



Biodiesel Production from *Terminalia catappa* (Tropical Almond) Seed Oil using CaO Derived from Snail Shell as Catalyst

Chika Muhammad^a, Asiya Bello^a, Francis Agada^{a,*}, Muhammad Sabiu Jibrin^a, Yahaya Alhassan^b

^aDepartment of Pure and Applied Chemistry, Faculty of Science, Usmanu Danfodiyo University, Sokoto, Nigeria

^bPetrochemicals and Allied Department, National Research Institute for Chemical Technology, Zaria, Nigeria

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ABSTRACT

Biodiesel which is a biodegradable, nontoxic and ecofriendly fuel was produced from Tropical Almond seed oil. The almond oil was extracted using n-hexane and then transesterified using CaO catalyst derived from snail shell into biodiesel. The catalyst was calcined and characterized using Thermal Gravimetric Analysis (TGA) and Fourier Transform-InfraRed (FT-IR) methods. The Physicochemical and fuel properties of the biodiesel were determined and compared to ASTM approved ranges. The Fatty Acid Methyl Esters (FAME) present in Tropical Almond biodiesel after characterization analysis per area percent include; Hexadecanoic acid, methyl ester (55.95 %), 9,12-Octadecadienoic acid, methyl ester (5.88 %), 9-Octadecenoic acid (Z)-, methyl ester (9.23 %), Cyclopropane, (2-methylenebutyl) (0.07 %) and Methyl stearate (4.58 %). The optimum yield of biodiesel (73.60 %) was obtained at a temperature of 60 °C and time of 120 minutes. The experimental results showed the percentage yield of Almond Seed Oil to be 56.8 % and that of the biodiesel produced to be 65.71 %. Critical Fuel Properties of Almond Seed Oil investigated such as density (0.89 g/cm³), pour point (0.6 °C), cloud point (6.1 °C), flash point (148 °C) and specific gravity (0.90) are in conformity with ASTM D6751 standards. This makes Tropical Almond Seed Oil a good feedstock for biodiesel production with little modifications in its properties.

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1. Introduction

Biodiesel is an alternative fuel made from renewable biological sources such as vegetable oils (both edible and non-edible oil) and animal fats (Raja *et al.*, 2011). Biodiesel has become more attractive recently because of its environmental benefits and the fact that it is made from renewable sources. It can be defined as basically monoalkyl esters of long-chain fatty acids produced from animal fats or vegetable oils by transesterification or other methods with small chain alcohols, using different kinds of catalysts (Sruthi, 2013). Currently, more than 95 % biodiesel are produced from edible oil feedstock (soya bean oil, sunflower oil, rapeseed oil, palm oil and sesame oil), due to this there is a huge imbalance in the human nutrition chain versus fuel. This will make biodiesel economically unfeasible as compared to petroleum-derived fuels. To avoid these situations, nonedible seeds oil need to be used for commercial production of biodiesel (Sruthi, 2013). Vegetable oils are promising feedstock for biodiesel production since they are renewable in nature, and can be produced on a large scale and environmentally friendly (Patil and Deng, 2009).

Developing countries such as Nigeria have a comparative advantage for biofuel production because of greater availability of land, favourable climatic conditions for agriculture and lower labour cost, but yet many of the present problems of Nigeria are closely related to the problem of energy distribution. Energy plays a vital role in the economic, social and welfare development of any nation. Insufficient supply of energy restricts socio economic growth and adversely affects the quality of life (Mukhtar

et al., 2014). Biodiesel is advised for use as an alternative fuel for conventional petroleum based diesel chiefly because it is a renewable, domestic resource with an environmentally friendly emission profile and is readily biodegradable (Cholakov, 2013). Generally, biodiesel is produced by means of transesterification. Transesterification is the reaction of a lipid with an alcohol to form esters and a byproduct, glycerol. It is, in principle, the action of one alcohol displacing another from an ester, referred to as alcoholysis (cleavage by an alcohol) (Anitha and Dawn, 2010). A high free fatty acid content (>1 % w/w) will lead to soap formation which reduces catalyst efficiency, causes an increase in viscosity, leads to gel formation and make separation of glycerol difficult. Biodiesel is said to be carbon neutral as more carbon dioxide is absorbed by the biodiesel yielding plants than what is added to the atmosphere when used as fuel (Jaichandar and Annamalai, 2011). Biodiesel is gaining increasing acceptance in the market as an environmental friendly alternative diesel fuel. It is non-toxic, biodegradable, and free of sulphur or any carcinogenic compounds. The demand and cost of edible oils prevents its use in the production of biodiesel. So, a large variety of plants that produce non-edible oils are considered for biodiesel production (Vuppalandadiyam *et al.*, 2013). Other advantages of biodiesel over fossil fuel are higher flash point and higher lubricity (Alnuami *et al.*, 2014). The viscosity of vegetable oils however, is about 11-17 times higher than that of diesel. Their use in direct injection diesel engines is therefore restricted by some unfavorable physical properties, particularly their viscosity. The use of vegetable oil cause poor fuel atomization, incomplete combustion and carbon deposition on the injector and valve seats resulting in serious

* Corresponding Author: francisagada49@gmail.com

engine fouling (Ramadhas et al., 2004). This necessitates the reduction in viscosity of the vegetable oils for use as fuel in internal combustion engines. The commonly employed methods to reduce the viscosity of vegetable oils are blending with diesel, micro emulsion, pyrolysis and transesterification (Ramadhas et al., 2004).

There are a large number of oil plants that produce non-edible oils. From a list of 75 plants species containing oil in their seeds or kernel, 26 species were reported by Azam et al., (2005) as potential sources for biodiesel production. The important non-edible oil plants are Castor, Jatropha, Karanja, Cotton, Neem, Mahua, Rubber, Tobacco, Sea Mango (Azam et al., 2005). Of these feedstocks, Jatropha, Moringa and Castor oils are used most often in biodiesel production (Azam et al., 2005).

2. Materials and Methods

2.1 Sample Collection and Treatment

The umbrella seeds used for this research were procured from a garden in Kaduna North local government, Kaduna state. The outer flesh was manually removed by eating. The hard-shell nut was sun dried and the seeds were removed from the dried shell by manually breaking it with a hammer. The oil-bearing seeds were cleaned, sun dried and further grinded into powdered form using clean mortar and pestle to ease extraction of oil. The sample was identified as *Terminalia catappa* (Botanical name) of the Combretaceae family in Herbarium Centre, Department of Biological Sciences, Usmanu Danfodiyo University, Sokoto by the Herbarium officer with a voucher number deposited at the Herbarium.

