Transesterification and Optimization of Methyl Ester from Baobab (*Adansonia digitata*) Seed Oil

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Abstract

Worry over current energy scarcity and environmental restrictions have raised interest in the development and use of non-petroleum-based renewable fuels. One of the attractive alternatives being developed is biodiesel, which is an oxygenated, diesel-like fuel consisting of fatty acid alkyl esters (most commonly fatty acid methyl esters, or FAMEs) that are derived from oils and fats. The most commonly used method for biodiesel production is transesterification of vegetable oils or fats with methanol or ethanol in the presence of a catalyst. In this research, biodiesel was produced from baobab seed oil where the oil was extracted using modified extraction method, characterized and transesterified to produce biodiesel using KOH as a catalyst. The influences of reaction temperature, concentration of methanol, concentration of catalyst and reaction time on FAME yield were investigated. Important properties of biodiesel such as free fatty acid (FFA), viscosity, pour point, density etc were also investigated. The result obtained shows that, oil was successfully extracted from the seeds of baobab plants. The oil gave an appreciable yield over the normal soxhlet extraction method. The transesterification of these oils yielded biodiesels with percentage greater than 90 %. Some of the biodiesel quality parameters examined in this research all met the American and European Standards. This study supports the production of biodiesel from the oil of baobab seeds as an alternative to diesel fuel.

Keywords: *Adansonia digitata*; biodiesel optimization; transesterification; fatty acid methyl esters; Catalyst

Introduction

Nowadays, the demand for energy has increased due to the advancement in technology and increasing industrialization. This fuel demand in 2006 was estimated to be about 85 million barrels per day compared to that of 2000. The worldwide rapid increase is projected to be around 107 million barrels of liquid fuel per day in 2030. Therefore, the reduction of fossil fuel reserve (1342 billion barrels oil as of January 2009) acts as a driving force behind the search for alternative fuels (Shafiee and Topal, 2009). This present energy demand is met primarily by petroleum based fuels, which being non-renewable in nature necessitates finding alternative fuels which are renewable. Fossil fuel is known to be the main energy supplier worldwide. However, this energy source is non-renewable, and will be exhausted in the near future (Shafiee and Topal, 2009). Presently, there is an urgent need for cheaper alternatives and renewable energy sources with little or no environmental impacts. The alternatives fuel sources being developed around the globe include biodiesel, alcohol, biomass, biogas, and synthetic fuels. Biodiesel, unlike other alternatives, has the advantage of being used directly without blending or modification with chemical additives. Other alternatives require some sort of modification before they can be used as

substitute of conventional fuels (Srivastava and Prasad, 2000).

Narwal and Sharma, (2014) stated that biodiesel is one of the alternatives since it is renewable. Biodiesel is a renewable fuel, produced from vegetable oils/fats. Transesterification is one of the methods use in converting these vegetable oils/fats into biodiesels. Transesterification is a chemical reaction used for the conversion of vegetable oil into biodiesel (Greg, 2005). The process involves reacting vegetable oils with an alcohol to produce biodiesel and glycerol in the presence of a catalyst. There are so many different chemical ways in which biodiesel (alkyl esters) could be produced; however, commercial synthesis of fatty acid methyl ester (FAME) can only be produced by transesterification of vegetable oil. Several factors like feedstock quality, type of catalyst and reaction conditions determine the process and appropriate chemical route to be used for the transesterification process. Generally, the process for refined edible vegetable oils involves transesterification, recovery of excess alcohol, separation of glycerol from ester phase, neutralization of catalyst and purification of FAME. (Demirbas, 2006) carried out an extensive research to optimize the overall process, but transesterification reaction has been a concern in many studies.

