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Methanolysis of Fluted Pumpkin seed (*Telfaria occidentalis*) oil

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Abstract
This work investigates the production of biodiesel using solvent extracted pumpkin seeds oil at 6:1 methanol to oil molar ratio in the presence of sodium hydroxide catalyst for 60 minutes. The oil extraction was achieved with the aid of Soxhlet extractor using n-hexane as solvent. The process for the production of biodiesel via an NaOH-catalyzed method comprised of glycerol separation and purification. Pumpkin seeds were examined for proximate analysis and found to contain; moisture 28.10 %, crude proteins 14.2 %, fat content 12.58 %, crude fiber 18.4 %, ash content 2.97 % respectively. Results of physicochemical Analyses carried out on the biodiesel are as follows: pH 6.8, Fire Point 130 °C, Pour Point 10 °C, Viscosity: 5.21 mm²/s, Acid Value 4.18 mg KOH/g, iodine value 72 g I_2/100g, Peroxide Value 3.8 meq O_2/kg, Saponification Value 184 mg KOH/g. These results provide a comprehensive overview of the physical and chemical properties of biodiesel synthesized from pumpkin seed oil. In the FTIR spectrum of pumpkin seed oil biodiesel, the absorption band or frequency from 1766.30 cm^{-1} shows the presence of five membered ring aldehyde and much more. This study not only contributes to the diversification of biodiesel feedstock but also adds value to fluted pumpkin seeds, which are often underutilized. The findings highlight the feasibility of producing high-quality biodiesel from fluted pumpkin seed oil through methanolysis, supporting the ongoing efforts towards sustainable energy solutions and the reduction of carbon emissions.

Keywords: Biodiesel, Extraction, Catalyst, Absorption, Methanolysis.

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INTRODUCTION

Fluted pumpkin (*Telfaria occidentalis*) commonly known as "Ugu" among the Nigerian populace is a leafy vegetable of great worth. It belongs to the family, *curcurbitaceae* and emanated from tropical West Africa. It is a plant with little or no woody tissue, cultivated as a yearly crop chiefly under the traditional farming system in West Africa, most especially in Nigeria. It produces tendrils that support young drupe-like pods which generally consist of male and female seeds. These seeds are known to have oil and protein composition of 29 % and 30 % respectively (Goodhead *et al*., 2021). Fluted pumpkin is grown principally for the leaves which make up an important constituent of the diet in West African countries. Farmers gather the leaves both for consumption and for sale. Several workers have reported the nutritional composition of fluted pumpkin seeds (Nishimura *et al* 2014; Goodhead *et al*., 2021).

Pumpkin seeds, often is obscured by the prominence of the vegetable itself, it hold significant importance in Nigeria and other African countries. Though the leaves of the pumpkin plant are often consumed as a vegetable, the seeds have valuable properties that contribute to both nutrition and sustainable energy production. Pumpkin seeds are abundant source of vital nutrients, including protein, healthy fats, vitamins, and minerals. Furthermore the most exceptional health benefit of pumpkin seed oil are prostate disease prevention, retardation of hypertension progression, reduction of bladder and urethra pressure etc. (Nishimura *et al*., 2014).

The extraction process for pumpkin seed oil involves established methods such as cold pressing and solvent extraction. Cold pressing is a mechanical method that preserves the quality of the oil by avoiding heat degradation, while solvent extraction uses chemical solvents to maximize oil yield. The subsequent transformation of the extracted oil to biodiesel is achieved through transesterification, a chemical process that reacts the oil with an alcohol (typically methanol) in the presence of a catalyst (such as sodium hydroxide). One of the strengths of pumpkin seed oil is that it has a high yield of weight, making it a sensible starting material for producing biodiesel. The physical and chemical properties of pumpkin seed oil have been experimentally analyzed and it has been confirmed that it is suitable for biodiesel production (Schinas *et al*., 2009).

Biodiesel holds significant potential as a non-conventional fuel. It has become the center of interest of many investigations with regard to the greenhouse carbon emission/carbon pollution and the environmental concerns. Biodiesel is a biodegradable, a carbon monoxide emission reducer and non-toxic fuel that can be recycled by process referred to as photosynthesis. This minimizes the impact of biodiesel combustion on the greenhouse effect. Moreover, biodiesel has the advantage of good fuel properties such as good lubricity, better quality exhaust gas emissions, sulphur free, carbon neutral and less emission of carbon dioxide in the atmosphere (Lateef *et al*., 2018), a cetane number and cloud point which depend heavily on the feedstock and a high flash point (~150 ^oC) which makes it volatile and easy to handle (Glisic *et al*, 2014); although, the challenges related with the growth of non-conventional and advanced fuels continue to attract thorough investigations. The conventional approach of biodiesel production is transesterification, using oil and alcohol in the presence of a catalyst (NaOH) with glycerol as a by-product of the reaction (Lateef *et al*., 2014). Product quality is dependent on the type and amount of catalyst, type of oil feedstock, alcohol-to-oil ratio, free fatty acid and water content in the oil and operating conditions such as agitation speed and temperature (Clark *et al*., 2013).