2.2 Extraction of Oil Using Soxhlet Extraction Method

The oil was extracted from 100 g of the powdered umbrella seed sample using 250 cm³ of n-hexane as a solvent in the soxhlet extractor. The extraction lasted for nearly two hours after which the flask was allowed to cool and the thimble was removed. The setup was reassembled to recover the solvent. The oil was transferred into a beaker and kept in an oven for about 20 hours to evaporate the remaining solvent present in the oil. A clean beaker was then weighted and the percentage oil yield was calculated using equation (1) (Hossain et al., 2008).

$$\% \text{ Yield} = \frac{\text{Weight of Extracted Oil}}{\text{Weight of Sample}} \times 100 \% \quad (1)$$

2.3 Physicochemical Properties of the Umbrella Seed Oil

2.3.1 Determination of Saponification Value

The oil (2.00 g) was weighed into a distillation flask and Ethanolic Potassium Hydroxide (20 cm³, 0.5 M) was added. The flask was heated under reflux for 30 minutes, and was allowed to cool to the room temperature. The excess potassium hydroxide was then back titrated with hydrochloric acid (0.5 M) using phenolphthalein indicator. A blank titration was conducted under the same condition without the oil. Saponification value was calculated using equation (2) (Ved and Padam, 2013.)

$$\text{Saponification Value} = \frac{28.05 \times (T_2 - T_1)}{W} \quad (2)$$

Where T_1 = Volume of hydrochloric acid used in blank titration
 T_2 = Volume of hydrochloric acid used in the test sample titration

2.3.2 Determination of Acid Value

The Acid Value measurement was carried out according to ASTM-D664 method. The solvent consisting of 50 % ethanol and 50 % toluene (20 cm³) was prepared in a beaker (250 cm³). The sample (2.0 g) was added to the beaker followed by phenolphthalein indicator (2 cm³). The solution was titrated with KOH (0.1 M) until the colour changed to pink. The acid value was calculated using equation (3) (Gandure et al., 2013).

$$AV = \frac{56.1 \times M}{W} \times \text{Titre Value} \quad (3)$$

Where AV= Acid value, M = Molarity of KOH, 56.1 = Molecular weight of KOH

W = Weight of the sample

While Free Fatty Acid (FFA) was calculated using equation (3) (Gandure et al., 2013).

$$\text{FFA} = 0.5 \times AV \quad (4)$$

2.3.3 Determination of Iodine Value

The sample (2 g) was weighed into a conical flask (250 cm³). Carbon tetrachloride (20 cm³) was added to dissolve the oil. Dam's reagent (25 cm³) was added to the mixture using pipette and then stoppered. The content was vigorously swirled and then placed in the dark for 1½ hour. Then potassium iodide (10 cm³, 10 %) and of water (50 cm³) were added into the content using measuring cylinder. The content was titrated against sodium thiosulphate solution (0.1 M) with vigorous shaking until the yellow colour disappeared, then starch indicator (1 cm³, 1 %) was added and titration continued to the colourless end point. A blank titration (without sample) was conducted using the same procedure. The iodine value was calculated using equation (5) (AlHarbaway and Al-Mallah, 2014).

$$\text{Iodine Value} = \frac{12.69 \times M \times (V_1 - V_2)}{W} \quad (5)$$

Where M = Molarity of Thiosulphate, V_1 = Volume of thiosulphate in blank titration

V_2 = Volume of sodium thiosulphate in the oil sample titration,

W = Weight of the sample.

2.4 Preparation of Catalysts

Calcium Oxide (CaO)

The snail shell was collected at a market and it was rinsed thoroughly with running water to remove dust and impurities and then sun dried. The snail shell was grinded to powdered form using pestle and mortar. It was calcined at 800 °C in a blast furnace for 4hrs. The calcined sample was kept in a closed vessel to avoid reaction with humidity in air and carbon dioxide before use. This is due to the fact that the CaO catalyst can react with CO₂ and be converted into CaCO₃, thus reducing its activity as a catalyst. The prepared catalyst was characterized using FT-IR spectroscopy and DTA/TG Analysis.

2.5 Characterization of Catalyst

2.5.1 FT- IR Method of Analysis

The FT-IR analysis was carried out at the Sokoto Energy Research Center, Usmanu Danfodiyo University, Sokoto using MB3000 model spectrophotometer. The transmission rate was set at the range of 4000-650 cm⁻¹ at 4 resolution value. The sample was mixed with alkali halide potassium bromide (KBr) and compressed into a thin transparent pellet using hydraulic press and placed in standard sample compartment of the spectrometer.

2.5.2 TGA / DTA Method of Analysis

Thermal Gravimetric (TG) and Differential Thermal Analysis (DTA) was carried out at Sokoto Energy Research Center, Usmanu Danfodiyo University, Sokoto using TA-60WS Thermal Analyzer at a heating rate of 5 °C per minute, starting from room temperature up to 800 °C in (air atmosphere) (Tan et al., 2015). The CaO derived from Snail Shell (14.323 mg) was weighed and inserted into the TGA machine for analysis.

2.6 Transesterification Process

The umbrella seed oil was divided into four portions and labeled A, B, C and D in four beakers. The oil (10 cm³, 8.29 g) was mixed with 9:1 methanol to oil ratio, catalyst (1%) by weight of the oil in each beaker, two of the mixtures were then placed on the water bath and the temperature was maintained at 60 °C for 60 minutes and 120 minutes respectively with constant stirring. The content (containing biodiesel at the top, glycerol at the middle and catalyst at the bottom) was transferred into a separating funnel and allowed to settle for 24 hours. After 120 minutes the same was applied to the other beaker. This allows the glycerol to settle down since it is denser than ester (biodiesel).

The glycerol was removed from the separating funnel (Asokan and Vijayan, 2014). Afterwards, the biodiesel was poured into a test tube and placed in a centrifuge and allowed to spin for an hour and then poured into a separating funnel. This facilitates ease of removal of traces of glycerol from the biodiesel as they are already settled at the bottom of the test tube. Another two set of beakers containing the same amount of methanol to oil ratio and catalyst were placed on the water bath and the temperature was maintained at 65 °C for 60 minutes and 120 minutes respectively. After 60 minutes and 120 minutes respectively, the same method of separation was applied as described above. The biodiesel was

washed with a mixture of warm distilled water and n-hexane and then heated to evaporate the water. The mixture was allowed to stand for 24 hours to enable the nhexane evaporate before carrying out analysis. The percentage biodiesel yield was calculated using equation (6) (Heror and Rahul, 2013).

$$\% \text{ Biodiesel Yield} = \frac{\text{Weight of Biodiesel}}{\text{Weight of Oil}} \times 100 \quad (6)$$

2.7 Experimental Design

Response surface (Box-Bechnken) statistical experimental design was used to design the optimization. Two independent variables namely reaction time and temperature were selected for investigation. Table 1 shows the lower and upper of factors employed based on literature survey (Highina et al., 2011). Each run was completely randomized to obtained a total of 4 runs. The experiment was designed using MINITAB 17 statistical software.

Table 1. The Process Variables and their Levels

Factor	Lower level	Upper level
Temperature (°C)	60	65
Time (min)	60	120

2.8 Fuel Properties of the Produced Biodiesel

Some of the properties of fuel which are used for assessing the nature and quality diesel fuel that include acid value, specific gravity or density, flash point, pour point, viscosity, cloud point, cetane number, etc. were determined.

2.8.1 Determination of Specific Gravity

Specific gravity is the ratio of the density of a fuel to the density of a reference substance or ratio of mass of a fuel to the mass of a reference substance. Specific gravity was determined according to ASTM D1298 method. A dry empty density bottle (50 cm³) was weighed and the mass was recorded as W₀, it was then filled with water and weighed again, the mass was recorded as W₁. The bottle was finally filled with the sample and it was weighed again, the mass was recorded as W. The specific gravity of all the sample were calculated using equation (7) (Alamu et al., 2010; Ved and Padam, 2013; Al-Harbayand Al-Mallah, 2014; Asmare and Gabbiye, 2014; Indhumathi et al., 2014).

$$\text{Specific Gravity} = \frac{W_2 - W_0}{W_1 - W_0} \quad (7)$$

2.8.2 Determination of Cetane Number

Cetane Number (CN) of the sample was calculated from saponification and iodine values using equation (8) (Salaheldeen et al., 2015).

$$\text{Cetane number} = 46.3 + \frac{5458}{SV} - 0.225(IV) \quad (8)$$

2.8.3 Higher Heating Value (HHV)

HHV of the sample was estimated from saponification number and iodine value using equation (9) (Demirbas, 2008; Sokoto et al., 2011).

$$\text{HHV} = 49.43 - 0.041SV - 0.015IV \quad (9)$$

2.8.4 Determination of Viscosity

The dynamic viscosity was determined using Cannon Viscometer model 2020. The spindle (spindle number 63 and 04 were used) through calibrated spring of viscometer was rotated in the sample (50 cm³) in a beaker (50 cm³). The viscous drag of the fluid against the spindle was measured by the spring deflection. The spring deflection was measured with a rotator transducer which provides a torque signal. The viscosity in centipoises was displayed on the screen of the viscometer. To obtained kinematic viscosity in centistokes

(1 centistoke = 1 mm²/s), the dynamic viscosity was divided by density (ASTM D445, 2017).

