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Research Article

A Comparative Analysis of the Physicochemical Properties of Oils Extracted from Common Species of the Niger Delta *Raphia* Palm Fruits and *Cocos nucifera* Kernels

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Abstract

Cocos nucifera oil is one of the most valuable, expensive and globally consumed vegetable oils. In many nations including Nigeria, the demand for *Cocos nucifera* and its oils has outweighed the supply. Moreover, *Cocos nucifera* cultivation has been reported to cause negative environmental, climatic and social impacts. Hence the search for a suitable feedstock that can either be used in conjunction with or as a substitute to *Cocos nucifera* 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 *Cocos nucifera* kernel. The prospects of using each of the *Raphia* palm oil as an alternative to *Cocos nucifera* oil in food, feeds, biofuels and oleochemicals industries were analysed based on the results of standard physiochemical properties analysis. The results of this study showed that most of the physiochemical properties of the oils extracted from common species of the Niger Delta *Raphia* palm fruits are comparable to those of *Cocos nucifera* oil and the standards set for food, feeds, biofuels and oleochemicals. However, the *Raphia* palm fruits oils are more suitable as alternatives to *Cocos nucifera* oil in the biofuels and oleochemicals sectors than in the food and feed sectors.

Keywords

Cocos nucifera Oil, *Raphia* Palm Fruits, Niger Delta, Physiochemical Properties, Food, Feeds, Biofuels and Oleochemicals

1. Introduction

Cocos nucifera Linnaeus (coconut) is one of the most important members of the *Arecaceae* / palmae family [1-4]. It is a commercial tree crop found in tropical and subtropical regions of the world [5-7]. Every part of the palm is useful to mankind [3, 7-13] and it is often called the ‘Tree of Life’ and ‘Tree of Heaven’ [2, 8, 9, 11, 14, 15].

Distinct about the coconut, is the fruit (a drupe) containing an endosperm in which the edible portion of the coconut are found. The edible portion includes the coconut kernel (meat) and coconut water [4, 12]. The coconut water is nutritionally and medically useful, it is fortified with vitamins, amino acids enzymes, minerals, sugars, cytokins, and auxins [2, 4, 12].

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The coconut kernel meat comprising about 48% - 62% moisture, 59% volatile matter, 35.5% oil and 16.5% oil free residue is also nutritionally and medically useful [2, 13].

The oil (coconut oil) obtained from the coconut kernel (meat) is the prime product of the *Cocos nucifera Linnaeus* [8, 9, 11, 13]. *Cocos nucifera* is one of the most globally produced oil crops (Figure 1) and its oil is one of the most highly demanded and valuable [4, 16-20].

Coconut oil is used extensively in food processing and pharmaceuticals/ health /medical sectors; as well as in the industrial production of biofuels, oleochemicals and their derivatives [2, 6, 8, 9, 11, 16, 21-23].

The nutritional and health benefits of coconut oil are myriads [4, 5, 8, 9, 15, 21, 24, 25]. They include skin care, hair care, stress relief, cholesterol level maintenance, obesity control /weight loss, boosted immune system, proper digestion and regulated metabolism [9, 21, 25]. It also provides relief from, heart diseases, high blood pressure, kidney problem, HIV, cancer and diabetes, while helping to improve dental quality and bone strength. Coconut oil is anti-viral, anti-bacterial, anti-fungal, and anti-microbial [24].

Like other vegetable oils, coconut oil is increasingly being used as raw material for the production of biofuel and oleochemicals [8, 9, 11, 17, 23, 26, 27]. Biofuels and oleochemical are valuable fuels and chemical comprising fatty acids, fatty acid methyl esters, fatty alcohols and amines, glycerol all of their derivatives) derived from natural fats and oils [8, 9, 26-28]. They are used to produce a wide range of chemicals and goods that are used in the household and industries [8, 9, 28].

Although, *Cocos nucifera* kernel oil is very valuable, it is more expensive than most common plant oils [14, 16, 18] and in most nations, the demand has outweighed the supply [14, 15, 17-20, 25, 29, 30] and thus could be adulterated [4, 16, 31]. While it may be sound logical to increase the cultivation so as to meet the demand, this is however far from reality. Like *Elaeis guineensis*, *Cocos nucifera* cultivation has been documented to put pressure on land with resulting negative environmental, climatic and social impacts [11, 32-36]. Moreover, as shown in Figure 2a and has been reported [8, 9, 14, 20, 37], coconut though currently cultivated in more than 85 tropical and subtropical countries worldwide and utilizing more than 49 improve varieties [9], the price of coconut oil (Figure 3) keep rising and fluctuating even though the global production of coconut has increased from 23 million metric tons in 1961 to over 62 million metric tons in 2022 [9, 37].

In Nigeria, the situation is worrisome. Nigeria, despites being among major coconut producing countries (Table 1), and despites belonging to International Coconut Community [8], the country still depends on the importation of coconuts and its products from other countries [29, 30, 38, 39]. Simply put, Nigeria's demand for coconuts and its oil has exceeded the nation's capacity to produce them. In fact, Nigeria's coconut production that rose to an average value of 265,439 metric tons between 2010 and 2014 from average value of 90,272 metric tons between 1961 and 1980 has slightly decrease to 225,526.79 tons in 2022 (Table 1 and Figure 3).

Based on the aforementioned reasons, there have been a concerted efforts to search for cheaper alternatives to coconut oil [40-42].

In Nigeria and in particular the Niger Delta, there are several plants species in the Niger Delta whose seeds and fruits are underutilized [36, 43, 44]. Among those in the *Arecaceae* plant family is the *Raphia* (Raffia) palm [36, 45-47]. *Raphia* palm is highly diversified (consist of over 20 species) [48-50]. *Raphia* palms are monoecious, monocarpic (hapaxanth) and can grow up to 16 metres (52 ft) tall [45, 47, 51].

In the Niger Delta, *Raphia* palms grow naturally, and are ubiquitous from the freshwater zone and swamps to the coastal mangrove, with a biomass productivity of 933 trees/ha to 1066 trees/ha [36, 47].

