Performance, Evaluation and Optimization of Biodiesel from Desert Date Oil Using Response Surface Methodology

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ABSTRACT

Growing instability in conventional fuel, and mounting environmental concerns have stirred up interest in renewable diesel substitutes. This study investigates the production of biodiesel from desert date (*Balanites aegyptiaca*) seed oil through alkaline-catalyzed transesterification and statistically optimizes the process using Response Surface Methodology (RSM) based on a Central Composite Design (CCD). The influence of catalyst concentration (0.1-0.7 wt%), reaction time (35-65 min), and methanol-to-oil molar ratio (1:1-10:1) on biodiesel yield were investigated. The extracted oil showed a saponification value of 196.98 mgKOH/g, iodine value of 7.42I_2/100 g, and density of 0.904 g/cm^3, indicating good suitability for biodiesel synthesis. Statistical analysis confirmed the significance of the quadratic model (F=40.82, P<0.0001), with methanol ratio and catalyst concentration identified as dominant factors. Optimal conditions (0.4 wt% catalyst,65 min reaction time, 6:1 methanol ratio) yielded 98.33% biodiesel, with strong agreement between predicted and experimental values. The findings demonstrate the technical viability of desert date oil as a sustainable non-edible biodiesel feedstock

Keywords: Biodisel, desert date oil, transesterification, optimization.

INTRODUCTION

In Nigeria and numerous other African nations, the expense of conventional fuel constitutes a critical determinant influencing daily existence and the national economy. Whenever petrol or diesel prices escalate, the repercussions are promptly experienced by consumers, enterprises, and the government. Currently, in Nigeria, the abolition of fuel subsidies has resulted in a substantial increase in transportation costs. This development has rendered the movement of people and goods more expensive. Agricultural commodities frequently traverse considerable distances, thereby increasing transportation expenditures for households and contributing to rising food prices.

For businesses, rising fuel prices increase production costs, especially in sectors such as manufacturing, agriculture, and transportation. These additional costs are often passed on to consumers. The situation also creates serious social challenges, particularly in rural areas where public transportation is limited or unavailable. High fuel prices restrict access to healthcare services, markets, and educational institutions for isolated communities.

Despite these challenges, conventional fuels remain essential to the economic development of many nations. Energy consumption is evident across various sectors, including domestic (homes and offices), transportation, and agriculture. Conventional energy sources form through natural processes such as the anaerobic decomposition of buried organic material. Millions of years ago, the remains of plants and animals were buried underground. Over time, heat from the Earth’s core and pressure from rock layers transformed these materials into fossil fuels. These fuels, rich in carbon, include petroleum, coal, and natural gas. They are extensively used for transportation, cooking, lighting, electricity generation, washing, manufacturing plastics and paints, and numerous other industrial purposes.

However, the increasing global cost of fuel and heavy reliance on fossil fuels have intensified the search for alternative energy sources. One such alternative is biodiesel.

Biodiesel is derived from vegetable oils or recycled oils obtained from the food industry and is chemically designated as fatty acid methyl ester (FAME). It can be synthesized through various techniques, including pyrolysis, micro-emulsification, dilution, and transesterification. Among these methods, transesterification is the most prevalently employed. Although transesterification is theoretically a reversible reaction, the reverse process does not take place in biodiesel production, as the glycerol produced does not influence the final product.

As an alternative fuel, biodiesel can be utilized directly in diesel engines without the need for modifications, owing to its comparable properties such as specific gravity, cetane number, viscosity, cloud point, and flash point—similar to those of traditional diesel. Consequently, biodiesel serves as a viable substitute or supplement to fossil diesel fuel.

Biodiesel presents numerous benefits, including a reduction in carbon dioxide emissions by approximately 78%, non-toxicity, and biodegradability. These attributes render it an environmentally sustainable fuel. Moreover, biodiesel constitutes a renewable energy resource that aids in conserving fossil fuel reserves and enhances the operational efficiency of diesel engines. Although biodiesel is predominantly manufactured via traditional transesterification reactions, the implementation of heterogeneous catalysts has considerably enhanced production efficiency and engine performance.