2.8.5 Determination of Flash Point

Flash point, as defined by ASTM D-93, is a measure of the temperature to which a fuel must be heated such that a mixture of the vapour and air above the fuel can be ignited. The flash point was determined according

to ASTM D93 method. The sample was placed in the test cup to the prescribed mark in the interior of the cup. The cup was mounted on to its position on the tester. Bunsen burner was used to supply heat to the apparatus at rate of 1 °C per minute with constant stirring. A small test flame was directed into the cup intermittently. The flash point was taken as the temperature when the test flame caused the vapour above the sample to ignite (Indhumathi et al., 2014).

2.8.6 Determination of Pour Point

Pour point is the minimum temperature at which a liquid will cease to flow. The pour point was determined according to ASTM D97 method. The sample was poured into the test jar to the mark. A thermometer was then immersed 3 mm below the sample surface and the jar was placed on the disk inside the bath jacket maintained at 6 °C. At every 3 °C decrease in temperature, the jar was removed from the bath jacket and was tilted to ascertain flow of the sample. This was repeated until the sample cease to flow when tilted for a period of 3 seconds. The temperature at this point was recorded. The pour point was calculated by adding 3 °C to the recorded temperature (Thirumarimurugan et al., 2012).

2.8.7 Determination of Cloud Point

Cloud point temperature is the minimum temperature at which haziness/cloud appears in the fuel sample. This is conducted on transparent samples. The sample was poured into the test jar to the mark. A thermometer was inserted until it nearly reached the base of the jar. The jar was placed on the disk inside the bath jacket maintained at 6 °C. At every 3 °C decrease in temperature, the jar was removed from the bath jacket to observe any appearance of haziness. This was repeated until cloudiness appears above the sample for a period of 3 seconds. The temperature at this point was recorded. The cloud point was calculated by adding 3 °C to the recorded temperature (Thirumarimurugan et al., 2012).

2.8.8 Determination of Sulphur Content

The Sulphur analyzer was turned on using a key and allowed to warm up for three minutes at a wavelength of 0.537 nm. The sample was poured into a sample container consistent with the instrument being used and filled above a minimum depth. A window cell sealed with transparent polyethylene was then used to cover the sample and a cap was used to close it tight. It was placed into the sample holder of the analyzer. The button bearing measure was pressed and triplicate readings after ten seconds each were displayed by the machine. The readings were recorded and the mean of the values represent the sulphur content in the sample (ASTM D4294, 1998).

2.8.9 GC-MS Analysis of the Biodiesel produced

The oil composition and methyl ester content were assayed using a GC-MS machine in multi-purpose laboratory in Ahmadu Bello University (ABU), Zaria. The GC-MS was equipped with an Econo-Cap EC-WAX Capillary Column (30.0 m in length × 250 μm in diameter × 0.25 μm in film thickness). The GC oven was maintained at 50 °C for 3 minutes, and then heated to 210 °C at a rate of 10 °C per minute and held at 210 °C for 9 minutes. The front inlet temperature of the oven was 255 °C (split less-mode). The carrier gas was helium with a flow rate of 12 cm³/min. The analysis of refined Tropical Almond oil composition and FAME of biodiesel was carried out by injecting 1.0 μL of a sample solution that was prepared by blending the biodiesel sample with a prepared internal standard of GC. The FAME content by weight was determined from Equation (10) (Zhou et al., 2013).

$$\text{wt. \%} = \left[\frac{\sum(A_i - A_R)}{A_R} \right] \frac{C_R V_R}{W} \quad (10)$$

Where A_i = the peak area from chromatogram of FAME; A_R = the peak area from chromatogram of internal standard; C_R = the concentration of the internal standard V_R = the volume of the internal standard; and W = the total weight of the biodiesel sample.

2.9 Data Analysis and Presentation

The experimental results were analyzed using MINITAB 17 statistical Analysis software. The results of statistical analysis were presented using Interval plot and Contour Plot.

3. Results and Discussion

The experimental design matrix which is a two-level factorial investigating two factors temperature and time while holding methanol to

oil and catalyst concentration 9:1 and 1 % respectively constant. The yield obtained from the experimental research work is represented in Table 2, below.

Table 2. Design Matrix and Experimental Result

Std Order	Run Order	Center Pt	Blocks	Temperature (°C)	Time (min)	Yield (%)
3	1	1	1	60	120	73.60
4	2	1	1	65	120	49.01
2	3	1	1	65	60	52.57
1	4	1	1	60	60	46.73

From figure 1 (a) below, using contour plot, the effect of temperature and time on the biodiesel yield is shown. When the temperature is 60-62.8 °C at a time of 60-68 minutes the biodiesel yield would be less than 50 %. Also at the temperature 63.8-64.9 °C and a time of 68-79 minutes, the biodiesel yield would be 50-55 %. At the temperature of 62.7-63.8 °C and a time of 78-89 minutes, the biodiesel yield would be 55-60 %. At the temperature of 61.862.8 °C and a time of 89-102 minutes, the biodiesel yield would be 60-65 %. At the temperature of 60.7-61.8 °C and a time of 102-113 minutes, the biodiesel yield would be 65-70 %. At the temperature of 60-60.7 °C and a time of 113-120 minutes, the biodiesel yield would be above 70 %.

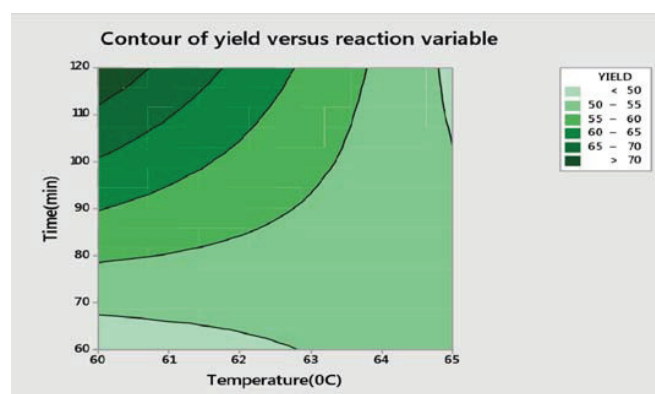


Figure 1 (a). Contour of Yield Versus Effect of the Reaction Temperature (°C) and Time (min)