Numerous studies regarding biodiesel production have concentrated on the use of vegetable oil or animal fat as feedstock in the presence of a catalyst. Edible oils are regarded as first generation biodiesel feedstock. The oils used as feedstock in the production of biodiesel have attracted much attention since they are renewable and readily available (Atabani *et al*., 2013). The main objective of this work was to produce biodiesel using solvent extracted pumpkin seed oil on 6:1 methanol to oil molar ratio.

MATERIALS AND METHODS

Sample Collection

Samples of pumpkin seeds were procured from Okenya, Kogi state, North-Central Nigeria.

Figure 1: (a) Fluted Pumpkin Seed Pod (b) Fluted Pumpkin Seed (c) Grinded Fluted Pumpkin Seed

Sample Preparation

Seeds were cleaned using subsequent washings with distilled water to remove foreign materials and the seeds were sun-dried for about 30 days to lessen the moisture content. The pods were carefully cut open to expose the seeds which were embedded in an orange–yellowish fibrous material. The seeds were cracked manually to expose kernels needed for oil extraction and were washed thoroughly with clean water. Kernels were further sun dried to reduce the moisture content. After the kernels were properly dried, they were ground manually using a manual grinder. All reagents used were analytical grade, manufactured by Aldrich Chemicals.

Proximate analysis of pumpkin seed

Pumpkin seed chemical composition was determined according to Pearson (1976) and A.O.A.C (1996) for Crude protein, Crude fibre content, Moisture content and Fat content.

Solvent Extraction Process

Process Description of extraction process of pumpkin seed oil

A uniform quantity of grinded pumpkin seed (100 g) was used throughout the experiment and was measured with a digital weighing balance (MCTTTCER YOLEDO: PR2002). Two hundred milliliters of Methanol was poured into round bottom flask and 100g sample (particle size 0.25 to 2 mm) was added to filter paper. Extraction process variables included extraction time (12 h), under constant temperature (80 °C). Solvent recovery was achieved by rotary evaporator and residual solvent was removed by drying in an oven at 78 °C for 1 h.

Figure 2 (a) Soxhlet extraction apparatus set up (b) Extracted fluted pumpkin seed oil

Production of biodiesel

Biodiesel production was carried out using Lateef *et al*., 2014 method. One hundred milliliters of the pumpkin oil sample was heated to 65 °C and placed in a 250 mL batch reactor at 6:1 alcohol (methanol) to oil molar ratio. 100 mL of pumpkin seed oil needed 2 mL of methanol. 0.5 mL of sodium hydroxide (NaOH) catalyst was utilised. The sodium hydroxide was dissolved into the alcohol and stirred vigorously in the 200 mL beaker. The alcohol-catalyst mixtures were poured into the oil and final mixture was vigorously stirred for 60 minutes in the beaker. The reaction product mixture were allowed to separate into two phases at the end of the reaction by allowing it stand for 24 hours in a separating funnel so as to separate glycerol from the biodiesel. The inferior layer (glycerol) was evacuated by opening the tap of the separating funnel. The crude biodiesel was left in the separating funnel.

Biodiesel Purification
Fifty milliliters hot distilled water was used to wash the crude biodiesel three times in order to remove residual by-products. The biodiesel obtained was dried in an oven at 105 °C for 60 minutes. The volumes of the biodiesel obtained were recorded, and the products were used for characterization.

Figure 3: Separation of biodiesel from glycerol

Physiochemical characterization of Biodiesel
Standard analytical methods were used for the characterization of biodiesel produced. The determination of the biodiesel pH was carried out using benchtop pH meter (Jenway 3510ph) which was standardized with pH 4, 7 and 10 buffer solutions. The acid value, saponification value, iodine value (Wij's method), peroxide value was determined using A.O.A.C (1996) method.