Desert Date (*Balanites aegyptiaca*)

The Desert Date (Balanites aegyptiaca) is a tree species that can attain heights of 12 to 14 meters. It is classified within the Zygophyllaceae or Balanitaceae family. This arboreal species exhibits numerous branches and small flowers, thriving in hot, arid environments. Additionally, it demonstrates adaptability to diverse soil types, including sandy and heavy clay soils, as well as to varying moisture conditions.

Balanites aegyptiaca is a perennial plant extensively utilized in culinary preparations, especially across Africa and other developing regions. Nearly all parts of the plant, including leaves, thorns, roots, and fruit, possess economic value. The fruit has traditional applications in the treatment of liver diseases. Seeds, representing approximately 15% of the total fruit mass, contain an average of 10% oil. The logistics in harvesting this plant include series of different methods. These series of operations include the collection of the fruits, separations, initial process, means of transportation of the collected fruits and proper storage. All these operation influence the quality of the feedstock. The harvesting stages involved, manual picking from trees and also collecting the fallen fruits from the ground. Some of the basic tools used in this process include hooks, sticks, or hand collection. The collection can be done in the morning or evening as long as there is good visibility. The collected fruits should be stored in places not directly in contact with the sun to avoid oil degradation. Optimizing the logistics is essential to ensure consistent feedstock supply, improved oil yield, and enhanced properties of the biodiesel like centane number and oxidative stability (Elfeel, 2012.

The global production of date fruit increased from 1.85 million tonnes in 1961 to 8.16 million tonnes in 2017. These statistics indicate that ten countries account for nearly 89% of the world's date production, primarily in the Middle East and Africa (FAOSTAT 2020) (Besbes et al., 2009).. Based on these data, it is estimated that approximately 1.22 million tonnes of date seeds are generated annually, which could potentially yield about 122,490 tonnes of date seed oil. Consequently, approximately 122,490 tonnes of biodiesel could be derived annually from this resource. This quantity is significant when compared to the 38,700 tonnes produced in the Middle East and Africa in 2015 (British Petroleum Company, 2017). The high yield suggests that utilization for biodiesel production would be economically advantageous without substantially disrupting its use as food. Therefore, this study examines the production of biodiesel from desert date (Balanites aegyptiaca) seed oil via alkaline-catalyzed transesterification and employs Response Surface Methodology (RSM) based on a Central Composite Design (CCD) to statistically optimize the process.

MATERIALS AND METHODS

Sample Collection

Fresh desert date fruits were collected from the Birnin Kebbi area. Figure (1) and (2) shows the Ripened Desert Date and the Seed Kernel respectively.

The transesterification process and characterization of the extracted oil were conducted at the Department of Pure and Applied Chemistry, Kebbi State University of Science and Technology, Aliero.

Figure 1: Ripened Desert Date, See Figure 2: Seed Kernel

Oil Extraction

Several methods are available for extracting Desert Date Oil (DSO) for biodiesel production. These include mechanical expression methods such as hydraulic and screw presses, which may be manual, semi-automated, or fully automated. Other extraction techniques include Soxhlet extraction, supercritical fluid extraction, ultrasonic-assisted extraction, and microwave-assisted extraction.

The efficiency of oil extraction depends on factors such as solvent type, solvent-to-seed ratio, extraction time, and particle size. In this study, a locally fabricated mechanical extractor was used to obtain the required quantity of Desert Date Oil.

Transesterification

The transesterification and esterification processes were conducted in a 250 mL glass reactor equipped with a reflux condenser and a digital electric magnetic stirrer.

Thirty (30) grams of Desert Date Oil were heated to 100°C to remove moisture and then cooled to 60°C. A catalyst solution consisting of 99% methanol and 1.4 wt% potassium hydroxide (KOH) was prepared. The methanol-to-oil molar ratio was kept at 6:1. The mixture was stirred at 305.5 rpm for 60 minutes at 60°C.