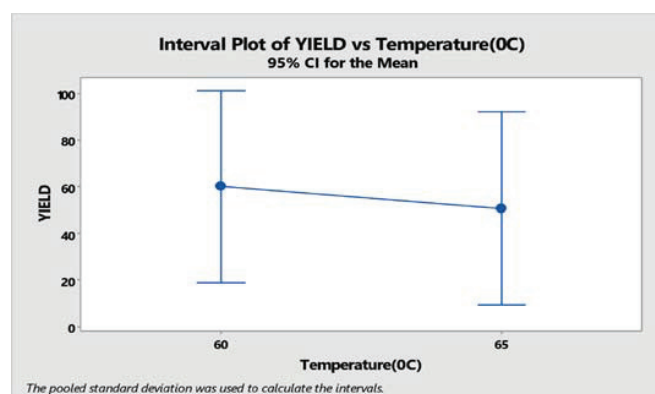


Figure 1 (b). Interval Plot of yield versus temperature (°C)

Table 3 below shows that, the oil yield of umbrella seed was found to be 56.8 % which is higher than the range specified by Adu et al., (2013) that is, 38-54 % and 52.11 % reported by Barku et al., (2012). In this study, the seed oil content was found to be higher than those reported for grape seed, corn (15 %) and tiger nut oil (23 %) (Lasekan and Abdulkarim, 2012). The high percentage of oil makes this seed a distinct potential for the oil industry. The extracted oil is liquid at room temperature, this makes it good for biodiesel production. According to Omeje et al., (2008). Variation in oil yield may be due to differences in variety of plant, duration of oil extraction, ripening stage, cultivation climate, harvesting time of

Table 3. Physicochemical Parameters of Tropical Almond Seed Oil

Properties	Unit	Almond seed oil
Yield of extracted oil	%	56.80
Density	g/cm ³	0.94±0.04
Viscosity@ 40°C	mm ² /s	31.90±2.4
Saponification Value	mg _{KOH} /g	70.13±0.28
Iodine Value	gI ₂ /100g	33.88±2.26
Acid Value	mg _{KOH} /g	5.05±0.20
Pour Point	°C	0.80
Free Fatty Acid	mg _{KOH} /g	2.50±0.20
Cloud Point	°C	10.01
Specific gravity	-	0.94±0.03

seeds and the extraction method used. The percentage yield of the biodiesel produced was 65.71 % (Table 4) which is lower than the 75.0 % reported by Orhevba et al., (2016). From the experimental design in Table 2, it can be seen that the highest yield was achieved at a temperature of 60 °C and the time of 120 minutes.

Table 4. Physicochemical Parameters of Biodiesel from Tropical Almond Seed

Oil Properties	Unit	Biodiesel	ASTM Standard
Yield of biodiesel	%	65.71	-
Density	g/cm ³	0.89±0.02	0.86-0.90
Viscosity@ 40°C	mm ² /s	19.1±0.71	1.9-6.0
Saponification Value	mg _{KOH} /g	78.54±0.28	-
Iodine Value	gI ₂ /100g	36.67±0.28	> 130
Acid Value	mg _{KOH} /g	3.23±0.07	0 - 0.8
Free Fatty Acid	mg _{KOH} /g	1.61±0.07	-
Pour Point	°C	0.6	-15 to 10
Cloud Point	°C	6.1	-3 to 12
Flash Point	°C	148	130 - 170
Sulphur content	%	0.0079±0.0024	0.0005
Cetane Number	-	107.5	48 - 65
Higher heating value	MJ/kg	46.76	-
Specific gravity	-	0.88	-

Acid Value measures the extent to which glycerides in the oil have been decomposed by liquid. The acid value and free fatty acid of Tropical Almond oil were determined to be 5.05 mg_{KOH}/g and 2.52 mg_{KOH}/g respectively as shown in Table 3. This acid value is higher than 0.78 mg_{KOH}/g and FFA is higher than 0.38 mg_{KOH}/g reported by Barku et al., (2012) for Tropical Almond oil but the acid value of the oil is lower than 15.37 mg_{KOH}/g reported by Bello and Agge, (2012) for groundnut oil. The acid value of the biodiesel is 3.23mg_{KOH}/g, this value is slightly higher than 0.8 mg_{KOH}/g specified by ASTM but less than 3.366 mg_{KOH}/g reported by Bello and Agge, (2012) for groundnut oil biodiesel. The free fatty acid of the biodiesel is 1.61 mg_{KOH}/g. The acid value and FFA values are higher than 0.84 mg_{KOH}/g and 0.42mg_{KOH}/g respectively reported by (Orhevba et al., (2016) for Tropical Almond biodiesel. The nature of fatty acids can have influence on the characteristics of biodiesel (Jaichandar and Annamalai, 2011). The differences can be related to variation in sample used. Acid value and FFA can be used to check the level of oxidation deterioration of the oil by enzymatic or chemical oxidation (Nangbes et al., 2013). Increase in FFA of oil lower the chances of conversion to biodiesel with different types of side reactions. It also serves as one of the key factors that determined the suitability of oil for use in biodiesel production (Knothe, 2008). Low acid value indicates that ethyl ester biodiesel produced may not cause severe corrosion in internal combustion engine and fuel system (Mukhtar et al., 2014).

Saponification Value is used in checking adulteration. The saponification value of the oil was found to be 70.13 mg_{KOH}/g, this result is lower than 168.27 mg_{KOH}/g reported by Barku et al., (2012) for Tropical Almond. This may be due to the method of extraction of the oil and the method at which the saponification value was determined. Also, the value is lower than the values for cashew nut oil 168.3 mg_{KOH}/g (Aremu et al., 2006), coconut oil (253 mg_{KOH}/g), palm oil (247 mg_{KOH}/g) and butter fat

(225 mg_{KOH}/g). The saponification value of the biodiesel was 78.5 mg_{KOH}/g, slightly higher than that of the oil. The value is lower than 182.4 mg_{KOH}/g reported by Orhevba *et al.*, (2016) for Tropical Almond biodiesel. Oils with higher saponification values contain higher proportion of lower fatty acids (Pearson, 1976). High saponification value is a measure of molecular weight of fatty acid in oil and it indicates the amount of saponifiable matter present in oil (Mohammad *et al.*, 2006). The saponification value is good enough since high saponification values implies the possible tendency to soap formation and difficulties in separation of products if utilized for biodiesel production (Ofofule *et al.*, 2013).

Iodine Value is a measure of the degree of unsaturation in oil and it is an identity characteristics nature of oil. This value could be used to quantify the amount of double bond present in the oil which reflects the susceptibility of oil to oxidation. The iodine value of the oil is

33.88 gI₂/100g; this value is lower than 121.19 gI₂/100g reported by Barku *et al.*, (2012) for Tropical Almond. However, vegetable oil would likely to be prone to weather degradation agents like free atmospheric oxygen, heat, moisture, etc. because of its high iodine value (Mohammad *et al.*, 2006). While that of the biodiesel is 36.67 gI₂/100g, this value is lower than 122.71 gI₂/g reported by (cited in [52]) for Champaca seed oil and higher than 13.30 gI₂/g reported by Okoronkwo *et al.*, (2014) for African Bush Mango. The Iodine Value obtained is low suggesting the presence of saturated fatty acid and this places the oil in non-drying groups as drying oil have an Iodine Value above 100 (Duel, 1951).

Specific Gravity and Density values must be within tolerable limit to allow optimum air to fuel ratio for complete combustion because high density biodiesel or its blends can lead to incomplete combustion and particulate matter emission (Mukhtar *et al.*, 2014). The yellowish colour oil had specific gravity of 0.94 indicating that it is less dense than water. This value is slightly higher than 0.92 reported by Barku *et al.*, (2012) for Tropical Almond seed oil. While that of the biodiesel is 0.90. The value of the biodiesel specific gravity is the same as 0.90 reported by Orhevba *et al.*, (2016) for Tropical Almond. The result obtained is slightly higher than 0.870 reported for *Mangifera indica* oil biodiesel (Ogunsiyi, 2012) and 0.83 for waste cooking oil biodiesel reported by Adepoju and Olawole, (2014).