A Pensky Martin Flash Point (closed cup) apparatus was used to measure the flash and fire point of the fuel samples. The flash and fire point of the fuel samples was determined as per Indian standard for petroleum and its products - Methods of Test IS 1448 [P: 32]: 1992.
Kinematic viscosity value of biodiesel sample was determined with Ferranti portable viscometer (Model VL for fluted pumpkin seed oil) at room temperature (30 °C) following the standard method as outlined in the Ferranti portable viscometer manual.
Calorific value was determined with an Oxygen bomb calorimeter model XRY-1A.
The Cloud and Pour point of fuel samples were determined as per Indian standard for petroleum and its products - Methods of Test IS 1448 [P: 10]: 1970 using the Cloud and Pour point apparatus.

Infrared Spectroscopy – Biodiesel Product Analysis
Biodiesel produced was analyzed with Shimadzu FTIR. Model IR-Affinity-1, Japan.
0.4g of KBr was weighed and ground to powder. 0.001g of the sample was weighed into the ground KBr and both were completely mixed together and moulded into a disc. The disc was inserted into the sample compartment of the instrument. The scan button was pressed and the IR spectrum data were collected.

RESULTS AND DISCUSSION

Proximate analysis
Table 1 shows the results of the proximate composition of Pumpkin seeds. This analysis includes the measurement of percentage composition of moisture content, ash content, crude fiber, crude protein and fat content

Table 1: Proximate analysis results on pumpkin seed oil

Proximate analysis (%)	Result
Moisture content	28.10
Ash content	2.97
Crude fibre	18.4
Crude protein	14.2
Fat content	12.58

The proximate analysis of pumpkin seed oil is crucial for determining its suitability for biodiesel production. These results were compared with findings from other studies to provide a comprehensive evaluation. These results provide valuable insight into the composition of pumpkin seed oil, which can influence its effectiveness and efficiency in biodiesel production.

Moisture content
The moisture content of the pumpkin seed oil analyzed in this study was found to be 28.10%. This value is significantly higher than the standard moisture content recommended for biodiesel feedstock, which is generally below 5% (Knothe *et al.*, 2005). The result obtained (28.10%) agreed with those reported in literature (Gohari *et al.*, 2012). High moisture content can lead to challenges in the biodiesel production process, particularly during the transesterification reaction, where excess water can cause soap formation and reduce the overall yield of biodiesel. The lower moisture content reported by these authors suggests that environmental factors, such as humidity during seed storage or inherent differences in the pumpkin seed varieties, could play a significant role in determining moisture levels and the high moisture content in this particular research is as a result of not drying the pumpkin seed very well, so it is advisable to sundry the seed in other to reduces excess water. The high moisture content in this analysis might be connected to the hygroscopic nature of the pumpkin seeds, which tend to absorb moisture from the environment even after oil extraction, particularly if stored in humid conditions.

Ash Content
The ash content obtained from this research work is 2.97 %. The analysis indicates a moderate presence of inorganic minerals. Echioda *et al.*, (2018) observed ash content to be 3.48 %. According to industry standards, the ash content for biodiesel feedstocks should ideally be below 1% (Knothe *et al.*, 2005).Ash content is a major parameter as it depicts the amount of non-combustible residue that remains after the oil is burned, which can impact the quality of biodiesel and its combustion properties. Higher ash content can lead to increased deposits in

the engine and may affect the long term performance of the biodiesel. The consistency of these results across different studies suggests that the ash content in pumpkin seed oil is relatively stable, likely influenced by the mineral content of the soil where the pumpkins are grown. The slightly lower ash content in this analysis compared to the standard could indicate that the seeds used were grown in soils with lower mineral content or that effective refining processes were applied to reduce the ash content. This consistency suggests that pumpkin seeds generally maintain a stable level of inorganic minerals, essential for the catalytic processes in biodiesel production. Inorganic minerals can affect the combustion quality and emissions of biodiesel, making this parameter significant.

Crude Fiber

The crude fiber content obtained from this research is 18.4 %. This value is relatively high when compared to the standard range of 5-10 % typically expected for oil feedstocks used in biodiesel production (Knothe *et al.*, 2005). High fiber content can impede oil extraction efficiency and may result in lower oil yield. When compared with other studies, Miteu and Eze (2022) observed crude fibre of 2.06 % for raw fruited pumpkin. The elevated fiber content in this analysis may be ascribed to the specific variety of pumpkin seeds utilized in this study, as well as geographical location and environmental factors, which might naturally have higher fiber content. The oil extraction method used could influence the fiber content, with less efficient extraction techniques potentially leaving more fiber in the oil. The analysis is relatively high. High crude fiber content is beneficial for biodiesel production as it can enhance the efficiency of the transesterification process by acting as a natural catalyst (Gohari *et al.*, 2012). Additionally, fiber can influence the viscosity and stability of the biodiesel, impacting its overall performance in engines.