The different species of *Raphia* palms found in the Nigeria are *Raphia Africana*, *Raphia farinifera*, *Raphia hookeri*, *Raphia longiflora, Raphia mannii*, *Raphia mambillensis*, *Raphia palma-pinus, Raphia regalis*, *Raphia sudanica Chev.*, *Raphia taedigera* and *Raphia Vinifera* [36, 49, 51-58].

Raphia palms are as valuable as the *Cocos nucifera*, every part of *the Raphia* palm is useful [8-10, 49, 51, 53-55, 59, 60]. But unlike *Cocos nucifera*, whose fruits and oils are highly valued [4, 8, 9, 14, 16-20, 24], *Raphia* palm fruits despites its acclaimed oil contents [36, 46, 47, 51] are left to rot in the swamps and creeks. Due to its monocarpic (hapazanthic) nature, it is often not appealing to cultivate the *Raphia* palms and utilize some its biomass particularly the fruits for commercial purposes [47, 51].

Raphia palms, nevertheless, are prolific in fruit production, readily, naturally and spontaneously propagated and can spread quickly [36, 51]. It is therefore, worthwhile to extract and evaluate the potential of the *Raphia* palm fruit oils for food and industrial applications especially in the production of biofuels and oleochemicals.

The physicochemical properties and the oil contents are vital for determining the quality, worth and utility of vegetable oils [61-64]. Thus, in this study, the potentials of oils extracted from common species of the Niger Delta *Raphia* palm fruits were evaluated and compared to the highly valued *Cocos nucifera* oil based on their oil contents and physiochemical properties.

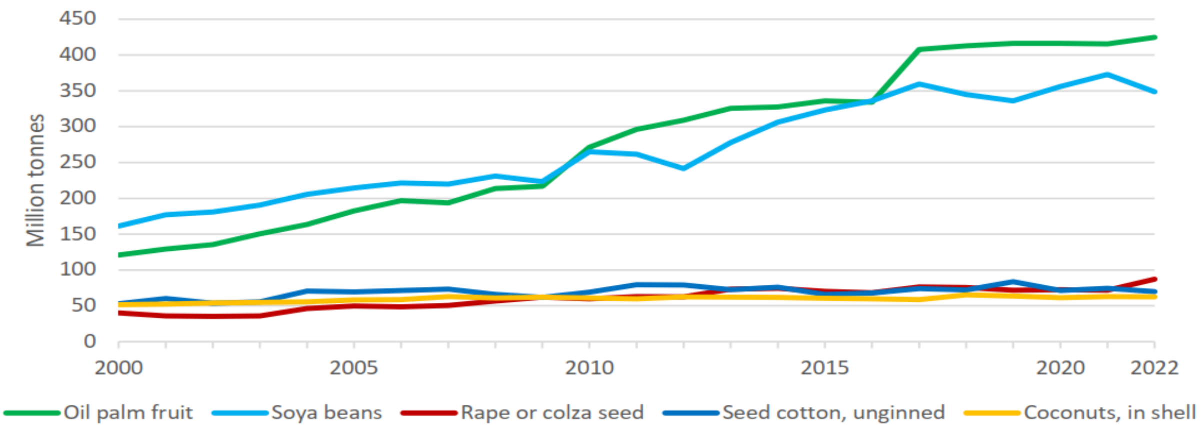

Figure 1. Global production of top oil crops (FAO, 2023b) [65].

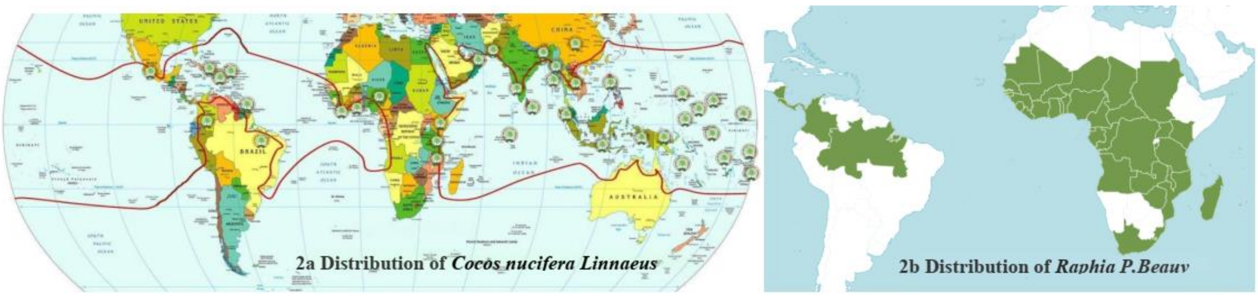

Figure 2. Cocos nucifera Linnaeus and Raphia Palm Distributions [8, 58].

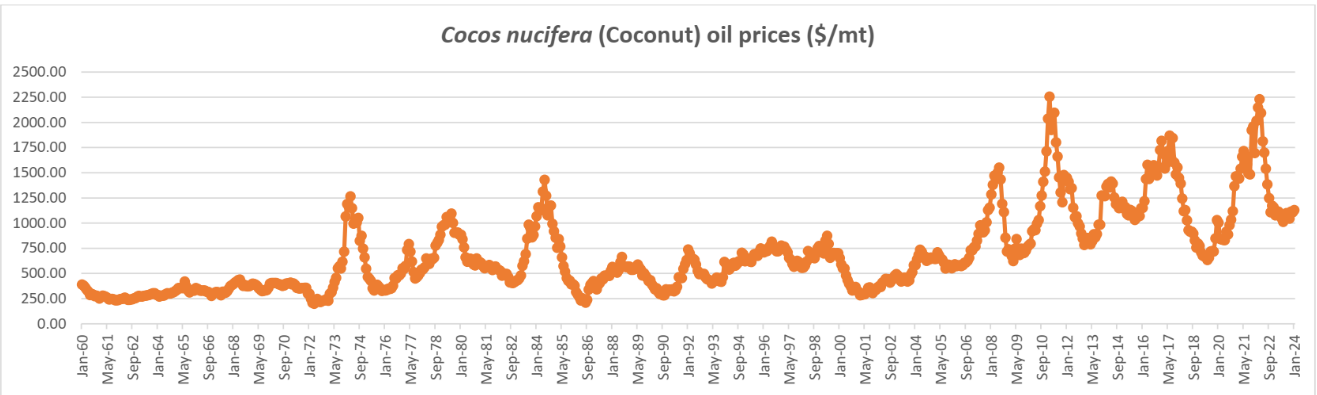

Figure 3. Coconut Oil prices ($/MT) Adapted from World Bank, (2024) [66].