The Density determines the specific gravity of both the oil and the diesel. The density of the oil is 0.94 g/cm³ while that of biodiesel is 0.89 g/cm³. The density of the biodiesel is lower than 0.96 g/cm³ reported by Orhevba *et al.*, (2016) for Tropical Almond biodiesel. The value of density obtained for biodiesel is within the range specified in the ASTM standard. The density of the biodiesel affects the performance of the pump and atomizers.

The Kinematic Viscosity of the oil at 40 °C was 31.90 mm²/s while that of the biodiesel was 19.10 mm²/s. The higher the temperature the lower the kinematic viscosity. However, the result is higher than 9.1 mm²/s for Algae oil biodiesel reported by Indhumathi *et al.*, (2014) and 5.20 mm²/s reported by Orhevba *et al.*, (2016) for Tropical Almond biodiesel. 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 (Bello and Agge, 2012).

The Cloud Point and Pour Point of the oil were 10.1 °C and 0.2 °C respectively, this shows that when the oil cool to a temperature of 10.1 °C a wax or cloud is formed and that if the temperature keep on reducing to about 0.2 °C, the oil will seize to flow and become semi-solid.

The Flash Point of the biodiesel obtained from Tropical Almond seed oil is 148 °C. The 148 °C value obtained is in agreement with ASTM biodiesel standard. Flash point is a measure of the flammability of fuel and thus an important safety criterion in transport and storage. The result shows that at 148 °C the biodiesel will ignite on application of an ignition source.

The Cetane Number of the biodiesel from Tropical Almond seed oil is 107.5. This value is higher than the range specified by ASTM, Generally, the higher the cetane number, the shorter the ignition delay and the higher the propensity of the fuel to ignite (Mukhtar and Dabai, 2016). The results obtained is higher than 51.70 obtained for biodiesel from Tropical Almond by Orhevba *et al.*, (2016) and 94.24 reported for biodiesel produced from gingerbread plum seed oil by (Mukhtar and Dabai, 2016).

One important parameter of biodiesel fuel is the higher heating value which represents the amount of heat transferred to the chamber during combustion and indicates the available energy in a fuel (Demirbas, 2008). The result obtained, 46.76 MJ/kg is higher than 29.88 MJ/kg reported for *Hevea brasiliensis* seed oil biodiesel (Muhammad *et al.*, 2016). This indicates that the biodiesel produced contain appreciably high amount of energy. Fuel having higher heating value gives higher power output and

its small quantity will cover long distance drive (Gulum and Bilgin, 2015).

The biodiesel has a sulphur content of 0.0079 % ± 0.0024 %. This value is higher than that reported for rubber methyl ester by Ndana *et al.*, (2011) and 0.0061 % reported for coconut oil by EPA, (2009) which is slightly above the specific value given by ASTM D2622 of 0.0005 %. This indicates that the diesel could emit permissible SO_x upon combustion that have no environmental implication (EPA, 2009).

From the result of GC-MS Analysis shown in Table 5, the fatty acid methyl esters present in Tropical Almond biodiesel after characterization analysis per area percent include; Hexadecanoic acid, methyl ester (55.95 %), 9,12-Octadecadienoic acid, methyl ester (5.88 %), 9-octadecenoic acid (Z)-, methyl ester (9.23 %), Cyclopropane, (2-methylenebutyl)- (0.07 %) and Methyl stearate (4.58 %). The result indicates successful conversion of *Terminalia catappa* seed oil to methyl ester during transesterification using CaO derived from Snail Shell.

Table 5. Fatty Acid Methyl Ester Profile of Biodiesel produced from Tropical Almond Seed Oil using GC-MS Machine

Saturated fatty acid methyl ester	Quality	Area percent
Hexadecanoic acid, methyl ester	99	55.94
9,12-Octadecadienoic acid, methyl ester	99	5.88
Methyl stearate	95	4.58
Total		66.40
Unsaturated fatty acid methyl ester		
9-Octadecenoic acid, (Z)-, methyl ester	99	9.23
Cyclopropane, (2-59-methylenebutyl)	0.26	
Total		9.49
Non-fatty acid methyl ester		
Hexanoic acid	78	0.11
n-Hexadecanoic acid	99	10.29
9-Octadecenoic acid	25	4.85
9-Oxabicyclo [6.1.10]nonane, cis	43	0.06
9,17-Octadecadienal, (Z)-	96	7.13
2-Heptenal, (E)-	78	0.26
2-Decenal, (E)-	90	0.33
2,4-Decadienal, (E,E)-	83	0.41
2,4-Decadienal	91	0.53
Cyclohexanemethanol, chlorodifluoroacetate	25	0.11
Acetonitrile, 2,2'-imminobis-	5	0.09
Morpholine	9	0.08
Total		24.25

From the DTA/TGA Spectrum in Figure 3 below, at 40 minutes and a temperature of 477 °C, the weight of the catalyst reduced to 13.43 mg from the initial 14.323 mg. This may be due to loss of moisture and other impurities initially absorbed by the catalyst. At 67.32 minutes, the weight of the catalyst was 13.09 mg indicating further loss of moisture and impurities. As the temperature rose to 863.11 °C at a time of 83.96 minutes, the weight of the catalyst was significantly reduced to 9.33 mg. This might be due to loss of CO₂ as it escapes to air and other uncalcined carbonates that are within the catalyst

From the FT-IR spectrum in Figure 4 (a-b) below, it shows the infrared spectrum of calcium carbonate (CaCO₃) and calcined calcium oxide (CaO) respectively from snail shell. A sharp peak can be seen at 1470 cm⁻¹ of snail shell calcium carbonate. The absorption peaks correspond to C–O symmetrical stretching vibration of carbonates (Garcia *et al.*, 2008). The absorption peaks at 1800 cm⁻¹ and 2525 cm⁻¹ correspond to C=O stretching vibration of carbonates. The absorption peaks at 3400 cm⁻¹ correspond to O–H asymmetrical stretching vibration of carbonates. The two weak peaks at 885 cm⁻¹ and 730 cm⁻¹ correspond to out-of-plane bending vibration of C–O bonds of carbonates (Ismail *et al.*, 2016).

