A Study of the Lipid Structure of Castor Seed Oil (*Ricinus communis L*), Biodiesel and Its Characterization

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Authors' contributions

This work was carried out in collaboration among all authors. Authors EIB and AOA conceived and designed the study, while authors KB and FA performed most of the laboratory works, wrote the first draft of the manuscript under the supervision of authors AOA and EIB and they both reviewed the work for a journal article. All authors read and approved the final manuscript.

Article Information

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ABSTRACT

The paper characterized and transesterified castor seed oil. The resulting product was tested as feedstock for biodiesel production. It was carried out at the Department of Mechanical Engineering, the Federal University of Technology, Akure, Ondo State, Nigeria, over a period of eight months. The oil was extracted in a soxhlet extractor with n-hexane as the solvent. The oil obtained was filtered and then characterized. Transesterification was carried out using a laboratory scale biodiesel processor. The fuel and physico-chemical properties of the oil and its biodiesel were determined following ASTM, EN and AOCS methods. The results revealed that all the properties of the biodiesel are within the ASTM limits for biodiesel except the kinematic viscosity. The oil contains 89% ricinoleic acid and has high solubility in methanol due to the hydroxyl group and requires minimum amount of catalyst to give maximum biodiesel yield. The heating value obtained for the oil and its biodiesel were 32 MJ/kg and 38 MJ/kg. The castor seed oil investigated has oil content of 34%, and the properties characterized are all within the limits for biodiesel. Castor oil has excellent solubility in methanol and hence theoretically an ideal feedstock for biodiesel production.

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1. INTRODUCTION

The diesel engine is predominantly used to power trucks and farm tractors because of better fuel economy, more durable engine and higher maximum power output than can be developed by petrol engines. In the process, proportional increase in pollution from noise and exhaust gases emissions have been created. The large scale use of diesel has resulted into high cost and has triggered a need to preserve the environment hence the search for fuel that can be used as alternative for diesel engines. The search has been focused on vegetable oil because of the similarity of its molecular structure to diesel fuel and its renewable source from agriculture and animal fats. The idea of using vegetable oil as a diesel engine fuel, actually dated back to 1895 when Rudolf Diesel (1858-1913), developed the first diesel engine (German patent No. 67207) to run on peanut (Ground nut) oil and which he demonstrated at the World Exhibition in Paris in 1900 [1,2] and was latter modified to run on diesel fuel.

However, the relatively high viscosity of vegetable oils is about 15- 20 times higher than that of diesel. The consequential poor fuel atomization characteristic, fuel injector blockage due to soot formation during combustion and cold starting problems resulting from its high viscosity, have led to adverse operational problems that has made vegetable oils unsuitable for use as engine fuel in neat form. This created the need for a process of conversion of vegetable oil to methyl esters, which are commonly known as biodiesel. Biodiesel is a mono-alkyl ester of vegetable oils or animal fats [3,4]. It has very similar physic-chemical properties to diesel fuel and a higher Cetane number, which allows it to be used as substitute fuel in diesel engines with minor modifications. Since it is produced from renewable and domestically grown feed-stocks, it can reduce the demand for petroleum based fuels and possibly lower the overall cost of diesel fuel. In this paper, castor oil was tested as feedstock for biodiesel production. Castor seed oil was obtained from castor (*Ricinus communis)* plant, *w*hich belongs to the family of euphorbiaceae, It grows very well on marginal land, matured trees are able to resist draught to some extent and the leaves are not eaten by animals because it contains toxin and pest attack

is limited to the leaves. The seeds contain 35 – 55 % oil by weight, have one of the highest viscosities among vegetable oils and a molecular weight of 298 [5]. The oil is a viscous, pale yellow, non-volatile and non-drying oil [6]. Castor seed oil is a mono-fatty acid oil, with ricinoleic acid (12-hydroxy-9-*cis*-octadecenoic acid) constituting about 80 - 90% of the oil by weight. It is the sole known source of ricinoleic acid [7,8,9]. The fatty acid is shown in Fig.1 and contains carboxyl at site1, a double bond at site 9 and hydroxyl at site 12. Even though it is a monounsaturated oil, the fact that it constitutes about 90% of the oil means that there are several reaction sites that makes the oil highly polar and provides reaction points for the production of a wide range of natural and synthetic resins, waxes, polymers and elastomers [10]. It also has excellent emollient and lubricating properties, a marked ability to wet and disperse dyes, pigments and fillers [11,12], as well as several medicinal values [13]. It is described as hard non-drying oil, in that it exhibits the characteristics of multigrade engine oil which neither become too stiff when cold nor too thin when heated. It is widely used as additive to lubricant for high performance car engines [14].

