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Physicochemical Characteristics Study of Oil Extracted from Raffia Palm Seed

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Raffia oil, physicochemical properties, saponification, transesterified, energy generation

A B S T R A C T

The Physicochemical properties of the extracted oil from Raffia palm (Raphia regalis) were investigated. Physical properties such as refractive index, specific gravity, viscosity, moisture content, flash point, smoke point, fire point, pour point and cloud point; and chemical properties such as acid value, free fatty acid, saponification value, unsaponifiable matter, iodine value, ester value and peroxide value were investigated for both raw Raffia oil and transesterified raffia oil. The various properties were investigated using ASTM standard methods and calculations. Results obtained for physical properties: refractive index, specific gravity, viscosity, moisture content, flash point, smoke point, fire point, pour point and cloud point were 1.437, 0.765, 1.420 mm^2/sec, 8.0%, 154ºC, 140ºC, 160ºC, -3ºC and -7ºC respectively for the raw Raffia oil, and 1.341, 0.840, 1.21 mm^2/sec, 1.6%, 70ºC, 66ºC, 72ºC, -5ºC and -12º for the transesterified raffia oil. Results for the chemical properties: acid value, free fatty acid, saponification value, ester value obtained in (mgKOH/g), iodine value (mgI_2/g), peroxide value (mEq/kg) and unsaponifiable matter (%) were determined to be, 18.849, 9.472, 136.043, 117.194, 5.076, 192.000 and 1.814% respectively for the raw Raffia oil; and 31.977, 16.069, 193.545, 161.568, 167.50, 350.800 and 2.481% for the transesterified raffia oil. It was concluded that Raffia oil when processed have great potentials for use as alternative fuel for energy generation.

1. Introduction

As the world population increases, energy demand for consumption also increases. In any nation, energy is the most fundamental requirement for human existence and activities. Unfortunately, the non-renewable energy sources that contribute over 86% of the global energy supply are depleting, (Atadashi *et al.,* 2011; Oshewolo, 2012). This depleting effect is being felt more in countries that depend on importation. Also, the greenhouse gas emission from the use of fossil fuel contributes significantly to climate change. This problem has resulted in intense search for alternative feedstock and sustainable technology that can counter the shortcomings of non-renewable energy sources. Among the alternative energy considered to replace the dwindling conventional fuel are biodiesel, straight-chain vegetable oil, bio-ethanol, bio-oil, and bio-hydrogen. Biomass has contributed significantly to the biofuel industry because vegetable oil has certain features that makes them attractive substitute for fossil fuels, (Raja *et al.,* 2011; Akinola and Fapetu, 2015). Vegetable oil such as soybean oil, palm oil, castor oil, *Parkia biglobbossa* oil, *Jatropha curcas* oil, sunflower oil, coconut oil, rapeseed oil, ground nut oil, Neem oil, pea nut oil and cotton seed oils have been intensively studied as raw materials especially for biodiesel production (Akoh *et al.,* 2007; Alamu *et al.,* 2007; Hasibuan *et al.,* 2009; Robles-Medina, *et al*., 2009; Aransiola *et al.,* 2012). Other potential vegetable feedstock for biodiesel production includes tobacco *(Nicotianatabacum*), desert date *(Balanites aegyptiaca*), castanhola (*Terminalia catappa)*, rubber tree (*Hevea brasiliensis)*, tung *(Vernicia fordii*), milkweed (*Asclepias syriaca*),

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Zanthoxylumbungeanum, radish *(Raphanus sativus*), Ethiopian orAbyssinian mustard (*Brassica carinata*), false flax or gold-of-pleasure (*Camelina sativa*), Polanga *(Calophyllum)* seeds oil.

