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Harnessing local biodiversity for sustainable energy: A comparative study of *Detarium microcarpum*, *Citrullus lanatus*, and *Sclerocarya birrea* seeds oils for biodiesel production

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Abstract

This paper examines the viability of biodiesel as a sustainable alternative to diesel fuel, with a focus on the use of non-edible plant oils from Northern Nigeria. The study investigates the extraction and characterization of oils from *Detarium microcarpum*, *Citrullus lanatus*, and *Sclerocarya birrea*, assessing their physicochemical properties and suitability for biodiesel production. The research involved sourcing fruits locally, extracting oils using a Soxhlet extractor, and determining oil yield and key properties such as specific gravity, acid value, and cetane number. The biodiesel production process included pre-treatment and transesterification, with the final product undergoing characterization to meet ASTM-D standards.

The study found significant variability in the physicochemical properties of the seeds and seed oils, which influences their potential applications. *Citrullus lanatus* and *Sclerocarya birrea* showed higher oil yields and favorable properties for biodiesel production, while *Detarium microcarpum*'s high-quality oil may be better suited for specialty markets. The findings highlight Northern Nigeria's untapped potential for biodiesel production and the need for comprehensive studies on local feedstocks.

The research emphasizes the importance of comparative analyses and detailed research on the availability, viability, and cost of different feedstocks specific to Northern Nigeria. Developing a biodiesel industry could contribute to economic growth, sustainability, and energy security in the region.

Keywords: Biodiesel; Transesterification; Renewable Energy; *Detarium microcarpum*; *Citrullus lanatus*; *Sclerocarya birrea*

1. Introduction

The increasing reliance on diesel fuel has spurred research into sustainable and eco-friendly alternatives (Younis et al., 2009; Atabani et al., 2020; Mehra & Pant, 2021). Biodiesel, a biofuel derived from vegetable oils or animal fats, has properties closely resembling those of fossil diesel, making it a promising replacement. It is as a mixture of long-chain monoalkylic esters from fatty acids, sourced from renewable resources. It is produced through transesterification, reacting vegetable oil or animal fat with alcohol in the presence of a catalyst. The transesterification process involves displacing glycerol in vegetable oil with a lower molecular weight alcohol to produce fatty acid esters. The reaction is represented as:

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$$\text{Glyceride (G)} + n\text{ROH} \rightarrow \text{RCO}_2\text{R}^{!} + \text{Glycerine}$$

where ($R^{!}$) and (R) are hydrocarbon chains of the fatty acid and alcohol, respectively, and n is the number of moles of alcohol. The resulting biodiesel exhibits combustion properties akin to petro diesel, including energy content and cetane rating, but with higher purity and quality.

Despite its advantages, raw vegetable oils are unsuitable as direct diesel substitutes due to their molecular structure, viscosity, and flash point (Negm et al., 2017; Woma et al., 2019; Torres-Garcia et al., 2020). These issues lead to poor atomization and incomplete combustion, causing engine deposits. However, biodiesel, particularly when produced from seed oils, can run diesel engines without modifications due to its similar chemical and performance characteristic (Kumar & Chauhan, 2013; Suresh et al, 2018; Palani et al., 2022).

Detarium microcarpum, also known as sweet dattock, is a tree native to the drier regions of West and Central Africa, including Northern Nigeria. It can grow up to 15 meters tall and produces sweet fruits rich in carbohydrates and proteins. The seeds contain essential amino acids and are a source of oil, which includes beta-carotene, phytosterols, phospholipids, and glycolipids, with linoleic acid being the predominant fatty acid (Mariod et al, 2019). Its abundance and the presence of valuable oil components make it a promising candidate for biodiesel production. Likewise, *Citrullus lanatus* (Water Melon) is widely cultivated in Nigeria. The seeds are a rich source of edible oil, with an oil content ranging from 31-59%. This oil is suitable for biodiesel production due to its favorable properties and the seeds' high protein content (Giwa and Akanbi, 2020). The cultivation of water melon is an income-generating activity, especially for women in northern Nigeria, highlighting its economic importance and availability (Ndanitsa et al., 2021). More so, *Sclerocarya birrea*, known as Marula, is another indigenous tree to Africa, found in the Sudano-Sahelian zone, which includes Northern Nigeria. The seed oil of Marula is characterized by a high percentage of mono-unsaturated oleic acid, which is beneficial for biodiesel production. The oil's physicochemical properties, such as high saponification value and viscosity, make it a prospective oil for engine crankcase bio lubricants with anti-wear and friction reduction properties (Ejilah et al., 2012). These plants are not only readily available and abundant in Northern Nigeria, but they also offer a sustainable and economically viable source of oil for biodiesel production, which could contribute to the region's energy independence and economic development.

