

BIODIESEL PRODUCTION FROM CITRULLUS LANATUS AND CUCUMIS MELO SEED OIL BLENDS: A SUSTAINABLE ALTERNATIVE FEEDSTOCK

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Abstract

Biodiesel, or fatty acid methyl ester (FAME) is a renewable, biodegradable and non-toxic alternative to petroleum diesel. In this study, biodiesel was synthesized from crude seed oils of two Cucurbitaceae species *Citrullus lanatus* L. (watermelon) and *Cucumis melo* L. (muskmelon) through base-catalyzed transesterification. The process was optimized at 60 °C for 2 hours using NaOH as a catalyst and a 1:6 molar ratio of oil to methanol, achieving conversion yields of about 50% for both oils. Altering these parameters led to reduced biodiesel yield and increased soap formation due to free fatty acid interactions. The resulting biodiesel was evaluated for key physicochemical and fuel properties, which were in close agreement with ASTM standards and comparable to conventional diesel. These results demonstrate that watermelon and muskmelon seed oils represent promising, underutilized feedstocks for sustainable biodiesel production, with potential application as an eco-friendly substitute for fossil-based diesel owing to their lower carbon and nitrogen oxide emissions.

INTRODUCTION

Global dependence on fossil fuels raises concerns over climate change, environmental degradation, and finite petroleum reserves. Diesel, in particular, is widely used in transportation, power generation, and agriculture, but its combustion contributes significantly to greenhouse gas emissions and air pollution (Knothe, 2008). Biodiesel defined as fatty acid methyl esters (FAME) produced from biological feedstocks is emerging as a renewable, biodegradable, and less toxic substitute for

petroleum diesel (Demirbas, 2009; Nwfoa, Nzebukab, Okonkwoa, Okorafor, Onwuachua, & Igbokwea, 2023). Its advantages include lower carbon monoxide, sulfur oxides, and particulate emissions, with comparable engine performance (Rashid, Rehman, Hussain, Ibrahim, & Haider, 2011). Feedstock cost and availability remain the main challenges for biodiesel commercialization (Atabani et al., 2012). To avoid competition with food crops, attention has shifted toward non-edible

or underutilized oils. The Cucurbitaceae family provides such options. Seeds of *Citrullus lanatus* (watermelon) and *Cucumis melo* (muskmelon) are often discarded after fruit consumption, yet they contain 30–45% oil with favorable fatty acid profiles (Adam, Galander, Osman, & Alhassan, 2025; Maria Ameen, Zafar, Nizami, Ahmad, Munir, Sultana, Usma, & Rehan, 2022). Watermelon seed oil is rich in linoleic and oleic acids, whereas muskmelon seed oil contains high proportions of linoleic acid along with palmitic and oleic acids, offering potential for biodiesel production (Yunus, 2016; El-Adawy & Taha, 2001). Transesterification is the most common route to biodiesel, involving reaction of triglycerides with alcohol (usually methanol) in the presence of a catalyst. Reaction efficiency depends on alcohol-to-oil molar ratio, catalyst type and concentration, temperature, and reaction time (Fukuda, Kondo, & Noda, 2001). For watermelon seed oil, Nwufoa et al. (2023) achieved a 93.68% yield at 55 °C using NaOH, reporting properties such as calorific value (40.10 MJ/kg), viscosity (5.82 mm²/s), and cetane number (53.17) that conform to ASTM D6751. Similarly, muskmelon (*C. melo* var. *agrestis*) biodiesel has achieved yields over 90% using MgO nano-catalyst, with physicochemical properties within ASTM limits (Maria Ameen et al., 2022). However, crude seed oils often contain free fatty acids (FFAs). In base-catalyzed transesterification, FFAs react with alkali to form soap, reducing yield and complicating separation (Yunus, 2016). Acid esterification pretreatment or two-step methods are therefore sometimes required (Fukuda et al., 2001). Soap formation and variability in oil composition remain practical challenges for scale-up. Several studies confirm that biodiesel derived from watermelon and muskmelon seed oils meets ASTM standards for density, viscosity, cetane

number, and cold flow properties (Nwufoa et al., 2023; Rashid et al., 2011). Microwave-assisted transesterification and heterogeneous catalysts have been explored to improve efficiency (Okolo et al., 2023; Rashid et al., 2011). Yet, blending seed oils may offer further benefits by balancing fatty acid composition, lowering free fatty acid levels, and improving yields, while also utilizing agricultural by-products that are often wasted. This study aims to investigate biodiesel production from mixtures of *Citrullus lanatus* and *Cucumis melo* seed oils using alkaline transesterification. By examining conversion yield, soap formation, and compliance with ASTM standards, it aims to demonstrate the potential of Cucurbitaceae seed oils as viable, sustainable feedstocks for commercial biodiesel production.

