Journal of Basics and Applied Sciences Research (JOBASR)
ISSN (print): 3026-9091, ISSN (online): 1597-9962
Volume 3(6) November 2025
DOI: https://dx.doi.org/10.4314/jobasr.v3i6.16

Effects of Banana Peel as Additive on the Physical Properties of Transesterified Calabash Oil

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ABSTRACT
The aim of this paper is to examine the impact of adding banana peel on the physical properties of transesterified calabash oil. The morphology and elemental composition of banana peels (BP) were analyzed using Scanning Electron Microscopy (SEM) and X-ray Fluorescence (XRF), respectively. The crude calabash oil was purified and transesterified, then varying amounts of banana peel additive ranging from 0.1 wt% to 1.0 wt% at intervals of 0.1 wt% were incorporated. Physical properties such as pour point, fire point, flash point, and density were measured for the crude, purified, transesterified oil, and transesterified oil with banana peel additives. SEM analysis showed that banana peels have a mountainous, irregular, dispersed, and cloudy texture. XRF results indicated calcium as the predominant element in the banana peels with 58.21%. The pour point, flash point, fire point, and density were all found to decreased after purification and transesterification, both with and without the banana peel additive, but the values stabilized at an additive concentration of 0.5 wt% with values; -8°C, 158°C, 176°C, and 870 kg/m³, respectively. The findings demonstrate that adding banana peel enhances the physical properties of the biodiesel, with 0.5 wt% identified as the optimal concentration. This shows that banana peels are a promising additive that can be used for improving the quality of calabash oil-based biodiesel which in turns will help in reducing the environmental pollution and will contributes to the economic development of a nation principles as it transforms agricultural residues into value-added materials

Keywords:
Banana peels,
Calabash Oil,
Density,
Fire Point,
Flash Point,
Pour Point

INTRODUCTION

Fossil fuels remain the dominant global energy source (Durumin-Iya and Ismail, 2024). However, their extensive use releases harmful gases into the atmosphere, contributing to environmental degradation. This has created an urgent need for renewable and sustainable alternative fuels such as solar energy, geothermal, hydropower, biodiesel among others to replace conventional fossil fuels (Ismail *et al.*, 2022; Babatunde et al., 2025).

Biodiesel has emerged as a promising renewable substitute for fossil fuels due to its sustainability, biodegradability, and environmental friendliness. It shares similar properties with petroleum-based diesel and plays a crucial role in reducing carbon emissions and overall environmental impact (Cruz *et al.*, 2025).

Biodiesel is produced via the transesterification process, where vegetable oils (such as peanut, clove, sesame, and palm kernel, Jatropha, castor, calabash, neem etc) or animal fats react with alcohol in the presence of a catalyst to form esters (Gebremanian and Marchetti, 2018; Aji *et al.*, 2024). However, animal fats are rich in saturated fatty acids but tend to be solid at room temperature, often complicate the production process and increase costs of biodiesel. As a result, vegetable oils are generally considered more suitable and have gained greater research and industrial attention as biodiesel feedstock (Ismail *et al.*, 2022).

Calabash seeds (*Lagenaria siceraria*) come from a climbing plant commonly found across regions of Asia and Africa (Elendu *et al.*, 2024). The plant can grow rapidly, reaching lengths of up to 9 meters,

How to cite this article: Auwalu I. A., Sambo H. S., Ismail U. I., Inuwa M. B., Durumin-IYA S. G., & Zakari M. M. (2025). Effects Of Banana Peel as Additive on The Physical Properties of Transesterified Calabash Oil. *Journal of Basics and Applied Sciences Research*, *3*(6), 152-158. https://dx.doi.org/10.4314/jobasr.v3i6.16

and produces seeds that have a sweet taste and a high oil content approximately 38–40% (Abubakar *et al.,* 2025). Calabash plants begin to bear fruit about three months after planting, with each fruit typically containing between 80 and 100 seeds, depending on its size (Awulu *et al.,* 2015).

The characteristics of biodiesel can differ considerably based on its chemical composition and fatty acid profile, both of which influence engine performance and exhaust emissions (Uba *et al.,* 2024). Consequently, evaluating the physical properties of biodiesel such as pour point, flash point, fire point, and density is crucial for assessing its performance (Gwadabe *et al.,* 2024).

