farinifera*) were slightly higher than those of the *Elaeis guineensis* oils 2.18 % and 1.79 % for palm oil and palm kernel oil respectively). They are below the CODEX Alimentarius (2013) [129] maximum specified free fatty acids value of 5.0%.

3.3.2. Peroxide Values

A good quality and well-preserved oil are indicated by a low peroxide value. For oil with peroxide high value; the antioxidants are either very low or absent. Such oils are prone to oxidative rancidity and thus have short shelf life. According to NAFDAC and WHO recommendations, fresh oils and edible oil should have a peroxide value of less than 10 milliequivalents/kg [94, 120-124]. Higher peroxide values above the recommended values leads to rancid odor, rancid flavor and bad taste., The peroxide values of the oils extracted from common species of the Niger Delta *Raphia* palm fruits were 6.84 $mEqO_2$/Kg for *Raphia vinifera*, 8.36 $mEqO_2$/Kg for the *Raphia hookeri*. and 9.02 $mEqO_2$/Kg for *Raphia farinifera* compared to those of *Elaeis guineensis* oils (5.96 $mEqO_2$/Kg and 4.38 $mEqO_2$/Kg for palm oil palm kernel oil respectively). These values are lower than the NAFDAC and WHO recommendations for those of *Elaeis guineensis* oils of not more than 10 milliequivalents peroxide oxygen per kilogram. These peroxides values indicate a long shelf life for the extracted oils. Therefore, they could be stored and used over a long period of time in the nutritional and oleo-chemical industries without being prone to rancidity.

3.3.3. Iodine Values

The degree of unsaturation in oil components can be quantified in terms of Iodine value Saturated oils are characterized by low iodine values while unsaturated oils are characterized by high iodine values. Oils with iodine value above 150 are classified as drying oils; those with iodine value 125 –150 are classified as semidrying oils and those with iodine value less than 125 are considered as nondrying oil. Oil with low Iodine numbers (saturated oils) are well suited for soap/ detergent production [103, 130, 131]. Oils/fats with low iodine values are also well suited for wafer baking [132]. Oil with high Iodine numbers (unsaturated oils or drying oil) are favourable for producing oil paints [103, 130-141]. For biodiesel productions, the required limit for Iodine value is 120 g I_2/100 g [143]. Iodine value can also be used in studying oxidative rancidity of oils. Oils with high degree of unsaturation are prone to rancidity.

The results of this study (Table 2) showed that the iodine values of the Raffia Palm Fruits oil are between 52.3-58.6 g I_2/100 compared to *Elaeis guineensis* oils of 50.8 and 20.6 g I_2/100 for palm oil and palm kernel oil respectively. Thus, these oils are suitable to be used in wafer, soap, biodiesel and glycerol productions.

3.3.4. Saponification and Ester Values

Saponification value can be defined as the number of milligrams of potassium hydroxide (KOH) or sodium hydroxide (NaOH) needed to saponify one gram of oil / fat under the conditions specified [141, 144].

Oils with high saponification values represent higher medium chain fatty acids and are favourable for soap/detergent and cosmetics production [103, 121, 130, 131]; and thus, glycerol production. In biodiesel production, oils with a high saponification value require more methanol, and produce more glycerol but less biodiesel than longer chain oils.

The results of this study (Table 2) showed that the saponification values of oil extracted from common species of the Niger Delta *Raphia* palm fruits oils are between 210.2-216.4 mgKOH/g compared to *Elaeis guineensis* oils of 202.9 and 247.8 mgKOH/g for palm oil and palm kernel oil respectively. Consequently, oil extracted from the common species of the Niger Delta *Raphia* Palm Fruits can be used as alternative to palm oil and palm kernel oil in the production of soap, biodiesel and glycerol. The FAO/WHO maximum recommended saponification value of most oils for nutritional purposes ranges between 187–209 mgKOH/g [121, 124].

Ester value is the difference between saponification value and acid value. The high ester values recorded (Table 2) indicates the presence of high amount of ester and low molecular weight fatty acid content.