Majority of these feedstocks are found in Nigeria, being a tropical country that has a wide variation of climate and soil conditions that can ease their cultivation. However, inadequate information on the utilization and composition of the oil seeds indigenous to Nigeria is a major challenge (Akintayo, 2004). Beside vegetable oils, animal oil has been investigated for biodiesel production alongside with algae, microalgae, bacteria and fungi (Amin, 2009; Demirbas, 2009); wastes oils and fats (beef tallow, lard and yellow grease), hemp oil, grease by-product from omega-3-fatty acids production from fish oils have also been considered as feedstock for biodiesel production (Demirbas, 2003; Marchetti *et al.,* 2007; Antczak *et al.,* 2009). Other sources of biodiesel feedstock include animal fats from varieties of domesticated animals such as cows, chickens, pigs as well as insects such as melon bug (*Aspongubus viduatus*), sorghum bug (*Agonoscelis pubescens*) and waste oil from cooking and vegetable oil soap (Moser, 2009).

Biofuel confer several advantages over fossil fuels because of its lower aromatic content, liquid nature, portability, low sulphur content, renewability and availability, whereas, high viscosity, flash and fire points, lower volatility and reactivity are the major shortcomings (Demirbas, 2003; Raja *et al.,* 2011). The analytical characteristics and fatty acid compositions of extracted oil from raffia palm seed, besides their value for reference purposes, serve as useful guides to oil analysts in the determination of the components of unknown mixtures and for checking the specifications of suppliers and products (Cocks and Rede Van, 1966). Fats and oils from vegetable and animal sources do not have fixed compositions since they are subject to the effect of parameters such as geographical location and climatic conditions during the growth period in the case of vegetable oils, especially those derived from annual plants. Changes in agronomic practices and the introduction of new cultivars in recent years have been shown to affect tree nut compositions (Asiedu, 1989).

Therefore, effort was made in this work to perform a physicochemical characteristics study of oil extracted from raffia palm seeds that includes free fatty acid, iodine value, acid value, saponification value and Unsaponifiable matter, specific gravity, viscosity, ester value, gross heat of combustion, cloud point, pour point, flash point, refractive index, peroxide value, moisture content, and estimation of Cetane number for energy applications.

2. MATERIALS AND METHODS

2.1 Materials and Equipment

The materials and equipment used for the study include raffia palm fruits, Soxhlet extractor, Pycometer bottle, Abbe's refractometer, Electric Pensky Marten Flash Point Apparatus, digital viscometer, combustion calorimeter, conical flask and solvents.

2.2 Methods

2.2.1 Sample Collection and Preparation

Fresh raffia palm fruits were collected from two raffia palm trees that were cut down in Akure, Ondo State, Nigeria. The fruits were sundried for a month for the shells to be removed and further sundried for another three months and pulverised in a hammer mill, from which oil was extracted.

2.2.2 Oil Extraction

Oil was extracted from the pulverised seeds using soxhlet apparatus with n-hexane and petroleum other as solvents. Pulverised seeds (200 g) were put into a 1000 ml capacity Soxhlet extractor. The two solvents; n-Hexane and petroleum ether were used separately so as to be able to compare the yield.

2.2.3 Transesterification

A portion of the extracted oil was subjected to a series of post extraction, catalyzed transesterification processes. A two-step acid catalyst esterification and alkali catalyst transesterification (Hanny and Shizuko, 2008), were employed because the free fatty acid (FFA) content of the extracted oil was greater than 1%. After the first acid pre-treatment process of esterification using methanol and sulphuric acid as catalysts, the FFA content of the raffia oil was reduced to less than 1%. Thereafter, the oil with a lower FFA content was subjected to the alkali based transesterification process to yield high methyl ester content oil which may be considered as a useful biofuel for energy generation.

2.3 Physical and Chemical Characteristics of Oil

Melting Point: The oils were first frozen to solid in a refrigerator and little of the samples were put into a test tube with a thermometer. The solidified sample was tested for its melting point.

Refractive index: Abbe's refractometer was used to determine the refractive index. Refractive index of oil is the ratio of speed of light at a defined wavelength to its speed in the oil itself (Hoffmann, 1986). The meter was reset with light compensator; the oil sample was smeared on the lower prism of the instrument and closed. A light was passed by means of angled mirror and telescope tubes were moved until shadow appeared (Brown *et al.,* 1999). The refractive index was calculated using equation (1)

$$n = \frac{\sin(i)}{\sin(r)} \quad (1)$$

Where; i is the angle of incident ray with respect to the vertical plane, and r is the refracted ray passing through the extracted oil.