File : C:\MSDCHEM\1\DATA\2017\Dr. Yahaya Alhasan\S8.D
 Operator : Multi-User Science Research Laboratory
 Acquired : 26 Oct 2017 03:45 using AcqMethod Fatty Acid Methyl Esters .M
 Instrument : GCMSD
 Sample Name : Umbrella Seed Oil
 Misc Info :
 Vial Number : 8

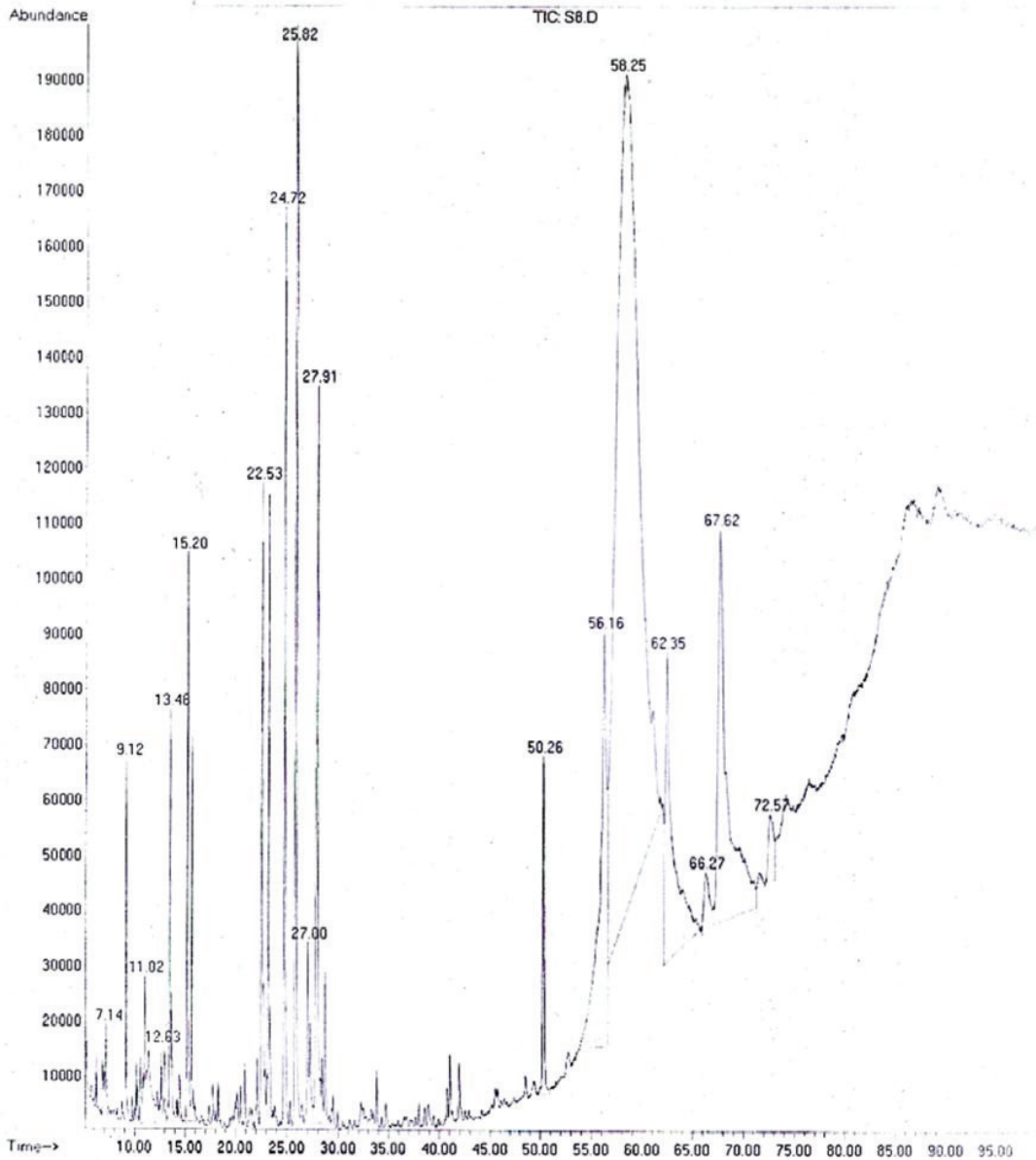


Figure 2. GC-MS chromatogram of Fatty Acid Methyl Ester (FAME) of Biodiesel produced from Tropical Almond Seed

Upon calcination, the calcium carbonate was thermally decomposed into calcium oxide and loses carbonate as shown in figure 4 (b) below. Thus, this leads to the decrease of characteristic peaks of carbonates on the IR spectrum of the synthesized calcium oxide. The reduced intensity of absorption band which corresponds to carbonates can be seen at 2520 cm^{-1} , 1800 cm^{-1} , 880 cm^{-1} , and 720 cm^{-1} on the IR spectrum of calcium oxide from snail shell (GalvanRuiz *et al.*, 2009). A sharp peak around 500 cm^{-1} of the infrared spectrum corresponds to functional group Ca-O from calcium carbonate. The Ca-O peak intensity reduced as calcium

carbonate was decomposed to calcium oxide (GalvanRuiz *et al.*, 2009). The absorption band in the range of 3651-3870 cm^{-1} on the infrared spectrum corresponds to hydroxyl group. The absorption peak of hydroxyl group is normally ascribed to the presence of calcium hydroxide. The existence of hydroxyl group resulted from absorption of atmospheric moisture during FT-IR analysis which subsequently formed calcium hydroxide. This phenomenon was common due to the high hydrophilicity nature of the compound (Tan *et al.*, 2015).

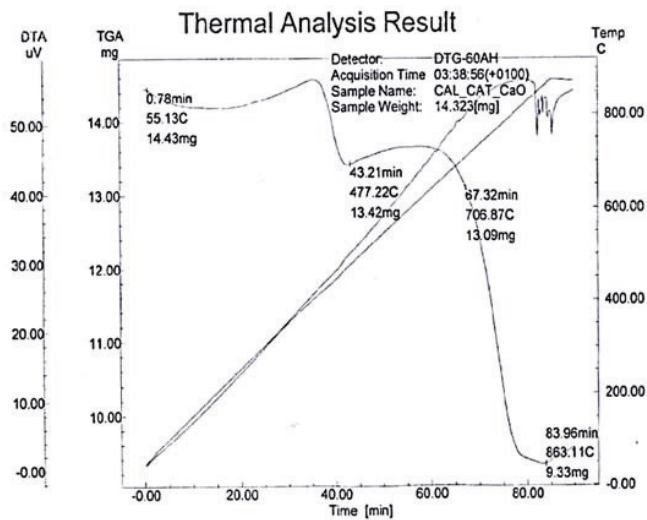


Figure 3. DTA/TGA spectrum of calcined snail shell

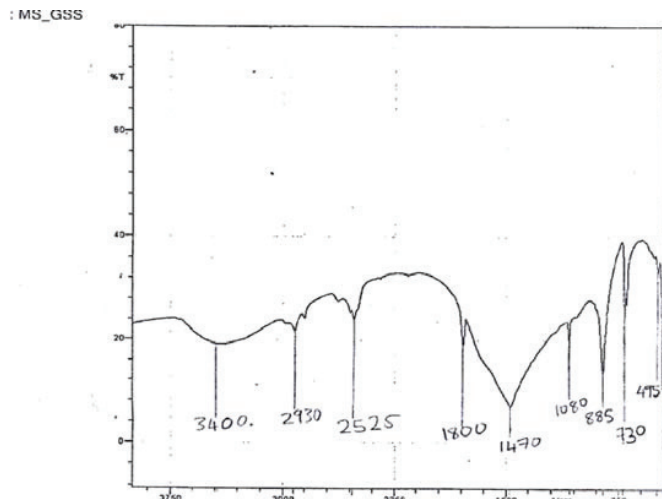


Figure 4 (a)

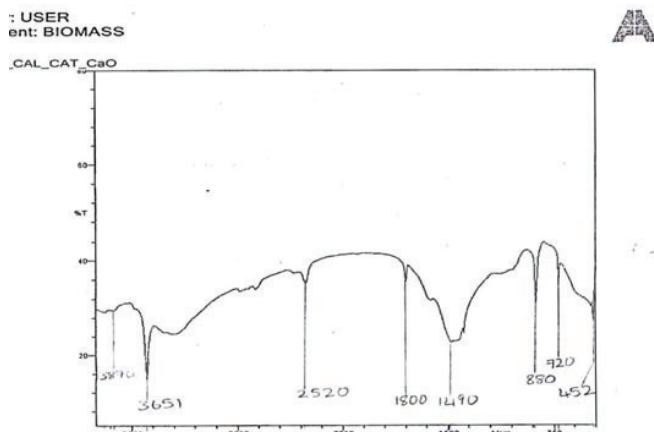


Figure 4 (b)

