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Waste-Valorized Biodiesel from Avocado Seed Oil: Production, Blending and Fuel-Property Characterization

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ABSTRACT

Biofuels, particularly biodiesel, offer renewable, biodegradable and sustainable alternatives to fossil fuels, alleviating ecological problem such as greenhouse gas emissions from petroleum dependence. This study produced biodiesel from avocado seed oil (ASO) which is an underutilised non-edible waste- and evaluated its blends with petroleum diesel. Seeds were washed, sun dried, ground and extracted using a Soxhlet instrument with n-hexane, yielding 12.50 % oil. ASO exhibited an acid value of 3.02 mg KOH/ g, free fatty acid content of 1.55 %, specific gravity of 0.90, kinematic viscosity of 6.20 mm^2/s and pH of 6.90. It was observed that fatty acid profiling revealed oleic acid (66%) as dominant, followed by palmitic acid (13.05%). Base-catalysed transesterification (6:1 methanol-to-oil molar ratio, NaOH catalyst) yielded 92 % B100 biodiesel. Its characteristics include an acid value of 1.61 mg KOH/g, kinematic viscosity of 8.70 mm^2/s, specific gravity of 0.90, flash point of 120 °C, cloud point of 2 °C, and cetane number of 51. Blends B10(10:90 v/v; i.e., biodiesel: diesel) and B20 (20:80 v/v) showed acid values of 0.96 and 1.02 mg KOH/g, viscosities of 4.80 and 5.90 mm^2/s, specific gravities of 0.85 and 0.89, flash points of 105 and 110 °C, cloud points of 1 and -1 °C and cetane numbers of 52 and 50, respectively. Most properties met ASTM D6751 and EN14214 standards, except B100 viscosity (slightly elevated). These results affirm ASO-based biodiesel and blends as viable petroleum diesel substitutes, advancing waste valorisation for sustainable energy.

Keywords: *Avocado seed, biodiesel, Soxhlet extraction, Iodine value, fatty acid composition, flash point.*

INTRODUCTION

Rapid increase in global population, urbanisation and industrialization has all increased energy demands primarily met by fossil fuels, leading to pollution menace [1]. Over the years, fossil fuel dominance has raised concerns about environmental degradation, non-renewability and health risks, prompting developed nations and researchers to seek renewable, eco-friendly alternatives with minimal health impacts [2]. Fossil fuel pollution causes many serious effects on human health; for instance, particulate matters (PM), nitrogen oxides (NO_x), unburned hydrocarbons, and carbon monoxide released from petroleum and coal operations can cause lung cancer, fetal harm and increased morbidity [3]. Among renewable energy sources like solar, wind, and biofuels (bioethanol, biodiesels), biofuels obtained from vegetable oils, animal fats, and used cooking oils offer viable substitutes due to their renewability [4][5][6]. Notably, biodiesel, an example of a biofuel is obtained from renewable resources such as plants and animals [7]. Biodiesel, especially monalkyl esters from renewable feedstocks for diesel engines, provides advantages over petroleum diesel, including sustainability, non-toxic emissions, biodegradability, high cetane numbers for smoother operation, ease of production, lower health risks, superior flash points(>100°C) for safer handling, and blend compatibility [8-16]. Compared to petro-diesel, biodiesel exhibits favourable combustion profiles with reduced CO, particulate matter, and hydrocarbon emissions [7].

Prevalent process of generating biodiesel is via transesterification which implies to a catalyzed chemical reaction involving the use of vegetable oil and an alcohol to yield fatty acid alkyl esters and glycerol [17]. Dominant biodiesel generation method, transesterification (alcoholysis) involves the relocation of alcohol from ester with a different alcohol [18]. Research showed that production of biodiesel by transesterification includes the use of alcohols, especially C_1 and C_2 chain alcohol (methanol and ethanol), in a chemical reaction with animal fats or vegetable oil in the presence of alkaline condition to yield long chain of fatty acid methyl ester [19]. Catalysts used in transesterification may either be alkaline, acid or enzyme materials. For alkaline catalysts, the predominantly used substances are sodium hydroxide (NaOH) and potassium hydroxide (KOH) [17]. Avocado (*Persea americana*), a tropical Lauraceae species grown in Central/ South America, West Indies, the Caribbean, and African nations including Nigeria Cameroon and Ghana produce seeds containing biodiesel-convertible triglycerides. [20]. Studies confirm optimal yields from Hass avocado seeds at 6:1 oil: alcohol ratios while heterogeneous H_2SO_4 / KOH catalysis also achieved high yields with physicochemical properties meeting ASTM standards [17][18] This study extracted oil from avocado seeds via Soxhlet-n-hexane extraction, produced B100 biodiesel through alkali-catalysed transesterification, blended as B10 and B20 with petroleum diesel, and evaluated properties against ASTM D6751/EN 14214 standards to validate their potential as sustainable petro-diesel substitutes.