Biodiesel can be produced from different feedstock, among which are; jatropha seed, rubber seed, baobab seeds and many other. Among all, baobab has the potential to be used as a main source for FAME production. The baobab tree (*Adansonia digitata*) is one of the most intriguing trees growing on the African continent and is often referred to as the "upside down" tree which can live up to 6,000 years. The tree is found in many African countries and is probably the best known tree found in Africa. At present *Adansonia digitata* seed does not find

any major applications and hence even the natural production of the seeds it remains underutilized (Husin, 1981). The trees are planted on more than 1.2 million ha land all over northern country (Nigeria) and each hectare can give an approximate amount of 150 kg of the seeds(Yusup and Khan, 2010).The oil content in the seeds varies from 45 to50%. It is semi-drying and consists of saturated (33%) mono-saturated (36%) and poly-unsaturated (31%) fatty acids (Danbature *et al.*, 2016) and is comparable to drying oils commonly used in surface coating (Aigbodion and Pillai, 2000). Its essential linoleic acid is of special interest. Baobab seed oil has been found to have potential applications in many areas amongst which are in the production of biodiesel as fuel for compression engines (Ikwuagwu, 2000; Ramadhas *et al*., 2005). Therefore baobab seed oil has the potential to replace/substitute for edible oils such as palm oil, coconut oil, etc. as a raw material for biodiesel production and other industrial uses during periods of high food sector demand. Danbature *et al*.,(2016) worked on Production and optimization of ethyl ester from baobab seed oil and they found that, the optimum percentage yield was 96 % at a molar ratio of 12:1 ethanol to oil. Hence, it could be concluded that baobab seed oil would be a potential source for biodiesel production based on the ethyl ester quality parameters examined in their research. Similarly (Buhari *et al.*, 2014) produced biodiesel from *Adansonia digitata* seed oil and they concluded that, the seed of *Adansonia digitata* have been shown to contained reasonable amount of oil and the fuel was within the recommended standards of the biodiesel fuel. The aim of this research is to investigate the potential of *Adansonia digitata* seed oil as a source for the production of methyl ester and also to find out appropriate conditions for the optimization process.

Materials and Methods
Sample collection and preparation
Baobab fruits were harvested from baobab plant in the premises of Gombe State University Campus, Tudun Wada, Gombe, Nigeria. The plant was identified by a botanist in the Department of Biological Sciences of the University. The harvested fruits were cracked in other to release the fleshy pulp. The pulps were pounded with pestle and mortar to release the seeds. Some of the pulps still attached to the seeds were then washed with water. During the washing, defective seeds were removed, leaving the good ones. The baobab seeds have hard seed coats. In order to obtain the soft kernel, the selected seeds were sundried and then pulverized using a hammer mill and sieved. The sieved powder was stored in an air tight container at room temperature prior to oil extraction process.

Oil Extraction
The seed oil was extracted using a modified extraction process as described by Danbature *et al.*, (2015) thus: Batches of 100 g weight sample of the baobab ground seed were placed into a distillation flask, after which 300 cm^3 of *n*-hexane was added. A stirring bar was dropped into the distillation flask containing the weighed sample and a condenser was fitted unto it. The complete reaction set up was then placed in an oil bath and the oil bath was placed on a hot plate equipped with a magnetic stirrer at a temperature of 100 ºC and a stirring speed of 500 r.p.m for eight (8) hours. The crude mixture was suction filtered while hot. The solvent (*n*-hexane) was recovered using a rotary evaporator. The volume yield per 100 g sample was measured and recorded. Activated molecular sieves (size 3A) were added to the oil and left for two days to dry the oil. The dried oil was filtered and stored for characterization and the transesterification process.

Oil Characterization
Moisture content determination
The moisture content was determined by a method described by (Danbature *et al.*, 2015) where an empty crucible was weighed (Wc). Two drops of oil was put into the empty crucible and weighed (Wco). The crucible and the sample were then placed in an oven programmed at 105ºC and left for 8 hours; after which it was removed and re-weighed (Wo). The percentage moisture content was computed as follows.

$$Moisture\ content = \frac{Wco - Wo}{Wco - Wc} \times 100\% \ldots (1)$$

The process was repeated twice and the average moisture content computed.