2. MATERIALS AND METHODS

2.1 Oil Extraction

Two kilograms of castor seed were dried in the sun at 35ºC for 3 days to reduce the moisture content, after which the pods opened up and the seeds were released. The hard layer on the seeds was removed and the seeds were crushed in a blender to expose more area and allow for faster and maximum oil extraction. The oil was extracted in a soxhlet extractor with *n*-hexane as the solvent and operated at 60ºC. The residual *n*-hexane in the oil was removed using a vacuum rotary evaporator operated at 75ºC. The oil obtained was filtered through a Whatman 541 filter paper. After filtration, the oil was weighed and the percentage oil yield was calculated using equation (1).

$$Oil\ Content\ \% = \frac{Weight\ of\ oil\ extracted}{Weight\ of\ seed\ used}\ x\ 100 \quad (1)$$

2.2 Characterization of the Oil

The Free Fatty Acid (FFA) value of the oil (oleic acid %) was first determined by titrating with

alcohol, phenolphthalein and sodium hydroxide until the pink colour appeared, to establish if pretreatment was necessary before alkaline transesterification. High FFA can promote soap formation that can inhibit biodiesel yield.

2.3 Transesterification Procedure

Transesterification was carried out using a laboratory scale biodiesel processor. Methanol, which is low cost, short-chain and fast acting, was used as the reagent. The alkaline transesterification was done at a molar ratio of 6 to 1 and 1% by weight sodium hydroxide as catalyst [8]. The reactor was stirred continuously for 1 hour at 600 rev/min. and at a constant temperature of 60ºC. It was next poured into a separating funnel and left overnight for the reaction to reach equilibrium and separate into biodiesel and glycerol. The glycerol and biodiesel were separated and the biodiesel was washed with distilled water. Finally, the washed biodiesel was dried by passing it through anhydrous sodium sulphate.

2.4 Determination of Fuel and Physico-chemical Properties

The fuel and physico-chemical properties of the oil and its biodiesel were determined following ASTM, EN and AOCS methods.

2.4.1 Density

The density was measured by a hydrometer following IP-160/ASTM D-1298 protocol. The measurements were made in triplicate and then averaged.

2.4.2 Pour and cloud points

To determine the pour point, a 50 ml sample, initially at 45ºC was cooled in Herzog HCP852 apparatus at specified rate. Checks were made at intervals of 3ºC until the sample stopped flowing to give the pour point. A cloud point meter, equipped with a waveguide sensor of a total-reflection type was used to determine the cloud point.

2.4.3 Kinematic viscosities

The kinematic viscosities of the samples were determined using a Herzog GmbH MP – 480 capillary viscometer. This involved measuring the time for a given volume of the fuel sample to flow through the capillary under gravity.

2.4.4 Flash point

The flash point was determined according to ASTM D6751 using the Kehler Model K-16270 flash point apparatus.

2.4.5 Heating values

The lower heating value was determined by burning the fuel in an oxygen bomb calorimeter (Parr Instrument Company, US) according to ASTM D240 protocol.

2.4.6 Cetane index

The Cetane index   (CI) was calculated using the distillation characteristics of the samples that was computed using equation 2 [15].

$$CI= -420.34 + 0.016G2 + 0.192G (\log T50) + 65.01(\log T50)2 – 0.0001809T50 \qquad (2)$$

where G is the specific gravity as specified by the American Petroleum Institute, while T50 is the distillation temperature at 50 vol.% fuel sample distilled and condensed in a unit of °F. The results were cross checked using a Cetane index meter.

2.4.7 Iodine, peroxide, free fatty acid and acid values

The iodine, peroxide, free fatty acid and acid values were analyzed, by titration according to AOCS methods.

2.4.8 Oxidative stability

The oxidative stability test was conducted in a glass ware apparatus (ASTM D 2274). The accelerated degrading of the samples was achieved by applying heat and bubbling with oxygen for 16 hours at a constant temperature of 95ºC. After this, the insoluble formed were filtered and then measured. The duration that the sample can be stored before deterioration by acidification was then measured to give the oxidative stability in hours.