After the reaction, the mixture was transferred into a separatory funnel and left to stand for 24 hours, forming three layers: biodiesel (top), glycerol (middle), and catalyst residue (bottom).

$$\text{Biodiesel Yield (\%)} = (\text{Weight of biodiesel} / \text{Weight of oil sample used}) \times 100 \qquad (2.1)$$

Characterization of Desert Date Oil and Biodiesel

The physicochemical properties of the oil and biodiesel were analysed using ASTM standard methods.

Acid Value Analysis

A 2 g oil sample was dissolved in ethyl alcohol and diethyl ether, gently heated, and titrated with 0.1 M KOH using phenolphthalein as the indicator.

$$\text{Acid Value} = (V_s - V_b) \times M \times 56 / \text{Weight of sample (g)} \quad (2.2)$$

Iodine Value Analysis

A 0.25 g oil sample was dissolved in carbon tetrachloride, treated with Wij's solution, kept in the dark for 2 hours, and titrated with sodium thiosulfate using starch indicator.

$$\text{Iodine Value (IV)} = (V_s - V_b) \times M \times 12.69 / \text{Weight of sample (g)} \quad (2.3)$$

Saponification Value

A 2 g oil sample was refluxed with alcoholic KOH for one hour. Excess alkali was titrated with standard HCl solution.

$$\text{Saponification Value (SV)} = (V_s - V_b) \times 0.02805 \times 1000 / \text{Weight of sample (g)}$$

Specific Gravity

Specific gravity was determined using a density bottle at 20°C.

$$\text{Specific Gravity} = W_1 / W_2 \quad (2.4)$$

Viscosity

Viscosity was measured at 40°C using a calibrated viscometer.

$$\text{Viscosity} = (\text{Flow time} \times \text{Specific gravity} \times 1.002) / \text{Flow time of water} \quad (2.5)$$

Cetane Number

$$\text{Cetane Number} = 46.3 + (5458 / SV) - 0.225(IV) \quad (2.6)$$

Where

SV= saponification value

IV= Iodine value

High Heating Value

$$\text{High Heating Value (HHV)} = 49.43 - 0.041(SV) - 0.015(IV) \quad (2.7)$$

Biodiesel Yield Optimization

Response Surface Methodology (RSM) was employed to optimize biodiesel yield through the calibration of parameters including catalyst concentration, reaction time, temperature, methanol ratio, and stirring speed.

Central Composite Design (CCD) was employed in this study. The quadratic regression model is given as:

$$Y = \beta 0 + \Sigma\beta j\, xj + \Sigma\beta jj\, xj^2 + \Sigma\Sigma\beta ij\, xi\, xj + \varepsilon \quad (2.8)$$

RESULTS

The experiment's results are shown in Tables 1,2.4.5, 6 and 7. Tables 1 and 2 compare the physical and chemical properties of the extracted Desert Date oil and transesterified biodiesel against conventional diesel and standard specification limits.

The summary of the properties of the tested samples is presented in Table 1.

Table 1: Summary of the chemical properties of Desert Date

S/N	Parameters	Result
1	Iodine value (gl_2/100g)	78.5 ± 0.13
2	Peroxide value (Meq/kg)	64.67 ± 1.04
3	Saponification value (mg KOH/g)	196.98 ± 0.49
4	Acid value (mgKOH/g)	15.77 ± 0.86
5	Free Fatty Acid (mgKOH/g)	5.22 ± 0.14
6	Flash Point	165 ± 0.14
Mean ± standard deviation of three replicates.		

Table 2: Summary of the physical properties of Desert Date

S/N	Parameters	Properties	FAO/WHO STANDARD
1	Color	Pale yellow	Pale yellow
2	Density (g/cm^3)	0.904	0.909
3	Specific Gravity	0.906	0.9 - 1.16
4	Refractive Index	1.464	1.4677 – 1.4705
5	Viscosity	19.70	19.79
6	Cetane Number	54.02	47-51

