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An Investigation into the Fuel Properties of Ackee Apple (*Blighia sapida*) Seeds Oil

Adeosun, Y.M. [a], Adeoti, O [a] and Oyedele, O.A. [a*]

[a] *Department of Agricultural and Bio-Environmental Engineering, The Federal Polytechnic, Ado-Ekiti, Ekiti State, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Research interests in biofuel in Nigeria are primarily driven by the Nigerian Biofuel Policy and Incentives of 2007. Palm oil, one of the agricultural produce suggested for biodiesel production in Nigeria, has food and industry value. Therefore, there is a need to investigate crops/plants that are food and industry neutral. The fuel properties of ackee apple seeds oil were investigated in this study. Using standard test methods, the results revealed that the average density of the ackee apple seeds oil was 789.3 ± 0.12 kg/m3 at 15 0C and the average kinematic viscosity was 4.73 ± 0.12 mm2/s at 40 0C. Compared with those of petroleum-based diesel fuels, the density of the ackee apple seeds oil was slightly lower, while the kinematic viscosity was slightly higher. While ackee apple seeds have appreciable amount of oil (average oil yield was 42.96 ± 0.12 %), its use in the raw form in diesel engines is limited. For ackee apple seeds oil to serve as an alternative fuel in diesel engines, further investigations are needed beyond these initial results.

**Corresponding author: Email: oyedele_oa@fedpolyado.edu.ng;*

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Keywords: Fuel property; ackee apple seeds oil; density; kinematic viscosity; oil yield.

1. INTRODUCTION

Worldwide multiple factors drive biofuel research. These include [1-5] a) crude oil price shocks, b) environmental concerns, c) availability of spent vegetable oils, d) fuel security, and e) decreasing crude oil reserves. In the case of Nigeria, interests in biofuel research are primarily driven by the Nigerian Biofuel Policy and Incentives of 2007. The Policy document, which links wealth creation, energy, agriculture, and the environment together, has an initial target of 480 million litres of biodiesel production in Nigeria (at 20 per cent (%) blending ratio), to increase to 900 million litres by 2020. The suggested feedstocks include palm oil, jathropha oil, and any other oil crops as may be approved by the Biofuel Energy Commission. Oil from crops can be transesterified to biodiesel to serve as an alternative fuel for diesel engines. Although not cost free, the purpose of transesterification is to reduce the oil viscosity to a range closer to the petroleum-based diesel fuels. While palm oil has food and industry value in Nigeria, the Policy document has remained silent on Ackee apple seeds despite its availability, food and industry neutrality. This has provided both the motivation and the justification for this study. The initial assessment made in this study aims to understand and explain whether oil from ackee apple seeds can be used neat in diesel engines.

Ackee (*Blighia sapida*, Koenig), belonging to the family, Sapindaceaea, is an evergreen perennial herbaceous plant, which grows to a height between 7 and 25 metres (m) [4]. The plant is native to the Guinean forests of West Africa [6,7]. When ripe, the ackee apple fruit splits to expose fleshly cream coloured pulps (called arils) attached to shiny black oblong seeds [8]. The ripe ackee apple arils are edible and can be eaten fresh, dried, fried, boiled, roasted or made into a sauce or soup [6, 8]. The immature or unripe arils of ackee apple can be toxic [9, 10], and its consumption can result into vomiting, drowsiness, coma, or even death [11,12]. The pod containing both the arils and the seeds is pear- or oval-shaped and opens spontaneously (or self-split) into three fragments when ripe and can contain three or more black seeds attached to cream-coloured arils [10]. The arils are the cream coloured edible part with a large black seed attached to the end of each aril [13].

After consuming the arils, the seeds are usually thrown away or discarded [6. As measured by Omobuwajo et al [14], the ackee apple seeds can have an average moisture content of 9.88 % (wet basis), length, width and thickness of 24.3, 19.7 and 12.9 mm, respectively, mass of 2.8 grammes (g) and true density of 888.73 kg/m^3. [15 also reported an average seed mass between 2 and 4.55 ± 0.20 g, whole fruit mass between 30 and 38.98 ± 0.13 g, and fresh aril mass between 3.66 and 4.41 ± 0.52 g [15]. According to Orhevba et al [16], each fruit can weigh between 0.1 and 0.2 kg. Ackee can be propagated by seed, use of cuttings or by grafting [17]. Being rich in potash, the seed oil is used in soap-making and has potential application in the paints and varnish industries [14], can be useful as a low-cost tablet/pharmaceutical lubricant [17], and can be suitable for bioresin production [17]. Besides this, the fruits, capsules, roots, bark, leaves and seeds have some important applications in traditional medicine [16-19,6]. Unlike in Jamaica where it fruits twice a year [7], the plant fruits once a year in Nigeria between May and August. Pod or fruit population on mature trees can be up to 400 or more. Ackee apple tree population in Ekiti State can be up to 6,000 or more.