2.4.9 Moisture content

The moisture content of 5ml of each of the samples was measured following (ASTM D 6304), using Karl-Fisher Method 831 KF Coulometer (Metrohm Company, Switzerland).

2.4.10 Carbon residue

To mimick the carbon deposits mechanism in the combustion chamber of an internal combustion engines, the samples were heated at a controlled rate to 500ºC in a chamber filled with nitrogen to make the sample coke without burning. The mass of the remaining coke measured after flushing out the volatile compound with nitrogen was then taken as the carbon residue.

2.4.11 Sulfated ash

The combustion residue was treated with sulfuric acid and heated in an Isotherm muffle furnace to 750ºC for the carbon to be completely oxidized before allowing it to cool down to room temperature. The resulting ash formed was again treated with sulfuric acid and heated to 750ºC until the weight became constant. The percentage ash content was calculated by dividing the final weight by the initial weight and multiplying by 100.

2.4.12 Water and sediment

A 100 ml of the fuel sample was spun in a centrifuge model HNS II (Thermo Electron Corp, US) at 800 rev/min for 10 minutes The amount of water and sediment that settled in the tip of the centrifuge was then read as the percentage water and sediment.

2.4.13 Glycerine content

The wet AOCS Official method Ca 14-56 was used for the determination of the monoglycerides, diglycerides and triglycerides contents.

2.4.14 Vacuum distillation

The reduced pressure Advanced Distillation Curve (ADC) apparatus was used for the determination of vacuum distillation temperature according to ASTM D1160. The system pressure range was set between 1 kpa and 83 kPa. Distillation temperatures were selected to correspond to 5, 50 and 95 volume % of the liquid fuel distilled and condensed. The distillation results are useful in the calculation of the Cetane index according to EN ISO 4264 standard.

2.4.15 Copper strip corrosion test

This test was undertaken according to ASTM D130 procedure. A piece of copper strip was polished and dipped into 50 ml of the samples and agitated gently at a constant temperature of 60ºC. After 3 hours of continuous agitation, the strip was removed, washed in acetones and the tarnish and corrosion were compared with those of standard scale for assessment. This test is essential because several components of the fuel system and fuel tank are made from copper or copper alloys and which are liable to corrosion when exposed to the fuels.

2.5 Elemental Analysis

The elemental analysis of the fuel samples were done in a teledyne biodiesel metal analyzer following the ASTM D6751 protocol. Samples were prepared by diluting 50 mL of the oil and biodiesel with kerosene in the ratio 1:10 (w/w) to act as co-solvent and to reduce the viscous effects, which can reduce accuracy. The analyzer was calibrated with standards prepared by diluting plasma-pure biodiesel stock standards. The standards were 0.00, 10.00, 20.00, 30.00 and 40.00 levels for Na, K, Ca, Mg and S respectively.

2.6 Fatty Acid Profile

The fatty acid components and composition of the castor seed oil was were determined using GC-MS and GC-FID, respectively. The GC analysis was performed on an Agilent 7890A GC equipped with a Flame Ionization Detector (FID) while the MS analysis was performed on the same Chromatography equipment but was coupled to an Agilent 5975 quadrupole Mass Selective Detector (MSD). Separation was achieved on a fused silica capillary type column HP-5 (25 m × 0.25 mm x 0.40 μm film thickness) with split ratio 40:1. The carrier gas was nitrogen and the oven initial temperature was at 60ºC. The first ramping was at 10ºC/min for 20 min and maintained for 4 minutes. The second ramping was at 15ºC/min for 4 minutes and maintained for 10 minutes. The detector temperature was 320ºC while hydrogen and compressed air pressures were 22 and 35 psi respectively

3. RESULTS AND DISCUSSION

The oil and biodiesel (samples) were characterized according to ASTM protocols for biodiesel and the results obtained are shown in Table 1.

All the properties of the biodiesel are within the ASTM limits for biodiesel except the kinematic viscosity.