Crude Protein

The crude protein content of this analysis is 14.2 %. , which is within the typical range for oil seeds used in biodiesel production, generally between 10-30 % (Miteu and Ezeh 2022; Knothe *et al.*, 2005). Miteu and Ezeh (2022) observed 30.2, Echioda *et al.*, (2018) reported a crude protein of 29.15 %.While protein content does not directly impact biodiesel production, it is an important factor for the nutritional value of the residual seed cake, which can be used as animal feed or fertilizer. The results from this analysis align well with these findings, indicating that the protein content in pumpkin seeds is relatively consistent across different studies. The protein content may be influenced by factors such as seed variety, soil fertility, and growing conditions, which could account for the slight variations observed. The analysis is consistent with the findings of Stevenson *et al*. (2007), who reported a protein content of 14.5 %. Protein content is a critical factor in biodiesel production as it can impact the quality of the oil extracted from the seeds. Proteins may act as emulsifying agents during the transesterification process, influencing the yield and quality of the biodiesel. Furthermore, understanding the protein content helps in optimizing the extraction methods for maximum oil yield.

Fat Content

The fat content of this analysis was determined to be 12.58 %. Fat content is significant because it represents the amount of extractable lipids, which are essential for the transesterification process to produce biodiesel. The standard fat content for pumpkin seed oil typically ranges from 40 % to 50 %, depending on the variety, growing conditions, and extraction methods used (Lazos, 1986). The value of 12.58 % obtained in this study is notably lower than the standard range. This deviation could be attributed to several factors, including the efficiency of the oil extraction process, the maturity of the seeds, or the specific variety of pumpkin used in this analysis. Miteu and Ezeh (2022) found fat content of 38.13 for raw fruited pumpkin. El-Adawy and Taha (2001) reported a fat content of 42.0 % in pumpkin seed oil. A plausible explanation for the lower fat content could be the specific variety of pumpkin seeds used, as different cultivars can have varying lipid concentrations. Environmental factors such as soil type, climate, and seed maturity at the time of harvest can influence the oil content. For instance, seeds harvested before full maturity tend to have lower lipid content, which could account for the reduced fat percentage in this analysis. In conclusion, while the fat content observed in this study is lower than the typical range reported in the literature, it highlights the importance of optimizing extraction methods and selecting appropriate seed varieties to maximize oil yields. Fat content is a vital parameter as it directly correlates with the oil yield from the seeds. Higher fat content indicates a higher potential for oil extraction, making it a critical factor for biodiesel production. The slight variation observed in our study does not significantly affect the overall potential of pumpkin seed oil as a biodiesel feedstock.

The proximate analysis results indicate that pumpkin seed oil has a favorable composition for biodiesel production. The moderate ash content ensures a good balance of minerals, which can aid in the catalytic processes. The high crude fiber content suggests that the oil can act as an efficient natural catalyst, enhancing the transesterification process. The consistent crude protein content across different studies highlights the stability and quality of the oil extracted from pumpkin seeds. Finally, the substantial fat content ensures a good yield of oil, making pumpkin seed oil a viable feedstock for biodiesel production. The proximate analysis of pumpkin seed oil reveals that it possesses several favorable properties for biodiesel production. The consistency of our findings with those of other studies reinforces the potential of pumpkin seed oil as a reliable and efficient feedstock for biodiesel production.

Physicochemical Characterization

These results provide a comprehensive overview of the physicochemical properties of biodiesel produced from pumpkin seed oil as shown in table below.

Table 2: Physicochemical Analysis Results on Pumpkin Seed Oil

Physiochemical properties	Result
pH	6.8
Fire point (cP) 30 ^{0}C	130
Flash point (^{0}C)	124
Pour point (^{0} C)	10
Viscousity (mm^2/s)	52.1
Acid value(mg KOH/g)	4.18
Iodine value (g I_2/100g)	72
Peroxide value (Meq O_2/kg)	3.8
Saponification value (mgKOH/g)	184

The physicochemical properties of biodiesel are essential for determining its quality and suitability for use as an alternative fuel. This analysis includes parameters such as pH, fire point, pour point, kinematic viscosity, acid value, iodine value, peroxide value, and saponification value.