The production of biodiesel from local fruits and vegetable oils in Northern Nigeria has garnered attention due to the region's rich biodiversity and the pressing need for sustainable energy sources. Recent studies have highlighted the technical feasibility and environmental benefits of biodiesel production via heterogeneous acid-catalyzed esterification and transesterification (Guo et al., 2023). The acid-catalyzed method is particularly advantageous when utilizing feedstocks with high free fatty acid content, such as non-edible oils from local fruits and vegetables. This method is less sensitive to the purity of reactants, making it suitable for lower-quality oils that would otherwise necessitate extensive pre-treatment (Su Fang & Guo YiHang, 2014). Despite its slower reaction rate compared to alkali-catalyzed processes, the acid-catalyzed approach is gaining traction due to its ability to process a wider range of feedstocks with minimal pre-processing (Vasić et al., 2020).

On the other hand, alkali-catalyzed transesterification remains the most common method for biodiesel production due to its faster reaction times and higher yields under optimal conditions (Mandari & Devarai, 2022). Recent research has focused on optimizing the reaction conditions for alkali-catalyzed transesterification of various seed oils, including those available in Northern Nigeria. The optimization of parameters such as alcohol-to-oil molar ratio, catalyst concentration, and reaction time has been achieved using statistical methods like the Taguchi method, resulting in significant improvements in yield and process efficiency (Sajjad et al., 2022).

Northern Nigeria's potential for biodiesel production is largely untapped, with a variety of local fruits and vegetable oils that could serve as feedstocks. Groundnut oil, for example, is widely grown in the region and has been identified as a promising source for biodiesel production[6]. Studies like that of Bello & Agge (2012) have shown that groundnut oil can be effectively converted to biodiesel using both acid and alkali-catalyzed methods, with properties closely resembling those of diesel fuel.

The current landscape of biodiesel research in Northern Nigeria reveals a significant research gap, particularly in the comprehensive analysis of local feedstocks for biodiesel production. While there is an understanding of the general benefits of biodiesel and its potential to mitigate climate change, detailed studies on the availability, viability, and cost of different feedstocks specific to the region are lacking (Igwebuike, 2023). This gap extends to the economic viability of biodiesel production, distribution, and use within Nigeria, which remains underdeveloped.

Moreover, there is a pressing need to compare and contrast the potential of various local plants for biodiesel production. Comparative analyses are crucial as they provide insights into the efficiency, economics, and sustainability of different feedstocks (Joyce et al., 2022). Such studies can help identify the most promising crops that could lead to a more robust biodiesel industry in Northern Nigeria. The selected plants, *Detarium microcarpum*, *Citrullus lanatus*, and *Sclerocarya birrea*, are abundant in the region and could be pivotal in establishing a sustainable biofuel sector. However, without thorough comparative research, the full potential of these plants remains unrealized.

The search for renewable and sustainable energy sources has led to a growing interest in the development of biodiesel from non-edible feedstocks. Among the various non-edible plant species, *Datarium microcarpum*, *Citrullus lanatus*, and *Sclerocarya birrea* have emerged as potential candidates for biodiesel production due to their high oil content and adaptability to diverse climatic conditions (Singh et al., 2014). These plant species are not commonly used for food purposes, thereby mitigating the competition between food and fuel production.

The present study aims to investigate the extraction and characterization of oils from *Datarium microcarpum*, *Citrullus lanatus*, and *Sclerocarya birrea*, and to evaluate their suitability for biodiesel production. By conducting comparative studies on the biodiesel potential of local plants, the research will have significant impact on the advancement of the biofuel industry in Northern Nigeria, and in promoting economic growth, sustainability, and energy security in the region.

2. Material and Methods

Tallow, Watermelon and Marula fruits were sourced from a local market in Bauchi, Nigeria. The seeds were manually extracted, dried, and ground for oil extraction using a Soxhlet extractor with N-hexane and petroleum ether as solvents. The oil yield was calculated as a percentage of the weight of the oil to the weight of the sample. Physicochemical properties of the oil were determined to assess its suitability for biodiesel, including specific gravity, density, acid value, free fatty acid content, iodine value, peroxide value, saponification value, and viscosity. These properties were measured using standard laboratory procedures, such as titration and viscosity flow through a calibrated viscometer, to ensure the oil's compatibility with biodiesel standards as adopted by previous researchers (Ali & Tay, 2013; Kyari, 2008; Ogunwole, 2012; Omotoso et al., 2011; Giwa et al., 2010; Vera et al., 2005; Leadbeater & Stencel, 2006).