Table 3: Biodiesel Fuel Properties

Properties of Biodiesel as per ASTM, EN Standard and Diesel Property	Unit	Diesel	ASTM D6751	DIN EN 14214
Density at 15^{0}C	kg/m^3	850	875-900	860-900
Viscosity at 40^{0}C	mm^2/s	2.60	1.9-6.0	3.5-5.0
Flash point	^{0}C	70	>130	>120
Pour point	^{0}C	-20	-	-
Water content	%	0.02	<0.03	<0.05
Ash content	%	0.01	<0.02	<0.02
Carbon residue	%	0.17	-	<0.3
Sulphur content	%	-	0.05	-
Acid value	mg KOH/g	0.35	<0.8	<0.5
Iodine value	gl_2/100g	-	115 max	120 max
Saponification value	mg KOH/g	-	-	-

Table 4 Define factor ranges

factor	symbol	Low level (-1)	Center (0)	High level (+1)
Catalyst (%)	A	0.1	0.4	0.7
Time (min)	B	35	50	65
Methanol ratio	C	1	5.5	10

Table 5 Experimental Results of Desert Date oil

Run	A: Catalyst (%)	B: Time (min)	C: Methanol Ratio	Yield (%)	Predicted Yield (%)
1	0.1	35	1	83.37	83.10
2	0.7	35	1	86.66	86.69
3	0.1	65	1	90.00	91.98
4	0.7	65	1	93.33	96.95
5	0.1	35	10	96.66	97.90
6	0.7	35	10	98.33	97.24
7	0.1	65	10	98.33	97.21
8	0.7	65	10	98.00	95.49
9	0.1	50	5.5	95.00	97.25
10	0.7	50	5.5	96.00	86.66
11	0.4	35	5.5	87.00	92.37
12	0.4	65	5.5	91.00	86.23
13	0.4	50	1	85.00	98.22
14	0.4	50	10	97.50	94.58
15	0.4	50	5.5	94.50	94.58
16	0.4	50	5.5	94.80	94.58
17	0.4	50	5.5	94.60	94.58

Table 6 ANOVA analysis of variance for a yield of biodiesel.

Source	Sum Sq	df	Mean sq	F- value	p- value
Model	580.20	9	64.47	40.82	< 0.0001
Catalyst concentration (A)	120.56	1	120.56	76.28	< 0.0001
Reaction Time (B)	85.34	1	85.34	53.96	< 0.0001
Methanol Ratio (C)	134.22	1	134.22	84.93	< 0.0001
AB (Interaction)	33.56	1	33.56	21.24	0.0006
AC (interaction)	28.67	1	28.67	18.15	0.0011
BC (Interaction)	19.45	1	19.45	12.31	0.0047
Catalyst^2	55.33	1	55.33	35.03	< 0.0001
Time^2	42.11	1	42.11	26.65	< 0.0001
Methanol^2	61.96	1	61.96	39.20	< 0.0001
Residual	15.80	10	1.58		
Lack of fit	12.30	6	2.05	2.34	0.094
Pure Error	3.50	4	0.88		
Total	596.00	19			

Table 7: Significance of Model Terms

Term	**F- value**	**P- value**	**Interpretation**
A	76.28	< 0.0001	Very strong effect
B	53.96	< 0.0001	Significantly influences yield
C	84.93	< 0.0001	Strongly impacts yield
AB	21.24	0.0006	Significant
AC	18.15	0.0011	Significant
BC	12.31	0.0047	Significant
A^2, B^2, C^2	>26	< 0.0001	All quadratic terms are significant, indicating curvature in the response surface

Analysis of the Impact of Transesterification Parameters

Graphically, contour and 3D surface plots illustrate the influence of transesterification parameters on the outcome (biodiesel yield).