Table 1.Properties of castor seed oil and biodiesel

Property	Oil	B100	ASTM
Density (kg/m^3)	969.5	890	
Cloud point (ºC)	24	8.50	-
Pour Point (ºC)	2.7	8	
Flash point (ºC)	222	175	130
Kinematic viscosity (mm^2/s at 40 ºC)	240	12.5	6
Lower heating value (kJ/kg)	32	38	
Cetane number	52.00	64.00	47 Min
Iodine value (mg/100g)	88.40	58.40	83-88
Peroxide value (mEq/kg)	17	49.8	-
Oxidation index (Hrs.)	65	1.5	
Free fatty acid (%)	0.13	0.26	
Acid value (mgKOH/g)	1.042	0.658	2 Max
Water and residue (%)	0.47	0.01	0.05 Max
Carbon residue (%)	0.542	0.015	
Sulphated ash (%)	0.045	0.036	0.02
Copper strip corrosion test (3hr at 50ºC)	4	1	1
Distillation (10% recovery) ºC	310	309	
Distillation (50% recovery) ºC	355	346	
Distillation (90% recovery) ºC	380	368	360
Free glyceride (%)	0.584	0.028	0.02 Max
Total glycerin (%)	1.266	0.315	0.24 Max
Methanol (%)	0.002	0.096	0.2 Max

3.1 Density

The density of the oil and biodiesel are 969.5 and 890 kg/m^3 respectively. These values agreed with the values of 947.2 and 891.2 obtained by [16]. Both are higher than that for diesel. Density affects several fuel properties including kinematic viscosity, and fuel economy.

3.2 Cloud Point and Pour Point

Cloud point is the temperature at which wax formation first becomes visible as the fuel temperature is lowered. The cloud point of the oil and biodiesel are 24ºC and 8.5ºC respectively. This difference could be attributed to the lowering temperature during processing.

Pour point is the temperature at which the fuel will solidify enough to prevent it from flowing. The pour point of the oil and biodiesel are 3ºC and 8ºC respectively.

Cold temperature behavior of biodiesel is an important quality criterion, as frozen fuel may cause blockage of the fuel lines and filters and starve the engine of fuel [8].

The cold point characteristics of biodiesel products depend on chain length and degrees of unsaturation, with long chain saturated fatty acid esters displaying particularly unfavorable cold temperature behavior [17].

3.3 Flash Point

This is the lowest temperature to a barometric pressure of 101.3 kPa at which a liquid fuel sample produces sufficient vapour for the air-vapour mixture above the surface to flash momentarily on exposure to a standard source of ignition [8,18]. It is a measure of flammability of fuels and thus an important fuel safety criterion. The castor oil had a flash point of 222ºC and its biodiesel 175ºC. That of biodiesel satisfies the ASTM limits for biodiesel of 130ºC minimum.

3.4 Kinematic Viscosity

Viscosity is an important property of biodiesel since it affects the operation of fuel injection equipment; particularly at low temperatures when the increase in viscosity affects the fluidity of the fuel or leakage at high temperature when too thin [18]. The kinematic viscosity of the oil and biodiesel produced were 240 and 12.5 mm^2/s respectively. These are consistent with the results of [16]. The kinematic viscosity of the biodiesel is above the ASTM and EN limits for biodiesel but can be reduced to the limits by blending with diesel [19].

3.5 Lower Heating Value

The heating value is the amount of heat energy generated when one kg of the fuel is burnt in a bomb calorimeter. The heating value obtained for the oil and its biodiesel were 32 MJ/kg and 38 MJ/kg respectively and is lower than the 48 MJ/kg for diesel fuel. The reason for the difference is the oxygen content of the biodiesel which has lower specific heat value than the carbon and hydrogen molecules displaced by the oxygen [8].

3.6 Cetane Index

Cetane Index (CI) quantifies the ignition quality of diesel fuels. It affects the ignition delay time for combustion to be initiated upon injection of the fuel into the combustion chamber. It influences ease of starting, duration of white smoke after start up, drivability before warm up and intensity of diesel knock at idle [20]. Biodiesel usually have higher Cetane index than diesel fuel because of its oxygen content which promotes better combustion and also because the fatty acids present in the fuel have very high octane number. The Cetane index of the oil and biodiesel are 52 and 64 respectively and are above the ASTM minimum limits of 47 for biodiesels.