pH

The pH value of the biodiesel produced from solvent-extracted pumpkin seed oil was determined to be 6.8.which is comparable to the findings of Zhang *et al* (2003), who reported pH value of 6.5 for biodiesel produced from vegetable oil. The pH is a critical parameter that reflects the acidity or alkalinity of the biodiesel, which can significantly influence its corrosiveness, storage stability, and compatibility with engine components. Ideally, biodiesel should have a pH close to neutral (pH 7), as a more acidic or basic biodiesel can lead to increased corrosion of fuel system parts, ultimately affecting engine longevity and performance. Industry standards for biodiesel pH generally recommend a value close to neutral, with slight deviations acceptable depending on the feedstock and processing methods (Knothe *et al*., 2005). Moser *et al*. (2009) found a pH of 6.9 for biodiesel derived from soybean oil, and Akbar *et al*. (2009) observed a pH value of 7.0 for biodiesel produced from *Jatropha curcas* L. oil. The pH value of 6.8 observed in this analysis is slightly acidic, which may be attributed to the presence of residual free fatty acids. The slight acidity may also be influenced by the natural characteristics of the pumpkin seed oil, which could have a higher inherent free fatty acid content compared to other feed stocks

Fire Point

The fire point of the biodiesel was recorded at 130 °C. The fire point is the temperature at which the biodiesel produces enough vapor to ignite in the presence of a flame. It is a critical safety parameter, as a lower fire point indicates a higher risk of ignition under elevated temperatures, which can pose safety hazards during storage and handling. According to biodiesel standards, the fire point should typically range between 120 °C and 170 °C, depending on the feedstock and processing conditions (Knothe *et al*., 2005). The fire point of 130 °C observed in this study falls within this range, suggesting that the biodiesel has a satisfactory level of safety concerning ignition risks under normal operating conditions. Moser *et al*. (2009) found a fire point of 128 °C for soybean oil biodiesel, which is close to the fire point obtained for pumpkin seed oil biodiesel. Akbar *et al*. (2009) observed a fire point of 140 °C for biodiesel from *Jatropha curcas* L. oil. The fire point of 130 °C recorded in this analysis suggests that the pumpkin seed oil biodiesel has comparable safety characteristics to biodiesel derived from other vegetable oils. The slight variation in fire points could be attributed to differences in the fatty acid composition of the feedstock, as well as the presence of impurities or residual alcohols from the transesterification process. The fire point of pumpkin seed oil biodiesel suggests that it can be safely used under typical operating conditions, though care should be taken during storage and transport to ensure that the biodiesel is kept below its fire point to avoid accidental ignition.

Flash Point

The flash point of the biodiesel was measured at 124 °C. Moser *et al*. (2009) reported a flash point of 130 °C for soybean oil biodiesel, which is slightly higher than the value observed in this study. Akbar *et al*. (2009) observed a flash point of 126 °C for *Jatropha curcas* L. biodiesel. Foroutan *et al* (2019) observed a flash point of 52 ^{0}C. These values are all within a similar range, suggesting that the flash point of pumpkin seed oil biodiesel is comparable to other common biodiesel feedstock. The standard flash point for biodiesel is typically above 130 °C, as specified by the ASTM D6751 and EN 14214 standards (Knothe *et al*., 2005; Foroutan *et al* (2019). The flash point is a critical safety parameter that indicates the temperature at which the biodiesel vapors can ignite when exposed to an open flame. A higher flash point is desirable as it reduces the risk of accidental ignition during handling and storage. The flash point of 124 °C observed in this study exceeds this minimum requirement, indicating that the biodiesel produced from pumpkin seed oil is safe for handling and storage under normal conditions. The flash point of 124 °C in this study is consistent with the flash points reported for other biodiesel sources, confirming that pumpkin seed oil can produce biodiesel with a safe and stable flash point. This characteristic makes the biodiesel suitable for use in various climates and transportation conditions without posing a significant fire hazard.

Pour Point

The pour point of the biodiesel was determined to be 10 °C. This value is in line with the findings of Singh and Singh (2010), who reported pour points ranging from 8 °C to 12 °C for biodiesel from different feedstocks. Industry standards for biodiesel typically specify a pour point that ensures the fuel remains fluid at low temperatures, with a general range from -15 °C to 10 °C, depending on the feedstock and processing techniques (Knothe *et al*., 2005; Foroutan *et al* 2019). Moser *et al*. (2009) found a pour point of 6 °C for soybean oil biodiesel, indicating better cold flow properties. Akbar *et al*. (2009) observed a pour point of 4 °C for biodiesel derived from *Jatropha curcas* L. oil. Ved and Padam (2013) observed a pour point of 6 ℃ for sorghum oil. The pour point is the lowest temperature at which the biodiesel remains fluid and can be poured. This property is particularly important for the performance of biodiesel in cold climates, where lower temperatures can cause the fuel to solidify, leading to flow issues in fuel lines and filters. The pour point of 10 °C observed in this analysis is at the higher end of this range, suggesting that the biodiesel may not be well-suited for use in extremely cold environments where lower pour points are desirable to maintain fuel flow. The relatively high pour point in this analysis could be attributed to the specific fatty acid composition of the pumpkin seed oil, which may contain higher amounts of saturated fatty acids. These saturated fatty acids are known to increase the solidification temperature, leading to a higher pour point. This characteristic could limit the biodiesel's usability in colder regions, as it may solidify at temperatures that are common in winter. To enhance its cold flow properties, the biodiesel could undergo additional processing, such as winterization, or be blended with biodiesel from other feedstock that have lower pour points.