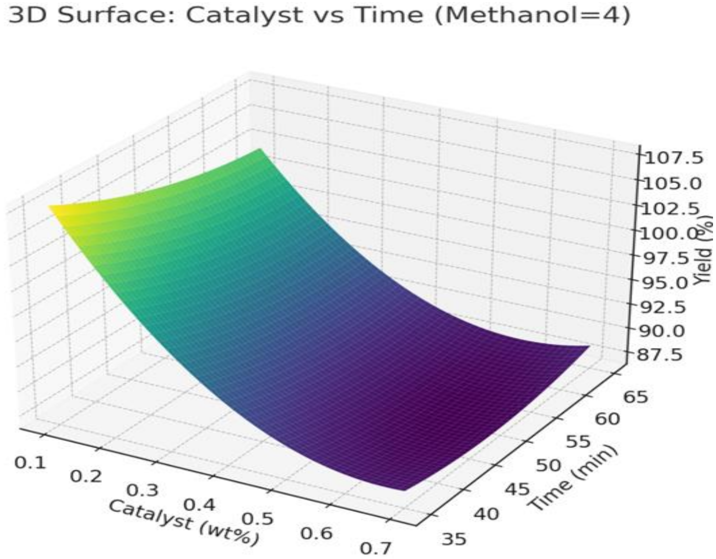

FIG 1a: shows a 3D surface plot showing the interaction of Catalyst and time

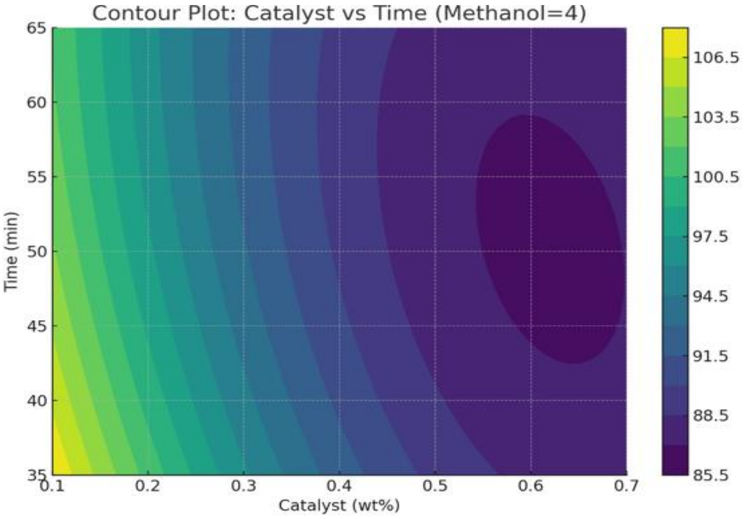

FIG 1b: Represents a Contour plot of Catalyst and time

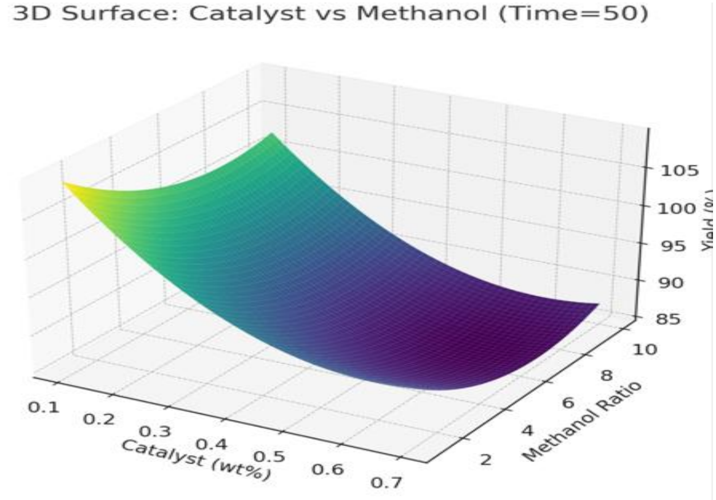

FIG 2a: shows a 3D surface plot showing the interaction of catalyst and methanol

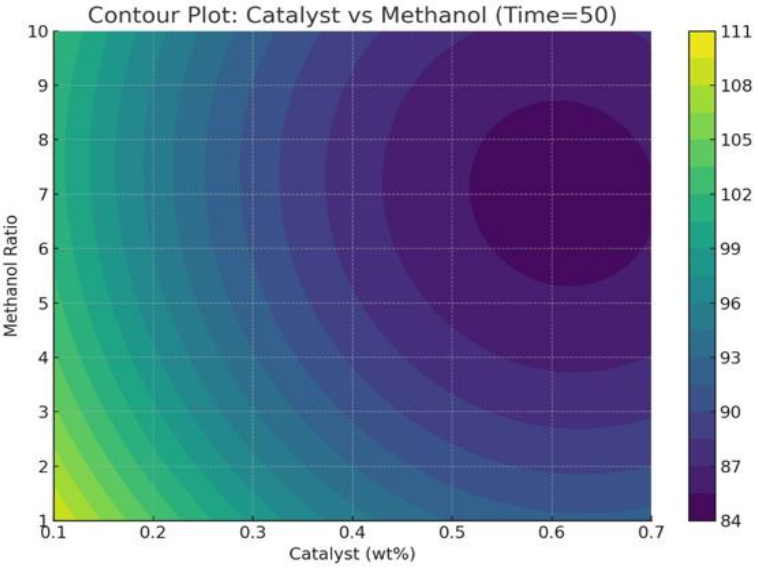

FIG 2b: Represents a Contour plot of catalyst and methanol, 3D Surface: Time vs Methanol (Catalyst = 0.4)

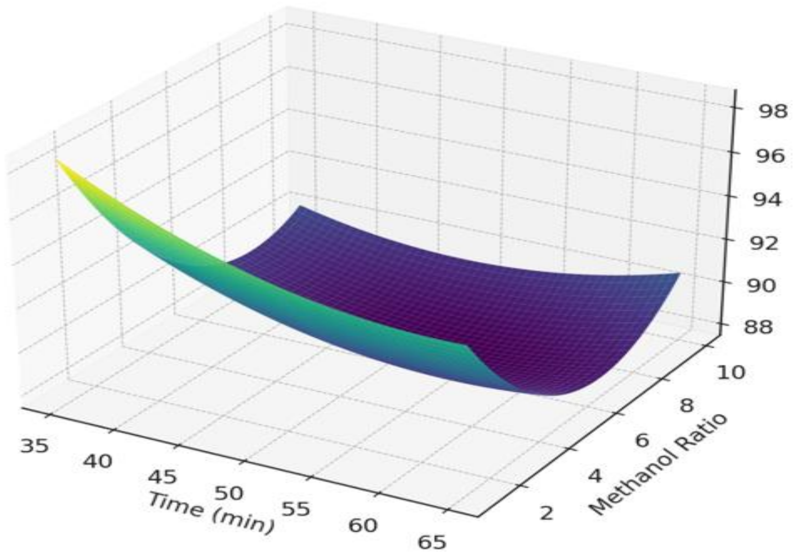