The pour point represents the temperature at which sufficient wax crystals form to cause the fuel to gel, marking the lowest temperature at which the fuel remains capable of flowing (Atabani *et al.,* 2012). Studies by Taiwo *et al.,* (2020) and Onukwuli *et al.,* (2021) reported pour points of 8.3°C and 4°C, respectively, for transesterified neem oil. Likewise, Nura *et al.,* (2023) observed that the pour point of transesterified calabash oil decreased from 10°C to 6°C following purification, transesterification, and the addition of fly ash.

The flash point is the temperature at which a fuel produces enough vapor to ignite when exposed to a flame or spark, and it generally decreases as the fuel's volatility increases (Atabani et *al.,* 2012). Banu *et al.,* (2018) and Sekhar *et al.,* (2019) reported flash points of 147°C and 128°C, respectively, for neem oil biodiesel, while Awulu *et al.,* (2015) recorded a value of 116°C for calabash oil biodiesel.

The fire point is defined as the minimum temperature at which a fuel's vapors burn continuously for at least five seconds once ignited (Babu and Anand, 2019). Dash *et al.,* (2021) found the fire point of neem oil biodiesel to be 173°C, while Awulu *et al.,* (2015) reported a value of 138°C for calabash oil biodiesel.

Density, which expresses the ratio of a substance's mass to its volume (in g/L or kg/m³), is another vital physical property (Belewu *et al.,* 2019). Awulu *et al.,* (2015) recorded a density of 920 kg/m³ for calabash oil biodiesel, whereas Nura *et al.,* (2023) found that the density of transesterified calabash oil with fly ash additive decreased from 875 kg/m³ to 861 kg/m³ after purification and transesterification. However calabash oil was successfully yielded high biodiesel content of about 78% (Mukhtar *et al.,* 2014) and physical properties that are within ASTM standard but it has to be improved using additive so that it can be in comparable with conventional diesel (Nura *et al.,* 2023).

Several solid materials and fruit base additive such as fly ash, calcium oxide, silicon oxide, eggshell, crab shell, and banana peel have been employed as biodiesel additives to improve the lubricity of methyl esters, yet no similar assessment exists for calabash oil methyl ester using banana peels. (Zakari *et al.,* 2024).

Banana peel (*Musa sapientum*) ash contains various minerals, including phosphorus, iron, calcium, magnesium, sodium, zinc, copper, potassium, and manganese (Hikal *et al.,* 2022). Betiku *et al.,* (2016) analyzed the mineral composition of banana peel ash and found it to contain K (51.34%), Na (37.20%), Mg (7.60%), Ca (31.20%), Cu (20.10%), Fe (1.30%), Zn (2.90%), and Pb (2.80%). Meriatna *et al.,* 2023 shows that banana peel contains lignin, cellulose, and polyphenols, which may act as natural antioxidants or friction modifiers when incorporated into methyl esters. While banana peel has been studied as a bio adsorbent and feedstock for bioethanol (Tarigan, *et al*., 2023), its potential as an additive in transesterified calabash oil remains largely unexplored, particularly regarding its influence on the physical properties of transesterified calabash oil (Nura *et al.,* 2023). Therefore, the aim of this research is to investigate the effects of banana peel as additive on the physical characteristics of transesterified calabash oil biodiesel with emphasis on pour point, fire point, flash point and density. This study will contributes to circular economy principles by transforming agricultural residues into value-added materials.

MATERIALS AND METHODS

Chemicals and Equipment

The chemicals, reagent and materials used in carrying out this research were; crude calabash oil, sodium hydroxide (NaOH), banana peel, methanol, 64% citric acid (C6H8O7, purity: 99.7%), Silicon reagent, activated carbon, acetone and distilled water (H_2O).

The equipment used in carrying out this research were: magnetic stirrer with thermostatically controlled rotary hot plate (IKA C-MAG HS10), thermometer, measuring cylinder, Digital weight balance (AND model GT2000 EC), beakers, conical flask, 24 cm filter paper, funnel, Digital stop watch, sampling bottles, spatula, Scanning Electron Microscope Machine model PHENOM PRO X MVE01570775 and ARL QUANT'X EDXRF Analyzer (S/N 9952120) machine.