Specific Gravity: This is the ratio of oil sample in gram weight to that of equal volume of water which was determined for the extracted oil using method proposed by Joslyn (1970). A 50ml pycometer bottle was thoroughly washed with detergent, water and petroleum ether, then dried and weighed (w_1). The bottle was filled with 10ml of water and weighed (w_2). The bottle was emptied and dried. 10ml of the oil sample was weighed into the bottle and weighed together (w_3). It was calculated using equation (2).

Specific gravity = $1213wwww--$ (2)

Kinematic Viscosity: The viscosity of the oils was measured using OSTWALD viscometer in accordance with ASTM D445 in which oil sample was heated up to 40°C, so as to flow under gravity through calibrated capillary (the open right arm) and drawn up into the upper bulb of the 2 bulbs (the left arm) separated by a length of capillary tubing so that it completely fills the bulb. The time during which the oil sample flows through the capillary was determined. A similar measurement was made with water with known viscosity which served as a standard for comparison.

The kinematic viscosity was estimated using equation (3)

Kinematic viscosity = time taken × viscosity factor (3)

Pour point: This was determined by putting the transesterified oil and the extracted oil samples of 60 ml into two separate beakers. The samples were put into the freezer and the temperatures of the samples were taken at regular intervals of 20 minutes with a thermometer. The lowest temperature at which the oil was observed to flow is known and recorded as the pour point.

Cloud point: This was determined by putting two samples of 60 ml each into two separate 100 ml beakers. The temperatures of the samples were taken with a thermometer and the readings noted. The samples were put into freezer while the temperatures taken at regular intervals of 10 minutes with a thermometer. The temperature at which a cloud wax crystals appeared on the cooling stirring was noted and recorded as the cloud point.

Flash Point: The flash point was determined using ASTM D93 standard in an Electric Pensky Marten Flash Point Apparatus. About 50 ml of extracted oil was poured into the cup fitted with lid and shutter assembly while a thermometer was also inserted. The stirrer speed was set and the pilot and test flames were dipped into the sample. A beep of sound and flash were observed as the oil sample was being heated to give vapour. The temperature at which vapour formation started was recorded. The same process was done to transesterified oil.

Smoke and Fire Points: The same standard and apparatus was used for the determination of the smoke and fire points. The stirrer speed was set and the pilot and test flames were dipped into the sample and sample was heated continuously with apparatus until it gave off a thin but continuous stream of bluish flame. The temperature at that point was recorded as the smoke point, while the heating process was continued until sufficient vapour was produced and caused burning for more than a minute. The temperature reading was recorded as the fire point.

Moisture Content: Moisture content is the measure of water in a material and its percentage is calculated using equation (3.18). It was determined using EXTECH digital moisture meter. The oil sample was poured into a petri dish and the terminals of the meter were dipped into the oil while the meter was on. The readings were displayed on it and were read. It was estimated using equation (4)

$$\text{Moisture content, MC (\%)} = 100\frac{(b-c)}{(b-a)} \quad (4)$$

Where; a is the weight of empty beaker, b is the weight of beaker + oil before drying, c is the weight of beaker + oil after drying

Cetane number: The Cetane number was calculated as reported by Mohibbe et al, 2005 using equation (5).

$$\text{Cetane No} = 46.3 + \frac{5458}{(SV)} - 0.225(IV) \quad (5)$$

Where; SV is the saponification value, and IV is the iodine value.

Mean molecular mass: The mean molecular mass of the oil is calculated using equation (6).

$$\text{Mean molecular mass} = 100\left(\frac{56}{SV}\right) \quad (6)$$

Where; SV is the saponification value.

High Heating Value: The heating value was calculated using equation (7) (Demirbas, 2003).