Free fatty acid value determination
The method of (Kyari, 2008) as modified by (Danbature *et al.*, 2015) was adopted for calculating the free fatty acid. The seed oil (5.30 g) was weighed into a beaker; 25 cm^3 of diethyl ether and 25 cm^3 of absolute ethanol were mixed together and added to the oil. The mixture was then titrated against 0.1M NaOH, using phenolphthalein as indicator, until a pink color was observed. The process was repeated two more times. The free fatty acid was computed as follows;

$$FFA = \frac{Vo \times M \times 2.8}{5.3} \ldots \ldots \ldots (2)$$

Where
Vo is the titre volume,
M = molarity of NaOH = 0.1M and
2.82 = conversion factor for oleic acid.
Acid value = 1.99 x FFA

Determination of iodine value
The method adopted was that of (AOAC, 1990). A 2.0 g of the extracted oil was weighed into a clean conical flask, 15 cm^3 of CCl$_4$ and 25 cm^3 of Wij's reagent were added to the oil in the conical flask. In another conical flask containing no oil, 15 cm^3 CCl$_4$ and 25 cm^3 of Wij's reagent

were added. The contents of the two flasks were mixed thoroughly and left in the dark for an hour. Also, a 15 cm^3 of 10% KI and 100 cm^3 of distilled water were added and shaken thoroughly. The mixture was titrated against 0.1M $Na_2S_2O_3$ solution until a light yellow color was observed. Starch indicator (1 cm^3) was added and the titration continued until the blue-black color was discharged. The volume at the discharged point was recorded. The process was repeated two more times and the average titre volume computed.

$$Iodine\ value\ = \frac{[B-S]\times M \times 126.9}{wt\ of\ sample}\ldots\ldots (3)$$

Where
B = titre volume for blank titration
S = titre volume for the oil titration
M = molarity of $Na_2S_2O_3$ solution

Determination of saponification value
The method described by (Nkafamiya *et al.*, 2007) was adopted. A 2.0 g oil sample was weight and added to 0.1M alcoholic KOH in a conical flask. The resulting mixture was heated to 60ºC with constant stirring on a hot plate for five minutes for the oil. The unsaponified KOH was titrated with 0.5M HCl, using phenolphthalein as indicator until the solution turned pink. The process was repeated two more times and the average titre value was calculated. The saponification value SV was calculated as follows:

$$SV\ = \frac{M \times [B-S] \times 56.1}{wt\ of\ sample}\ldots\ldots\ldots (4)$$

Where;
B = blank titre
S = Sample titre volume
M = Concentration of HCl = 0.5M

Optimization of the Transesterification Process
The method described by (Ana *et al.*, 2013) was modified and used for the transesterification method as described thus: All the transesterification processes

were carried out in a 100 cm^3 three necked flask. A Liebig condenser was attached unto the middle neck; a thermometer was inserted through the second neck; while the third neck was used for sample introduction and withdrawal.

The transesterification process
The weighed amount of the catalyst (KOH) was first dissolved in the measured amount of the methanol. The measured amounts of the oil (baobab oil) and a stirring bar were introduced into the three necked flask. The flask and its content were heated on a hot plate equipped with a magnetic stirrer. On reaching the desired temperature, the catalyst-alcohol mixture was introduced into the reaction flask and timing commenced. At the end of the time period, the reaction was terminated by the addition of 0.5 M HCl and the contents of the flask was transferred into a separation funnel and allowed to settle overnight. Two layers were formed, the upper layer being the biodiesel, while the lower layer is glycerol. The lower layer was then drained off while the upper layer was transferred to reaction flasks where the excess alcohol was distilled off in a rotary evaporator. The biodiesel collected was then washed several times with distilled water until the water became colorless. It was then dried with activated molecular sieves (3A) and the weight of the filtered dried sample was recorded. The same procedure was used for studying the effects of various parameters as follows:

Effect of Reaction Temperature on FAME yield
The effect of temperature on the transesterification was studied by varying the temperature between 40 °C to 70 °C at an interval of 10 °C, using the following fixed parameters: reaction time of 90 minutes, rotational speed of 500

r.p.m., catalyst loading of (1wt%) KOH and molar ratio of oil-to-methanol of 1:6.