3.7 Iodine Value

Iodine Value (IV) is the amount of iodine, measured in grams, absorbed by 100 grams of a given sample. The iodine value is expressed in grams of iodine for the amount of halogens linked with 100 g test sample, and is used to ascertain the degree of unsaturated of fat and oils. Iodine values are used to classify oils as either drying oil (>130), semi-drying oil (115-130) and non-drying oil (<115). The oil and biodiesel have iodine values of 88.40 mgI$_2$/g and 71.8 mgI$_2$/g respectively. These values indicate that castor oil was non-drying with iodine numbers lower than 100 [21].

3.8 Peroxide Value

This value is an indication of oil auto ignition and high value indicate high degree of rancidity [20].The peroxide value for the oil and its biodiesel are 17 mEq/kg and 49.8 mEq/kg respectively.

3.9 Oxidation Value

Oxidation is a measure of the reactivity of a fuel and varies with the degree of saturation.

Unsaturated fuel becomes more reactive when the double bonds are broken and are able to attract oxygen to undergo oxidation. .The oxidation index for the oil was 65 hours and it reduced to 1.5 hour after transesterification. The oxidation value reduced drastically after transesterification because of the breaking of the single bond in the chain that reduces unsaturation [8].

3.10 Free Fatty Acid

This is the quantity of base required to titrate a sample to a specified end point. It is a measure of the amount free fatty acid in biodiesel. Excessive free fatty acid (FFA) will promote saponification, which inhibit biodiesel production. FFA can mix with water and form acidic solution which, can corrode metal components and degrade those of plastics. It can result from excess water in the fuel, inadequate washing and drying, and is evidence of oxidative degradation. The oil had a free fatty acid of 0.13% and its biodiesel 0.26%. The value for the oil will not promote soap formation and makes pretreatment of the oil before transesterification [22].

3.11 Acid Value

The acid number correlates to the fuel's long-term stability and corrosiveness, the smaller the acid value, the higher the quality of the fuel. The acid values for the oil and biodiesel are 1.042 and 0.658 mgKOH/g respectively.

3.12 Water and Residue

The amount of water in a fuel depends on the method of processing because water is commonly used for purification by washing. If the washed fuel is not dried adequately, the water content will be high. Water can affect the transesterification process, cause corrosion and promote the growth of bacteria. The water and residue percentages were 0.47 and 0.01 respectively. Though, higher than ASTM standard of 0.05, it is consistent with the reports of [23].

3.13 Carbon Residue

The carbon residue of a fuel is the tendency of carbon deposits to form under high temperature conditions in an inert atmosphere. It is a measure of the flammability, combustibility, molecular weight of biodiesel. The carbon residue of the oil is much higher than that for biodiesel and reflects

the proportion of the high molecular weight components of the oil. The residue for the oil was 0.542% while that of the biodiesel was 0.015%. Carbon residue is affected by impurities and additives present in the fuel.

3.14 Sulfated Ash

This is a measure of the mineral ash residue when a fuel is burned. It is an important test for biodiesel because it is an indicator of the quantity of residue metals in the fuel that came from the catalyst used in the transesterification process. Especially for base catalyzed transesterification in which the sodium hydroxide and potassium hydroxide commonly used have low melting points and may cause engine damage in combustion chamber, injector deposits or fuel system fouling.

The sulfated ash obtained for the oil was 0.0455% and reduced to 0.036% for the biodiesel. This is lower than the 0.05% ASTM maximum limit.

3.15 Copper Strip Corrosion Test

The oil has high corrosion value of 4 while that of the biodiesel of 1 is just as corrosive as diesel. The test is necessary because many parts of the fuel system and fuel tank are made from copper or copper alloys and are liable to corrosion when exposed to the fuel samples.

3.16 Free Glyceride

Free Glycerol is the amount of glycerol remaining in the biodiesel after water washing. Although largely removed during water washing because it is insoluble in biodiesel a small amount would remain suspended in the biodiesel. When the amount is high, it will settle at the bottom of the tank in viscous form which can block filters and course irregular combustion in the engine. The free glycerine in the oil was 0.584% and 0.028% for the biodiesel. This free glycerol value is consistent with standard, that biodiesel should contain a maximum of 0.02% of free glycerol [24].