Higher heating value (HHV), (MJ/kg) = 49.43 - 0.041(SV) - 0.015(IV) (7)

Where; SV = saponification value, and IV = iodine value.

pH Value: The pH value was determined using JENWAY 3505 pH Meter based on ASTM D664.About50ml of the oil sample was poured inside petri dish. The probe was dipped into the sample and the reading was taken.

Acid Value: The acid value was calculated using equation (8)

$$\text{Acid Value} = \frac{\text{Titre Value (ml)} \times 5.61}{\text{Wieght of the sample}} \quad (8)$$

Free Fatty Acid.

The free fatty acid was determined according to the Official Method (Ca 5a-40) of American Oil Chemists' Society (AOCS) (1993).

About10 g of the extracted oil sample was poured into a 250 ml Erlenmeyer flask using an analytical balance. A 20 ml of 95% neutralized ethanol was added to the flask. The solution was heated and maintained at 20°C to aid the dissolution of the oil in the alcohol. Two drops of phenolphthalein solution was added as indicator. The obtained yellowish solution was titrated with 0.1M standard sodium hydroxide solution while shaking the solution vigorously. The colour of the solution turned pink and at the point when the pink persisted for 30 s was termed the end point. The result obtained for free fatty acid was expressed as the acid degree value (ADV) which is the number of millilitre of 1M base required to titrate 100 g of fat. The figure is expressed as millilitre of 0.1M alkali and then multiplied by the oleic acid value of 0.282.

The percentage of free fatty acid in the oil was calculated using equation (9)

$$\%FFA = 100\left(0.282\frac{V.N}{W}\right) \quad (9)$$

Peroxide value: This was determined in accordance with AOAC method (1997). About 2.5 g of oil sample was weighed into 250 ml conical flask and 30 ml of ethanoic acid chloroform mixture in ratio of 3:2 and 5 ml of saturated potassium iodide (KI) were added. A 15 ml of sodium thiosulphate ($Na_2S_2O_3$) was also added until yellowish colour attained and 2 ml of starch solution (indicator) was added and titrated with 0.02 M sodium thiosulphate. The peroxide value was calculated using equation (10)

$$\text{Peroxide value} = 100M\frac{(b-s)}{M} \quad (10)$$

Where; b is the titre value of blank, s is the titre value of sample, and M is the molarity of sodium thiosulphate (0.02 M)

Saponification Value: The saponification value was determined using AOCS (1993) Official Method Cd 3-25. About2 g of the dried and filtered oil sample was weighed into a 250 ml Erlenmeyer flask. 25 ml potassium hydroxide was added using a pipette and the pipette was allowed to drain for some time. A blank was conducted simultaneously where all reagents were added with the exception of the oil sample. The air condenser was connected and the sample boiled gently, but steadily for 45 min. After the flask and condenser have cooled but not sufficiently to forming gel, the inside of the condenser was washed with a small quantity of distilled water and the condenser disconnected. 1 ml of phenolphthalein indicator was added to the sample and the sample titrated with 0.5N hydrogen chloride (HCl) until the pink colour just disappeared and the volume of the HCl recorded. The value was estimated using equation (11)

$$\text{Saponification Value (SV)} = \left(28.05\frac{V_{HCl} - V_{0.5M,HCl}}{W_o}\right) \quad (11)$$

Where; V_{HCl} = volume of HCl required by blank, $V_{0.5M, HCl}$ = volume of 0.5M HCl, and W_o = weight of oil sample.

Unsaponifiable Matter: The unsaponifiable matter was determined using Official method Ca 6a-40 of AOCS (1993). About 2.5 g of the oil sample well mixed was weighed into a 250 ml Erlenmeyer flask with ground glass joint. A 25 ml of about 95% ethyl alcohol and 1.5 ml of 50% potassium hydroxide solution was added. The solution was boiled gently but steadily under reflux with occasional swirling for 30 min until completely saponified and cooled to room temperature (25°C). The cylinder was corked with a stopper, shaken for at least one minute, and allowed to settle until both layers could be clearly identified. A glass siphon was used to remove the upper layer completely as possible without including any of the lower portions. The diethyl ether layer was transferred into a 250 ml separation funnel. The combined extract was washed in a separation funnel thrice using 20 ml portion of 0.5N potassium hydroxide while shaking vigorously. After each alkali was washed, washing was re-conducted using 20 ml of water. After the third washing of the alkali, the diethyl ether was washed with successive 20 ml of water until the washings did no longer appear pink on addition of phenolphthalein, indicating that the sample was no longer alkaline.