Effect of Varying the Concentration of Methanol on FAME yield
The effect of methanol concentration on the transesterification rate was studied by varying the concentration of methanol within the range of 10 cm^3 to 20 cm^3 at an interval of 5 cm^3 and using the following fixed parameters: reaction time of 90 minutes, rotational speed of 500 r.p.m. and catalyst loading of 1wt% KOH.

Effect of Varying the Concentration of Catalyst on FAME yield
The effect of varying the concentration of the catalyst on the transesterification rate was studied by varying the concentration of the catalyst from 1% to 1.5% at an interval of 0.5%KOH, using the following fixed parameters: reaction time of 90 minutes, reaction temperature of 50 ^{o}C, rotational speed of 500 r.p.m and molar ratio of oil to methanol of 1:6.

Effect of Varying the Reaction Time on FAME yield
The effect of varying the reaction time on the transesterification rate was studied by changing the reaction at an interval of 30 minutes starting from 30 to 90 minutes with the following fixed parameters: reaction temperature of 50 ^{o}C, molar ratio of oil to methanol of 1:6.

Characterization of Biodiesel
Viscosity determination
A suspended level viscometer was used in determining the viscosities of the methyl esters as described by (Danbature *et al.*, 2015). The viscometer was calibrated by clamping the viscometer on a retort stand and allowed to be suspended into water bath, maintained at a temperature of 40ºC. Water was sucked to the upper mark of the viscometer and held in that position for twenty minutes for the water to equilibrate with the

temperature of the water bath. The water was allowed to fall under gravity and the time taken to fall to the lower mark was noted and recorded. The procedure was repeated several times until the change in the time of flow did not differ from successive one by ±1s. The water in the suspended level viscometer was substituted with the methyl ester and the process repeated.

Relative density determination
A pycnometer was used for determining the relative density as described by (Danbature *et al.*, 2015). A pycnometer (100 cm^3) was washed with soap and rinsed with water and then with small amount of acetone. It was then dried in an oven. The dried flask and the stopper were weighed (Wo). The pycnometer was filled with water (at 20ºC) and weighed (W1). The water was emptied and the pycnometer was dried. The pycnometer was then filled with oil/biodiesel and weighed (W2). The density of the biodiesel was computed as follows;

$$\rho = \frac{M_B - M_o}{M_w - M_o} \dots \dots \dots \dots (5)$$

Where;
M$_B$ =   mass of the biodiesel
Mw   =   mass of water and
Mo   =   mass of pycnometer

Water and sediment determination
A Sovarl SS Automatic centrifuge DU pont instrument was used for the determination of water and sediment. Sample (100 cm^3) was measured into 100 cm^3 graduated curvettes. Four curvettes containing different samples were inserted into the centrifuge; the centrifuge was programmed at 6000 r.p.m for 10 minutes and powered on. After the time period, they were removed with the sediments settling at the bottom, while the water remaining on top. The volume of water was read from the graduated curvette and was converted to percentage.

Calorific value determination
Dry Cal Modular Calorimeter was used to determine the calorific values of both the oils and the biodiesels produced as described by Danbature *et al. (*2015).

Flash point determination
The flash point was determined by using a thermocouple. Small amount (10 cm^3) of the methyl ester was placed in a combustion tube in which a thermocouple was inserted. A lighted splint was passed over heated sample. The temperature at which the lighted splint ignited was detected by the thermocouple and recorded as the flash point.