2. Materials and Methods

2.1 Study Site

Quetta District, the provincial capital and administrative hub of Balochistan, is the fourth smallest district in the province, with a total area of 2,653 square kilometers. It is geographically positioned between 66°41'40"–67°17'25" E longitudes and 30°01'29"–30°28'25" N latitudes. The district is administratively divided into two tehsils and approximately 67 union councils. Located about 690 km southwest of Islamabad at a bearing of 237°, Quetta occupies a strategic position near the borders of Afghanistan and Iran. The city lies at an average elevation of 1,680 meters above sea level, which contributes to its unique climate. Winters are typically cold, with snowfall occurring mainly in January and February, while summers remain relatively moderate compared to other parts of Balochistan (Census, 1998).



Figure1: Map of Quetta District

2.2 Seed Collection.

Seeds of *Citrullus lanatus* L. (watermelon) and *Cucumis melo* L. (muskmelon) were sourced from cultivated fields, retail shops, and local markets of District Quetta. To eliminate dust particles and surface contaminants, the seeds were rinsed thoroughly with distilled water and air-dried under room conditions. Preliminary determination of oil content was carried out using a Soxhlet apparatus with methanol as the extraction solvent. For bulk extraction, the dried seeds were mechanically pressed using an electric expeller to obtain crude oil, which served as the raw material for subsequent biodiesel production experiments. Weight of extracted oil (g)

2.3. Oil Extraction from Seeds in Soxhlet

Equal quantities (10 g each) of *Cucumis melo* L. (muskmelon) and *Citrullus lanatus* L. (watermelon) seeds were used for extraction. The seeds were oven-dried at 60 °C for 72 hours and subsequently ground into a fine powder using an electric grinder. The powdered samples were placed in extraction thimbles of a Soxhlet apparatus fitted with a 200 mL round-bottom flask. Approximately 100 mL of methanol was added as the extraction solvent, and the process was continued for 15 hours. Following extraction, the solvent was evaporated, and the crude oil yield was recorded. The oil content was calculated on a dry-weight basis using the following relation, as described by Favi et al. (2018):

$$\text{Oil yield (\%)} = \frac{\text{Weight of extracted oil (g)}}{\text{Dry weight of seed sample (g)}} \times 100$$