Iodine value: The iodine value was determined according to Official Standard Method (Cd 1-25) of AOCS (1993). A 0.20 g of the filtered oil sample cooled at a temperature of 68– 71° C was weighed into a 500 ml flask. A 15ml of carbon tetrachloride was added to the sample and swirled to ensure that the sample was completely dissolved. A 25 ml of Wijs solution was dispensed into the flask containing the sample and swirled to ensure an intimate mixture. The flask with content was immediately kept in a dark place at a temperature of about 25– 30°C for two hours. Deionized water was added and excess iodine was titrated with sodium thiosulphate. The Iodine value was obtained using equation (12)

$$\text{Iodine value, (IV)} = 12.69\frac{N.(B-S)}{W_o} \quad (12)$$

Where; N is the concentration of sodium thiosulphate, B is the volume of sodium thiosulphate used for blank, S is the volume of sodium thiosulphate used for sample, and W_o is the weight of the oil

sample and the molecular weight of iodine is 12.69.

Ester Value: Ester value represents the number of milligrams of potassium hydroxide required to saponify the esters present in 1 g of the oil. It is obtained as the difference between the saponification value and the acid value.

3. RESULTS

Tables 1 and 2 show the details of the results of physical and chemical properties of the raw extracted oil and the transesterified oil of Raffia oil as compared with the standard limits and diesel oil using standard test methods of America System of Test Materials (ASTM).

Table 1: Physical Characteristics of Raw and Transesterified Oil of Raffia Palm Seed

PARAMETER	UNITS	EXTRACTED OIL	TRANSESTERIFIED OIL	ASTM LIMITS	DIESEL
Refractive Index @ 32ºC	ºC	1.437	1.341	-	-
Specific Gravity	-	0.765	0.840	-	-
Kinematic Viscosity @ 40ºC	mm^2/s	1.420	1.121	1.9-6.0	2.23
Pour Point	(ºC)	-3	-5	-9 max	-20
Cloud Point	(ºC)	-7	-12	-	-12
Smoke Point	(ºC)	140.000	66.000	-	-
Flash Point	(ºC)	154.000	70.000	45 min	68
Fire Point	(ºC)	160.000	72.000	-	-
Moisture Content	(%)	8.0	1.6	-	-
Cetane Number		61.19	75.96	40 min	-
Mean Molecular Mass	%	16.72	31	-	-
Higher Heating Value	(MJ/kg)	35.8	42.1	-	-
Heat of Combustion	(cal/g)	9452.084	14635.689	-	-
pH		4.83	12.62	-	-

Table 2: Chemical Characteristics of Raw and Transesterified Oil of Raffia Palm Seed

PARAMETER	UNITS	EXTRACTED OIL	TRANSESTERIFIED OIL	ASTM LIMITS	DIESEL
Acid Value	(mgKOH/g)	18.850	31.977	-	-
Free Fatty Acid	(mg/g)	9.472	16.069	-	-
Peroxide Value	(mEq/kg)	1.8	1.2	-	-
Saponification Value	(mgKOH/g)	330.99	179.52	-	159.89
Unsaponifiable Matter	(%)	1.184	2.481	-	-
Iodine Value	(mgI_2/g)	7.11	12.18	-	-
Ester Value	(mgKOH/g)	312.14	147.54	-	-

4. Discussiona

Refractive Index: The raffia oil and the transesterified Oil from the seeds of *Raffia regalis* had refractive indices of 1.437 and 1.341 at 32ºC respectively. These values are in agreement with result of Geicai *et al.*, (2012) that gave 1.465, 1.463, 1.459 and 1.455 at 20, 30, 40 and 50 °C respectively. The results also agrees with most of the seed oils reviewed that have their refractive index values within the acceptable range of 1.468 to 1.471 for virgin and refined oils according to Codex Standards for fats and oils from vegetable/plant sources. This indicates that there is high purity (Aremu *et al.*, 2015).