Kinematics Viscosity

The kinematic viscosity of the biodiesel was recorded to be 5.1 mm^2/s at 40 °C which is within the acceptable range for biodiesel. Moser *et al*. (2009) found a viscosity of 5.2 mm^2/s for soybean oil biodiesel, Akbar *et al*. (2009) observed a viscosity of 4.9 mm^2/s for biodiesel from *Jatropha curcas* L. oil. According to the findings of Alptekin and Canakci (2008) and Knothe *et al*. (2005), the standard range of biodiesel kinematics viscosity is typically between 4.0 and 6.0 mm^2/s at 40 °C. Foroutan *et al* (2019) also reported a value of 4.5 mm^2/s. The acceptable range for kinematic viscosity of biodiesel at 40 °C is between 1.9 to 6.0 mm^2/s (Knothe *et al*.2005). Viscosity outside this range may cause issues such as poor fuel atomization, incomplete combustion, and the formation of engine deposits, which can reduce engine efficiency and longevity.

Acid Value

The acid value of the biodiesel was determined to be 4.18 mg KOH/g. Moser *et al*. (2009) found an acid value of 0.30 mg KOH/g for soybean oil biodiesel, and Akbar *et al*. (2009) observed an acid value of 0.38 mg KOH/g for biodiesel from *Jatropha curcas* L. oil, Ved andPadam (2013), also observed an acid value of 0.31 for sorghum biodiesel. Industry standards recommend that the acid value of biodiesel should be below 0.5 mg KOH/g (Knothe *et al*., 2005). The acid value is an important indicator of the free fatty acid (FFA) content in the biodiesel, which can affect the fuel's stability, corrosion potential, and deposit formation in engines. A higher acid value suggests the presence of more FFAs, which can lead to the degradation of the biodiesel over time, as well as increased deposit formation in fuel injectors and combustion chambers. The acid value of 4.18 mg KOH/g observed in this analysis is significantly higher than the recommended standard, indicating that the biodiesel may be prone to oxidative degradation and could pose risks to engine components if used without further treatment. The significantly higher acid value in this study could be due to the incomplete conversion of FFAs during the transesterification process, or it may indicate that the pumpkin seed oil used was of lower quality, containing higher amounts of FFAs before processing.

Iodine Value

The iodine value of the biodiesel produced was recorded to be 72 g I_2/100g. Moser *et al*. (2009) found an iodine value of 70 g I_2/100g for soybean oil biodiesel, Akbar *et al*. (2009) observed an iodine value of 65 g I_2/100g for *Jatropha curcas* L. biodiesel. Ved and Padam (2013) also observed an iodine value of 101 for sorghum biodiesel. According to Knothe (2005), the iodine value for biodiesel typically falls within the range of 10 to 120 g I_2/100g. Maintaining the iodine value within this range is crucial for ensuring the biodiesel's oxidative stability and storage performance. The iodine value is a measure of the unsaturation level of the fatty acids in biodiesel, which influences its oxidative stability. A higher iodine value indicates a higher degree of unsaturation, which can lead to quicker oxidation and a shorter shelf life. The iodine value of 72 g I_2/100g in this study is within the acceptable range but on the higher side compared to the values reported by other authors. This could be due to a higher content of unsaturated fatty acids in the pumpkin seed oil used, which may vary depending on factors such as seed variety, cultivation conditions, and oil extraction methods. The higher iodine value suggests that while the biodiesel produced has good cold flow properties, it may be more prone to oxidation, which could affect its storage stability. However, this value remains within the standard range, indicating that the biodiesel should perform adequately under typical conditions. The kinematic viscosity and iodine value of the biodiesel produced from solvent-extracted pumpkin seed oil highlight important aspects of its performance and stability. The higher kinematic viscosity observed may require further processing or blending to ensure compatibility with engine systems, while the iodine value, though slightly higher, remains within the acceptable range, indicating reasonable oxidative stability. These results suggest that with proper refinement, biodiesel from pumpkin seed oil could serve as a viable alternative to conventional diesel fuels, contributing to sustainable energy solutions.

