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Optimization and Characterization of Biodiesel Production from Mango Seed Oil (*Magnifera indica)* via Transesterification Reaction

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Abstract

This study focuses on optimizing biodiesel production from Mango Seed Oil (MSO) extracted from Mangifera indica seeds using the transesterification reaction. Response surface methodology (RSM) was employed to optimize the process parameters, including catalyst type, concentration, alcohol to oil ratio, temperature, and reaction time. The physicochemical properties of the biodiesel were characterized and compared with international standards. The study highlights the viability of Mango Seed Oil as a promising feedstock for sustainable biodiesel production, contributing to the advancement of the renewable energy sector. the biodiesel obtained from mango seed oil by transesterification process was also found to be predominantly biodiesel with a good yield of 95 %

1. Introduction

The road to a sustainable energy future is the continuous development of substitute materials from available resources. Cleaner burning fuels improve engine performance, provide better lubrication, and leave behind fewer particulate deposits. They reduce emissions related to the life cycle of fuels, pollution, and CO_2 that causes global warming. The production of clean fuels from waste agricultural products can help countries become self-sufficient in their energy needs. [1]
Biodiesel is created using organic materials that are renewable, like animal and vegetable fats. According to the American Society for Testing and Materials' definition of biodiesel, it is a fuel made up of mono alkyl esters of long-chain fatty acids derived from vegetable or animal fats. The main method for producing biodiesel is transesterification, which involves reacting an alkyl alcohol with a long chain ester linkage in the presence of a catalyst. Non-toxicity and eco-friendliness are some of the benefits of biodiesel. In terms of quality and effectiveness, biodiesel is superior to petro-diesel. [2]

There is a potential source for mango seed oil from the mango seeds, the availability of mango seed in abundant in this part of the world means a great potential source in the production of mango seed oil which can be converted into biofuel that is biodiesel. Lauric, capric, palmitic, margaric, linoleate, and methyl stearate make up 85% of the total fat in mango seed oil. There are large quantities of palmitic acid in soft mango seeds. There are a number of ways in which the production of biodiesel has been accomplished. There isn't a lot of information about the production of biodiesel from mango seed oil. Mango seeds are widely available. The manufacturing of industrial goods like soaps, creams, and other products puts edible oils in intense competition with one another. [3]
From past work done in this field, [1], [2], and [4] produced the biodiesel from the extracted oil and characterized the biodiesel using NaOH as the catalyst, [3] produced the biodiesel but performed kinetic studies on the production of biodiesel, [5] produced the biodiesel and performed efficiency test on the engine, [6] produced, characterized the biodiesel and blended it with conventional diesel, [7] produced biodiesel using transesterification method using both acid and base homogenous catalyst, [8] produced the biodiesel, characterized, blended at a particular ratio and performed efficiency test on the engine. My work centers on the optimization and characterization of biodiesel production from mango seed oil which is working on the optimum time, temperature, catalyst concentration and oil/alcohol ratio.

2.Material and Methods

2.1 Materials
Magnifera indica seed kernel sample that has been ground, N-hexane, methanol, vegetable oil that has been extracted from the plant's seed kernel, sodium hydroxide pellets (caustic soda), and a Soxhlet extractor were the tools used for oil extraction. To determine the kinematic viscosity, a Brookfield viscometer was used. Other machinery used for oil extraction and the creation of biodiesel includes an electronic weighing balance and a water bath shaker.

2.2 Methods
This experiment's objective was to extract oil from the sample using the following technique. Using an electric balance, 100g of the seed sample was measured and put into the thimble of the Soxhlet extraction apparatus. The oil was extracted from the thimble using 175ml of n-hexane solvent over the course of 2-4 hours at 68°C. The extract (oil and solvent mixture) was then placed in an oven to help the solvent evaporate, resulting in the production of pure oil.
An electric weighing balance was used to precisely measure the 84g seed sample. The Soxhlet extraction apparatus's thimble was filled with the measured sample. The thimble containing the seed sample was filled with 250ml of n-hexane solvent. It took between two and four hours for the solvent to successfully extract the oil from the seeds at a temperature of 68 °C. In an oven, the resulting mixture of oil and solvent was then heated until the solvent had completely evaporated, leaving only the pure oil. Following the described procedure, this extraction process was repeated for each sample until the desired amount of oil was obtained. [4](Hiwot 2018). From literature, several variations were carried out to know the range of the independent factors which has to with production of biodiesel. From the tested ranges, the values were input into the design expert application of which a total of 29 runs was concluded. 30ml of oil was measured into a conical flask, with methanol ratio was taken and measured (calculations was carried out to get the exact volume of methanol used), the catalyst of 0.3%wt/vol was measure into the conical flask (calculations was carried out to get the exact mass in gram of NaOH which is the catalyst used). The water bath shaker was used to carry out this experiment, the temperature of 35^{o}C, and time of 60 minutes and speed of 150rpm was input into the machine until the time elapsed. After which the sample was placed in a separating funnel, which the biodiesel was on top and the glycerol was at the bottom. The glycerol was removed