Figure 4. Result of FT-IR spectrum analysis (a) FT-IR Spectrum of Powdered Snail Shell (CaCO_3), (b) FT-IR Spectrum of Calcined Snail Shell (CaO)

4. Conclusion

Tropical Almond seed appeared to have a high percentage oil yield after extraction as reported for other oil rich seeds. The oil was converted to biodiesel via transesterification reaction (using n-hexane a solvent for extraction), methanol and CaO as catalyst derived from snail shell. The maximum conversion to ester was achieved at a temperature of 60°C and time of 120 minutes. The biodiesel was characterized and majority of the properties were within ASTM standard limits for biodiesel such as density, pour point, specific gravity and flash point fall within the range specified by ASTM. This indicates that biodiesel from Tropical Almond can be treated with suitable additives used in biodiesel fuel blends to improve its properties and can further be used as an alternative fuel in diesel engines.

References

- [1] Adepoju, T.F. and Olawale, O. (2014). Acid Catalyzed Esterification of Waste Cooking Oil with High Free Fatty Acid for Biodiesel Production. *Chemical and Process Engineering Research*, 12: 80 – 85.
- [2] Adu, B.O., Omojufehins, M., Esanboro, O.M., Abe, A.D., Shofolahan, O.A., Uzodinma, E. Badmus, K. and Martins, O. (2013). "Effect of Processing on the Quality, Composition and Antioxidant Properties of *Terminalia catappa* (Indian Almond) seed oil. *African Journal of Food, Agriculture, Nutrition and Development*, 13: 7662-7678.
- [3] Alamu, O.J., Dehimbo, O. and Sulaiman, A.M. (2010). Production and Testing of Coconut Oil Biodiesel Fuel and Its Blend. *Leonardo Journal of Sciences*, 95 – 104.
- [4] Al-Harabawy, A.W. and Al-Mallah, K. (2014). Production and Characterization of Biodiesel from Seed Oil of Castor (*Ricinus Communis L.*) Plants. *International Journal of Science and Technology*, 3(9): 508-513.
- [5] AINUAMI, W., BUTHAINAH, A., ETTI, C.J., JASSIM L.I. and GOMES, G.A. (2014). Evaluation of Different Materials for Biodiesel Production. *International Journal of Innovative Technology and Exploring Engineering*, 3(8): 18.
- [6] Anitha, A. and Dawn, S.S. (2010). Performance Characteristics of Biodiesel Produced from Waste Groundnut Oil using Supported Heteropolyacids. *International Journal of Chemical Engineering and Applications*, 1(3): 261-265.
- [7] Aremu, M.O., Olonisakin, A., Bako, D.A. and Madu, P.C. (2006). A Compositional Studies and Physicochemical Characteristics of Cashew Nut (*Anacardium Occidentale*) Flour. *Pakistani Journal of Nutrition*, 5: 328-333.
- [8] Asmare, M. and Gabbiye, N. (2014). Synthesis and Characterization of Biodiesel from Castor Bean as an Alternative Fuel for Diesel Engine. *American Journal of Energy Engineering*, 2(1): 1 – 15.
- [9] Asokan, M.A. and Vijayan, R. (2014). Effective Conversion of Kapok Seed (*Ceiba Pentandra*) Oil into Biodiesel and Investigation of Effects of Catalyst Concentrations and Chromatographic Characterization. *International Journal of Chemical Technology and Research*, 6(14): 5709 – 5715.
- [10] ASTM, American Standard for Testing and Materials, (1998). Standard Test Method for Sulphur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry, Annual Book of ASTM Standards, Vol. 05(3): 805808.
- [11] Azam, M.M., Amtul, W. and Nahar, M.N. (2005). "Prospects and Potential of Fatty Acid Methyl Esters of Some Non-Traditional Seed Oils for Use as Biodiesel in India. *Journal of Biomass and Bioenergy*, 29: 293302.
- [12] Barku, A.V., Nyarko, H. and Dordunu, P. (2012). "Studies on the physicochemical characteristics, microbial load and storage stability of oil from Indian almond nut (*Terminalia Catappa L.*)". *Studies*, 8: 9-17.
- [13] Bello, E. and Agge, M. (2012). "Biodiesel production from groundnut oil. *Journal of Emerging Trends in Engineering and Applied Science*, 3: 276-280.
- [14] Cholakov, G., Yanev, S., Markov, V. and Stoyanov, S. (2013). Esterification Mixtures of Pure Fatty Acids with Methanol. *Journal of Chemical Technology and Metallurgy*, 48(5), 489-496.
- [15] Demirbas, A. (2008). Biofuels Sources, Biofuel Policy, Biofuel Economy and Global Biofuel Projections. *Energy conversion and management*, 49(8): 2106-2116.
- [16] Doolittle, H.J. (1951). *The Lipids: Their Chemistry and Biochemistry*, Vol 1, New York: Interscience Publishers, New York, pp 53-57.
- [17] Environmental Protection Agency (EPA) May 29, 2009. Biodiesel from Fuel Crops in Hawaii. www.oceanicinstitute.org.
- [18] Galván-Ruiz, M., Hernández, J., Banos, L., Noriega-Montes, J., Mario, E. and Rodríguez, G. (2009). "Characterization of Calcium Carbonate, Calcium Oxide and Calcium Hydroxide as Starting Point to the Improvement of Lime for Their Use in Construction. *Journal of Materials in Civil Engineering*, 21(11): 694-698.
- [19] Gandure, J., Ketlogetwe, C., and Temu, A. (2013). Fuel Properties of Jatropha Methyl Ester and Its Blends with Petroleum Diesel. *Journal of Engineering and Applied Science*, 8(11): 900 – 903.
- [20] Garcwa, J., Lypez, T., Álvarez, M., Aguilar, D.H. and Quintana, P. (2008). "Spectroscopic, Structural and Textural Properties of CaO and CaO/SiO_2 Materials Synthesized by sol-gel with Different Acid Catalysts". *Journal of Non-Crystalline Solids*, 354: 2-9, pp 729-732.
- [21] Gülüm, M. and Bilgin, A. (2015). Density, Flash Point and Heating Value Variations of Corn Oil Biodiesel– Diesel Fuel Blends. *Fuel Processing Technology*, 134: 456–464.
- [22] Heroor, S.H. and Rahul, S.D. (2013). Production Of Biofuels From Crude Neem Oil and It Performance. *International Journal of Environmental Engineering and Management*, 4(5): 425 – 432.