Cloud point determination
A thermometer was placed in a test tube containing 20 cm^3 methyl ester. It was held vertically in a beaker containing ice and sodium chloride. The temperature at which the first appearance of cloud was noticed was recorded as the cloud point. The process was repeated two more times and the average calculated.

Pour point determination
Methyl ester (20 cm^3) was poured in a test tube and allowed to super cool in a deep freezer (reading up to -20ºC). It was then removed and placed in test tube rackets under room temperature and a thermometer was held vertically in the test tube. The temperature at which the sample began to melt was recorded as the pour point. The process was repeated two more times.

Copper strip corrosion measurements
Polished copper strips were placed in the methyl ester at a constant temperature of 50 ºC for 3 hours. The strips were removed and washed with acetone and compared with specified profiles (Gerpen *et al*., 2004).

Results and Dicussion
Oil Properties
The oil content of 49.0 % v/wt (Table 1) obtained from the modified extraction method of the baobab seed oil is higher than that reported using soxhlet extraction (Danbature *et al*., 2015); Birnin-Yauri and Garba, 2011). The oil yields of baobab seeds is higher than that of soy bean (15-21 %) and rape seed (>40 %) (Okieimen and Eromosele, 1999). This value (49.0%) is considered as reasonable recovery yields. According to (Jibrail and Kaet, 2013), a crop that produces high amount of oil is desirable for biodiesel production as it could be used as a feasible alternative. The improvement in the oil recovery of baobab seed oils could be attributed to the modified method of extraction.

The acid value of 0.28 mgKOH/g for the baobab seed oil is very much lower than 3.14 mgKOH/g reported by (Birnin-Yauri and Garba, 2011); and 0.33 mgKOH/g by (Nkafamiya *et al*., 2007) and those reported by (Bashir *et al*., 2014) from rubber seed oil. The low acid value could be attributed to the new improved method of oil extraction that produced refined oil. The low acid value demonstrates the feasibility of alkali – catalyzed transesterification (Nakpong and Wotthikanokkhan, 2010).The iodine value of 114 g I_2/100g for the baobab seed oil is this study is greater than 82.58 gI_2/100g reported by (Birnin-Yauri and Garba, 2011) and 87.9 gI_2/100g reported by (Nkafamiya *et al*., 2007), but lower than 124.87 gI_2/100g reported by (Buhari *et al.*, 2014). The differences observed in the iodine values for both oils could be due to differences in geographical locations.

Table 1: Oil Quality Parameters of Baobab Seed Oil

Parameter	Value
Oil yield (wt %)	49
Moisture content (%)	1.67
Density (g/cm^3 at 20°C)	0.8935
Kinematic viscosity(mm^2/s at 40°C)	18.69
Acid value (mgKOH/g)	0.28
Saponification value (mgKOH/g)	96.8
Iodine value (I$_2$/g)	114.2
Calorific value (MJ)`	36.30

The computed saponification value of baobab seed oil (96.8 mgKOH/g) is very much lower than 196 mgKOH/g reported by (Nkafamiya *et al*., 2007); 210 mgKOH/g by (Buhari *et al*., 2014); and 186 mgKOH/g by (Birnin-Yauri and Garba, 2011). This could be attributed to the new method of extraction which seems to drastically lower the saponification value. The density of 0.8935gcm^{-3} for baobab seed oil is similar to the results obtained by (Buhari *et al.*,2014) but lower than that of neem oil which has a value of 0.920 gcm^{-3} (Pradeep *et al.*, 2013). (0.9078 gcm^{-3}) is higher than that obtained by (Abdulhamid *et al.*, 2012), but lower than that reported by (Okieimen and Eromosele, 1999). The density of baobab seed oils fall within the European Standard of 0.86 – 0.90 gcm^{-3} (EN14214). The calorific value of baobab seed oil is 36.30. The value is lower than the calorific value of neem oil (44.65 MJ) as reported by (Pradeep *et al.*, 2013).

