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Properties of *Balanites Aegyptiaca* Biodiesel as a Pottential Energy Carrier in the Drylands of Nigeria

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Abstract There is a huge gap between demand and supply of energy carriers, which needs to be met through increased production of biodiesel using non-edible oil plants, without jeopardizing national food security. The study was conducted to investigate the fuel properties of desert-date (*Balanites aegyptiaca*)-based biodiesel for possible use as fuel for internal combustion engines. Biodiesel was produced from *Balanites aegyptiaca* oil using alkali catalyzed trans-esterification method. The fuel properties were determined in accordance with the Association of Official Analytical Chemists (AOAC 1990), American Society for Testing and Material (ASTM D6751) and European standard methods. The average oil yield was 396 g/kg, while the oil extraction efficiency was 88%. Trans-esterification of *Balanites aegyptiaca* oil revealed high biodiesel yield of 82.7%, 15.9% glycerol with 1.4% stir loss. Analysis of biodiesel fuel properties revealed a kinematic viscosity of 4.7mm^2/s at 40°C, higher heating value of 37.5 MJ/kg, acid value of 0.11mgKOH/g, peroxide value of 1.4mEq/kg, iodine number of 68.53 gI_2/100g, saponification number of 216 mgKOH/g, density of 886.79 kg/m^3 at 15°C and cetane number of 50.42. These results are in accordance with the ASTM and European standard for biodiesel except its higher heating value. The findings from the study suggest *Balanites aegyptiaca* as a raw material for biodiesel production and its biodiesel as suitable alternative fuel for communities in dryland areas of Nigeria.

Keywords Dryland areas, Balanites aegyptiaca, Vegetable oil, Trans-esterifcation, Biodiesel, Fuel properties

1. Introduction

As fossil fuels are depleting, there is need to search for alternative fuel in order to meet the world energy demand. In view of the above, increased attention has been given to biofuels, such as biodiesel, that can be used as an alternative energy carrier in compression–ignition engines. Biofuels have been gaining increased attention as a substitute for petroleum in the transportation sector to mitigate the effects of greenhouse emissions on climate change and offset the depletion of fossil fuels. Oil crops such as palm, sunflower, peanut, soybeans were the largest group of exploitable renewable biomass resources for liquid fuel and energy generation in Nigeria.

Chemically, biodiesel consists of mono-alkyl esters of long chain fatty acids derived from vegetable oil and animal fat, designated as B100, and it must meet the special requirements such as the ASTM D6751 and the European standards. The technical and economic advantages of biodiesel are that, it reduces greenhouse gas emissions because it reduces some exhaust emissions; it helps to reduce country's reliance on crude oil imports and supports agriculture by providing a new labor and market opportunities for domestic crops; it enhances the lubricating property; it is safer to handle, being less toxic, more biodegradable and it is widely accepted by vehicle manufacturers. Feedstock is about 80% biodiesel's total operating cost, this made it the major economic factor to consider for input costs of biodiesel production. Other important costs are labor, methanol and catalyst, which must be added to the feedstock [1]. Biodiesel is becoming commercialized, but biodiesel obtained from different oil sources have been reported to have different physical characteristics and chemical compositions [2].

Balanites aegyptiaca belongs to the *Kingdom:* Plantea; Division: Spermatophyta; Subdivision: Angiospermea; Class: Dicotyledonea; order: Balanitales; family: Balanitaceae; Genus: Balanites; Species: aegyptiaca; [3]. *Balanites aegyptiaca* tree is distributed in West Africa, especially in West African arid and semi-arid regions where the climatic environment and soil are not suitable to produce plants commonly used for the production of biofuels [4]. It is one of the most common but neglected wild plant species of dry land area of Africa and South Asia [5]. It is always green even in the worst drought, with wide ecological distribution [6]. It is sometimes described as a small to medium-sized semi-deciduous tree which attains a height of about 8-10 m and a stem diameter of 30 cm as depicted in figure 1 [7]. The seed (figure 2) has thin brittle

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epicarp, a fleshy mesocarp and a woody endocarp containing the oil seed or kernel. A mature tree could yield about 10,000 pieces of fruit per year [8]. *Balanites aegyptiaca* is widely distributed throughout Africa. It is also found in the relatively drier regions of Northern Africa from Mauritania to Nigeria and Ghana, to Egypt, across Palestine, Saudi Arabia and India [9].