3.3.5. Unsaponifiable Matter

In addition to fatty acid triglycerides and their hydrolytic products, vegetable oils also contain minor proportion of unsaponifiable matter that include sterols, higher molecular weight alcohols, phospholipids, pigments, waxes, terpanes, oil-soluble vitamins, hydrocarbons etc. [135, 136]. Although they may act as oxidation inhibitors, they do not react with base to form soaps. In addition, they are nonpolar therefore remain in the biodiesel after the transesterification reaction, thereby affecting the quality of biodiesel.

The values of unsaponifiable matters obtained for all the oil samples extracted were generally low (0.31 % for *Raphia* *farinifera*, 0.24 % for the *Raphia hookeri*, 0.46 % for *Raphia vinifera*, 0.53% for palm oil and 0.78% for palm kernel oil), which is less than the maximum recommended value of l0g/kg for edible oils [111, 137, 138]. The low values of the unsaponifiable matters are also favourable to biodiesel, soap and glycerol production.

3.3.6. Oxidative Stability

The oxidative stability of oils is an important qualitative parameter that determine how long an oil can be stored used before it goes bad (rancid) and thus if shelf life [139]. The higher oil stability index (induction period), the higher the shelf life. The oxidation stability analysis can also be used to evaluate the effectiveness of antioxidants in an oil.

The oxidative stability results of the *Raphia* palm fruit oils (10.3hrs for *Raphia farinifera*, 10.5hours for *Raphia hookeri* and 11.0hrs for *Raphia vinifera*) are slightly lower than those of the *Elaeis guineensis* oils of 11.6 hours. and 13.1 hours. for palm oil and palm kernel oil respectively. The oxidative stability results are in consonance with other parameters used to quantity rancidity such as peroxide values and refractive indices. These oxidative stability values are higher than the oil stability index of corn oil, grapeseed oil, hazelnut oil, olive oil, peanut oil, rapeseed oil, rice bran oil, Soybean oil, and Sunflower oil [97, 140, 141].

3.3.7. Ash Contents

The ash content is also use to indicate the incombustible components of oil [147, 148]. Analyzing oils for the ash contents are important for many reasons [145], among which are:

Ash content is important to the oil's nutritional values and longevity, the higher, the better.

The incombustible components of fuel are represented by the ash content. Oil with high ash level indicates that it contains fewer volatile materials than one with a lower ash level. Therefore, in order to produce the same amount of heat, more fuel is required.

This study shown that the ash contents of the *Raphia* palm fruit oils (1.01- 1.09 %) are slightly lower than those of the *Elaeis guineensis* oils of 1.68 % and 2.01% for palm oil and palm kernel oil respectively. Thus, *Raphia* palm fruit oils contain more volatile matter while *Elaeis guineensis* oils contain more incombustible /components.

3.4. Other Fuel Properties of the Oils

For a very long time, vegetable oils and their methyl esters have been thought of as viable substitute fuels for diesel engines [135]. Prior to such utilization, their cetane number, heat of combustion and heating values need to be determined.

3.4.1. Cetane Number

Cetane Number: The ease with which diesel fuel ignites is indicated by the cetane number) [143, 144]. The higher the value, the simpler it is to ignite. In this study, there is no significant difference between the cetane numbers of *Raphia* fruit oils (58.76 for the *Raphia farinifera*, 59.75 for the *Raphia vinifera* and 60.09 for the *Raphia hookeri*) and those of the *Elaeis guineensis* oils (61.77 and 63.69 for palm oil and palm kernel oil respectively).

3.4.2. Heat of Combustion

Heat of combustion: The heat of combustion of a substance (fuel or food) is the amount of heat released during the combustion of a given amount of it. In other words, the heat released when the oxygen from the air reacts with the hydrogen and carbon in the fuel. [145]. In this study, there is no significant difference between the heat of combustion of *Raphia* fruit oils (9347.64 - 9402.57cal/g) and those of the *Elaeis guineensis* oils (9472.67cal/g and 9092.03cal/g for palm oil and palm kernel oil respectively).