Optimization of Biodiesel Production
Effect of reaction temperature on FAME Yield
Temperature is one of the important aspects that affect the biodiesel production because it can facilitates the rate of reaction by breaking the cell wall of the seeds and allow the oil out of the kernel (Boocock, 1998 and Hincapié, 2011). The effect of temperature on the yields of the methyl esters of baobab seed oils are shown in Figure 1. There is a decrease in the yields of baobab seed oils methyl esters with increase in temperature. The optimum yield was observed at a temperature of 40° C and the lowest at 70° C. The reason for the increase in yield is that, increase in temperature is believed to facilitate the breaking of the seeds cell walls, thereby creating a void which serves as migratory space for the contents of the oil bearing cells (Chandraju and Prathima, 2004).
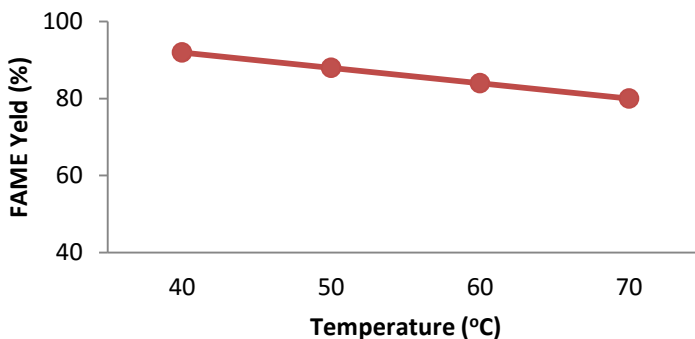
Figure 1: Effect of reaction temperature on the yield of baobab methyl ester
Conditions: Reaction time = 90 mins, Oil to MeOH molar ratio = 6:1, catalyst concentration = 1.0,

Effect of Catalyst on FAME Yield
The effect of catalyst loading on the yield of baobab methyl esters is shown in Figure 2. There is a decrease in yield, with increase in catalyst concentration from 0.5 to 1.5 for baobab methyl ester, and further increase in catalyst loading resulted in low yield. Addition of excess amount of catalyst, gave rise to soap formation which increased the viscosity and led to the formation of gels.

Transesterification does not take place for insufficient amount of catalyst (Monteiro *et al*., 2008).As stated by Monteiro *et al*., (2008), from physical appearance, the higher catalyst concentration, the darker the biodiesel produced. Therefore the addition of a suitable catalyst concentration is important to the physical appearance of biodiesel.
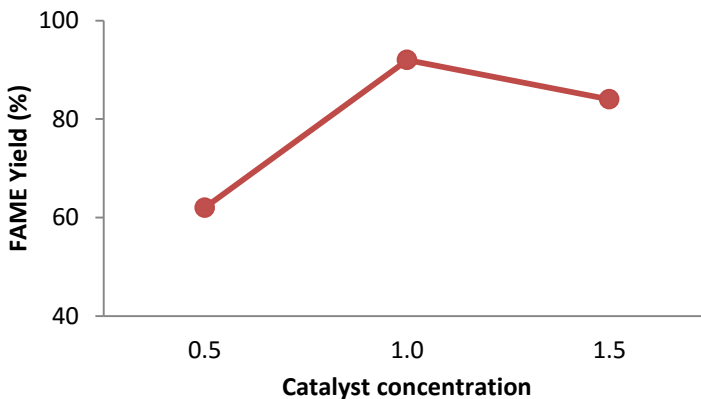
Figure 2: Effect of catalyst loading on methyl ester formation
Conditions: Reaction time = 90 mins, Oil to MeOH molar ratio = 6:1, Reaction temp. = 40°C.