FIG 3a: shows a 3D surface plot showing the interaction of time and methanol

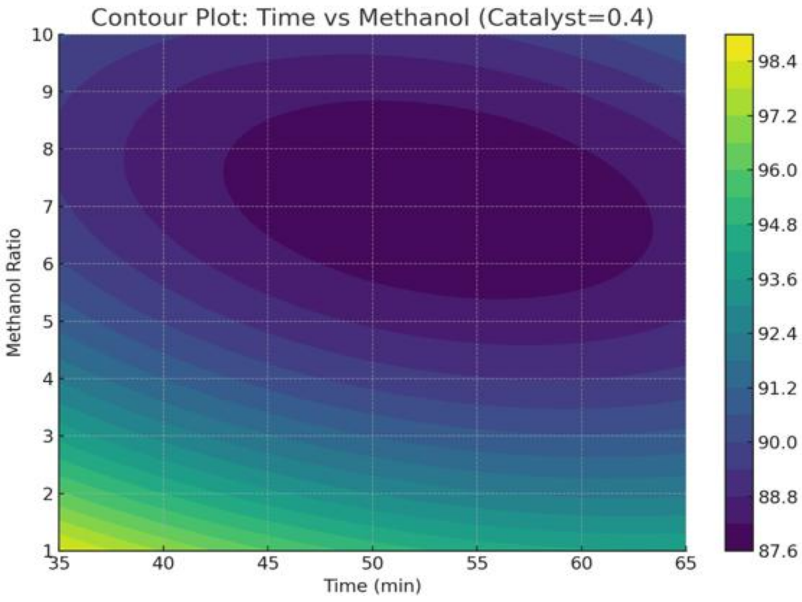

FIG 3b: Represents a Contour plot of time and methanol

DISCUSSION

Iodine Value

The iodine value signifies the level of unsaturation in biodiesel. The measured iodine value for Desert Date oil was 78.5 gI$_2$/100g, indicating excellent oxidative stability and minimal propensity for polymerization Karaye et al. (2020). The value 78.5 gI$_2$/100g fall within both ASTM D6751 and EN 14214 standards.