In Nigeria, *Balanites aegyptiaca* is commonly found in the northern part of the country with mean temperature of 20-30℃ and mean annual rainfall of 250-400 mm^3 [10]. It is one of the most neglected common trees, usually found throughout the dried regions of Africa, especially Nigeria.

Figure 1. *Balanites aegyptiaca* Tree

Figure 2. *Balanites aegyptiaca* Seeds

Irrespective of its source, the quality of biodiesel should meet certain standards in order to ensure better engine performance. Biodiesel from plants such as jatropha, soybean, peanut, sunflower, palm and rapeseed had been reported to have good fuel properties [11].

A number of works have been documented on biodiesel production and its characterization [12] [13]. Biodiesel produced were of good fuel properties, except the kinematic viscosity of castor oil biodiesel which was also not in agreement with the specified standards.

In order to analyze the fuel properties of soybean oil methyl ester, [14] carried out experiments at various temperatures for the biodiesel. The resulting measurements were compared with the properties of conventional diesel fuel. In their work, the specific gravity, density and the kinematic viscosity obtained shows conformity with the ASTM D6751 standard. In another study [15] biodiesel from Neem oil as a viable alternative to the diesel fuel was reported. The important fuel properties of the trans-esterified methyl esters such as flashpoint, viscosity, calorific value and density determined were nearer to that of petroleum diesel except its calorific value which was about 16% less than that of the petroleum diesel.

Transesterification of cottonseed oil and canola oil were carried out by [16] using low molecular weight alcohols and potassium hydroxide as catalyst. The resulting mixed methyl/ethyl canola esters exhibited enhanced properties in comparison to neat canola oil methyl esters and also satisfied ASTM D6751 and EN14214 standards with respect to kinematic viscosity and acid value.

Despite several attempts to produce biodiesel, [18] made it clear that the cost of biodiesel is the major hurdle to its commercialization in comparison to petroleum-based diesel fuel. The high cost is primarily due to the feedstock consumed in its production. In another study, [20] reported that *Balanites aegyptiaca* oil composed of moderately long chain fatty acids with high degree of unsaturation, making it a good raw material for biodiesel production. However, if biofuels are to obtain a substantial penetration into the transportation sector, their production must be highly scalable and result in minimal environmental impact. Moreover, the physical and chemical properties of biofuels must be consistent with the properties of petroleum-based transportation fuels [21]. This transition failed to take off due to inadequate production of biodiesel caused by complete reliance on a limited number of feedstocks.

A prominent oil crop that can grow on barren land such as the dryland of sub-Saharan Africa is *Balanites aegyptiaca*, but little is known about its fuel (biodiesel) properties. Therefore, this research was designed to investigate the fuel properties of Desert-date (*Balanites aegyptiaca*)-based biodiesel. This could be achieved by extracting oil from this promising crop, produce biodiesel from the oil extracted, and determine the fuel properties of the biodiesel produced. While the purpose of this study was to produce biodiesel fuel from *Balanites aegyptiaca*, the objective was to contribute to the attainment of energy security by the inhabitants of Nigerian drylands.

2. Methodology

2.1. Materials

The materials used in the current study include magnetic stirrer, ground sample of the *Balanites aegyptiaca* seed kernel. Other materials include, N-hexane, methanol, vegetable oil extracted from the plant's seed kernel, sodium hydroxide pellets (caustic soda), benzoic acid, ignition thread, B100 (Transesterified *Balanites aegyptiaca* oil). Soxhlet extractor depicted in figure 3 was the equipment used for the oil extraction. The setup used for biodiesel production is presented in figure 4. Brookfield viscometer was used to determine the kinematic viscosity, while Bomb calorimeter (G Cussons P6310) was used to determine lower heating value of the biodiesel sample. Other equipment used for oil extraction and biodiesel production includes: electronic weighing balance (Mettler Toledo), water bath and magnetic hot plate.