Kinematic Viscosity: The viscosity of the extracted oil and the transesterified oil were recorded 1.420 mm^2/sec and 1.121 mm^2/sec respectively. The kinematic viscosity in biodiesel standards has been determined as 1.9-6.0 mm^2/s by ASTM (2009). The results here showed that the two oils have superior ability to flow and the transesterified oil can be readily sprayed with little resistance in any injector of internal combustion engines or turbines.

Viscosity is an important parameter for the design and selection of handling, processing and transportation equipment for liquid fuels according to Gopakumar, (2012). Viscosity affects the atomization of a fuel upon injection into the combustion chamber and cause the formation of engine deposits. The lower the viscosity the lower the resistance to flow and the better the fluidity, mixture formation, the fuel sprays at the injector points and combustion process (Canakci and Sanli, 2008).

Pour Point: The pour point of the extracted oil and the transesterified oil were determined to be -3°C and -5°C which were within the range of the ASTM limits for standard specification of -9°C. Pour point of bio-oil is prescribed along with the conditions of storage and varies from -12°C to -36°C depending on the biomass (Oasmaa and Peacocke, 2001). Low viscosity of bio-oil is an indication of low pour point. Therefore, retrofits are needed for the direct applications of bio-oil in engines, turbines and boilers, **(**Gopakumar, 2012). Pour point is the lowest temperature at which the fuel becomes semi solid and loses its flow characteristics being no longer able to pump; hence it is a measure of the fuel gelling point. The pour point is always lower than the cloud point.

Cloud Point: The cloud point of the extracted oil and the transesterified oil were determined to be -7°C and -12°C respectively. The key flow properties for winter fuel specification are the cloud and pour point. Cloud point is the temperature at which wax form a cloudy appearance, it is measured as the temperature of first formation of wax as the fuel is cooled. The cloud point is not generally affected by additives called flow improvers, however, flow-improver additives can inhibit the formation of the wax crystallites formed upon cooling the fuel and thus lower the temperature at which wax plugging becomes a problem (Graboski and McCormick, 1998). Poor cold flow properties may result in fuel line blockage, ultimately leading to fuel starvation. These problems are particularly enhanced during cold starting particularly at low ambient temperatures.

Flash Point: The flash point is a measure of flammability of fuels i.e. the temperature at which a fuel must be heated such that the mixture of vapor and air above the fuel can be ignited; this property makes it a safety criterion in storage, transport and handling**.** The flash point of biodiesel is usually higher than pure diesel fuel which makes it much safer in handling than diesel. Extracted oil and the transesterified oil have flash point of 154°C and 70°C respectively. The value for that of extracted oil was within the ASTM limits for biodiesel (130°C min) and the flash point of transesterified oil is higher than that of pure diesel fuel which is 68°C. This is a good fuel characteristic that could enhance the use of *Raphia regalis* oil as a substitute for fossil fuel.

Smoke Point: This is the temperature at which oil when heated gives off the first smoke. The smoke point of oil is dependent on the level of its purity and time duration between when the oil was produced and smoke tested. The smoke point for the extracted and the transesterified oils were 140°C and 66°C respectively. Since, the flash point of the produced oil and the transesterified oil is favourable, it can be suggested that the smoke point for both oils are favourable for the safe handling of the oil, thus lowering the risk of fire outbreak during handling.

Fire Point: This is the lowest temperature at which the vapours of the oil burn continuously for at least five seconds when a flame is brought near it. The fire point for the extracted and the transesterified oils are 160°C and 72°C respectively. These values favour the safe handling, storage and transportation of the oil. It has been noted that the transesterified oil has flash point similar to that of diesel oil, hence the smoke and fire points of the transesterified oil may be relatively similar to that of the diesel fuel, since there was no complementary data for diesel oil on such properties. This makes the transesterified oil to be a viable source of alternative fuel for internal combustion engine.