Table 1. Major Coconut Producing Countries/Regions from 2017 – 2022 (MT) [37].

Rank	Country/ Region	2017	2018	2019	2020	2021	2022
1	Indonesia	17,200,000	17,100,000	17,000,000	16,800,000	17,100,000	17,190,328
2	Philippines	14,049,131	14,726,165	14,765,057	14,490,923	14,717,294	14,931,158
3	India	11,166,772	16,413,000	14,682,000	14,006,000	14,301,000	13,317,000
4	Brazil	2,210,139	2,345,400	2,348,663	2,434,095	2,465,180	2,744,418
5	Sri Lanka	1,960,000	2,098,400	2,468,800	2,233,600	2,496,000	2,204,150
6	Vietnam	1,499,228	1,571,709	1,677,044	1,720,661	1,866,700	1,930,182

Rank	Country/ Region	2017	2018	2019	2020	2021	2022
7	Papua New Guinea	1,780,312	1,780,312	1,780,312	1,180,000	1,180,000	1,258,149
8	Myanmar	1,225,690	1,414,010	1,276,095	1,252,215	1,220,000	1,217,442
9	Mexico	1,112,800	1,111,600	1,090,000	1,074,400	1,074,400	1,119,847
10	Thailand	761,914	858,235	866,416	618,246	651,866	679,232
11	Malaysia	517,589	495,531	536,606	560,984	568,894	604,428
12	Ghana	460,800	474,000	484,800	494,400	494,000	504,363
13	Tanzania	642,000	525,000	504,000	459,000	459,000	479,711
14	Dominican Republic	390,939	404,482	421,559	423,887	433,807	471,804
15	Bangladesh	408,635	466,975	431,596	431,596	402,852	411,969
16	China	327,000	403,000	395,440	402,639	391,346	400,585
17	Vanuatu	360,000	360,000	364,000	364,000	364,000	366,382
18	Mozambique	239,078	247,919	246,555	244,517	246,330	245,801
19	Nigeria	231,200	228,000	229,000	226,000	226,000	225,527
20	Kiribati	238,000	209,000	174,300	174,300	174,300	180,793

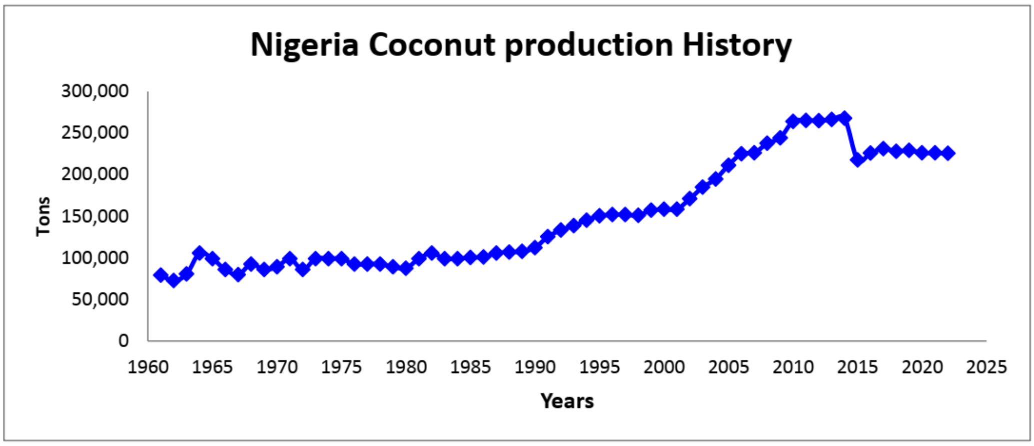

Figure 4. *Coconut Production in Nigeria from 1961 – 2022 Adapted from FAO, (2015) [67]; ICC, (2019) [68] and FAOSTAT, (2023) [37].*

2. Materials and Methods

2.1. Materials

The materials used in the study included:

Raphia palm fruits of *farinifera*, *hookeri* and *vinifera* species and Copra coconuts (Tall varieties).

Reagents: n-hexane 98%, Distilled water, Potassium hydroxide pellet (BDH, 95%), Potassium iodide (M&B, 95%), carbon tetrachloride, Wijs solution, Iodine monochloride, Acetic Acid (BDH), Phenolphthalein, sodium thiosulphate ($Na_2S_2O_3$, - BDH, 95%), Ethanol (BDH, 95%), Hydrochloric acid (BDH95%).

Apparatus, Equipment and Accessories: Soxhlet apparatus, Desiccator, Hanna pH meter, Pycnometer, Lovibond Tintometer F Model, Brookfield viscometer, Stanhope-Seta Point Apparatus, Cleveland Open Cup Apparatus, Abbe refractometer, Rancimat apparatus, Crucibles, Portable Electronic Balance (Ohaus - 30253019 Scout Pro), Thermometer, Rotary evaporator (Rikakikai, Tokyo), Pyrex laboratory glass wares (Erlenmeyer flasks, Separating Funnel, Pipettes, Burettes, Measuring Cup, Beakers, Flasks, Measuring Cup, Filter Paper, Graduated Cylinders: 10ml, 25ml, 50ml and 100ml, Sample Containers etc.), Splinter sticks.

2.2. Methods

2.2.1. Sourcing of Materials

Coconuts and *Raphia* palms are ubiquitous in the Niger

Delta. However, the selected areas in Niger Delta where Coconuts fruits (Tall varieties) and *Raphia* palm fruits (*farinifera*, *hookeri* and *vinifera* species) were sourced include 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. They were authenticated by Taxonomists in the Department of Biological science, Igbinedion University, Okada.

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

2.2.2. Extraction of Oils

Solvent method of oil extraction was utilized based on its advantages as discussed by various authors [36, 69-71]. Oils were extracted from the pulverized mesocarp of the *raffia* palm and pulverized coconut copra using Soxhlet extractor and n-hexane following the procedures outline in the literatures [71-74].