2.2. Methods

2.2.1. Oil Extraction Using Soxhlet Extractor

The aim of this experiment was to extract oil from the sample according to the following procedure. 100g of the seed sample was weighed using electric weighing balance and placed into the thimble of the Soxhlet extraction apparatus. 175ml of n-hexane solvent was poured into the thimble and allowed to extract the oil at 68℃ for about 2-4 hours. The extract (mixture of oil and solvent) were then taken to an oven which facilitates evaporating of the solvent and the pure oil was obtained. The procedure was repeated nine times for the remaining 900g seed samples and the readings recorded.

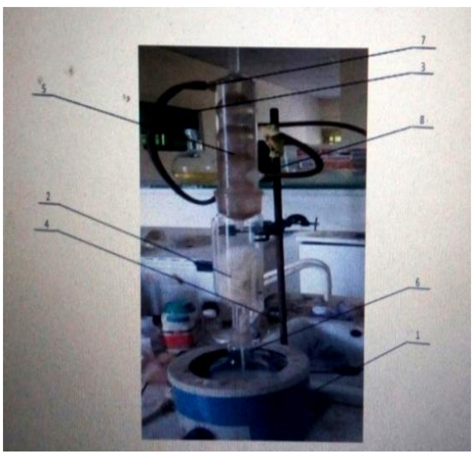

Figure 3. Soxhlet Extractor. 1: Heating Mantel, 2: Thimble, 3: Hose, 4: Tripod stand, 5: Condenser, 6: Distillation Flask, 7: Siphon Top, 8: Siphon Exit

2.2.2. Biodiesel Production Using Alkali Catalyzed Transesterification Method

The aim of this experiment was to synthesize biodiesel from the oil extracted according to the following procedure. One hundred (100) ml of the oil was measured and poured into a 250 ml conical flask and heated to a temperature of 50℃ using a water bath. A solution of sodium methoxide was prepared in a 150ml beaker using 0.5g of NaOH pellet and 30ml of methanol. The sodium methoxide solution produced was then poured gently into the warm oil and stirred vigorously for about 90 minutes using a magnetic stirrer. The mixture was then poured in a separating funnel and allowed to settle for about 24 hours. After settling, the upper layer (biodiesel) was decanted into a separate beaker while the lower layer which consists of glycerol and soap were collected from the bottom of the funnel. The decanted biodiesel was washed with warm water of about 45℃ in order to eliminate soluble methanol, excess catalyst and other impurities. The washing process left the biodiesel looking a bit cloudy which indicated the presence of moisture. The biodiesel was heated slowly to a temperature slightly above 105℃ in the oven until all moisture present evaporated. The procedure was repeated three times for the remaining oil samples and the readings recorded.

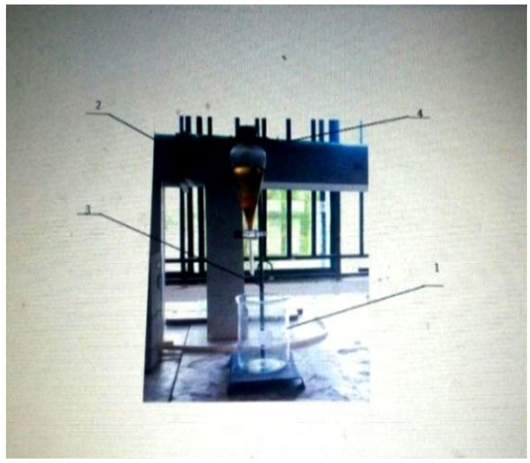

Figure 4. Biodiesel Separator. 1: Separating funnel, 2: Tripod stand, 3: clamp, 4: Beaker