Banana Peel Powder Preparation

The waste banana peels were collected from the market and washed with water five times and then cut into pieces. The banana peels were dried in an oven at 120 °C overnight and then crushed and sieved using a 2mm sieve (Hikal *et al.,* 2022). The waste banana peel powder was then subjected to characterization.

Scanning Electron Microscope (SEM) Analysis of Banana Peels

The surface morphology of banana peels was examined using a multipurpose Scanning Electron Microscope (SEM), model PHENOM PRO X MVE01570775. A 1g sample of banana peel was subjected to a focused electron beam. As the electrons interacted with the atoms in the sample, they generated various signals that revealed the peel's microstructural features. The SEM scanned the sample in a raster pattern, and the detected signal intensities were mapped according to beam position to produce detailed images of the banana peel surface (Zakari *et al.,* 2024).

X-ray Fluorescence (XRF) Analysis of Banana Peels

The elemental composition of the banana peels was determined using an ARL QUANT'X EDXRF Analyzer (S/N 9952120). During the analysis, a 1g sample was exposed to X-rays, causing atomic excitation and the emission of characteristic high-energy radiation. These emitted X-rays were captured, processed, and translated into elemental concentration data, providing a comprehensive profile of the chemical constituents of the banana peels (Durumin-Iya *et al.,* 2024).

Purification of Calabash Crude oil

The purification of crude calabash oil was carried out through a series of treatment steps. Initially, 200 ml of the crude oil was heated on a hot magnetic stirrer, after which 0.5g of citric acid dissolved in 1.5 ml of distilled water was added. The mixture was continuously heated and stirred for 15 minutes. Subsequently, 4 ml of an 8% sodium hydroxide (NaOH) solution was introduced, and the process was maintained for another 15 minutes. The treated mixture was then transferred into a vacuum oven for 30 minutes to remove residual moisture. Afterward, 2g of a silicone reagent was added, and the mixture was again heated and stirred for 30 minutes. Finally, 4g of activated carbon was introduced per 100 ml of oil, followed by heating and stirring for 30 minutes. The resulting mixture was separated using a separating funnel to obtain purified calabash oil (Abubakar *et al.,* 2025).

Transesterification of Calabash Oil

A 500 ml of calabash oil was heated up to 70ºC in a round bottom flask to drive off moisture and stirred vigorously. A methanol of 99.5 % purity having density of 0.791 g/cm³ is used. 2.5 gram of catalyst NaOH is dissolved in Methanol in bi molar ratio, in a separate vessel and was poured into round bottom flask while stirring the mixture continuously. The mixture was maintained at atmospheric pressure and 60°C for 60 minutes. After completion of transesterification process, the mixture is allowed to settle under gravity for 24 hours in a separating funnel. After cooling, two layers were formed within the separating funnel; the upper layer (biodiesel) and the lower layer (triglyceride fatty acids) (Abubakar *et al.,* 2025).

Nanofluid Preparation Using Banana Peels

Banana peel powder was dispersed in transesterified calabash oil to form nanofluids of varying concentrations (0.1–1.0 wt%). Specifically, 0.1wt% to 1.0wt% of banana peel nanoparticles were added to 10g of the transesterified oil. Each sample was stirred continuously for 2 hours using a magnetic stirrer before being subjected to subsequent analyses (Musa *et al.,* 2022).

Measurement of Pour Point

The pour point of the crude, purified, transesterified, and banana peel-based nanofluid samples was determined using ASTM method where by each oil sample was cooled in an ice bath at a rate of 3°C per minute. The lowest temperature at which the sample exhibited flow within 5 seconds upon tilting was recorded as the pour point (Nura *et al.,* 2023).

Measurement of Flash Point and Fire Point

Flash and fire points of the oil samples were measured separately via ASTM method. Each oil sample was placed in an aluminum container and heated using a Bunsen burner at a rate of 10°C per minute. A thermometer was inserted into the sample, and at every 5°C increase, a small flame was passed over the oil surface. The temperature at which a flash appeared was recorded as the flash point. Heating continued beyond this temperature until a flame sustained for at least 5 seconds over the oil surface—this was recorded as the fire point (Awulu *et al.,* 2015).