Effect of Molar Ratio on Biodiesel Yield
One of the important variables affecting the ester yield during the

transesterification reaction is the mass ratio of alcohol to vegetable oil. Molar ratio is the ratio of number of moles of

alcohol to number of moles of oils (Monteiro *et al.*, 2008). Theoretically; transesterification reaction requires three moles of alcohol for each mole of oil. However, for transesterification process, the molar ratio should be higher than that of stoichiometric ratio in order to drive the reaction towards completion. The effect of molar ratio on the yield of baobab seed oils is shown in Figure 3. There is a decrease in yield of both methyl esters, with increase in the molar ratio of oil to methanol from 1:6 to 1:12.

The highest yield was obtained using a molar ratio of 1:6, while the lowest yield is at a ratio of 1:12.

Also, it was observed that, a further increase in molar ratio did not show any improvement in the FAME yield, instead a decrease in FAME yield was observed. This is because excess methanol may move over the ester layer and it can cause decreases in the flash point of the biodiesel. The excess methanol can be removed by washing (Monteiro *et al.*, 2008).
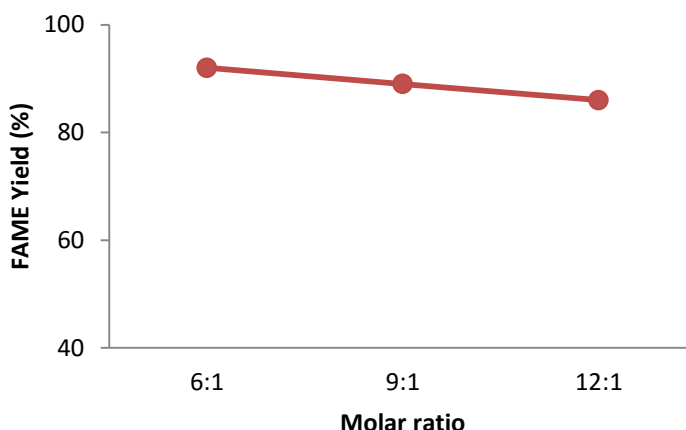
Figure 3: Effect of methanol to oil molar ratio on the yield of baobab methyl ester
Conditions: Reaction time = 90 mins, Catalyst concentration = 1.0, Reaction temp. = 40°C.

Effect of Reaction Time on Biodiesel Yield
The effect of reaction time on the yield of baobab methyl esters is shown in Figure 4. There is an increase in esters as the

reaction time is increased from 30 to 90 minutes. The excess reaction time did not promote the FAME yield but may cause major soap formation (Ramadhas, 2005).

Properties of FAME Produced
The properties of the biodiesel produced obtained from baobab seed oil in comparison with rubber seed oil (RSO) biodiesel is shown in Table 2. The majority of the properties of the obtained FAME are similar with that of RSO and with ASTM and EN standard. Based on the results, the FAME consists of huge quantity of C_{18}. The present investigation shows that, the FAME obtained from

baobab seed oil enhanced the biodiesel properties in respect to density, viscosity, specific gravity, acid value, etc. The observed viscosity of the produced biodiesel is within the range of biodiesel standard. The cloud point and pour point of the biodiesels are closely the same, falling within the ranges of 4.5 to 6.0 ^{o}C and -1.5 to -2 ^{o}C, respectively. The flash points of the biodiesels are within the range of 150 to 160°C, and are all above

the minimum of both the ASTM and EN standards. The outcome of this research shows that, baobab seed oil FAME method enhanced biodiesel properties in respect to density, pour point, cloud point, viscosity and specific gravity. Comparison of these characteristics with petro diesel or diesel fuel confirmed that, biodiesel has a closer fuel property values relatively to that of diesel. Viscosity is the most important property of biofuel since it affects the operation of fuel injection equipment, particularly at low temperatures when the increase in viscosity affects the fluidity of the fuel (Aigbodion, 1994). Biodiesel has a viscosity close to that of diesel fuels. High viscosity leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors (Eka, 1978). In this study the viscosity obtained was 1.883 mm^2s^- at 40 °C as shown in Table 2 which fall within the range of ASTM standard, this shows that FAME produced from baobab seed oil will serve as an excellent alternatives to the energy crisis since it has low viscosity. Density is a significant property of biodiesel. Density is the mass per unit volume of any liquid at a given temperature while specific gravity is the ratio of the density of a liquid to the

density of water. Density/specific gravity is very important in diesel-engine performance since fuel injection operates on a volume metering system (Aigbodion, 1994).