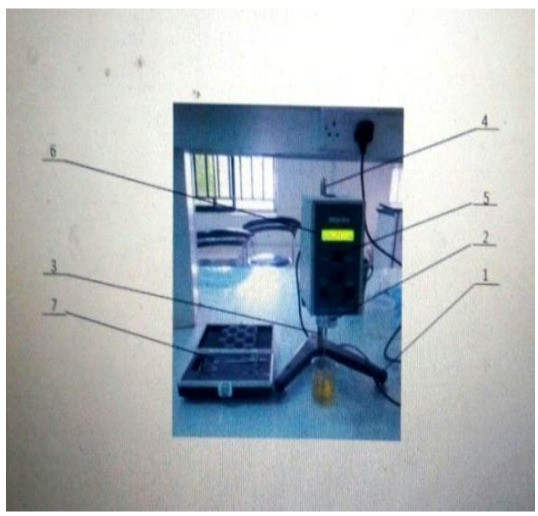

Figure 5. Brookfield Viscometer. 1: Guard Legs, 2: Spindle, 3: Extension Shaft, 4: Clutch level, 5: Switch, 6: Screen, 7: Extension Shaft Box

2.2.3. Analysis of Fuel Properties

The fuel properties of the biodiesel sample such as iodine value (IV), saponification value (SV), peroxide value (PV), acid value (AV) and density at 15℃ were determined according to Association of Official Analytical Chemists (AOAC) official method. The kinematic viscosity was determined at 40℃ using a Brookfield Viscometer as shown in figure 5 according to the American Society for Testing and Materials (ASTM D445), while the higher heating value was determined according to ASTM D7042 using Bomb calorimeter as shown in figure 6, while the cetane number was obtained empirically according to [24].

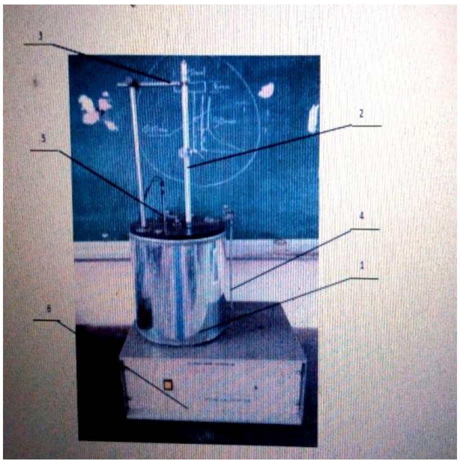

Figure 6. Bomb Calorimeter. 1: Calorimeter Vessel, 2: Beckman Thermometer, 3: Thermometer Clamp, 4: Stirrer Drive, 5: Charged bomb, 6: Firing Terminals

3. Results and Discussion

3.1. Oil Extracted and Biodiesel Produced from *Balanites aegyptiaca*

Balanites aegyptiaca seed kernel (1.0 kg) obtained from about 12 kg of its fruits collected yield an average of 396 g (426 ml) oil using soxhlet extractor. The extraction efficiency indicates that the extractor is capable of extracting about 88% of the available oil as presented in Table 1.

Table 1. Average oil Yield and Extraction Efficiency

Weight of seed sample (kg)	Theoretical oil content (g/kg)	Oil yield (g/kg)	Extraction efficiency (%)
1	450	396	88

The oil after being trans-esterified with 119 g (128 ml) sodium methoxide solution produced 426 g (458 ml) biodiesel and 82 g (88 ml) glycerol, translated to give 82.7% biodiesel yield, 15.9% glycerol with 1.4% stir loss as presented in Table 2. This shows effectiveness of alkali catalyzed transesterification method in producing biodiesel from the oil. Such that, single tonne of *Balanites aegyptiaca* seed kernel could produce 426kg (458 liters) biodiesel and 82 kg (88 liters) glycerol. [25] reported 688 liters biodiesel and 86 liters glycerol for Jatropha using methanol and sodium hydroxide as catalyst during the transesterification process, which is 33% higher than the result obtained in current study for the biodiesel.