3.17 Total Glycerin

This is the sum of the concentrations of free glycerol and glycerol bounded in the form of mono-, di- and triglycerides. High content of free glycerin in the biodiesel indicates incomplete esterification reaction. Excessive free glycerol can lead to high amount of carbon deposits in the combustion chamber and deposits in the fuel tank. The total glycerine are 1.266% and 0.315% for the oil and biodiesel respectively. The total glycerin is higher than standard given by [24], that biodiesel should contain a maximum of 0.24% total glycerol by weight.

3.18 Methanol

This is the methanol remaining in the biodiesel after water washing. Excessive methanol can reduce density, lubricity, reduce flash point and distillation characteristics due to its high volatility, distort the operation of the injectors and can affect some materials in the fuel system. The value increased because of the residual methanol after transesterification.

The methanol content for the oil and biodiesel are 0.002% and 0.096% respectively.

3.19 Elemental Composition of the Oil and Biodiesel

Fig. 1 shows the elements in the oil and biodiesel. The alkaline components reduced considerably after transesterification because they are absorbed by the glycerol during the water washing process. However, sulphur unlike the others, did not reduced much as it does not react with water. It forms sulphur dioxide after during, which is harmful to the environment and is reduced using a catalytic converter. Sulfur dioxide in the biodiesel confers lubricity. The type and amount of elements in the fuel depends on the area where the crops was grown and processing methods. High amount of the alkaline can block injector nozzle holes.

3.20 Distillation Characteristics

The distillation curves for the samples are shown in Fig. 2. The distillation curves for the oil and biodiesel are higher than that of diesel. The threshold temperature for distillation of the pure oil is 200ºC higher than that for diesel and this explains the difference in their kinematic viscosities and flash points. The curve for biodiesel rises very sharply up to 10 vol. % and then increased gradually showing that 10% of biodiesel B100 contains fatty acids of which boils below 300ºC and the difference between T50 and T95 is 52ºC as against 19ºC for the oil. The curve for biodiesel B100 increases gradually from 320ºC to 350ºC at 95% volume because the constituents have similar boiling point and there is very little difference between the boiling points of the oil and biodiesel.
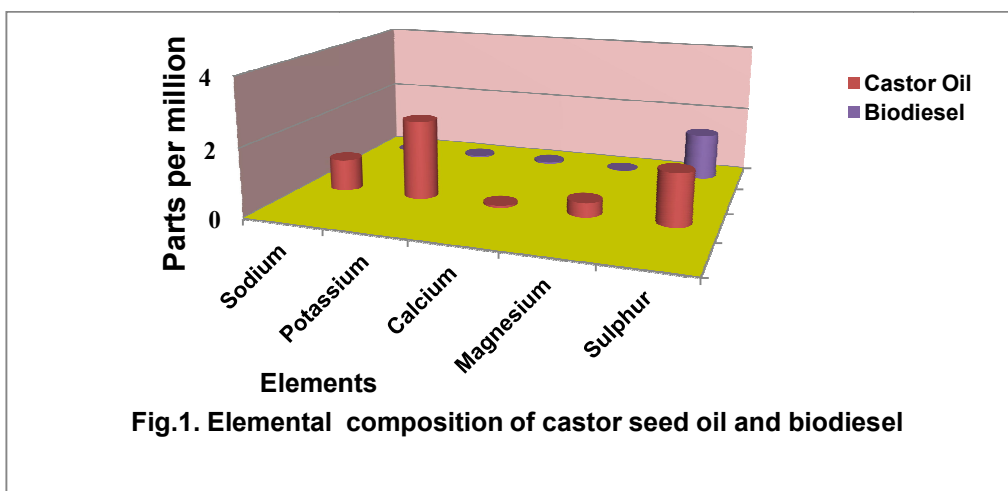
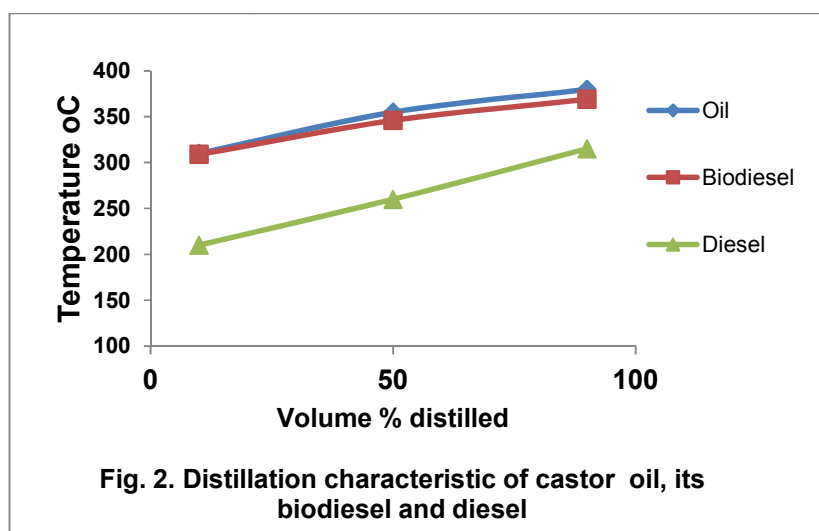**Fig.1. Elemental composition of castor seed oil and biodiesel**