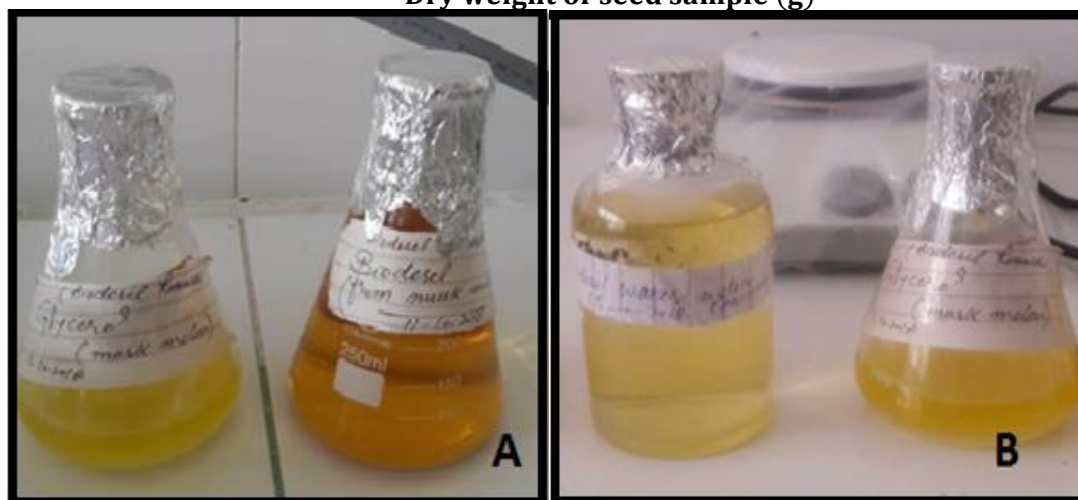


Figure 2: Biodiesel Production Processes

2.4.1. Esterification Process (two step method)

The esterification process was performed to reduce the free fatty acid (FFA) content in the extracted seed oils prior to biodiesel production. This step was carried out in the Botany Laboratory using a titration-based approach. Acid-catalyzed esterification was conducted before the base-catalyzed transesterification to minimize FFA levels, typically reducing them by approximately 2%. The crude oils from *Citrullus lanatus* L. (watermelon) and *Cucumis melo* L. (muskmelon) were heated in a flask at temperatures ranging from 40 °C to 60 °C to facilitate the conversion of free fatty acids to methyl esters. For the reaction, sodium hydroxide (NaOH) was dissolved in 300 mL of methanol and added to the oil, followed by a few drops of concentrated sulfuric acid. The mixture was stirred continuously for 30 minutes, after which the reaction was halted and the mixture allowed to cool to room temperature. The resulting product was then allowed to settle, separating impurities and yielding oil with reduced FFA content, which was subsequently used in the base-catalyzed transesterification process (Cristiane, de Oliveira, & dos Santos, 2009).

2.4.2 Transesterification Process

Following free fatty acid reduction, biodiesel was synthesized from the purified seed oils via base-catalyzed transesterification. Equal amounts (50 g each) of *Citrullus lanatus* (watermelon) and *Cucumis melo* (muskmelon) oils were blended and preheated at 60 °C for 20 minutes under continuous stirring to achieve homogeneity. A catalyst solution, prepared by dissolving anhydrous NaOH in 100 mL of methanol, was gradually introduced into the oil mixture with constant agitation. The reaction mixture was transferred to a separating funnel and allowed to settle for 24 hours, yielding two distinct layers: a lower glycerol phase, which was discarded, and an upper methyl ester phase, representing biodiesel. The biodiesel was subsequently collected, washed, dried, and preserved for physicochemical and fuel property evaluation.

2.5. Purification of Sample

Following transesterification, the crude biodiesel was purified by successive washing with water to remove residual catalyst, methanol, glycerol, and other impurities. This purification step is critical to ensure the quality and stability of the biodiesel, as residual contaminants can negatively influence its physicochemical properties, combustion efficiency, and overall engine performance.

2.6. Factors Influencing the Transesterification Reaction

The efficiency of biodiesel production from fats and oils depends on several critical variables, such as reaction duration, catalyst selection and concentration, operating temperature, and the molar ratio of alcohol to oil. Alterations in these conditions can substantially affect the overall yield.

2.6.1 Reaction temperature

Reaction temperature plays a critical role in biodiesel production, as it directly influences both ester conversion efficiency and overall yield during transesterification. Maintaining an optimal temperature is essential because surpassing the boiling point of methanol (approximately 333 K; 60 °C) can result in evaporation losses, thereby lowering biodiesel output. For neat oils, operating above 323 K often reduces product yield, whereas in high-viscosity waste oils, moderately higher temperatures may improve reaction kinetics. Thus, precise control of reaction temperature relative to the boiling point of methanol under atmospheric conditions is crucial. Empirical studies suggest that 333 K (60 °C) provides an optimal balance between reaction rate and yield, particularly for vegetable oils such as watermelon and muskmelon seed oils.

2.6.2 Effect of catalyst amount and its type

Catalysts play a crucial role in the transesterification process, as they increase the reaction rate and improve biodiesel yield. Depending on the type, catalysts can be acidic, basic, or enzymatic. Base (alkali) catalysts are generally preferred for vegetable oils, as even small amounts (around 0.5% w/w of oil) can produce high conversion rates. For the production of ethyl esters,

potassium methoxide is considered one of the most effective catalysts. Among homogeneous catalysts, sodium hydroxide (NaOH) at a concentration of 0.5% and room temperature has been reported to achieve yields up to 71.2%, which is higher than that obtained with potassium hydroxide (KOH). In certain cases, particularly at elevated reaction temperatures, acid catalysts such as hydrochloric acid (HCl) can be employed, resulting in higher biodiesel production, especially when oils have elevated free fatty acid content.