Being a poorly researched plant in terms of its seeds oil fuel properties, this study estimates the oil yield of ackee apple seeds and determines some physicochemical properties of the seeds oil relevant to evaluating its fuel properties. According to Alptekinet al [20], density and kinematic viscosity are two important properties for evaluating the suitability of fuels for diesel engines. These are the two fuel properties measured in this study.

2. MATERIALS AND METHODS

2.1 Sample Sourcing and Preparation

Ripe and mature ackee apple fruits were harvested from the trees between the months of September and October 2022 within Ekiti State. The seeds were manually detached from the arils, peeled, crushed, dried (in a solar tent dryer), milled manually, screened (using a sieve, 0.5 mm), and stored in nylon bags against moisture migration for: a) post-drying moisture content (MC) determination, b) oil yield determination, and c) the extraction of oil for physicochemical analysis. Seeds from freshly harvested fruits were peeled, crushed and prepared for the determination of seeds initial MC (in wet basis (w.b)). Also, from the freshly harvested fruits (containing arils and seeds), samples were obtained for physical characteristics determination.

2.2 Physical Characteristics

Using appropriate tools and equipment (vernier calliper, digital weighing balance, model: XY2000C), the mass of the freshly harvested ackee apple fruits, arils + seeds, and seeds were measured. Also measured were the ratio of seed coat to kernel, and seeds true density.

2.3 Moisture Content Determination

Pre- and post-drying seeds moisture contents (in wet basis) were determined. 5 g of crushed ackee apple seeds were dried in an air oven at 65 ^{0}C to constant weight. The $MC_{wet\ basis}$ was evaluated according to Equation 1.

$$MC_{wet\ basis} = \frac{\beta - \gamma}{\beta} \times 100\ (\%) \qquad (1)$$

Where, β = mass of sample before oven drying, kg, and γ = mass of sample after oven drying, kg

2.4 Oil Yield Determination

The soxhlet extraction technique, using n-hexane as the solvent, was used. 30 g sample of crushed, dried ackee apple seeds was fed into the apparatus, heated at a temperature of 100 ^{0}C, and the process time was 8 hours. The oil obtained was re-heated (or dried) in a dish to drive out any remnant of n-hexane. The oil yield was calculated using Equation 2.

$$\text{Oil yield}\ (\%) = \frac{\varepsilon}{\delta} \times 100 \qquad (2)$$

Where, ε = mass of oil obtained, kg, and δ = mass of sample fed, kg

2.5 Physicochemical Analysis

The soxhlet apparatus was further used to extract more oil from the crushed, dried seeds. The oil obtained was dried, made ready for the physicochemical analysis: a) density, and b) kinematic viscosity. The measurements were carried out using ASTM D6751 and EN 14214 standard test methods. Both density and kinematic viscosity are temperature dependent.

2.6 Data Analysis

Descriptive statistical analysis (mean, standard deviation, and percentages) was conducted on the quantitative data obtained using Microsoft Excel 2013.

3. RESULTS AND DISCUSSION

3.1 Physical Characteristics

The freshly harvested ackee apple fruits had an average mass of 67.47 ± 0.15g (mean ± standard deviation) and higher than the value (between 30 to 38.98 ± 0.13 g) reported by [15 but lower than the value (0.1 to 0.2 kg) reported by Orhevba et al [16]. The fresh seeds had an average mass of 26.38 ± 0.15 g. This is higher than the value, 2.8 g, reported by Aloko et al [17], but comparable with those reported (between 2 and 4.55 ± 0.20 g) by [15. The mass of fresh arils was 26.38 ± 0.15 kg and higher than between 3.66 and 4.41 ± 0.52 g reported by Hoba et al [15]. The obtained true density of fresh ackee apple seeds was 1248.3 kg/m^3 and slightly higher than 888.73 kg/m^3 obtained by Omobuwajo et al [14]. Therefore, should ackee apple seeds oil be found useful as a fuel, data about its physical characteristics offer opportunity to quantify the average total amount of oil that is harvestable in Nigeria?

3.2 Moisture Content

The average MC (w. b) of the freshly harvested ackee apple seeds was 36.6 ± 0.15 %. Related studies have obtained 9.88 ± 0.53 % (w. b) [14 and 44.85 % (w. b.) [21]. Before oil extraction, the MC of the crushed, dried ackee apple seeds was 9.2 ± 0.12 %. This was less than the 10 % needed to satisfy the use of the soxhlet apparatus.