2.2.3. Determination of Oil Yields

The oil yields in percentage 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 observation in conjunction with colour charts [36, 44, 74-75] as well as Lovibond tintometer measurement in accordance to AOCS Cc 13b – 45 standard procedures [76-78].

The odour was determined by smell (Olfactory) organ [79] using a glass stoppered bottle. The bottle was first rinsed with 4 M HCl internally and thereafter rinsed with distilled water. The bottle was the filled halfway with the oil sample and shaken vigorously for about 2 minutes. The stopper was then removed and odour was observed by putting nostrils close to the tip of the bottle.

(ii). Determination of Specific Gravity

The specific gravity of the oils were determined using pycnometer because pycnometer enables the density of a fluid such as oil to be measured correctly by reference to an appropriate working fluid such as water or mercury [75, 80]. A 50 ml pycnometer was used in line with AOCS and ASTM D891-09 standards as discussed by several authors [81-83]. 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

Hanna pH meter and beaker were used to determine the pH of the oil samples [84]. The pH meter was calibrated, and the electrode dried. 40cm^3 of the different oil samples were poured into different beakers. The pH of respective oil was measured by immersing the pH meter electrode into the beaker containing the oil [36].

(iv). Determination of Viscosity

The viscosities of oil samples were determined with the aid of Brookfield viscometer in line with ASTM D2983 following with the procedures discussed by various researchers [77, 85, 86]. The dynamic (absolute) viscosities of the oil samples determined by a Brookfield viscometer were converted to kinematic viscosities using equation 3.

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

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

(v). Determination of Cloud, Cold Filter Plugging. Pour and Slip Melting Points

The cloud points and pour points of the oil were determined according to the ASTM-D2500 and ASTM D97 standards, respectively, using Stanhope-Seta point [36]. In line with procedures discussed by some notable authors [87, 88], each of the oil samples is first heated to a temperature above its expected cloud point and then cooled at a specified rate and examined periodically. The temperature at which the oil becomes cloudy or hazy is recorded as the cloud point. The oil further cooled at the specified rate and examined periodically, the temperature at which oil just ceases to flow is recorded as the pour point.

Cold filter plugging point (CFPP): This is the lowest temperature at which a fuel provides trouble-free flow in a fuel system. The CFPP of the oil samples were calculated using equation 4 [89, 90].

$$CFPP = 0.8537 \times CP - 4.72 \quad (4)$$

Where: CFPP = Cold filter plugging point, CP = Cloud point.

The open-tube capillary-slip method (AOCS Cc 3-25) [91] was used to determine the slip melting points of the oil.

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

The Cleveland Open Cup apparatus, a thermometer, and Splinter sticks were used to determine the smoke, flash, and fire points of the oil samples.

The smoke points were determined according to the AOCS method 9a-48 [36, 92]. The flash and fire points were determined according to the ASTM D92 standard [93, 94].

(vii). Determination of Moisture Content

The OAC 984.20 standard procedure (moisture loss on drying) was used to evaluate the moisture contents of the oil samples [86, 91, 95-98]. The percentage of moisture content of each oil sample was calculated using equation 5.

$$Moisture\ Content\ (\%) = \left(\frac{W_2 - W_3}{W_2 - W_1}\right) \times 100 \quad (5)$$

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 Abbe refractometer (LEICA MARK II) was used to determine the refractive indices of the oil samples at room temperature in following the ASTM D1218 standard procedures discussed by various authors [86, 91, 99, 100].

2.2.5. Determination of Chemical Properties

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

The titrimetric method was used to determine the acid values and free fatty acid compositions of the oils in accordance with the AOCS Cd 3a-63; AOCS 5a-40; AOAC Official Method 940.28; ASTM D 5555-95, and ASTM D664 standard [86, 99, 101, 102]. The acid value was calculated using Equation 6.

$$Acid\ Value\ (mgKOH/g) = \frac{V \times C \times 56.1}{m} \quad (6)$$

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 7.

$$\%\ Free\ Fatty\ Acid = \frac{Acid\ Value}{2} \quad (7)$$

(ii). Determination of Iodine Value

The titrimetric method was also used to determine Iodine values of the oil samples based on Wijs method following the AOAC 993.20, ASTM D5768 / ASTM D5554 and AOCS Cd 1-25 standard procedures [86, 88, 98-100, 102-105].

The iodine value was calculated using Equation 8.

$$IV\ (gI_2/100g\ oil) = \frac{(B-S) \times N \times 12.691}{Weight\ of\ Sapmple} \quad (8)$$

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 titrimetrically determined in line with AOAC 965.33 and AOCS Cd 8b-90 (97) standard procedures [86, 87, 102, 103, 105]. The peroxide values of each oil sample were calculated using equation 9.

$$Peroxide\ Value = \frac{1000 \times (S-B) \times N}{W} \quad (9)$$

Where: S = Volume of $Na_2S_2O_3$ solution (ml) used for samples; B = Volume of $Na_2S_2O_3$ solution (ml) used for blank; N = Normality of $Na_2S_2O_3$ solution and W = Weight of oil sample in gram.

(iv). Determination of Saponification and Ester Values

Titrimetric method was used to determine the saponification values of the oil samples based on ASTM D 5558 – 95 standard; AOCS Cd 3-25 and AOAC 920.160 standard procedures [86, 99, 102, 105, 106]. The saponification value was then calculated using equation 10.

$$Saponification\ Value\ (SV) = \frac{5.61 \times (B-S)C}{m} \quad (10)$$

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 using equation 11 [43].

$$Ester\ Value = Saponification\ Value - Acid\ Value \quad (11)$$

(v). Determination of Unsaponifiable Matter

The unsaponifiable matter contents of the oil samples were determined based on AOCS method Ca 6a-40 and Ca 6b-53 [77, 102, 107-109]. The Unsaponified matter was then calculated using equation 12.

$$Unsaponified\ Matter = \frac{R-(B+F)}{W} \quad (12)$$

Where: R is the weight of residue (g), F is the weight of fatty acid (g), B is the weight of blank (g), and W is the weight of sample (g).