and the biodiesel was washed several times with room temperature distilled water until the water was clear, then the sample was placed in the oven to remove any form of water before allowing to cool. This process was repeated for all the runs with the different time, temperatures, catalyst concentration and oil/alcohol ratio. Then the samples were package to take for analysis. All results analysed are in the table in my results.
'Design Expert®' (Version 13.0.0, Stat Ease, Inc., USA) software was used to optimize the production of biodiesel from mango using response surface methodology (RSM) with the Box-Behnken module. In this study, the methanol-to-oil ratio, catalyst loading, temperature, and reaction time were all taken into account.

Table 1: Independent factors used for Box-Behnken in transesterification of the extracted oil

Variables	Low	High	Unit
Temperature	35	75	^{O}C
Time	60	180	Minutes
Catalyst Concentration	0.3	0.7	%wt/vol
Methanol to Oil Ratio	3:1	9:1	vol/vol

3.Results and Discussions

Table 2 shows the physical and chemical characteristics of the oil from Magnifera Indica seeds. Magnifera Indica seed oil has the potential to be used in the production of biodiesel, according to the findings. The yield of the seed oil is significant, and it is within the range of vegetable oils that can be used to make biodiesel. The oil has a non-drying characteristic and is suitable for the production of biodiesel.

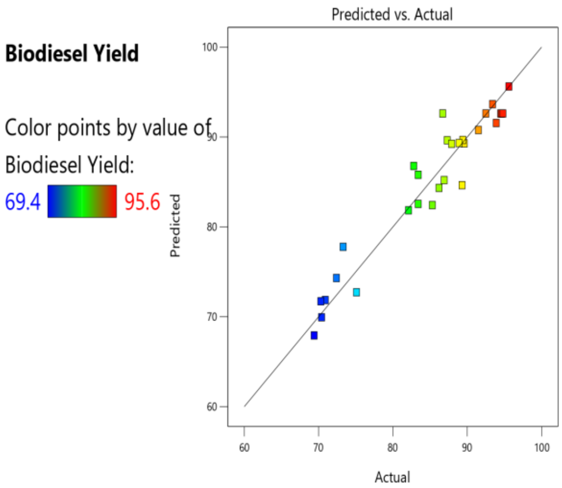
Table 2: Physiochemical Properties of Mango seed Oil

Property	Unit	ASTM	Mango oil	Idimogu *et al. (2021)*
Specific gravity	-	0.957– 0.968	0.87	0.877
Saponification Value	MgKOH/g	175-187	190.05	207.57
Iodine value	gI_2/100g oil	82-88	17.8	7.11
Acid value	mgKOH/g	0.4-4.0	11.23	21.03
Viscosity	Cst	35	6.4	2.6
Refractive index	-	-	1.4643	1.46
Peroxide value	meq/kg	5.00	8.4	-
%FFA	%	25	5.61	10.525
Density	g/cm^3	0.7-0.95	0.92	-
Molecular weight	-	300-314	941.17	-

The American Society for Testing and Materials has set a range of 190 for mango oil's saponification value. This demonstrates that stearic acids are present. The range for mango oil's free fatty acid content is 5. Accordingly, it is likely that the mango oil won't be corrosive, which could harm fuel tanks and pumps. When making biodiesel, oils with high free fatty acid values can form soap easily and are challenging to separate.
Because of its low iodine content, mango oil has a low level of unsaturation. Oils with low iodine content can be used to make biodiesel because heating oils with higher levels of unsaturation can

result in the formation of deposits. The peroxide value of the mango oil is higher than the benchmark, demonstrating the oil's strong oxidative stability. Mango oil has a lower density than water. Compared to water, oils have a lower density. The density of oil rises with the degree of unsaturation.