The result also shows proximity with 333kg (400 liters) biodiesel and 40kg glycerol reported by [26] for Rapeseed using methanol and potassium hydroxide as catalyst during the biodiesel production process. *Balanites aegyptiaca* fruit yield per tree per year is about 72kg [27]. It gives on average 7.2kg seed kernel capable of producing about 3kg (3.3 liters) biodiesel and 590g (634ml) glycerol using the alkali catalyzed transesterification method. The biodiesel yield is 27% higher than 2.4 liters biodiesel and 300ml glycerol reported by [28] for a single tree of Jatropha. The variation in the biodiesel yield might be due to differences in oil content and the seed yield per tree. The by-product (Glycerol) in more sophisticated operations could be distilled to higher purity and sold into the cosmetic and pharmaceutical markets.

Table 2. Average Biodiesel Yield

Weight of oil Sample (g)	Weight of Methoxide Solution (g)	Biodiesel yield (g/kg)	Glycerol Yield (g/kg)
396	119	426	82

3.2. Fuel Properties of *Balanites aegyptiaca* Biodiesel

The results in Table 3 show average fuel properties of *Balanites aegyptiaca* biodiesel. The acid value is an important factor in evaluating the quality of biodiesel as it measures the amount of acids present in the fuel (hydro peroxide in biodiesel that further oxidized in to acids). The *Balanites aegyptiaca* biodiesel acid value was determined to be 0.11 mgKOH/g as presented in Table 3. The result showed appreciable consistency with the ASTM and EN standards. Similar results have also been reported by [29] for Peanut (0.3 mgKOH/g), Palm kernel (0.26 mgKOH/g) and Moringa biodiesel (0.18 mgKOH/g). The small variations in acid value could be due to the variation in composition, Production procedures and conditions.

Peroxide value measure of the quantity of oxygenated fatty compounds in the biodiesel. These oxygenated fatty compounds are inherently unstable and more often marks the beginning of oxidative degradation in biodiesel. The average peroxide value was 1.4 mEq/kg determined for the *Balanites aegyptiaca* biodiesel sample as presented in Table 3. Although, there were no specification for this parameter in the biodiesel specification standards, but the result is quite impressive when compared with 5.0 mEq/kg for Jatropha and *Peanut* methyl ester reported by [30] and [31]. This indicates a relatively good quality of biodiesel since high peroxide value in biodiesel is an indication of early oxidation.

Kinematic Viscosity is a very important property since it directly affects combustion of the fuel in the engine. Higher viscosity fuel flows with difficulty while fuels with lower viscosity flow more easily. The quality of spray on injection is also attributed to the viscosity of the fuel. Current study shows that the kinematic viscosity of the biodiesel at 40℃ is 4.7 mm^2/s. The recorded value as presented in Table 3 was within the minimum ASTM and EN recommended range whilst showing proximity to 4.3mm^2/s, 5.7mm^2/s, and 4.2 mm^2/s for Neem, Jatropha and Rapeseed biodiesel respectively [32] and [33]. The recorded value from current study shows higher fuel injection spray penetration property than that of Jatropha biodiesel.

The iodine value refers to an index of the amount of double bonds in biodiesel which quantifies the degree of unsaturation of the biodiesel. The iodine value of biodiesel sample obtained from current study was 68.53 I_2/100g as presented in Table 3, which is in conformance with the specified standard and in agreement with [34] who reported 84 I_2/100g, 83I_2/100g, 59 I_2/100g and 132 I_2/100g for Jatropha, Neem, Palm kernel and Rapeseed biodiesel respectively. The results confirm that iodine value of biodiesel purely depends on the source from which biodiesel is produced.