Measurement of Density

The density of crude calabash oil has been measured by using this relation 1 (Nura *et al.,* 2023).

$$\text{Density of crude calabash oil} = \frac{\text{Mass of crude calabash oil}}{\text{Volume of crude calabash oil}} \qquad (1)$$

The mass of crude calabash oil was measured using digital balance machine and its volume using graduated cylinder. The same method was applied in measuring the density of purified, trans-esterified and nano fluid with banana peels.

RESULTS AND DISCUSSION

SEM of Banana Peels

Figures 1shows the SEM of the banana peels at 500x 100μm and 15kV which indicates the presence of mountainous, irregular, dispersed and cloudy structure. In a research conducted by Abubakar *et al.,* (2025) similar result was obtained.

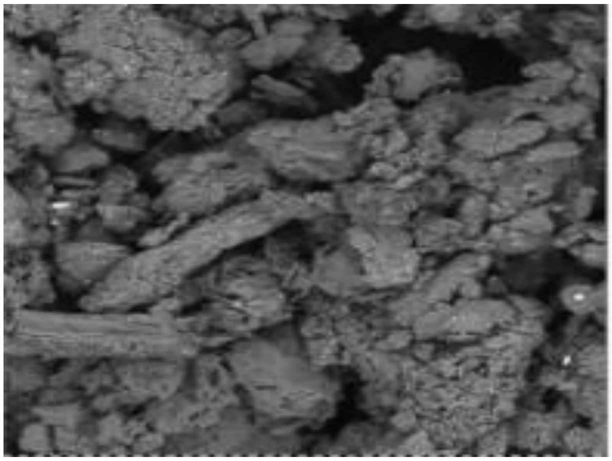

Figure 1: SEM of banana peel at 500x magnifications.

XRF of Banana Peels

Table 1: XRF of banana peels in terms of elemental percentage concentration.

Elemental concentration

S/NO	Elements	Percentage Concentration (%)
1	Ca	58.21
2	K	23.22
3	O	10.62
4	Cl	3.90
5	Fe	2.13
6	Zn	0.74
7	P	0.34
8	Na	0.27
9	S	0.15
10	Mg	0.14
11	Rb	0.13
12	Others	0.03
13	Lost of ignition	0.12

Table 1 shows that calcium (Ca) constitutes 58.21%, potassium (K) 23.22%, oxygen (O) 10.63%, chlorine (Cl) 3.90%, iron (Fe) 2.13%, zinc (Zn) 0.74%, phosphorus (P) 0.34%, sodium (Na) 0.27%, sulfur (S) 0.15%, magnesium (Mg) 0.14%, rubidium (Rb) 0.13%, while other elements make up 0.03%, and the loss on ignition accounts for 0.12%. The high concentrations of Ca and K suggest that these are the dominant elements present in banana peels. This composition implies that banana peels can serve as effective biodiesel additives with minimal environmental impact. Similar results were obtained by Hikal *et al.*, (2022); Meriatna, *et al*., (2023) and Abubakar *et al.*, (2025).

Pour Point, Flash Point and Fire Point of the Samples

Table 2 shows the Pour point, Flash Point and Fire Point of crude calabash oil, purified calabash oil, transesterified calabash oil and transesterified calabash oil with the addition of banana peels.

Table 2: Pour point, Flash Point and Fire Point of crude, purified, transesterified, and transesterified calabash oil with the addition of banana peels.

S/N	Calabash oil	Pour Point (℃)	Flash Point (℃)	Fire Point (℃)
1	Crude	5	130	148
2	Purified	4	134	152
3	Trans-esterified	2	138	156
4	Trans-esterified with (0.1w% banana peels)	-1	142	160
5	Trans-esterified with (0.2w% banana peels)	-3	146	164
6	Trans-esterified with (0.3w% banana peels)	-4	150	168
7	Trans-esterified with (0.4w% banana peels)	-6	154	172
8	Trans-esterified with (0.5w% banana peels)	-8	158	176
9	Trans-esterified with (0.6w% banana peels)	-5	153	173
10	Trans-esterified with (0.7w% banana peels)	-3	148	170
11	Trans-esterified with (0.8w% banana peels)	-1	143	167
12	Trans-esterified with (0.9w% banana peels)	3	138	164
13	Trans-esterified with (1.0w% banana peels)	5	133	161
14	**Biodiesel standard**	**-15 to 16**	**100 to 170**	**>130**