(vi). Determination of Ash Content

The ASTM D 482 [86, 96] and AOCS Ba 5a-49 [102] methods were adopted in the determination of ash content of the oil samples. The ash contents were calculated using Equation 13.

$$Ash\ Content\ (\%) = \left(\frac{W_3 - W_1}{W_2 - W_1}\right) \times 100 \quad (13)$$

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 oil stability was measured in terms of induction period using Rancimat apparatus, 3g of oil sample at 120 ℃ and 20 L/h of air flow following the AOCS Cd 12b-92 and ASTM D 6751 procedures described by several researchers [110, 111].

2.2.6. Determination of Other Fuel Properties of the Oils

(i). Determination of Cetane Number

Equation 14 [112-114] was used to calculate the cetane numbers of the oil samples.

$$Cetane\ Number = 46.3 + \frac{5458}{SV} - 0.225 \times IV \quad (14)$$

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

(ii). Determination of Heat of Combustion

Equation 15 [115] was used to calculate the heat of combustion of the oil samples.

$$Heat\ of\ combustion\ (cal/g) = 11380 - IV - 9.15 \times SV \quad (15)$$

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

(iii). Higher Heating Value

Equation 16 [114, 116] was used to calculate the high heating value (HHV) of the oil samples.

$$HHV\ (MJ/Kg) = 49.43 - 0.041 \times SV - 0.015 \times IV \quad (16)$$

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

2.2.7. Determination of Tastes

After ascertaining the toxicity levels of the oil, physical methods were used to determine the tastes of oils.

3. Results and Discussion

Shown in Table 2 are the yields, physical, and chemical properties of oils extracted from the Niger Delta *Raphia* Palm fruits and *Cocos nucifera*. Each value is the mean of three independent experiments.

3.1. Oil Yield

Results (Table 2) showed that oil yields from *Raphia* palm fruits were 44.5% for the *Raphia vinifera*, 45.2% for the *Raphia farinifera* and 45.8% for the *Raphia hookeri*. These values are higher than that of the *Cocos nucifera* oil (38.6 %) and most plants found in the Niger Delta [36]. Thus, just like the *Cocos nucifera*, the common species of the Niger Delta *Raphia* Palm fruits could serve as viable source of oil for the food, feeds, biofuels and oleochemicals industries.

3.2. Physical Properties

3.2.1. pH

Vegetable oils with pH range of 6.9 to 6.7 are suitable for cooking [117]. pH is important for the synthesis of biodiesel; a low pH value affects catalyst during the transesterification reaction [36].

The pH values of the Niger Delta *Raphia* palm fruits oils ranged between 5.86 and 6.22 compared to *Cocos nucifera* oil of 6.8 (Table 2) Thus, oils extracted from common species of the Niger Delta *raffia* palm fruits could serve as suitable alternatives to *Cocos nucifera* oil in food, feeds, biofuels and oleochemicals applications.

3.2.2. Colour

Table 2 showed that the Niger Delta *Raphia* palm fruit oils were reddish, while *Cocos nucifera* oil was yellowish white. These colours are in consonance with the Lovibond values. Typically, reddishness of vegetable oils is due to presence of high beta-carotene content [36, 118], while the light yellowish colour can be attributed to the presence of compounds like carotenoids and polyphenols from fresh coconuts.

3.2.3. Tastes and Odours

The taste, smell, and flavor of vegetable oils that are ideal for use in a recipe, while cooking, or during frying are mild, pleasant, or neutral. Oils used in industrial processes, should not have objectionable odour or flavor. Table 2 showed that the Niger Delta *Raphia* palm fruit oils are bitter to taste with mild odour unlike the *Cocos nucifera* oil that is characterized by pleasant coconutty odour, tastes and flavour due to δ-octalactone [119, 120].

On the account of their bitter tastes, Niger Delta *Raffia* palm fruits oils are more suited as replacement to *Cocos nucifera* oil in the production of biofuels and other oleochemicals than for food or edibility purposes.

3.2.4. Specific Gravity/Density

The combustion efficiency of diesel engines is significantly influenced by several factors, one of which is density [84, 121]. The design of pipelines, their accessories, and related equipment is significantly influenced by density as well; pressure losses are closely correlated with density [84, 121-123]. Although, high-density oils have higher energy content per unit volume than low-density oils, they can cause pumping problems and can also lead to incomplete combustion and particulate matter emissions [36, 84].

Table 2 showed that the specific gravity values were 0.886 for the *Raphia vinifera*, 0.890 for the *Raphia farinifera* and 0.893 for the *Raphia hookeri*. These values are lower than that of the *Cocos nucifera* oil of 0.915. The specific gravity of the nucifera oil is within the NAFDAC values of 0.908 – 0.921 for coconut oil [124]. Thus, Niger Delta *Raphia* palm fruit oils have slightly lower energy content per unit volume than nucifera oil. Nevertheless, the specific gravity results showed that the *Raphia* fruit oils better suited than nucifera oil for optimal injection and complete combustion in engines.

Table 2. *Oil Yields and Physicochemical properties of oils extracted from common species of the Niger Delta Raphia Palms and Cocos nucifera.*

Parameters	***Raphia* Fruits Oils**			***Cocos nucifera* Kernel Oil**
	Farinifera	***Hookeri***	***Vinifera***	
Yield (%)	45.2	45.8	44.5	38.6
pH	5.86	6.05	6.22	6.8
Colour	Reddish (50R 20Y)	Reddish (50R 20Y)	Reddish (50R 20Y)	Yellowish white (5R 50Y)
Odour	Mild	Mild	Mild	Slightly coconutty
Taste	Mildly bitter	Slightly bitter	bitter	Slightly coconutty
Specific gravity	0.890	0.893	0.886	0.915
Kinematics Viscosity at 40℃ (cSt)	34.1	34.4	33.7	30.1
Cloud point (℃)	25.8	25.6	25.2	23
Cold filter plugging point (℃)	17.31	17.13	16.79	14.92
Pour point (℃)	19.5	19.4	19.1	17
Slip Melting point (℃)	30.3	30	29.4	25
Smoke Point (℃)	210	215	207	194
Flash point (℃)	288	292	286	278
Fire point (℃)	305	310	303	301
Moisture Content (%)	0.20	0.21	0.24	0.15
Refractive Index	1.452	1.454	1.451	1.448
Acid number (mgKOH/g)	7.14	6.52	6.08	2.48
Free Fatty Acid (%)	3.57	3.26	3.04	1.24
Peroxide Value (mEqO_2/Kg)	9.02	8.36	6.84	4.02
Iodine value (I_2g/100g)	58.6	54.1	52.3	9.2
Saponification Value (mgKOH/g)	212.8	210.2	216.4	256.4
Ester Value (mgKOH/g)	205.66	203.68	210.32	253.92
Unsaponifiable Matter (%)	0.31	0.24	0.46	0.65
Oxidative stability (hours)	10.3	10.5	11.0	16.8
Cetane Number	58.76	60.09	59.75	65.52
Heat of Combustion (cal/g)	9374.28	9402.57	9347.64	9024.74
HHV (MJ/Kg)	39.83	40.00	39.77	38.78
Ash Content (%)	1.05	1.01	1.09	1.20