3.3 Oil Yield

The average oil yield was 42.96 ± 0.12 %. This result is higher than 12.5 % obtained by Aloko et al [17, 14]. 10 ± 0.72 % by [14,15]. 26 % by Omosuli [18], 23.41 % by [16] and 37.01 % from ackee arils oil by [4]. Nonetheless, the result is comparable with those obtained from other oil bearing seeds: 41.47 % for moringa seeds [21,22] and 44.0 % for cashew seeds [23], but relatively higher than those of amaranthus hydridus seeds, 13.95 % [24], mango kernel oil, 19.6 %, soya oil, 21.4 %, palm oil, 30.2 %, hemp seed oil, 32.4 % [16] and lower than that of sesame seeds, 48.0 % [25]. The obtained oil has a dark-brown colour. Variations in oil yield can be attributed to differences in the genetic formations of the plant, the level of maturity of the fruits at

Table 1. Densities and kinematic viscosities of ackee apple seeds oil and petroleum-based diesel fuels

S/No	Parameter	Ackee apple seeds oil	Petroleum-based diesel fuel*	
			S.E	N.D
a.	Density (kg/m^3) at 15 ^{0}C	789.3 ± 0.11	842.4	836.8
b.	Kinematic viscosity (mm^2/s) at 40 ^{0}C	4.73 ± 0.12	3.43	2.71

*S.E means shell extra diesel; N.D means normal diesel; Mean ± standard deviation *Obtained from 4. Anderson-Foster et al [4]*

the time of harvest, the location of the plant, the MC of the dried samples, as well as the method of oil extraction. The ackee apple seeds oil is found to contain both monounsaturated and saturated fatty acids [17].

3.4 Physicochemical Determination: Density and Kinematic Viscosity

Density is a principal fuel property for diesel engines which directly affects engine performance. As indicated in Table 1, the average density of the ackee apple seeds oil was 789.3 ± 0.12 kg/m^3 at 15 ^{0}C. This is lower than 900 kg/m^3 obtained by Aloko et al [17] and 810 kg/m^3 obtained by Orhevba et al [16]. Compared with other oil bearing seeds, the obtained density of ackee apple seeds oil is lower than those of groundnut seeds oil, 903, castor (*Ricinus communis*) seeds oil, 948, pumpkin seeds oil, 921, cashew nut seeds oil, 1160, jatroph curcas seeds oil, 895, cotton seeds oil, 847 kg/m^3 [26], rosigold mango kernel seeds oil, 874, palm oil, 931, hemp seeds oil, 893, soya bean oil, 908, Orhevba et al [16] and almond seeds oil, 910 kg/m^3, but slightly higher than that of African star apple seeds oil (*Chrysophyllum alibidum*), 711 kg/m^3 [26]. To serve as an alternative to petroleum-based diesel fuels, the density is expected to be within the range of 836 and 842 kg/m^3 (Table 1). However, the obtained value for ackee apple seeds oil was lower, suggesting that the oil was lighter than those of petroleum-based diesel fuels. The reason for this remains unknown, although the properties of the feedstock may be an influencing factor. For lighter oils, more oil may be needed to achieve the same engine output power compared with petroleum-based diesel fuels. As noted by Anderson-Foster et al [4], since diesel fuel injection systems measure the fuel by volume, any changes in fuel density may affect engine output power due to the different mass of fuel injected.

Another important fuel property for diesel engines is the fuel kinematic viscosity. This property refers to the resistance to flow of a fluid, and may affect the atomization quality, size of fuel droplets and penetration in diesel engines [4. As shown in Table 1, the ackee apple seeds oil had an average kinematic viscosity of 4.73 ± 0.12 mm^2/s, slightly higher than those of petroleum-based diesel fuels (see Table 1). The tendency of a fuel to cause atomisation and other operational problems including engine deposits is higher with increase in viscosity [26]. However, compared with other plant-based seed oils; coconut seeds oil, 43.30 [27], : Cotton seed oil, 44.0 [28], and jatroph seeds oil, 17.0 [30, soy bean seeds oil (*Glycine max*), 17.99, cotton seeds oil, 74.00, African pear (*Dacryodes edulis*) seeds oil, 17.27, pumpkin seeds oil (*Telfairia occidentalis*), 32.22, Jatroph curcas seeds oil (*Jatropha curcas* L.), 41.40, and almond seeds oil (*Prunus amygdalus*), 302.39 mm^2/s [29] that of ackee apple seeds was relatively lower, meaning less viscous. In practice, high viscous fuels, especially during cold conditions, may raise the energy needed to pump the fuel and wear fuel pump and injector elements [4]. However, to keep the viscosity of the ackee apple seeds oil within the band of petroleum-based diesel fuels would require additional processing, for example, transesterification [30]. On the other hand, straining the impurities in the oil may also help to lower the viscosity of the oil.

4. CONCLUSIONS

This study has investigated the fuel properties of ackee apple seeds oil from two important diesel engines fuel properties: density and kinematic viscosity. For diesel engines these two fuel properties are crucial. While ackee apple seeds have appreciable amount of oil, its use in the raw form in diesel engines is limited. The oil kinematic viscosity was slightly higher than those of the petroleum-based diesel fuels. For ackee apple seeds oil to serve as an alternative to petroleum-based diesel fuels, further investigations are required beyond these initial results. Additionally, future studies may need to look at the: a) pour point (^{o}C), b) cetane index, and c) flash point (^oC) of the ackee apple seeds oil and compare with those of the petroleum-based diesel fuels.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

The authors whose names are listed below certify that they have no affiliations with or involvement in any organization or entity with any financial interest such as educational grants, membership, employment, consultancies, stock ownership, or other equity interest in the subject matter or materials discussed in this manuscript.

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