Peroxide Value

The peroxide value of the biodiesel was determined to be 3.8 meq O/kg. Moser *et al*. (2009) reported a peroxide value of 5.2 meq O_2/kg for soybean oil biodiesel, which is slightly higher than the value observed in this study, suggesting that pumpkin seed oil biodiesel may have better initial stability. Akbar *et al*. (2009) reported a peroxide value of 6.0 meq O_2/kg for *Jatropha curcas* L. oil biodiesel, which is higher, indicating that Jatropha oil biodiesel might oxidize more readily. Industry standards suggest that the peroxide value of biodiesel should be below 10 meq O_2/kg to ensure good oxidative stability (Knothe *et al*., 2005). The peroxide value measures the extent of primary oxidation in the biodiesel, indicating the amount of peroxides and hydro peroxides formed during the initial stages of oxidation. Lower peroxide values are indicative of better oxidative stability, which is crucial for the storage and shelf life of biodiesel. The peroxide value of 3.8 meq O_2/kg observed in this study is well within the acceptable range, indicating that the pumpkin seed oil biodiesel has good initial oxidative stability and should remain stable during storage. The low peroxide value of 3.8 meq O_2/kg in this analysis suggests that the pumpkin seed oil biodiesel has a low tendency to oxidize, which is beneficial for maintaining fuel quality during storage. However, long-term storage or exposure to air and light could increase the peroxide value over time, so it may be advisable to include antioxidants in the biodiesel formulation to further enhance its stability.

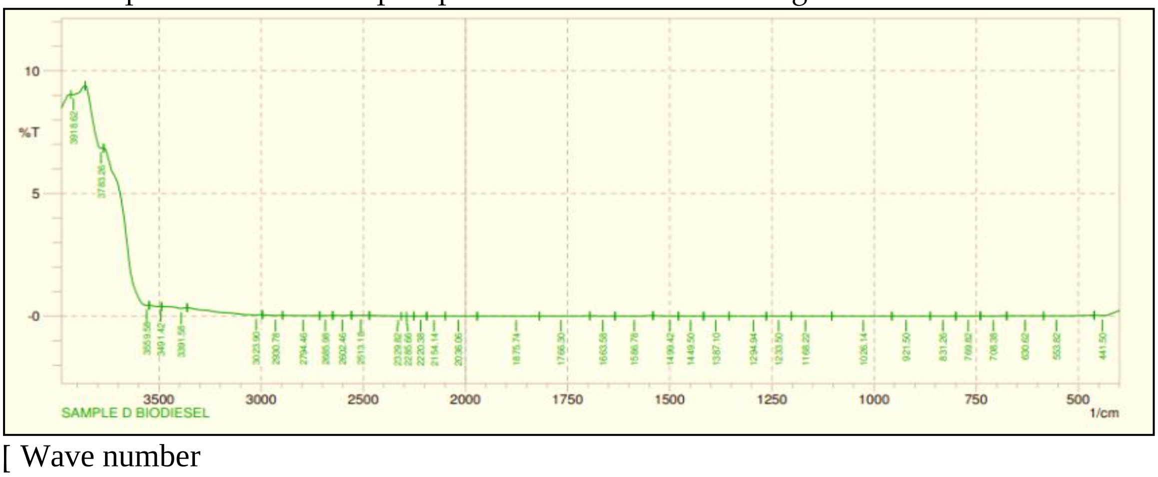
Saponification Value

The saponification value of the biodiesel was determined to be 184 mg KOH/g, Moser *et al*. (2009) reported a saponification value of 190 mg KOH/g for soybean oil biodiesel, which is slightly higher than the value observed in this study, suggesting slightly shorter-chain fatty acids in soybean oil. Akbar *et al*. (2009) reported a saponification value of 185 mg KOH/g for *Jatropha curcas* L. oil biodiesel, which is very close to the value observed in this study. Ved and Padam (2013) observed a saponification value of 165 mg KOH/g for sorghum biodiesel. The standard saponification value for biodiesel typically ranges from 180 to 200 mg KOH/g, depending on the feedstock (Knothe *et al*., 2005). The saponification value is a measure of the average molecular weight (or chain length) of all the fatty acids present in the biodiesel. It indicates the amount of potassium hydroxide (KOH) required to saponify one gram of the oil. Higher saponification values suggest shorter-chain fatty acids, which can influence the biodiesel's combustion properties. The saponification value of 184 mg KOH/g observed in this study is within the standard range, indicating that the pumpkin seed oil biodiesel contains fatty acids with a typical chain length, conducive to good combustion properties in diesel engines. The saponification value of 184 mg KOH/g indicates that the fatty acids in pumpkin seed oil biodiesel are of a moderate chain length, which is favorable for producing biodiesel with good ignition quality and energy content. This suggests that pumpkin seed oil is a suitable feedstock for biodiesel production, yielding fuel that meets industry standards for combustion and engine performance.