Fig. 2. Distillation characteristic of castor oil, its biodiesel and diesel

3.21 Fatty Acid Profile

The fatty acid profile of the oil and biodiesel are shown in Table 2.

Ricinoleic fatty acid constitutes 89.92% of the oil and 90.74 of the biodiesel. The oil and biodiesel are 98.16% and 98% unsaturated respectively [25].

3.22 Structure of the Fatty Acids

The fatty acids are composed of carbon, hydrogen and oxygen skeleton configuration with a carboxyl group (-COOH) at the right hand end and methyl group (-CH$_3$) at the left hand end. At the double bonds, the carbon atoms are held firmly together which prevent them from rotating and making rearrange of the atoms impossible without first breaking the bonds. When the double bonds are broken, by transesterification, another molecule such as hydrogen or oxygen can be attached to the vacant bonds hence the higher the degree of unsaturated the more reactive is the acid. This is why reactions like oxidation, rancidification and Peroxide formation increases with higher degree of unsaturation.

Ricinoleic fatty acid is unique among vegetable oil in that it has a functional hydroxyl group at site 12, a double bond at 9, apart from the carboxyl group at the left hand side and a methyl group at the right hand ends. This makes it the only known source of ricinoleic acid and the structure increases the polarity of the oil and provides sites for a wide range of reactions for the production of chemicals. The hydroxyl functionality present in the chain makes the oil a natural polyol, gives it an unusually high oxidative stability and a rela-