The two main factors for low-temperatures function that affect the methyl ester or fuel are cloud point (CP) and pour point (PP). The cloud point (CP) is the temperature at which a crystal of a cloud first emerges in a liquid when cooled under certain circumstances as illustrated based on ASTM. The pour point (PP) is the temperature at which the quantity of wax from solution is adequate to clot the oil; therefore it is the lowest temperature at which the fuel can flow. The pour point (PP) is the lowest temperature at which a fuel variety can be moved. It can determine based on the approved ASTM standard. These properties (CP and PP) are used to state the cold-temperature usability of a fuel (Ramadhas, 2005). For this experiment, both the pour point and cloud point fall within the ASTM standard as described in Table 2. Also, it has been observed in this study that, the acid value was less than 1 % which is within the acceptable limit of ASTM.

**Table 2:** Properties of FAME from baobab seed oil in comparison with other esters

Parameter	FAME from baobab	RSO FAME*	ASTM	EN14214
Cloud point (°C)	6.0	4.0	-	-
Pour point (°C)	-2.0	-2.5	-	-
Flash point (°C)	150	156	130 Min.	120 Min.
Copper strip corrosion index	2.0	-	3.0	-
Water and sediment (%)	0.003	-	0.05 Max.	0.5 Min.
Density at 20 °C (g/cm^3)	0.8324	0.897	0.8796	0.86 – 0.90
Kinematic viscosity /mm^{2}s$^-$ at 40 °C	1.883	4.68	4.5.15	3.5-6.0
Acid number (mmKOH/g)	0.14	0.65	0.8 Max.	0.5 Max.
Calorific value (MJ)	35.577	39.12	-	-

*Abubakar *et al.*, 2015

Conclusion
This research revealed that, biodiesel can be produced by transesterification method from the seeds of baobab tree, and it was found that, the highest biodiesel yield obtained was 92 % at 90 minutes reaction time, reaction temperature of 40 ^{o}C with oil to methanol mass ratio of 1:6, and 1.0 catalyst concentration, and stirring speed of 500 r.p.m. It could be concluded that baobab seed oil would be a potential for biodiesel production based on the methyl ester quality parameters examined in this research.
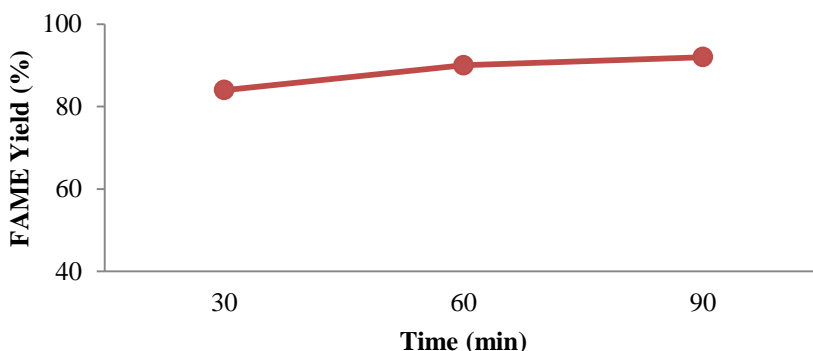
Figure 4: Effect of reaction time on the yield of baobab methyl ester
Conditions: Catalyst concentration = 1.0, Oil to MeOH molar ratio = 6:1, Reaction Temp. = 40°C.

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