- [23] Highina, B.K., Bugajc, I.M., and Umar, B. (2011). Biodiesel Production from *Jatropha* *Caucus* Oil in a Batch Reactor using Zinc Oxide as Catalyst. *Journal of Petroleum Technology and Alternative Fuels*, 2(9):146-149.
- [24] Hossain, S.A., Salleh, B.M., Boyce, A., Chowdhury, A.N. and Naquiuddin, M. (2008). Biodiesel Fuel Production from Algae as Renewable Energy. *American Journal of Biochemistry and Biotechnology*, 4(3): 250 – 251.
- [25] Indhumathi, P., Shabudeen, P.S., and Shoba, U.S. (2014). A Method for Production and Characterization of Biodiesel from Green Micro Algae. *International Journal of Bio-Science and Bio-Technology*, 6(5): 111 – 122.
- [26] Ismail, S., Ahmed, S.A., Reddy, A. and Hamdan, S. (2016). Biodiesel Production from Castor Oil by Using Calcium Oxide Derived from Mud Clam Shell. *Journal of Renewable Energy*, volume 2016, pp 3.
- [27] Jaichandar, S. and Annamalai, K. (2011). The Status of Biodiesel as an Alternative Fuel for Diesel Engine – An Overview. *Journal of Sustainable Energy and Environment*, 2:71-75.
- [28] Knothe, G. (2008). “Designer Biodiesel: Optimizing Fatty Ester Composition to Improve Fuel Properties. *Energy Fuels*, 22: 1358-1364.
- [29] Lasekan, O. and Abdulkarim, S.M. (2012). Extraction of Oil from Tiger Nut (*Cyperus esculentus* L.) with Supercritical Carbon Dioxide (SC-CO₂). *LWT-Food, Science and Technology*, 47(2): 287-292.
- [30] Muhammad, A.B., Muyibat O., Hassan L.G., and Aliero A. A. (2016). Optimization of Process Variables in Acid Catalyzed In-Situ Transesterification of *Hevea Brasiliensis* (Rubber Tree) Seed Oil into Biodiesel. *Biofuels*. Taylor and Francis Group. Available Online at <http://dx.doi.org/10.1080/17597269.2016.1242689>. Accessed on 18/10/2016.
- [31] Muhammad, C., Ladan, M.J. and Wasagu, R.U.S. (2006). Comparative Analysis of Vegetable Oils Sold in Bodinga, Sokoto State, Nigeria. *Biological and Environmental Sciences Journal for the Tropics*, 3(1): 113-116.
- [32] Mukhtar, M. and Dabai, M.U. (2016). Production and Fuel Properties of Biodiesel from Gingerbread Plum (*Parinari Macrophylla*) Seed Oil using MgO/Al₂O₃ Catalyst. *American Journal of Environmental Protection*, 5(5): 128-133.
- [33] Mukhtar, M., Muhammad, C., Dabai, U.M. and Mamuda, M. (2014). Ethanolysis of Calabash (*Lageneria siceraria*) Seed Oil for the Production of Biodiesel. *American Journal of Energy Engineering*, 2(6): 141-145.
- [34] Nangbes, J.G., Nvau, J.B., Buba, W.M. and Zukdimma, A.N. (2013). Extraction and Characterization of Castor (*Ricinus communis*) Seed Oil. *International Journal of Engine Sciences*, 2(9): 105-109.
- [35] Ndana, M., Garba, B., Hassan, L.G. and Faruk, U.Z. (2011). Evaluation of Physicochemical Properties of Biodiesel Produced from Some Vegetable Oils in Nigerian Origin. *Bayero Journal of Pure and Applied Sciences*, 4(1): 67-71.
- [36] Ofoefule, A.U., Ibeta, C.N. and Ugwumore, I.E. (2013). Determination of Optimum Catalyst Concentration of Biodiesel from Coconut (*cocos nucifera*) Oil. *International Research Journal of Pure and Applied Chemistry*, 4(3): 357-365.
- [37] Ogunsiyi H.O. (2012). Acid and Base Catalyzed Transesterification Of Mango (*Mangifera indica*) Seed Oil To Biodiesel. *Journal of Applied Chemistry*, 2(2):18-22.
- [38] Okoronkwo, C.U., Agoha, E. E. C., Ogodo, A. C. and Nwachukwu, N. O. (2014). Physical and Chemical Characteristics of African Bush Mango (*Irvingia Gabonensis*) Seed Oil. *International Journal of Advances in Engineering and Management*, 1(6): 28 – 31.
- [39] Omeje, E.O., Okide, G.B., Esimone, C.O. and Ajali, U. (2008). Kinetics of Autoxidation of An Oil Extract from *Terminalia Catappa*. *Indian Journal of Pharmaceutical Sciences*, 70: 260-262.
- [40] Orhevba, B.A., Adebayo, S.E. and Salihu, A.O. (2016). Synthesis of Biodiesel from Tropical Almond (*Terminalia Catappa*) Seed Oil. *Current Research in Agricultural Sciences*, 3(4): 57-63.
- [41] Patil P.D., and Deng S. (2009). Optimization of Biodiesel Production from Edible and Non-Edible Vegetable Oils. *Fuel*; 88: 1302-6.
- [42] Pearson, D. (1976). *The Chemical Analysis of Foods*. 7rd Edn. Churchill Livingstone, Edinburgh, U.K., pp 488-496.
- [43] Raja, A.S., Robinson, S.D.S. and Robert-Lee, L.C. (2011). Biodiesel Production from *Jatropha* Oil and its Characterization. *Research Journal of Chemical Sciences*, 1 (1) 81-85.
- [44] Ramadhas, A.S., Jayaraj, S. and Muralcedharan, C. (2004). Use of Vegetable Oils as Internal Combustion Engine Fuels- A Review. *Renewable Energy*, 29: 727-742.
- [45] Salaheldeena M, Aroua, M.K., and Mariod, A.A. (2015). PhysicoChemical Characterization and Thermal Behavior of Biodiesel and BiodieselDiesel Blends Derived from Crude *Moringa Peregrina* seed Oil. *Journal of Energy Conversion and Management*, 92: 532-542.
- [46] Sokoto, A.M., Hassan, L.G., and Dangoggo, S.M. (2011). Influence of Fatty Acid Methyl Ester on Fuel Properties of Biodiesel Produce from Curcubita Popo, Nigerian Journal Basic Applied Science, 19:81-86.
- [47] Sruthi, K., Kumar, R. and Shirisha, G. (2013). Determination of Physicochemical Properties of Castor Biodiesel: A Potential Alternate to Conventional Diesel. *International Journal of Advanced Research in Engineering and Technology (IJARET)*, 4(3):101-107. [61] Tan, H.Y., Abdullah, M.O, Nolasco-Hipolito, C. and Taufiq-Yap, H.Y. (2015). “Waste Ostrich and Chicken Eggshells as Heterogenous Base Catalyst for Biodiesel Production from used Cooking Oil: Catalyst Characterization and Biodiesel Yield Performance. *Applied Energy*, 160: 58-70.
- [48] Thirumarimurugan, M., Sivakumar, V. M., Xavier, A. M., Prabhakaran, D. and Kannadasan, T. (2012). Preparation of Biodiesel from Sunflower Oil by Transesterification. *International Journal of Bioscience and Bioinformatics*, 2(6): 441 – 444.
- [49] Ved, K. and Padam, K. (2013). Study of Physical and Chemical Properties of Biodiesel from Sorghum Oil. *Research Journal of Chemical Sciences*, 3(9): 64 – 67.
- [50] Vuppaladadiyam, V.K., Sangeetha, C.J. and Sowmya, V. (2013). Transesterification of *Pongamia Pinnata* Oil Using Base Catalysts: A Laboratory Scale Study. *Universal Journal of Environmental Research and Technology*, 3(1): 113-118.
- [51] Zhou-Ling, R.S. (2013). Reaction Kinetics of Biodiesel Production by Using Low Quality Feedstock. Thesis Submitted to Faculty of Graduate Studies and Research, Environmental System Engineering, University of Regina, 25-60.