The data presented in the Table 2 show that the pour point of crude calabash oil was 5°C, while those of the purified, transesterified, and transesterified samples with the addition of banana peel (BP) at varying concentrations (0.1–1.0 wt%) were 4, 2, -1, -3, -4, -6, -8, -5, -3, -1, 3, and 5°C, respectively. It is evident that the pour point decreased after purification and continued to drop steadily following transesterification up to 0.5wt% BP this was attributed due to the reaction between the banana peels and the calabash oil. Beyond this concentration (0.6–1.0 wt% BP), the pour point fluctuated irregularly. The observed decrease is attributed to the removal of impurities during processing. This trend indicates that the pour point of calabash biodiesel is adaptable to a wide range of climatic conditions across the globe. Similar findings were reported by Awulu *et al.*, (2015), Taiwo *et al.*, (2020), Onukwuli *et al.*, (2021), and Nura *et al.*, (2023).

It can also be seen from Table 2 that the flash point values for the crude, purified, transesterified, and transesterified samples with BP additives (0.1–1.0 wt%) were 130, 134, 138, 142, 146, 150, 154, 158, 153, 148, 143, 138, and 133°C, respectively. This demonstrates a progressive increase in flash point after purification and transesterification, reaching a maximum at 0.5wt% BP, after which the value gradually declined from 0.6 wt% to 1.0 wt% BP. The enhancement at 0.5wt% BP indicates a notable improvement in the volatility characteristics of the oil which shows that it is safe for storage at a high temperature. Comparable outcomes were observed in studies by Awulu *et al.*, (2015), Banu *et al.*, (2018), Sekhar *et al.*, (2019) and Nura *et al.*, (2023)

Similarly, the fire point of the samples followed the same trend as the flash point, with values of 130, 134, 138, 142, 146, 150, 154, 158, 153, 148, 143, 138, and 133°C. This consistent pattern suggests enhanced thermal stability and improved safety of the biodiesel for handling, storage, and transport under various temperature conditions. Comparable results were also reported by Mukhtar *et al.*, (2014), Awulu *et al.*, (2015), Dash *et al.*, (2021), and Nura *et al.*, (2023).

Density of the Samples

Table 3, presents the results of the density of crude, purified, trans-esterified, and trans-esterified calabash oil with the addition of banana peels.

Table 3: Density of crude, purified, trans-esterified and trans-esterified calabash oil with the addition of banana peels

S/N	Calabash oil samples	Density (/Kg/m^3)
1	Crude	898
2	Purified	894
3	Trans-esterified	890
4	Trans-esterified with (0.1w% banana peels)	886
5	Trans-esterified with (0.2w% banana peels)	882
6	Trans-esterified with (0.3w% banana peels)	878
7	Trans-esterified with (0.4w% banana peels)	874
8	Trans-esterified with (0.5w% banana peels)	870
9	Trans-esterified with (0.6w% banana peels)	875
10	Trans-esterified with (0.7w% banana peels)	880
11	Trans-esterified with (0.8w% banana peels)	885
12	Trans-esterified with (0.9w% banana peels)	890
13	Trans-esterified with (1.0w% banana peels)	895
14	**Biodiesel Standard**	**870 to 890**

Table 3 revels that the density of the crude sample decreases after purification and further decreases following trans-esterification due to the removal of impurities presence on the crude oil sample. Consequently, the trans-esterified oil sample with the addition of 0.5wt% which has a density of 878 Kg/m^3 is the optimal choice as it falls within the ASTM standard for biodiesel. Similar results were obtained by Awulu *et al.,* (2015), Nura *et al.,* (2023) and Elendu *et al.,* (2024).

CONCLUSION

The study found that the physical properties of biodiesel produced from calabash oil specifically pour point, flash point, fire point, and density showed notable improvement after transesterification and the addition of banana peels, particularly at a concentration of 0.5 wt%. The optimized biodiesel exhibited a lowest pour point of −8 °C, a high flash point of 158 °C, a fire point of 176 °C, and a density of 870 kg/m^3. All measured values fell within the ASTM biodiesel standards, indicating that banana peels can effectively serve as a biodiesel additive when calabash oil is used as the feedstock, especially at 0.5 wt% concentration. It is recommended that other properties of biodiesel such as rheology, chemical and thermal for calabash oil and banana peels additive has to be measured so that it can be fully characterized.

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