3.2.5. Viscosity

The utilization of vegetable oils in industries as lubricants has been well documented [94, 125, 126]. The use of vegetable oils in engines and process equipment such as such as distillation column, heat exchangers, piping, and reactors are also well recorded [122, 125, 127, 128]. Viscosity is a one of the major factors that affect the performance [36, 71, 84; 121-123, 129]. Low viscosity can cause poor lubrication, excessive heat and increased wear and friction. Excessive viscosity can cause poor flow, energy waste and start-up problems. Viscosity also has a tremendous impact on the combustion efficiency of oils in diesel engines as well as the efficiencies of process units (distillation column, heat exchangers, piping, reactors etc.) [71, 121, 123, 129, 130]. Excessive viscosity leads to poor fuel atomization, low quality of fuel injection and spray processes, low evaporation rate and reduced lifespan of other fuel system parts [133].

Results (Table 2) showed that the kinematics viscosity of the *Raphia* palm fruit oils were 33.7 cSt for *Raphia vinifera*, 34.1 cSt for *Raphia farinifera* and 34.4 cSt for the *Raphia hookeri* while that of *Cocos nucifera* oil was 30. 1 cSt. Although these viscosity values are high, they are comparable to those of *other vegetable* oils, and could still be pumped and inject into the engines. However, their viscosities need to be reduced to improve their direct utilizations in engines, machines and process units.

3.2.6. Cloud, Pour, Cold Filter Plugging 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, (crystallization temperature) and the temperature at which it stops flowing or pouring is known as the pour point [90, 134]. The lowest temperature at which a fuel system delivers trouble-free flow of fuel is known as the Cold filter plugging point [89, 90]. Oils with low cloud, pour and cold filter plugging points are suitable for cold climate usages [89, 90, 134]. 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 higher than that of *Cocos nucifera* oil (23℃). 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 higher than that of *Cocos nucifera* oil (17℃). The cold filter plugging points of *Raphia* palm fruit oils (16.79℃ for *vinifera*, 17.13^{o}C, *hookeri* and 17.31℃ for *farinifera*) are slightly higher than that of *Cocos nucifera* oil (14.92℃).

The temperature at which fat softens or becomes sufficiently fluid to slip or run is known as the slip melting point [91]. Problems with fuel supply flow can result from high melting point values [36, 135]. The slip melting points of *Raphia* palm fruit oils (29.4℃ for *vinifera*, 30.0℃, *hookeri* and 30.3℃ for *farinifera*) are slightly higher than that of *Cocos nucifera* oil (25℃).

3.2.7. Flash, Fire and Smoke Points

The flash and fire points are used to determine the volatility and fire resistance of oil [136]. 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^{o}C and 303℃ to 310℃ respectively. These values are higher than that the flash point and fire point of *Cocos nucifera* oil (278℃ and 301℃ respectively). These values are higher than the minimum ASTM limit of 130℃. Thus, *Raphia* palm fruits and *Cocos nucifera* oils can be transported, stored and utilized without the risks of fire incidence.

Oils with high smoke points are used mostly in cooking. Oil burns when its smoke point reached. This destroys nutrients and phytochemicals in the oil as well as releases harmful free radicals that are detrimental to health [36, 137]. 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 higher than that the smoke point of *Cocos nucifera* oil (194℃). In the same vein, it is detrimental to use oils with low smoke points in engines.

3.2.8. Moisture Content

High moisture contents are not ideal for edible oils. Edible oils with high moisture contents are known to go rancid, which reduces their quality as well as shortens their shelf lives. The maximum moisture content for edible oil according to WHO standard is 0.2% [79, 139].

Apart from rancidity problems, oils with high moisture contents causes corrosion in internal combustion engine [84], and can shorten filter life or plug fuel filter and promote microbial growth [130].

High moisture contents can also cause problem in transesterification. The traditional transesterification of fats and vegetable oils for the synthesis of biodiesel is always hampered by moisture (water) and free fatty acids because they induce soap formation, catalyst consumption, and lower catalyst efficiency, all of which result in a low conversion rate [36, 138].

Despites these shortcomings, oils having higher value of the moisture content can be used for food texturing, baking, and frying and industrially in the manufacture of soaps, detergents, cosmetics and oil paints [140, 141].

Table 2 showed that the moisture contents *Raphia* palm fruits oils (0.20-0.24 %) were slightly higher than that of *Cocos nucifera* oil (0.15 %).

3.2.9. Refractive Index

Refractive index is a crucial optical property that characterizes the way light passes through a material. In the field of oil chemistry, it is employed to assess the probability of rancidity in oil due to oxidation [142]. Oils with high the refractive indices are more prone to oxidation rancidity [36]. Table 2 showed that the refractive indices of *Raphia* palm fruit oils (1.451- 1.454) are slightly higher than the refractive index of *Cocos nucifera* oil (1.448). Thus, there is no significant difference between refractive indices of *Raphia* and *Cocos nucifera* oils.

3.3. Chemical Properties

3.3.1. Acid Values and Free Fatty Acids

Acid value and free fatty acid are among the major physicochemical parameters that determine the suitability of oil for industrial applications and edibility purposes [36, 77].