The predicted value is shown in Figure 1 along with a graph of the actual values obtained during the transesterification of mango seed oil. It was discovered that the actual and predicted values differed slightly, so they are aligned with the straight line. They all fall on the line of the normal residual plot when compared to the actual and predicted value.



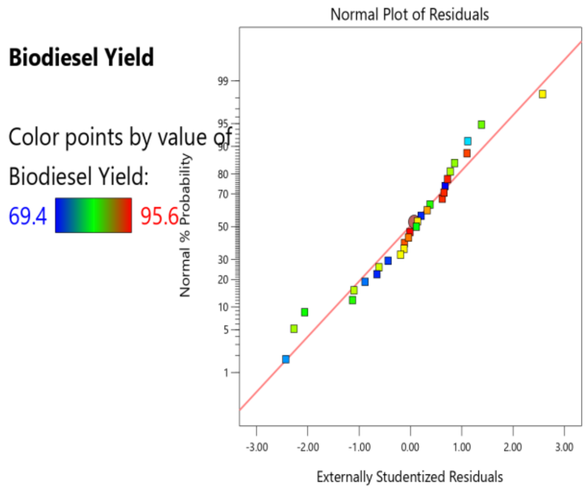
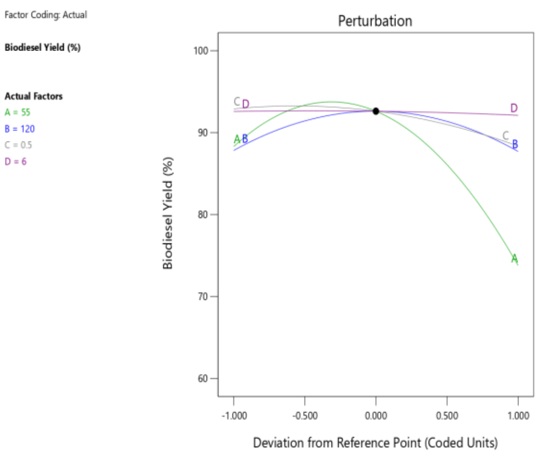


Figure 1: Predicted values vs. actual values **Figure 2: Normal Plot of Residuals**

The graph displays the relationship between each independent variable. The yield is plotted against a reference point in the graph. The reference point represents a baseline or typical condition. When all of the independent factors are in agreement, the deviation from the reference point is zero. After this, it fluctuates between 90 and 100 percent. The yield is consistent with the best experimental results attained during biodiesel production in figure 3 and 4.



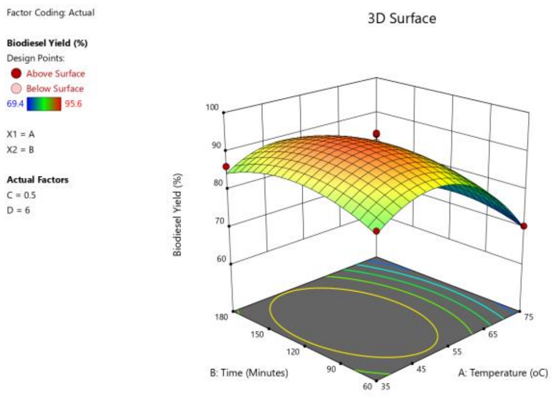
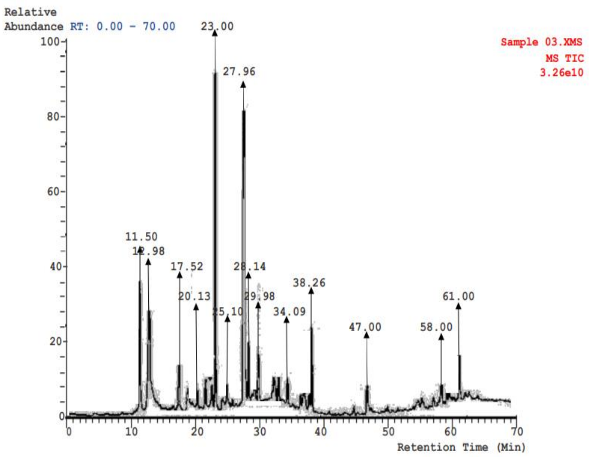