2.6.3 Optimized Alcohol-to-Oil Molar Ratio for Efficient Biodiesel Production

The alcohol-to-oil molar ratio is a fundamental parameter that strongly influences the efficiency and yield of biodiesel production. It denotes the proportion of alcohol molecules available relative to triglycerides in the feedstock. In the transesterification process, three moles of methanol are theoretically required to react with one mole of triglyceride, producing three moles of fatty acid methyl esters (FAME) and one mole of glycerol. Ratios below this stoichiometric requirement often result in incomplete conversion, thereby reducing biodiesel yield. Conversely, excessively high alcohol levels do not necessarily improve conversion but can introduce several drawbacks, including soap formation, catalyst dilution, and difficulties in separating methyl esters from glycerol. These issues ultimately lower both the quality and the quantity of the final product. Hence, careful optimization of the alcohol-to-oil molar ratio is essential to achieve efficient transesterification, maximize yield, and ensure desirable fuel properties.

2.6.4. Impact of Reaction Time on Biodiesel Production

Reaction time is a key factor influencing the yield and quality of biodiesel during transesterification. Experiments conducted at varying durations, such as 90, 120 and 150 minutes at a specific temperature, indicate that increasing the reaction time generally enhances biodiesel yield. However, exceeding the optimal duration beyond 150 minutes can lead to biodiesel degradation and increased soap formation. For most vegetable oils, including watermelon and muskmelon seed oils, the ideal reaction time for transesterification typically ranges between 90 and

120 minutes to achieve maximum conversion efficiency without compromising product quality.

2.7 Quantitative and Qualitative Analysis.

After biodiesel production from the seed oils of *Citrullus lanatus* (watermelon) and *Cucumis melo* (muskmelon), the resulting biodiesel was characterized and analyzed using Fourier Transform Infrared (FTIR) spectroscopy to identify functional groups and confirm the conversion of triglycerides to methyl esters.

2.7.1 Fourier Transform Infrared (FT-IR) Analysis

Fourier Transform Infrared (FTIR) spectroscopy is commonly employed to analyze the chemical structure and functional groups of biodiesel. In this study Bio-Rad Excalibur FTIR was used, covering a spectral range from 4000 to 400 cm^{-1} . Each sample was scanned 15 times at a resolution of 1 cm^{-1} , enabling accurate identification of the characteristic bonds present in the biodiesel.

3. Results

The oil content of watermelon (*Citrullus lanatus*) and muskmelon (*Cucumis melo*) seeds was found to be 50% (w/w) on a dry-weight basis, indicating a high potential for biodiesel production. The oils were successfully extracted using Soxhlet apparatus with methanol as the solvent. Biodiesel was then produced from these oils through a two-step process involving esterification and transesterification. The maximum biodiesel yield obtained from both watermelon and muskmelon seed oils was 50% under optimized conditions, which included 0.5 g NaOH as a catalyst, a methanol-to-oil molar ratio of 1:6, a reaction time of 120 minutes, and a reaction temperature of 60 °C.

The effect of various reaction variables on biodiesel yield was also investigated. Biodiesel production increased with reaction time up to 120 minutes, but yields decreased when the reaction time exceeded 150 minutes. Catalyst concentration significantly influenced the yield, with 0.5 g of NaOH providing optimal results. Higher concentrations of catalyst led to soap formation, reducing methyl ester separation and overall biodiesel yield. The methanol-to-oil molar ratio of 1:6 was found to be ideal, as deviations from this ratio resulted in lower conversion efficiency. Similarly, reaction temperature played a crucial role,

with the highest yield observed at 60 °C. Temperatures above or below this optimal point led to reduced conversion due to alcohol evaporation or insufficient reaction kinetics.

FTIR spectroscopy was used to characterize both the seed oils and the resulting biodiesel. In watermelon oil, characteristic peaks were observed at 3000 cm^{-1} (C-H asymmetric stretching of lipids), 1750 cm^{-1} (C=O stretching of esters), 1500 cm^{-1} (CH_2 asymmetric bending), and 1250–730 cm^{-1} (C-H and $-(\text{CH}_2)_n$ methylene rocking vibrations). The biodiesel

mixture from watermelon and muskmelon exhibited peaks at 3315 cm^{-1} (O-H stretching of alcohols), 2937 and 2381 cm^{-1} (C-H stretching of alkanes), 1448 and 1405 cm^{-1} (C-C stretching in aromatic rings and C-H bending of alkanes), and 1000–600 cm^{-1} , corresponding to functional groups such as ethers, alkyl halides, alcohols, carboxylic acids, and esters. These results confirm the successful conversion of seed oils into fatty acid methyl esters (FAMES).