tively high shelf life compared to other oils by preventing peroxide formation [26]. The hydroxyl functional group allows a variety of chemical reactions including halogenation, dehydration, alkoxylation, esterification, and sulfation to be carried out. Hence its use in industrial applications such as paints, coatings, inks, and lubricants.
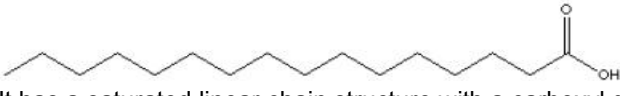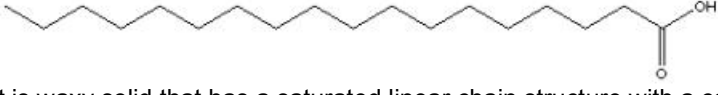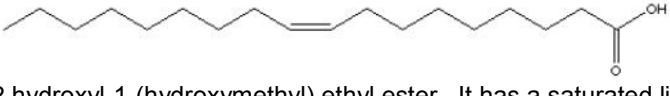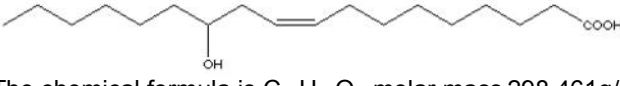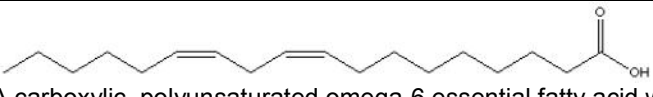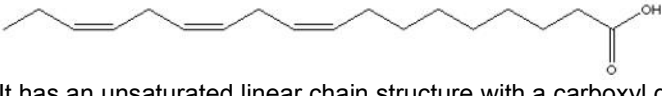
Fatty Acid	Molecular structure
Myristic Tetradecanoic acid (14:0)	The chemical formula is $C_{14}H_{28}O_2$ and molecular weight 228. It has a saturated linear chain structure with a carboxyl group at the right and a methyl group at the left hand end.
Palmitic n-Hexadecanoic acid (16:0).	It has a saturated linear chain structure with a carboxyl group at the right and a methyl group at the left hand end. The chemical formula is $C_{16}H_{32}O_2$ and molecular weight 256. .
Stearic Octadecanoic acid (18:0).	It is waxy solid that has a saturated linear chain structure with a carboxyl group at the right and a methyl group at the left hand end. The chemical formula is $C_{18}H_{36}O_2$ and a molecular weight of 284. It has a saturated linear chain structure with a carboxyl group at the right and a methyl group at the left hand end. Melting point 69-70ºC, boiling point 383ºC
Oleic 9-Octadecenoic acid (C18:1).	2 hydroxyl-1-(hydroxymethyl) ethyl ester. It has a saturated linear chain structure with a carboxyl group at the right, a double bonds on site 9 and a methyl group at the left hand end. Chemical structure is $C_{18}H_{34}O_2$ and molecular weight of 282.
Ricinoleoic 12-hydroxyl-cis-enoic -9,12-octadecadienoic acid (C18:1-9).	The chemical formula is $C_{18}H_{34}O_3$, molar mass 298.461g/mol and density of 0.945 kg/m^3. A hydroxyl fatty acid with a carboxyl group at the right hand side, a functional (hydroxyl) group at site 12, a double bond at 9 and a methyl group at the left hand end. It constitutes almost 90% of castor oil.
Linoleic 9,12-Octadecadienoic acid (18:2).	A carboxylic, polyunsaturated omega-6 essential fatty acid with an unsaturated linear chain structure with a carboxyl group at the right, double bonds in cis configuration at sites 9 and 12, and a methyl group at the left hand end. The chemical structure is $C_{18}H_{32}O_2$ and molecular weight of 280.
Linolenic 9,12,15-Octadecadienoic acid (18:3).	It has an unsaturated linear chain structure with a carboxyl group at the right, double bonds at sites 9, 12 and 15, and a methyl group at the left hand end. The chemical structure is $C_{18}H_{30}O_2$ and molecular weight of 280. The three double bonds which make the molecule highly unstable. Thus, these molecules oxidize or polymerize easily, thereby creating acids or sludge.

Table 2. Fatty acid profile of castor seed oil and biodiesel

Fatty Acid	Systemic name	Structure	Chemical formula	Mass % Oil	Mass % Biodiesel	Changes (%)
Myristic	Teradecanoic	C14:0	$C_{14}H_{28}O_2$	0.02	0.12	83
Palmitic	Hexadecanoic	C16:0	$C_{16}H_{32}O_2$	0.82	0.90	0.09
Stearic	Octadecanoic	C18:0	$C_{18}H_{32}O_2$	0.97	0.83	-17
Oleic	Cis-9-Octadecenoic	C18:1	$C_{18}H_{34}O_2$	3.15	3.06	-5.6
Ricinoleic	Hydroxyoctadeca-9-enoic	C18:1	$C_{18}H_{34}O_2$	89.92	90.74	0.009
Linoleic	9-12-Octadecadienoic	C18.2	$C_{18}H_{32}O_2$	4.22	3.39	-0.24
Linolenic	9-12-15 Octadecadienoic	C18:3	$C_{18}H_{30}O_2$	0.87	0.81	-0.74
			Others	0.092	0.15	
			Saturation	0.18	1.83	
			Unsaturation	98.16	98.00	

4. CONCLUSIONS

The castor seed oil investigated has oil content of 34%. The properties characterized are all within the limits for biodiesel except the kinematic viscosity, which can easily be corrected by blending with diesel. The oil contains 89% ricinoleic acid and has high solubility in methanol due to the hydroxyl group and requires minimum amount of catalyst to give maximum biodiesel yield. Although the unsaturation is 95%, it is essentially ricinoleic with a single bond hence liquid at room temperature of 30ºC in the tropics and a high oxidation stability of 65 hours. The oxidative stability reduced drastically after transesterification because of the breaking of the single bond in the chain that reduces unsaturation. Castor oil has excellent solubility in methanol and hence theoretically an ideal feedstock for biodiesel production, as far as solubility is concerned, requiring a minimum amount of catalyst and heating, which can substantially reduce the costs of production when produced on a large scale.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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