Figure 3: Perturbation. **Figure 4: Response surface plot of the interaction effect of reaction time and reaction temperature**

Table 3: Physiochemical properties of mango biodiesel

Property	Unit	ASTM (D6751)	ASTM (D975)	EN 14214	Mango biodiesel	Hiwot (2018)
Kinematic viscosity 40°C	mm^2s^{-1}	1.9– 6.0	1.9-4.1	3.5-5.0	35.20	5.63
Pour Point	°C	-15 to 10	-	-	26	-
Cetane Number	-	47 min	40	51 min	46 mins	-
Acid Value	71g.KOH/g	0.50 max	-	0.50 max	11.13	0.12
Cloud Point	°C	-3 to 12	-		-	-
Flash point	°C	130 min	52 min	-	216	132
Ash Content	%	-	0.01	-	0.09	-
Specific gravity	-	0.80-0.90	-	-	0.91	0.87
Density	g/cm^3	0.79-0.91	-	0.86-0.90	0.92	0.87
Saponification Value	71g.KOH/g	-	-	-	168.75	209.72
Peroxide value	meq/kg	-	-	-	12.65	12.63
Iodine Value	gI_2/100g oil	-	-	120 max	65.32	39.56

Table 3 compares the mango Biodiesel's values to industry standards and some academic works. Not all analysis was perormed but the ones listed are the ones that was done.



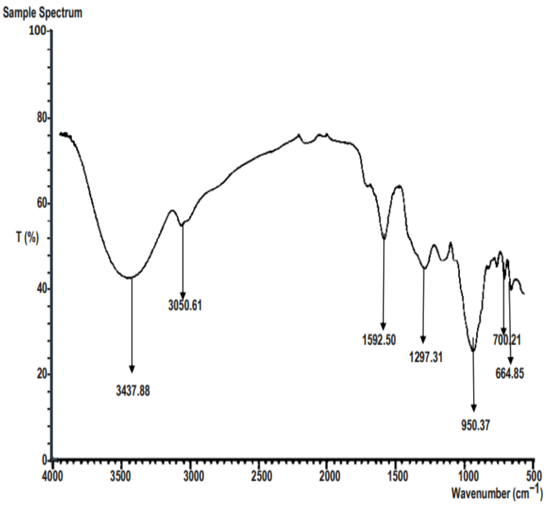


Figure 5: GC-MS Analysis of Mango Biodiesel Produced

Figure 6: FTIR Analysis of Mango Biodiesel Produced

Based on the band stretched across the absorbance or frequency axis in figure 6, the hydroxyl group, Alkanes, Carbonyl, Alkenes, Aromatics Hydrocarbon are in the group frequencies while Alkanes, Ether, Alkyl halides and Aromatics Carbons are in the molecular fingerprint frequencies In figure 5, Different hydrocarbon groups were distinguished based on the retention time of standard hydrocarbons (such as octadecane, heptadecane, eicosane, and tricosane) and the molecular carbon chain length. These groups were categorized as <C15, C15 – C20, C20 - C30, and >C30. The presence of specific compounds, such as 9,12-Octadecadienoic acid (Z,Z) and

Eicosanoic acid, indicated the presence of methyl esters and saturated fatty acids, respectively, in the biodiesel sample.

4. Conclusion

After the optimum results was achieved, it was concluded that the industrial utilization of Magnifera indica oil for the production of biodiesel is favorable because of its oil yield capacity from the plant and its limitation for utilization as edible oil. The promising plant having oil yield of 396 g/kg (42%) with 88% extraction efficiency revealed high oil yield, and fact that the Soxhlet extractor could extract about 88% of the available oil present in the seed. The predicted biodiesel yield for the desert date biodiesel was 96.144% with a reaction temperature of 50.364^{o}C, reaction time of 126 minutes, catalyst concentration of 0.319 and methanol to oil ratio of 7:1. However, after performing the experiment 5 times, the actual biodiesel yield achieved was 95.854% with a standard deviation of 0.290.

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