The biodiesel production process from the seeds oil involves pre-treatment to reduce impurities and enhance glycerine quality, followed by transesterification. Pre-treatment includes acidifying the oil with H_2SO_4 and methanol, then separating the treated oil for further drying. Transesterification was initiated by mixing sodium hydroxide with methanol to form methoxide, which was then combined with the treated oil and shaken to achieve a homogeneous mixture. After standing, the mixture was separated into biodiesel and glycerin, with the biodiesel undergoing washing and heating to remove contaminants and excess methanol. Characterization of the biodiesel was conducted to determine its flash point, fire point, cloud point, pour point, color, and cetane number, ensuring it meets ASTM-D standards. The cetane number, indicative of combustion quality, was calculated using the saponification and iodine values of the oil (Ogunwole, 2015; Nautiyal et al., 2014; Chakraborty & Baruah, 2013).

3. Results and Discussion

The results of detailed analyses conducted on the seeds and seed oils of three plant species: *Datarium microcarpum*, *Citrullus lanatus*, and *Sclerocarya birrea* are presented in tables 1, 2 and 3.

Table 1 Physicochemical Properties of Seeds

PROPERTIES	*Datarium Microcarpum*	*Citrullus lanatus*	*Sclerocarya birrea*
Moisture Content	5.81 %	5.5 %	4.14 %
Ash Content	2 %	-	-

Table 2 Physicochemical Properties of the Seeds Oil Produced

Properties	*Datarium Microcarpum*	*Citrullus lanatus*	*Sclerocarya birrea*	*ASTM Standard (Max)*
Oil yield (%)	10.25	46	46.7	N/A
Acid Value (mgKOH/g)	0.214	9.96	-	10
Iodine Value (g I/100 g)	17.36	156.1	9.56	123
Free Fatty Acid Value (mgKOH/g)	0.107	4.98	2.17	25
Protein Content (%)	36.1	-	28.52	N/A
Peroxide Value (mmol/kg)	1.62	7.5	1.28	<9
Saponification Value (mgKOH/g)	198.8	189.89	12.46	189 - 198
Relative Density	0.92	-	-	
Density (g/cm^3)	-	1.35	-	0.918 – 0.926
Specific gravity (kg/L)	-	0.923 kg/l	0.85	0.916
Viscosity (mm^2/sec)	-	1	-	35

Table 3 Fuel Properties of Biodiesel Produced From the Seeds Oil

Properties	*Datarium Microcarpum (tallow)*	*Citrullus lanatus (water melon)*	*Sclerocarya birrea (marula)*	*ASTM Standard*
Smoke point(°C)	210 °C	-	-	
Flash Point (°C)	250 °C	105 °C	166 °C	130-170
Fire Point (°C)	290 °C	123°C	-	100-170
Cloud Point (°C)	-	-2 °C	9 °C	-2 to 12
Pour Point (°C)	-	-5°C	3 °C	-15 to 10
Cetane No	-	43.1	64	47-65
Specific gravity at 30 °C (kg/L)	-	0.88	-	0.85
Density	-	0.8 g/cm^3		0.86-0.90

3.1. Physicochemical Properties of Seeds

The moisture content of seeds is a critical factor influencing their storage and stability. The moisture content for *Datarium microcarpum*, *Citrullus lanatus*, and *Sclerocarya birrea* was found to be 5.81%, 5.5%, and 4.14%, respectively. Lower moisture content is advantageous for prolonged storage as it reduces the risk of microbial growth and spoilage. Ash content provides an estimate of the total mineral content present in the seeds. In this study, only *Datarium microcarpum* had a recorded ash content of 2%. The absence of ash content data for the other two species limits direct comparison but highlights the need for further comprehensive analysis.

3.2. Physicochemical Properties of Seeds Oils

Oil yield is a significant parameter determining the economic viability of oil extraction. *Datarium microcarpum* had an oil yield of 10.25%, while both *Citrullus lanatus* and *Sclerocarya birrea* had significantly higher yields of 46% and 46.7%, respectively. These results indicate that *Citrullus lanatus* and *Sclerocarya birrea* have significantly higher oil yields compared to *Datarium microcarpum*, making them more suitable for large-scale biodiesel production.

The acid value is an indicator of the free fatty acids present in the oil, which can affect its quality and shelf life. *Datarium microcarpum* exhibited a low acid value of 0.214 mg KOH/g, indicating high oil quality. In contrast, *Citrullus lanatus* had a much higher acid value of 9.96 mg KOH/g, suggesting the presence of more free fatty acids which could lead to rancidity.