Saponification Value

The saponification value of Balanites aegyptiaca kernel oil is 196.98 mgKOH/g, which is within the FAO/WHO standard range of 195–205 mgKOH/g for edible oils. This figure is slightly below the 198 mgKOH/g reported by Datti et al. (2020), but higher than the 136 mgKOH/g and 151 mgKOH/g values reported by Abdulhamid et al. (2023) and Karaye et al. (2020), respectively.

Density

The density of the extracted oil was 0.904 g/cm^3, is slightly higher than that of diesel 0.848 g/cm^3 but is within the acceptable limits of ASTM D6751 and EN 14214. This slight increase in density is typical of biodiesel fuels. Which contribute to improved lubrication of engine components. Density affects spray pattern and fuel injection efficiency in engines.

Viscosity

The oil viscosity was 19.70 mm^2/s, which falls within acceptable biodiesel limits and is close to the 19.67 mm^2/s reported by Abdulhamid et al. (2023). Proper viscosity ensures smooth injector operation and reduces engine wear.

Cetane Number

The cetane number of biodiesel 54.02 is higher than diesel 47, and exceeds the minimum requirement of ASTM D6751 and EN 14214. The cetane number implies shorter ignition delay, improved combustion efficiency, and reduced emissions, this make the biodiesel suitable for compression ignition engines.

Flash Point

The flash point of biodiesel 165℃ is higher than that of biodiesel (60℃ − 80℃) and fall within the range of both ASTM D6751 and EN 14214 standards. This enhance the safety of the fuel during storage and transportation due to its lower volatility.

Yield Optimization

Central Composite Design (CCD) within Response Surface Methodology (RSM) was employed to optimise biodiesel yield based on methanol ratio, catalyst concentration, and reaction time.

The highest biodiesel yield (98.33%) was reached with 0.7 wt.% catalyst concentration, a 10:1 methanol ratio, and a reaction time of 35 minutes. The lowest yield was observed at 0.1 wt.% catalyst concentration, a 1:1 methanol ratio, and a reaction time of 35 minutes.

Quadratic regression model:

$$Y = 148.54 - 97.94A - 0.85B - 3.84C + 62.38A^2 + 0.0054B^2 + 0.19C^2 + 0.37AB + 0.54AC + 0.018BCsss$$

3.4 ANOVA analysis showed an F-value of 40.82 and p-value < 0.05, indicating that the quadratic model is statistically significant.

CONCLUSION

The Response Surface Methodology effectively optimized the biodiesel production process derived from Desert Date oil. The optimal parameters were identified as a methanol ratio of 6:1, a reaction duration of 65 minutes, and a catalyst concentration of 0.4%, resulting in a maximum yield of 98.33%. The physicochemical properties of the oil complied with ASTM and FAO/WHO standards. Elevated saponification and viscosity values enhance lubrication, whereas a low iodine value signifies robust oxidative stability. Consequently, Desert Date oil is deemed suitable for biodiesel production.