MATERIALS AND METHOD

Sample collections and preparation

The material (avocado seeds) used for this research were gathered from a farm in Awka, Anambra state, Nigeria. The avocado seeds were washed thoroughly to eradicate dirt and sun dried for two weeks in order to remove the water content of the seeds. The sundried seeds were cut into pieces, crushed to fine powder and corked in plastic bottles prior to all the experiments.

Extraction of avocado seed oil

About 300 g of the sample was measured into a thimble and loaded into Soxhlet extractor with 250 mL of n-hexane solvent in the extraction flask. Condenser was placed into the Soxhlet extractor. The instrument was insert on a heater and was left to reflux for about 2 h. The method was repeated until the oil was extracted from the avocado seeds. The solvent was recovered using a rotary evaporator [21].

Biodiesel Production

A measured volume of 200 mL of avocado seed oil was preheated to approximately 55 °C to reduce viscosity and facilitate the transesterification reaction. A methoxide solution was prepared by dissolving 1.006 g of potassium hydroxide (KOH) in 20 mL of methanol under continuous stirring until complete dissolution was achieved. The freshly prepared methoxide solution was then gradually introduced into the preheated oil under controlled conditions. The reaction mixture was subjected to reflux at 55 °C for 60 minutes with constant stirring to ensure efficient conversion of triglycerides into fatty acid methyl esters (FAME), commonly referred to as biodiesel. Upon completion of the reaction, the mixture was transferred into a separatory funnel and allowed to settle undisturbed for approximately 8 hours to achieve phase separation. Two distinct layers were formed: the lower glycerol-rich phase and the upper biodiesel phase. The glycerol layer was carefully drained off, and the crude biodiesel was subsequently washed multiple times with warm distilled water to remove residual catalysts, soap, and impurities. The washed biodiesel was then subjected to drying in a hot air oven at around 100 °C to eliminate any residual moisture, yielding purified biodiesel suitable for further analysis.

Characterization of Oil and Biodiesel

The physicochemical properties of both the raw avocado seed oil and the synthesized biodiesel were systematically evaluated following standard analytical procedures. The characterization was carried out to assess the quality, fuel suitability, and compliance with biodiesel standards. Physical properties analyzed included kinematic viscosity, relative density (specific gravity), pour point, cloud point, flash point, fire point, refractive index, and cetane number. These parameters are critical for determining fuel flow behavior, ignition quality, and storage stability under varying environmental conditions. Chemical properties evaluated comprised acid value, iodine value, saponification value, free fatty acid (FFA) content, and peroxide value. These parameters provide insight into the chemical stability, degree of unsaturation, oxidative degradation, and overall quality of the oil and biodiesel. The combined analysis of these properties enables a comprehensive assessment of the efficiency of the transesterification process and the suitability of the produced biodiesel as an alternative renewable fuel.

Determination of Relative Density (Specific Gravity)

The relative density of the oil and biodiesel samples was determined using a clean, dry specific gravity bottle following standard procedures. Initially, the empty specific gravity bottle was weighed using an analytical balance, and the mass was recorded as W1W_1W1. The bottle was then filled with distilled water at room temperature, ensuring no air bubbles were trapped, and weighed again to obtain W2W_2W2.

Afterward, the bottle was thoroughly emptied, cleaned, dried, and allowed to cool to room temperature. It was then filled with the test sample (oil or biodiesel), and the mass was recorded as W3W_3W3.