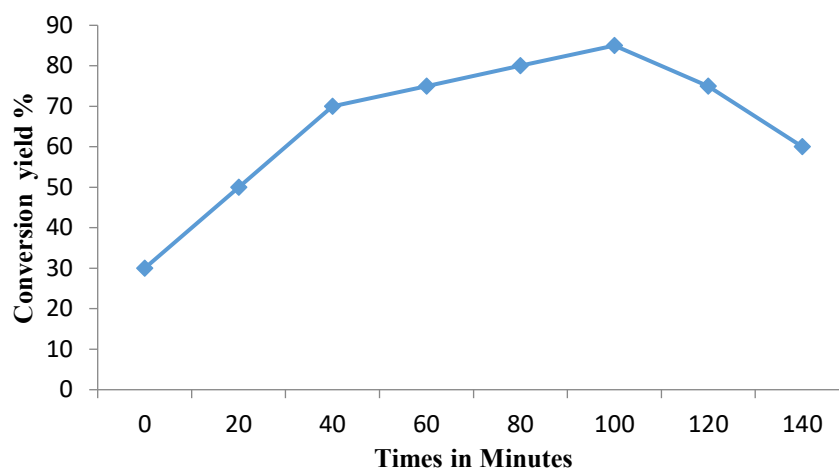


Figure 3: Effect of time reaction on Conversion yield%

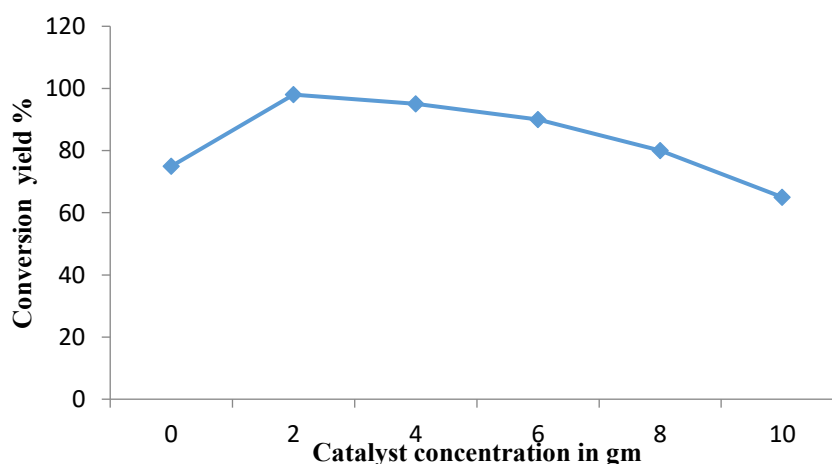


Figure 4: Effect of Catalyst concentration on Conversion yield%

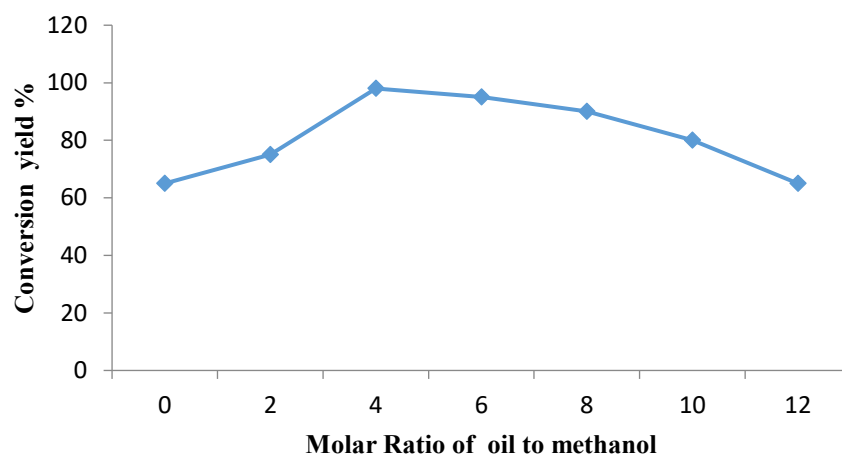