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REFERENCES

1. Abdulhamid et al. (2023). Biodiesel Production using Balanites aegyptiaca Seed as Raw Material. AJBAR, 2(2), 124–134.
2. Aboje et al. (2023). Optimization and Characterization of Biodiesel Production from Desert Date Seed Oil. Journal of Energy Technology and Environment, 5(2), 181–186.
3. ASTM (2023). American Society of Testing and Materials. *Standard Specification for Biodiesel Fuel (B100) Blend*, Philadelphia.
4. Besbes, S.; Drira, L.; Blecker, C.; Deroanne, C.; Attia, H. Adding value to hard date (Phoenix dactylifera L.): Compositional, functional and sensory characteristics of date jam. Food Chem. 2009, 112, 406–411. [CrossRef]
5. Demirbas, A. (2003). Biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterifications and other methods: a survey. Energy conservation and management. 44(13): 2093-2109.
6. FAOSTAT. Statistical databases of the Food and Agriculture Organization of the United Nations. 2020. Available online: http://www.fao.org/faostat/en/#home (accessed on 17 December 2023).
7. Elfeel, A.A. (2012). Variability in Balanites aegyptiaca seed oil content and fatty acid composition. Food chjemistry, 132(4), 1803- 1808
8. European Committee for Standardization. (2020). *EN 14214: Automotive fuels-fatty acid methyl esters (FAME) for diesel engines-requirements and test methods.*
9. Giwa, S. O., Haggai, M. B., & Giwa, A. (2021). Production of biodiesel from desert date seed oil using heterogeneous catalysts. International Journal of Engineering Research in Africa, 53, 180-189.
10. Karaye, I. U., Ladan, M. U., Adili, I. S., Shehu, A., Lawal, H. M. and Sahabi, M., H.(2020). Phytochemistry and Proximate Composition of Fruit Pulp and Seed of Desert Date, Balanites aegyptiaca (Del.). International journal of science for global sustainability, fugusau VOL 6(2): 109 – 117
11. Kumar Ghosh, U. and Mittal, V. 2021. Application of response surface methodology for optimization of biodiesel production from microalgae through nano catalytic transesteriication process. Fuel Process. Technol., 92(3): 407-413.
12. Manji, AJ; Sarah, EE; Modibbo, UU (2013). Studies on the potentials of Balanites aegyptiaca seed oil as raw material for the production of liquid cleansing agents. Int. J. Phys. Sci. 8(33): 1655- 1660.
13. Mohamed AA and Mohammed AA. (2018). Extraction and Physico-Chemical Properties of Balanites aegyptiaca (Heglig) Seed Oil Grown In Libya. International Journal of Agricultural Research and Review, 6(2), 674-679.
14. Mohammed F. B. , Muhammad I. M. , Gutti B. , Abdulkarim A. Y.& Ahmed S. I. 2018. Characterization and application of balanites aegyptiaca seed (desert date) kernel as natural coagulant and disinfectant for water purification. Nigerian Journal of Engineering Faculty of Engineering, Vol. 24, No. 2, 68-74.
15. Mohibbe M.A., Amtul W., & Nahar N.M. 2005. Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India, Biomass and Bioenergy 29 (2005) 293–302

16. The British Petroleum Company, BP. BP Statistical Review of World Energy, June 2017. Availableonline:https://www.bp.com/content/dam/bp/en/corporate/pdf/energyeconomics/statistical-review-2017/bp-statistical-review-of-world-energy-2017 -full-report.pdf (accessed on 23 August 2018).
17. Production from Waste Cooking Oil—A Case Study of Hong Kong. Int. J. Mol. Sci. 2015, 16, 4362–4371. [CrossRef]
18. Ogala, H., Elinge, C.M., Wawata I.G., Adegoke, A.I., Muhammad, A.B., & Ige, A.R., (2018), Extraction and Physicochemical Analysis of Desert Date (Balanite Aegyptiaca) Seed Oil, International Journal of Advanced Academic Research | Sciences, Technology & Engineering | ISSN: 2488-9849 Vol. 4, Issue 4.
19. Orhevba, B.A., Adebayo, S.E. and Salihu, A.O., (2016). Synthesis of Biodiesel from Tropical Almond (Termmalia Catappa) Seed Oil. Current Research in Agricultural Sciences. 3(4):57:63.
20. Yunus, M., and Zuru, A. (2017). Kinetics study of balanites aegyptiaca oil transesterification for the production of biodiesel. Nigerian Journal of Chemical Research, 22(1), 9-19. Biodiesel fuel (B100) Blend, Philadelphia.
21. Yun-Hin, Taufiq-Yap, Nurul FA, Manhiran B. Biodiesel Production via Transesterification of Palm Oil Using NaOH/Al2O3 Catalysts. Sains Malaysi. 2011, 40(6), 587-597
22. Waseem H., Asma El Zerey-B , Farwa N. and Iqra Y. (2016). The downside of biodiesel fuel – A review. International Journal of Chemical and Biochemical Sciences (ISSN 2226-9614, , 9(2016):97-106