According to NAFDAC, and FAO/WHO recommendations, acid values of less than 0.6mgKOH/g and free fatty acid value of less than 0.3% is ideal for oil for nutritional purposes [77, 124, 143-147]. Oil with very high acid value of oils is toxic to man and livestock [115, 145].

For industrial applications, acid value and the free fatty acids can be used to ascertain the amount of corrosive acid as well as oxidation products present in the oil [130, 148]. High acid / the free fatty acids component in vegetable oils vegetable oils can lead to corrosion in the fuel system, fuel injectors, pistons and cylinders, and crankcase, and thus detrimental to engines [130, 148]. The acid value/free fatty acid contents of oils have been reported to affect biodiesel yield and purity [149, 150]. High acid values/free fatty acids and water are inimical to biodiesel synthesis and yields because they increase catalyst consumption, decreased catalyst efficiency but promote soap formation [138, 151].

Acid value and free fatty acid contents are also used to express the deterioration and rancidity of the [43].

Table 2 showed that the acid values of the *Raphia* palm fruits oils (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 that of the *Cocos nucifera* oil (2.48 mgKOH/g). Similarly, the free fatty acids the *Raphia* palm fruits oil (3.04 % for the *Raphia vinifera*, 3.26 % for the *Raphia hookeri* and 3.57 % for the *Raphia farinifera*) were slightly higher than that of the *Cocos nucifera* oil (1.24 %). They are below the maximum recommended free fatty acids value of 5.0% for coconut oil [152-153].

3.3.2. Peroxide Values

The peroxide value of is used to indicate the degree of oxidation taking place in oil or fat and hence the shelf life [102, 153]. A low peroxide value indicates a high-quality and well-preserved oil. When the peroxide value is high, it suggests that the oil may not have many antioxidants, or that they may be very sparsely distributed. These oils don't last long on the shelf because they are easily rancid due to oxidation and are characterized rancid smell, rancid odor, and unpleasant taste [36]. Based on WHO and NAFDAC recommendation, fresh oils and edible oils should have a peroxide value of less than 10 milliequivalents/kg [77, 143-147]. The peroxide values of the *Raphia* palm fruits oils 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 that of *Cocos nucifera* oil (4.02$mEqO_2$/Kg). These values are lower than the NAFDAC and WHO recommended value. Thus, these oils could be kept and utilized for a long time in the oleochemical and nutritional industries without becoming rancid.

3.3.3. Iodine Values

Iodine value can be used to quantify the degree of unsaturation in oil components. Saturated oils are those with low iodine values while unsaturated oils are those with high iodine values [36]. Oils with iodine value above 125 are drying oils; those with iodine value 110–140 are semidrying oils while those with iodine value less than 110 are nondrying oil.

Saturated oils (low iodine values) are ideal for making soap and detergent [154-156]. They are also ideal for wafer baking [157]. Oils having high Iodine numbers, such as drying oils or unsaturated oils, are ideal for making oil paints [154-156]. The required limit for Iodine value for biodiesel synthesis is 120 g I_2/100g [158].

Oil oxidative rancidity can also be studied using iodine value. High unsaturation levels in oils make them more susceptible to rancidity [36]. With regards to the uses of vegetable oils in internal combustion engines, the maximum iodine value is 125 [134].

The results of this study (Table 2) showed that the iodine values of the *Raphia* palm fruits oils were 52.3 g I_2/100 for *Raphia vinifera*, 54.1 g I_2/100 for the *Raphia hookeri* and 58.6 g I_2/100 for *Raphia farinifera* compared to that of *Cocos nucifera* oil of 9.2 g I_2/100. These iodine values of these oils are low enough for them to be used in soap, biodiesel and wafer productions. The glycerol accompanying the soap and biodiesel productions is added advantage. They could also be use oils in internal combustion engines, since their iodine values are less than [134].

3.3.4. Saponification and Ester Values

The number of milligrams of potassium hydroxide (KOH) or sodium hydroxide (NaOH) required, under the given conditions, to saponify one gram of oil or fat is known as the saponification value [155].

The higher the saponification value of oil, the more readily it produces soap, detergent, cosmetics and glycerol [144, 153-156]. Besides, high foamability is imparted by oils with a high saponification value. Oils with a high saponification value require more methanols during the biodiesel synthesis, and they also produce more glycerol but less biodiesel [36].

For edibility purposes, the FAO/WHO recommended saponification value for most oils is between 187 and 209 mg KOH/g [144, 147, 153].

Table 2 showed that the saponification values of the *Raphia* palm fruits oils (210.2 mgKOH/g for the *Raphia hookeri*, 212.8 mgKOH/g for the *Raphia farinifera* and 216.4 mgKOH/g for the *Raphia vinifera*,) were lower than that of the *Cocos nucifera* oil (256.4 mgKOH/g). The same trend is observed for the ester values. These saponification values are these oils are ideal for soap, detergent, cosmetics, biodiesel and glycerol production but slighter higher than those recommended for nutritional purposes [124, 159, 160].

3.3.5. Unsaponifiable Matter

Though fatty acid triglycerides and their hydrolyzed derivatives are the main constituents of vegetable oils, a small amount of unsaponifiable matter is also present [102, 161, 162]. The unsaponifiable matter comprises sterols, higher molecular weight alcohols, phospholipids, tocopherols, carotenoids, phytosterols, tocotrienols, coenzyme, squalene, pigments, waxes, terpanes, oil-soluble vitamins, hydrocarbons etc. [102, 161-163]. Despite their potential oxidation-inhibiting potentials, they do not combine with bases to produce soaps. Furthermore, due to their nonpolarity, they remain in the biodiesel following the transesterification process, which degrades the biodiesel's quality [36].

The results of this study (Table 2) showed that the values of unsaponifiable for the *Raphia* palm fruits oils were 0.31 % for *Raphia farinifera*, 0.24 % for the *Raphia hookeri*, 0.46 % for *Raphia vinifera* compared to that of *Cocos nucifera* oil of 0.65 %. These are below the maximum of 10g/kg recommended for edible oils [124, 159, 160]. The low unsaponifiable matters in these oils further indicate that these oils are ideal in biodiesel, soap and glycerol production [43].