Figure 5: Effect of Molar Ratio on Conversion yield%

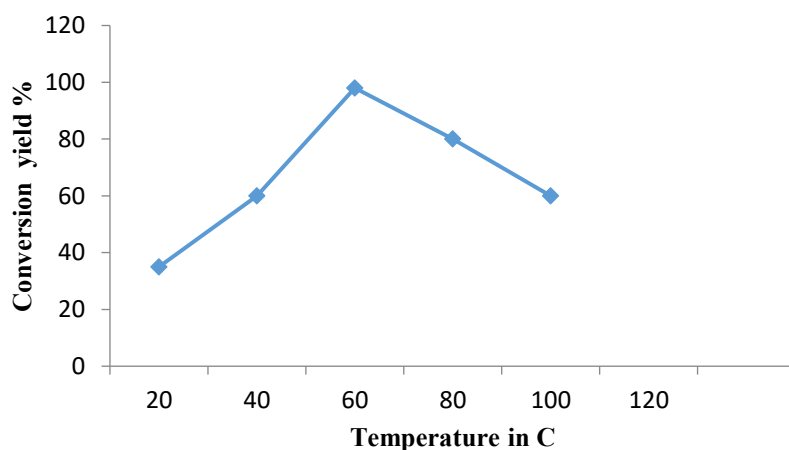


Figure 6: Effect of Temperature on Conversion yield%

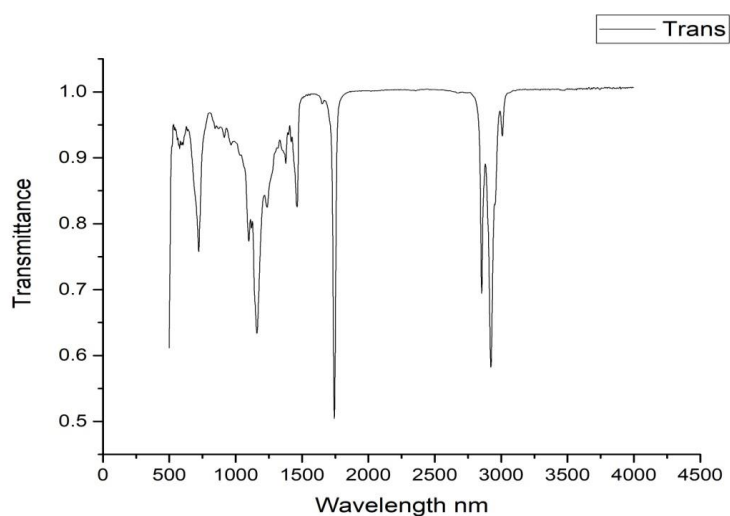


Figure 7: FT-IR spectrum of Water melon seed oil.