Moisture Content: The percentage moisture content in the extracted oil and the transesterified oil were determined to be 8% and 1.6% respectively. Water is a major source of fuel contamination. Therefore, the formation of gel during production might be due to the presence of moisture content which will cause low temperature that hinders glycerol separation (Madras, *et al,* 2004). In catalyzed methods, the presence of water has negative

effect on the yields of methyl esters; however, the presence of water positively affects the formation of methyl esters in supercritical methanol method (Kusdiana and Saka, 2004). Water in alternative fuel can cause three serious problems: corrosion of engine fuel system components, promotion of microbial growth, and hydrolysis of fatty acids methyl esters.

Cetane Number: The Cetane indices were estimated to be 61.19 for the extracted oil and 75.96 for the transesterified oil which are within the maximum range especially for diesel fuel. This is advantageous as a feasible biodiesel fuel since it has a high Cetane rating. Centane number is widely used as diesel fuel quality parameter related to the ignition delay time and combustion quality. The higher the centane number, the better is the ignition property (Meher, *et al,* 2006), and the greater the content of the methyl ester in the diesel fuel. An adequate centane number is required for good engine performance. High centane numbers help ensure good cold start properties and minimize the formation of white smoke. The Cetane number measures how easily and quickly the fuel starts to burn (auto-ignites) under diesel engine condition. The vegetable oil from *Raffia regalis* therefore can ignite easily and quickly which gives it a positive attribute and a potential biodiesel fuel for combustion engines.

Heat of Combustion: The estimated values of the heat of combustion for the Raffia oil and the transesterified oil from the fruit of *Raffia regalis* revealed that the extracted oil has 9452.08 cal/g and burning the transesterified oil in a diesel engine will yield about 14635.69 cal/g where 1 cal is 4.19×10^{-6} in MJ/g, which is 39.57 MJ/kg and 61.28 MJ/kg. This showed that combustion of a little volume of the methyl ester of the oil will yield a tremendous amount of energy to drive the pistons of internal combustion engines, thereby providing enough power to propel the engine. This is comparable to the recommended oil standard European standard for using biodiesel as heating oil, (EN 14213, specifies a minimum heating value of 35 MJ/kg) for use in a heavy duty combustible diesel engine (Krause, 1998; Klopfenstein and Walker, 2003).

pH value: This is the measure of the degree of acidity or alkalinity of a solution. The pH value of the extracted oil was measured as 4.83, which signifies that the raw oil is slightly acidic in nature, and may possess some corroding capabilities. However, the transesterified oil is strongly alkalinic with pH of 12.62. This is a good indication that the transesterified oil would be a viable fuel substitute as its corrosion ability is low.

Acid Value: The acid values of the extracted oil and the transesterified oil from the fruit of *Raffia regalis* were 18.849 mgKOH/g and 31.977 mgKOH/g which were 1.89% and 3.2% respectively. The acid value of the extracted oil was reasonably lower when compared to 4.49% reported for Afzelia Africana by Igwenyi *et al., (*2011); 1.68% – 5.05% reported by Igwenyi *et al.,* (2008) for *Raphia vinifera* seed pulp oil and 4%, reported by Ikwuagwu *et al*., (2000) for rubber seed oil used in the preparation of biodiesel. The 1.89% acid value of the extracted oil showed that the oil may be more advantageous for paint production, while the acid value of the transesterified oil has greater advantage in soap making (Aremu *et al.*, 2015). The obtained values were similar to the values of 3.0, 12.2, 0.8, 2.1 and 2.5 percent reported for sunflower, cotton seed, groundnut, olive oil and coconut oils respectively used as edible and industrial oils (Engler *et al.*, 1983).
The lower the acid values of oil, the fewer the free fatty acids it contains. (Roger *et al.,* 2010).
The low value showed that the oil if exposed without addition or treatment with antioxidants will be stable over a long period of time and protected against rancidity and peroxidation. This low level of the free fatty acids is an indication that the components were predominantly composed of triacylglycerol and presence of natural antioxidants (Ikwuagwu *et al*., 2000**;** Igwenyi *et al*., 2008).