Table 3. Average Fuel Properties of *Balanites aegyptiaca* Biodiesel

Fuel Properties	Units	Biodiesel		
		Current study	ASTM D6751	EN 14214
Kinematic viscosity at 40°C	mm^2/s	4.7	1.9-6.0	3.5-5.0
Acid value	mgKOH/g	0.11	<0.8	<0.5
Peroxide value	(mEq/kg)	1.4	-	-
Saponification value	mgKOH/g	216	_	_
Iodine value	gI_2/100g	68.53	115 max	120 max
Cetane number	-	50.42	47 min	51.0
Densityat 15°C	kg/m^3	886.79	875-900	860-900
Calorific value	MJ/kg	37.5	42	-

Density is an important design parameter for diesel fuel injection system. The density from current study (887 kg/m^3) as presented in Table 3 was higher compared to that of petro diesel (850 kg/m^3), but lie within ASTM standard (860-900 kg/m^3). Biodiesel density is usually higher than that of fossil diesel fuel as reported in the literature [35,36] which could be attributed to the higher molecular weight of triglyceride molecules present in biodiesel.

Calorific value (higher heating value) measures the amount of heat energy released by the combustion of a unit value of fuel. The calorific value (37.5 MJ/kg) recorded from current study as presented in Table 3 is below the ASTM standard (42 MJ/kg). The result shows quantitative agreement with 39.2 MJ/kg and 35.2 MJ/kg reported by [37] and [38] for Jatropha and *Azadirachta indica* biodiesel respectively. The result is also lower than 45 MJ/kg for diesel which is in agreement with the conclusion drawn by [39] that calorific value of methyl esters appeared to be 12.7–14.7% lower than that of petro-diesel. Low calorific value could be due the difference in composition or the presence of oxygen in the molecular structure of the biodiesel.

Cetane number predicts the ignition delay quality for fuels. Current study as presented in Table 3 revealed that the biodiesel displayed excellent cetane number (50.42) which appeared to be higher than 46 for petro-diesel. The result also shows quantitative proximity with 53 and 54 reported by [40] for Jatropha and Rapeseed biodiesel respectively. This is consistent with the conclusion drawn by [41] that biodiesels have higher cetane numbers than petro-diesel due to their oxygen content and the presence of fatty acid.

The induction period, which determines the oxidation stability as well as the extent of deterioration of biodiesel in storage, was not determined due to instrumental constraint.

4. Conclusions

The industrial utilization of *Balanites aegyptiaca* oil for the production of biodiesel is favorable because of its oil yield capacity from the plant and its limitation for utilization as edible oil. The promising plant having oil yield of 396 g/kg (42%) with 88% extraction efficiency revealed high oil yield, and fact that the soxhlet extractor could extract about 88% of the available oil present in the seed. The oil having biodiesel yield of about 82.7% shows the effectiveness of alkali catalyzed transesterification method in synthesizing biodiesel from the plant oil, its prospect as better alternative raw material for biodiesel production, and promise for local farmers in dryland areas.

The *Balanites aegyptiaca* biodiesel having kinematic viscosity of 4.7 mm^2/s, calorific value of 37.5 MJ/kg, acid value of 0.11 mgKOH/g, peroxide value of 1.4mEq/kg, iodine number of 68.53 gI_2/100g, saponification number of 216 mgKOH/g, density of 886.79 kg/m^3 and cetane number of 50.42 possessed biodiesel fuel properties as the fuel properties are proper in respect of ASTM D 6751 and EN 14214 specification standard, except its higher heating value. The study revealed that the biodiesel shows good fuel properties. Thereby, *Balanites aegyptiaca* is a potential feedstock for the production of biodiesel which can be used as an alternative energy carrier in the dryland areas of Nigeria. Development of the technology for harnessing the potentials in *Balanites aegyptiaca* will certainly contribute to the energy security of this vulnerable region. In addition, a cradle-to-grave analysis of the use of *Balanites aegyptiaca* biodiesel, as an energy carrier, is necessary to ensure its environmental, social and economic sustainability.

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