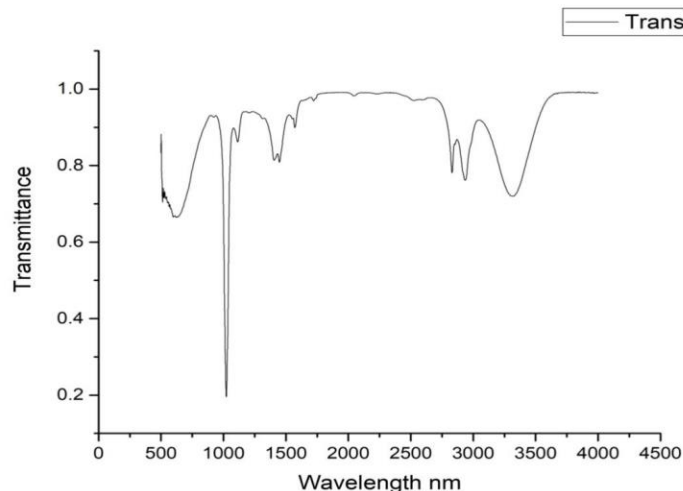


Figure 8: FT-IR spectrum of biodiesel samples of Water melon and Musk

4. Discussion

The experimental study aimed to evaluate the potential of watermelon (*Citrullus lanatus*) and muskmelon (*Cucumis melo*) seed oils as feedstocks for biodiesel production, focusing on their oil yields, biodiesel yields under varying reaction conditions, and chemical characterization through Fourier Transform Infrared (FTIR) spectroscopy. The oil extraction process yielded 50% oil from both watermelon and muskmelon seeds, indicating a substantial amount of oil available for biodiesel production. This oil content is comparable to other non-edible oils utilized for biodiesel synthesis, such as those from *Jatropha* and castor seeds (Rashid et al., 2011; Ismail et al., 2014). Transesterification of the extracted oils resulted in a biodiesel yield of approximately 50%, aligning with findings by Garuma et al. (2025) and Al-Bawwat et al. (2024), who reported similar yields from watermelon and muskmelon seed oils, respectively. The reaction conditions, including a catalyst concentration of 0.5 g NaOH in 100 mL methanol, a 1:6 molar ratio of methanol to oil, and a reaction time of 120 minutes at room temperature, were optimized to maximize biodiesel yield. These parameters are consistent with optimal conditions reported in the literature for biodiesel production from various seed oils (Farouk et al., 2024; Mohamad et al., 2017). It was observed that biodiesel yield increased with reaction time up to 120 minutes, beyond which there was a decline in

yield. This trend is corroborated by previous studies, such as those by Eevera et al. (2009) and Ma et al. (1998), who noted that prolonged reaction times can lead to the formation of soaps and a decrease in biodiesel yield due to reverse transesterification reactions. The optimal reaction time of 120 minutes balances complete transesterification with minimal side reactions, ensuring high biodiesel yield and quality. It was also found that a catalyst concentration of 0.5 g NaOH per 100 mL methanol was optimal for biodiesel production, as higher concentrations led to soap formation and reduced biodiesel yield. This finding aligns with research by Babajide et al. (2009) and Ojuego et al. (2014), who reported that excessive catalyst concentrations can cause soap formation, hinder biodiesel separation and reducing yield. Regarding the alcohol-to-oil ratio, a 1:6 molar ratio was found to be effective, as increasing the ratio beyond this point did not significantly enhance biodiesel yield and could lead to increased methanol consumption and process costs. This observation is consistent with findings by Demirbas et al. (2016), who emphasized the importance of optimizing the alcohol-to-oil ratio to achieve cost-effective biodiesel production. FTIR spectroscopy was employed to confirm the formation of biodiesel from both seed oils. The FTIR spectra of the biodiesel samples exhibited characteristic peaks corresponding to functional groups present in fatty acid methyl esters (FAMES).

Notably, the presence of peaks at 1740 cm^{-1} indicated ester ($\text{C}=\text{O}$) stretching vibrations, and peaks around 3000 cm^{-1} corresponded to C-H stretching vibrations of methyl and methylene groups. These findings are in agreement with studies by Rosset et al. (2019) and Ameen et al. (2018), who utilized FTIR spectroscopy to analyze biodiesel produced from various feedstocks, confirming the presence of ester functional groups characteristic of biodiesel.

5. Conclusion

This study confirms that watermelon (*Citrullus lanatus*) and muskmelon (*Cucumis melo*) seeds are viable non-edible sources for biodiesel production. Oil extraction from the seeds yielded approximately 50% oil for each species, providing a substantial feedstock for sustainable biofuel synthesis. Using optimized transesterification conditions catalyst concentration of 0.5 g NaOH per 100 mL methanol, reaction time of 120 minutes, a 1:6 molar ratio of alcohol to oil, and reaction temperature of 60°C biodiesel yields reached up to 50% from both seed oils. The study also highlighted how critical reaction parameters are in influencing biodiesel yield. Excessive catalyst or extended reaction time led to soap formation and reduced methyl ester conversion, whereas alcohol-to-oil ratios above the optimum did not improve yields and increased process costs. The selected reaction conditions ensured efficient conversion while minimizing unwanted side reactions, demonstrating the importance of controlled optimization in biodiesel synthesis. FTIR analysis verified the chemical structure of the produced biodiesel, with characteristic peaks indicating the presence of ester groups ($\text{C}=\text{O}$ stretching around 1740 cm^{-1}) and C-H stretching vibrations of methyl and methylene groups ($\sim 3000\text{ cm}^{-1}$). These results confirmed the successful formation of fatty acid methyl esters, validating the suitability of the biodiesel for use as an alternative fuel. Watermelon and muskmelon seed oils represent promising renewable feedstocks for biodiesel production. Their utilization not only adds value to agricultural by-products but also offers an environmentally friendly alternative to fossil fuels. The findings support the potential for scaling up biodiesel production from these Cucurbitaceae

seeds, providing a practical and sustainable option for renewable energy generation.

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