3.3.6. Oxidative Stability

The oxidative stability of oils is a crucial qualitative factor that establishes the shelf life of oils and how long they can be used before going rancid [164]. Higher oil stability index (induction period) indicate the higher the shelf life [164]. The efficacy of antioxidants in oil can also be assessed using the oxidation stability analysis [36]. The oil stability index recorded for the *Raphia* palm fruit oils (10.3hours for *Raphia farinifera*, 10.5hours for *Raphia hookeri* and 11.0hours for *Raphia vinifera*) were lower than that of the *Cocos nucifera* (oil 16.8 hours) but higher than those of corn oil, grape seed oil, hazelnut oil, olive oil, peanut oil, rapeseed oil, rice bran oil, soybean oil, and Sunflower oil [111, 165].

The oxidative stability results are reflections of the other parameters (peroxide value, refractive index etc.) that was used to quantity rancidity.

3.3.7. Ash Contents

Ash content is an important parameter that indicates the total mineral content / inorganic matter in the oils [96, 166, 167]. Ash content is also use to indicate the incombustible components of oil [168]. Vegetable oils with high ash contents are well suited for edibility and longevity purposes oils [96, 166, 167]. Vegetable oils with low ash contents are ideal as biofuels in oil burners [36, 169].

Table 2 showed that the ash contents of the *Raphia* fruit oils were 1.05 % for the *Raphia farinifera*, 1.09 % for the *Raphia vinifera* and 1.01 % for the *Raphia hookeri*. These are slightly lower than that of the *Cocos nucifera* oil (1.20 %).

3.4. Other Fuel Properties of the Oils

Vegetable oils and their methyl esters can be used as alternative fuel to conventional fossil-based diesel in diesel engines [133, 134, 158, 170]. However, before such usage, their cetane number, heat of combustion and heating values need to be determined [36].

3.4.1. Cetane Number

Cetane Number is one of most important property of fuel and it is used to indicate ignition delay characteristics the ease with which diesel fuel ignites [90, 158, 171]. The higher the value, the simpler it is to ignite [171]. In fact, vegetable oils used in diesel engines should have cetane numbers higher than 35-40 [36, 170].

This study showed that the cetane numbers of *Raphia* fruit oils were 58.76 for the *Raphia farinifera*, 59.75 for the *Raphia vinifera* and 60.09 for the *Raphia hookeri* while that of the *Cocos nucifera* oil was 65.52. Thus, there is no significant difference between the cetane numbers of *Raphia* fruit oils and *Cocos nucifera* oil.

3.4.2. Heat of Combustion

The heat of combustion is another important property of fuels and it is used to indicate the energy content of the fuel [36, 117, 158]. The heat of combustion is the heat produced when hydrogen and carbon in the fuel reacts with the oxygen from the air [172]. This study showed that the heat of combustion of *Raphia* fruit oils were 9374.28 cal/g for the *Raphia farinifera*, 9347.64 cal/g for the *Raphia vinifera* and 9402.57 cal/g for the *Raphia hookeri* These are slightly higher than that of the *Cocos nucifera* oil (9024.74 cal/g).

3.4.3. Higher Heating Value

Another significant property of fuels is the heating value. It is used to quantify the energy content of the fuel [117, 158]. 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 [36, 172].

This study showed that the higher heating value of *Raphia* fruit oils were 39.83 MJ/Kg for the *Raphia farinifera*, 39.77 MJ/Kg for the *Raphia vinifera* and 40.00 MJ/Kg for the *Raphia hookeri*. These are slightly higher than that of the *Cocos nucifera* oil (38.78 MJ/Kg).

4. Conclusions

Cocos nucifera kernel oil is one of the most valuable, expensive and highly consumed vegetable oils worldwide. In many nations demand outweighed the supply.

This study was therefore conducted based on the search for a suitable feedstock that can either be used in conjunction with or as a substitute to *Cocos nucifera* oils.

In the 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 *Cocos nucifera* kernel. The prospects of using each of the *raffia* palm oil as an alternative to *Cocos nucifera* oil were analysed based on the results of standard physiochemical properties analysis.

The results of this study showed that most of the physiochemical properties of the oils extracted from common species of the Niger Delta *raffia* palm fruits are comparable to those of *Cocos nucifera* oil and the standards set for food, feeds, biofuels and oleochemicals.

The oil yields from *Raphia* palm fruits were higher than that of the of the *Cocos nucifera* oil. While *Cocos nucifera* oil was yellowish white and characterized by non-objectionable odors and tastes, the *Raphia* oils were reddish and characterized by mild odour and are bitter to state.

While specific gravity values of the *Raphia* palm fruit oils were lower than that of the *Cocos nucifera* oil; the kinematics viscosities, smoke points, flash points, fire points, peroxide values, iodine values were higher than those of *Cocos nucifera* oil.

The pH, saponification and ester values, unsaponifiable matter, oil stability, cetane numbers, ash contents of the *Raphia* fruit oils were slightly lower than that of the *Cocos nucifera* oil.

The cloud, pour, cold filter plugging and slip melting points, moisture contents, acid values and free fatty acids, heat of combustion and higher heating values of the *Raphia* palm fruit oils were slightly higher than that of the *Cocos nucifera* oil.

These results showed that the *Raphia* palm fruits oils are more suitable as alternatives to *Cocos nucifera* oil in the biofuels and oleochemicals sectors than in the food and feed sectors.

Abbreviations

NTCB	NEDAC Training Centre, Bangkok
NEDAC	Network for Development of Agricultural Cooperatives
LINAC	Laxmanrao Inamdar National Academy for Coop Research & Development (NCDC, India)
NCDC	National Cooperative Development Corporation
HIV	Human Immunodeficiency Virus
NMBU	Norwegian University of Life Sciences
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
ICC	International Coconut Community
MT	Metric Tons
$Na_2S_2O_3$	Sodium Thiosulfate
AOCS	American Oil Chemists' Society
HCl	Hydrochloric Acid
ASTM	American Society for Testing and Materials
CFPP	Cold Filter Plugging Point
CP	Cloud Point
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
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
NaOH	Sodium Hydroxide

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Conflicts of Interest

The authors declare no conflicts of interest.

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