Futhermore, the free fatty acid value, reflects the amount of free fatty acids in the oil, which can influence its quality. *Datarium microcarpum* had the lowest value at 0.107 mg KOH/g, while *Citrullus lanatus* and *Sclerocarya birrea* had values of 4.98 mg KOH/g and 2.17 mg KOH/g, respectively. *Datarium microcarpum* again shows superior oil quality with the lowest free fatty acid value.

On the other hand, the iodine value measures the degree of unsaturation in the oil. *Datarium microcarpum*, *Citrullus lanatus*, and *Sclerocarya birrea* had iodine values of 17.36 g I/100 g, 156.1 g I/100 g, and 9.56 g I/100 g, respectively. Higher iodine values indicate a higher degree of unsaturation, which affects the drying properties of the oil. *Citrullus lanatus* has a very high iodine value, suggesting higher unsaturation and potentially better cold flow properties. However, this also means it is more prone to oxidation. *Sclerocarya birrea* has the lowest iodine value, indicating better oxidative stability but potentially poorer cold flow properties.

Another indicator for oil quality is Protein content which is important for nutritional evaluation. *Datarium microcarpum* and *Citrullus lanatus* showed protein contents of 36.1% and 28.52%, respectively.

The peroxide value is an indicator of the extent of primary oxidation in the oil. *Datarium microcarpum* and *Sclerocarya birrea* showed low peroxide values of 1.62 meq/kg and 1.28 meq/kg, respectively, indicating good oxidative stability. *Citrullus lanatus* had a higher peroxide value of 7.5 mmol/kg, suggesting higher susceptibility to oxidation

The saponification value, which measures the total fatty acid content, was highest in *Datarium microcarpum* at 198.8 mg KOH, followed by *Citrullus lanatus* at 189.89 mg KOH/g, and lowest in *Sclerocarya birrea* at 12.46 mg KOH/g. This suggests that *Datarium microcarpum* a higher content of short-chain fatty acids, which can be beneficial for biodiesel quality. *Sclerocarya birrea*'s very low saponification value suggests longer chain fatty acids predominance, which might not be as beneficial for biodiesel.

Datarium microcarpum had a relative density of 0.92, while specific gravity for *Citrullus lanatus* and *Sclerocarya birrea*, were 0.923 kg/l and 0.85, respectively. *Citrullus lanatus* has a viscosity value of 1 mm^2/s. These values are crucial for understanding the physical properties of the oils.

Lastly, the relative density and specific gravity are essential for understanding the oils' physical properties. *Datarium microcarpum* has a relative density of 0.92**,** while *Citrullus lanatus* and *Sclerocarya birrea* have specific gravities of 0.923 kg/l and 0.85**,** respectively. Additionally, *Citrullus lanatus*'s viscosity value of 1 mm^2/s further contributes to our comprehension of these oils' characteristics.

3.3 Biodiesels Properties

The smoke point was recorded for *Datarium microcarpum* at 210 °C. While *Datarium microcarpum* exhibited a flash point of 250 °C and a fire point of 290 °C. *Citrullus lanatus* showed a lower flash point at 105 °C and a fire point of 123 °C. The flash point of *Sclerocarya birrea* was 166 °C, but the fire point was not recorded.

The cloud point and pour point are critical for evaluating the cold flow properties of biodiesel. *Citrullus lanatus* had a cloud point of -2 °C and a pour point of -5 °C. *Sclerocarya birrea* had higher values at 9 °C for cloud point and 3 °C for pour point.

The cetane number, indicating the combustion quality of diesel fuel, was 43.1 for *Citrullus lanatus* and 64 for *Sclerocarya birrea*.

4. Conclusion

The physicochemical properties of the seeds and seed oils from *Datarium microcarpum*, *Citrullus lanatus*, and *Sclerocarya birrea* demonstrate significant variability, influencing their suitability for different applications. *Citrullus lanatus* and *Sclerocarya birrea* show higher oil yields and varying degrees of unsaturation and oxidative stability, making them potential candidates for biodiesel production, with *Sclerocarya birrea* having an edge due to its high cetane number and satisfactory yield. In contrast, *Datarium microcarpum*, with its lower oil yield but high quality, may be more suitable for nutritional and specialty oil markets. Further research and complete datasets are essential for a comprehensive understanding of these seeds' properties.

4.1. Dedication

This paper is dedicated to late Dr. Abdullahi Nuhu, an inspiring teacher and mentor whose encouragement and motivation were the driving forces behind this work. Though he passed away before seeing the realization of our efforts, his legacy continues to inspire us, and we owe our achievements to his profound influence. Dr. Nuhu's spirit lives on in the pages of this research, and we are forever grateful for his invaluable contributions to our academic and personal growth.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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