Peroxide Value: The peroxide value helps in determining which oil could be easily susceptible to oxidative rancidity, as higher peroxide value is indicative of higher susceptibility to oxidation (Akpabio *et al,* 2011).The peroxide values in mg/g for the extracted oil and the transesterified oil from *Raffia regalis* were 1.8 mEq/kg and 1.2 mEq/kg,. These were quite low when compared to the values of 6.40 mEq/kg reported for *Aphelia Africana* by Igwenyi *et al.,* (2011), 7.45 mEq/kg – 8 mEq/kg in *Sesame indicum* L. reported by Mohammed and Hamza (2008) and the peroxide values of 2.00 mEq/kg – 6.00 mEq/kg reported by Igwenyi *et al.,* (2008) for *Raphia vinifera* seed pulp (mesocarp) oil. This showed that the oil would be stable and this stability is further confirmed by the low level of free fatty acids. This is attributable to the presence of natural antioxidants like tocopherols in the oil which are effective in slowing down the rate of oxygen absorption by reacting with the fatty acid peroxy free radicals (Hoffman, 1986). The peroxide values of the oils produced are similar to those of rapeseed, sesame, sunflower and groundnut seeds which suggest their suitability and use as edible oils (Ibironke, *et al.,* 2005).

Saponification Value: Saponification value of oil serve as important parameters in determining the suitability of oil in soap making (William and Vida, 2015). Such oils with a higher saponification value give a clear solution in water; this type of oil is grouped among those yielding soaps of soft consistency. The

saponification values of the extracted oil and the transesterified oil from the fruit of *Raffia regalis* were 330.99 mgKOH/g and 179.52 mgKOH/g respectively. The saponification value of the extracted oil was higher when compared to the results for other oils; 188.8 mgKOH/g (avocado pear oil), 189 – 191 mgKOH/g (*Sesame indicum* L. seeds), 179 – 220 mgKOH/g (*Detarium microcarpum* and *Moringa oleifer*); 194.3 mgKOH/g (cotton seed oil), 185.20 mgKOH/g (shea butter oil), 194.7 mgKOH/g (conophor seed oil), and 137.00 mgKOH/g (cashew nut oil;) (Akpabio *et al*, 2011; Mohammed and Hamza, 2008; Eka, 1997; Asuquo *et al*, 2010; Akinhanmi and Alatise, 2008). It indicates the presence of high percentage of fatty acids in the oil and therefore implies the possible tendency to soap formation and difficulties in separation of products if utilized for biodiesel production (Cynthia *et al.,* 2012).

Iodine Value: Iodine number of oil is a measure of its degree of unsaturation and is a useful criterion for purity and identification. The iodine values of 17.11 mgI_2/g for the extracted oil and 12.18 mgI_2/g for the transesterified oil indicate that raffia oil was non-drying with iodine numbers lower than 100 (Kocchar, 1986). Non-drying oils is not volatile at room temperature and does not pose any danger of inflammability. It is also in line with the results of Adeyeye and Adewole (1992) for cereals, and the value was comparable to the values for edible vegetable oils reported by Simpson and Conner-Orgazally (1986). The iodine value confirmed the stability of the oil, and points to a low degree of unsaturation and a further confirmation of its low peroxide value.

Ester Value: The ester value obtained for the extracted oil and the transesterified oil of the Raffia fruit were 312.14 mgKOH/g and 147.54 mgKOH/g respectively. These were comparable to 172.8 mgKOH/g recorded by Akpabio *et al*, (2011) for avocado pear, 174.09 mgKOH/g for castor oil and 191 mgKOH/g for rubber seed oil by Asuquo, (2008) which are also viable sources of biofuel.

2. CONCLUSION

The physicochemical characteristics of extracted and transesterified raffia seed oil were studied. Results indicated that the oil is of high potential for nutritional and industrial applications. The physicochemical composition of the transesterified raffia palm oil showed that it will be very good fuel substitute for internal combustion engine with its high purity, lower molecular weight and ability to ignite easily.

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