3.4.3. Higher Heating Value

Heating Value: Heating value is a very important property of fuels. It measures the energy content of the fuel [107]. The quantity of heat released when a given mass or volume of fuel (originally at 25 ℃) is combusted and the products have returned to a temperature of 25 ℃ is known as higher heating value (HHV). The higher heating values of vegetable oils are similar to diesel fuels by about 88%; with most of the oil samples having higher heating values between 39.3 and 39.8 MJ/kg [146].

In this study, there is no significant difference between the higher heating values of *Raphia* fruit oils (39.77 MJ/Kg for the *Raphia vinifera*, 39.83 MJ/Kg for the *Raphia farinifera* and 40.00 MJ/Kg for the *Raphia hookeri*) and those of the *Elaeis guineensis* oils (40.35 MJ/Kg and 38.96 MJ/Kg for palm oil and palm kernel oil respectively). Ash Content

4. Conclusions

The demand for *Elaeis guineensis* oils for food applications as well as in the industrial production of biofuels and other oleochemicals has surpassed the supply worldwide, Nigeria inclusive. The demand has also raised considerable global concerns about their prices as wells as the environmental, climate and social risks associated with their production.

In this study, the possibility of using oils extracted from common species of the Niger Delta *Raphia* palm fruits (*Raphia farinifera*, *Raphia hookeri* and *Raphia vinifera*) as alternative to *Elaeis guineensis* (palm oil and palm kernel oil) were evaluated based on their physiochemical properties. The comparative study of physicochemical properties of these oils was carried out using standard analytical techniques.

The basic parameters that were evaluated and compared include yields, pH, Colour, Odour, Taste, specific gravity/density, Viscosity, Cloud point, Pour point, Smoke Point, Flash point, Fire point, Moisture Content, Refractive Index, Acid number, Free Fatty Acid, Peroxide Value, Iodine Value, Saponification

Value, Saponification Value, Ester Value, Unsaponifiable Matter, Oxidative Stability, Cetane Number, Heat of Combustion, Higher Heating Values and Ash Content

The study showed that oils extracted from common species of the Niger Delta *Raphia* palm fruits and are very similar to *Elaeis guineensis* oils especially palm oil in many aspects. However, most of the physiochemical properties results showed that oils extracted from common species of the Niger Delta *Raphia* palm fruits are more suited as replacement to *Elaeis guineensis* oils in the production of biofuels and oleochemicals than for edibility purposes.

Abbreviations

PO	Palm Oil
PKO	Palm Kernel Oil
MT	Metric Tons
$Na_2S_2O_3$	Sodium Thiosulfate
AOCS	American Oil Chemists' Society
ASTM	American Society for Testing and Materials
ISEDC	Innovation, Science and Economic Development Canada
FSSAI	Food Safety and Standards Authority of India
AOAC	Association of Official Analytical Chemists
mg	Milligram
g	Gram
KOH	Potassium Hydroxide
ml	Millilitre
N	Normality
FFA	Free Fatty Acid
IV	Iodine Value
SV	Saponification Value
HCl	Hydrochloric Acid
EN	Europäische/ European Norm (European Standards)
L/h	Litre Per Hour
IP	Induction Period
cal/g	Calorie Per Gram
HHV	High Heating Value
MJ/kg	Megajoules per Kilogram
NAFDAC	National Agency for Food and Drug Administration and Control
R	Red
Y	Yellow
cSt	Centistokes
℃	Degree Celsius
$mEqO_2$/Kg	Milliequivalent of Oxygen /Kilogram
I_2g/100g	Iodine (in Grams) Per 100 Grams of Substanc
WHO	World Health Organization
FAO	Food and Agriculture Organization
NaOH	Sodium Hydroxide

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Conflicts of Interest

The authors declare no conflicts of interest.

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