The physicochemical properties of biodiesel produced from solvent-extracted pumpkin seed oil indicates that it has several favorable attributes for use as an alternative fuel. The slightly acidic pH and moderate fire point enhance its safety and handling characteristics. The pour point suggests good cold flow properties, making it suitable for use in varying climatic conditions. However, the high kinematic viscosity and acid value may require further processing to meet standard specifications. The iodine, peroxide, and saponification values indicate good oxidative stability and the presence of long-chain fatty acids, contributing to the overall quality and performance of the biodiesel.

The physicochemical analysis of biodiesel produced from solvent-extracted pumpkin seed oil reveals its potential as a viable alternative fuel. The consistency of our findings with those of other studies reinforces the suitability of pumpkin seed oil for biodiesel production. Further research and optimization of production processes can enhance the quality and performance of biodiesel derived from pumpkin seed oil.

FTIR Spectra of biodiesel from pumpkin seed oil
The plot of percentage transmittance against the wave number for FTIR spectra of the biodiesel produced from the pumpkin seed oil is shown in Fig. 4



[Wave number

Figure 4: FTIR Spectrum Result for Biodiesel

Table 3: FTIR spectra of biodiesel produced from pumpkin seed oil (Transmittance against wave number (cm^{-1})

Wave number (cm^{-1})	Assignment/Functional group
1766.30	Five membered ring aldehyde.
1233.50	Aromatic ethers, aryl-O stretch.
1499.42	Aromatic ring stretch.
1026.14	Aromatic C-H in plane bend.
3559.58	Tertiary alcohol, OH stretch.
3491.42	Dimeric, OH Stretch.

Biodiesel produced from pumpkin seed oil FTIR analysis

The spectra obtained from biodiesel produced from pumpkin seed oil were characterized by infrared spectroscopy (FTIR). The infrared spectra of biodiesel from pumpkin seed is shown in Figure 4. The reflectance bands were used to identify the main functional groups present. The band assignment of the spectra is as contained in the interpretation of infrared spectra, The characteristics IR absorption frequencies as well as type of vibration of organic functional group of biodiesel produced from pumpkin seeds as speculated in figure 4 are as contained in the following interpretation of FTIR spectra by Nandiyanto *et al*., 2019; Sukamto and Rahmat, 2023.

Table 3 shows the functional groups present in the pumpkin seed oil. The functional groups present in the pumpkin seed oil were determined by comparing the vibration frequencies in wave numbers of the sample spectrograph obtained from an FTIR spectrophotometer with those of an IR correlation chart. FTIR spectra of pumpkin seed oils appear fairly similar. In the FTIR spectrum of pumpkin seed oil the absorption band or frequency from 1766.30 cm^{-1}shows the presence of five membered ring aldehyde, and 1233.50 cm^{-1} indicates the presence of Aromatic ethers, aryl-O stretch, 1499.42cm^{-1} showed the presence of aromatic ring stretch, 1026.14 cm^{-1}, aromatic C-H in plane bend and3559.58 cm^{-1}, indicate the presence of tertiary alcohol, OH -Stretch. The range of wave number from 3491.42 cm^{-1} indicates the presence of dimeric OH Stretch.

CONCLUSION

The project on producing biodiesel from pumpkin seed oil demonstrates an encouraging and novel approach to renewable energy production. As concerns about fossil fuel depletion and environmental degradation intensify, exploring alternative energy sources becomes imperative. Common biodiesel feedstock like soybean, canola, and palm oils often dominate the market due to their towering oil content and sustained supply chains. However, pumpkin seed oil offers a unique and valuable alternative, particularly in regions where pumpkins are widely cultivated. Unlike major crops, pumpkin seeds are typically a byproduct, making their utilization for biodiesel production an efficient way to minimize waste and add economic value to existing agricultural practices.

This approach aligns with sustainable development goals by promoting the use of locally available, non-food biomass resources for energy production.

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