The relative density (specific gravity) of the sample was calculated using the following expression:

$$RD = \frac{W3 - W1}{W2 - W1} 1$$

Where,

W_1 = weight of empty bottle

$W_{2=}$ weight of empty bottle + weight of water

$W_{3=}$ weight of empty bottle + weight of oil

Kinematic Viscosity

Determination of Kinematic Viscosity

The kinematic viscosity of the oil and biodiesel samples was determined using a calibrated viscometer following standard procedures. The sample was carefully introduced into the viscometer tube, which was then immersed in a constant-temperature viscometer bath maintained at 40 °C to ensure thermal equilibrium. Using a suction device, the sample was drawn above the upper calibration mark of the viscometer and then allowed to flow freely under the influence of gravity. The time required for the sample to pass from the upper mark to the lower mark was measured using a digital stopwatch. This procedure was repeated three times to ensure accuracy, and the average flow time was calculated.

The kinematic viscosity of the sample was determined using the following relationship:

$$\text{Kinematic viscosity } (KV) = t \times K \; 2$$

Where:

KV = Kinematic viscosity

t = time in seconds

K = Viscometer Constant = 0.00768

Flash point and fire point determination

Each of the samples was put into clean crucibles and mercury thermometers inserted in the centre of the samples. Heat was applied to the samples. Flame was subsequently passed over the samples at an interval until a point when a flash was noticed on the samples. The temperature at which it happened was the flash point and the subsequent temperature at which the samples ignited fire for at least 10 seconds was the fire point.

Refractive index

To achieve this, some drops of the samples were put on the measuring prism and closed with the cover plate. The refractive index was noted through the aperture in % Brix [23].

Determination of Cloud Point and Pour Point

The cloud point and pour point of the oil and biodiesel samples were determined using standard low-temperature evaluation procedures.

Each sample was transferred into a clean, dry test tube, which was then placed inside an air jacket containing a cooling medium composed of crushed ice and sodium hydroxide pellets to achieve progressively lower temperatures. The samples were cooled gradually, and the temperature was monitored continuously. At intervals of 5 °C, the test tube was removed briefly and visually inspected under adequate lighting conditions. The **cloud point** was recorded as the temperature at which the first visible haze or cloudiness appeared in the sample, indicating the onset of wax crystal formation. The **pour point** was determined as the lowest temperature at which the sample ceased to flow when the test tube was held horizontally for a minimum of five seconds. All measurements were conducted carefully to ensure uniform cooling and accurate observation, as these parameters are critical indicators of low-temperature flow properties and fuel performance under cold conditions.

Cetane number

The Cetane number was computed according to [8].

$$CN = 46.3 + \frac{5458}{SV} - 0.225 \times IV \quad 3$$

Where, CN = Cetane number;
IV = Iodine value;
SV = Saponification value.

Determination of Peroxide Value (PV)

The peroxide value of the oil and biodiesel samples was determined using an iodometric titration method to assess the extent of primary oxidation. Accurately, 10 g of each sample was weighed into a clean, dry conical flask, followed by the addition of 30 mL of an acetic acid–chloroform mixture (3:2 v/v). The flask was gently swirled to ensure complete dissolution of the sample. Subsequently, 0.5 mL of saturated potassium iodide (KI) solution was added, and the mixture was allowed to react in the dark for approximately one minute with intermittent shaking to liberate iodine. After the reaction period, 30 mL of distilled water was added to the mixture. The liberated iodine was titrated against standardized sodium thiosulfate solution with continuous stirring until the yellow color became pale. At this stage, a few drops of freshly prepared starch indicator were added, resulting in a blue coloration. Titration was continued until the blue color disappeared, indicating the endpoint. A blank determination was performed under identical conditions without the sample to correct for reagent impurities.

The peroxide value was calculated using the following expression:

$$\text{PV} = \frac{(\text{T} - \text{B}) \times N \times 1000}{\text{g}} \quad 4$$

Where: T = titration volume for sample;
B = Titration volume for the blank;
N = Normality of thiosulphate used;
g = weight of the sample.

Determination of Saponification Value (SV)

The saponification value of the oil sample was determined using a standard titrimetric method to estimate the average molecular weight of fatty acids present. Accurately, 2 g of the oil sample was weighed into a 250 mL round-bottom flask, and 25 mL of alcoholic potassium hydroxide (KOH) solution was added. The mixture was heated under reflux using an air condenser on a water bath for approximately 30 minutes to ensure complete saponification of the triglycerides.

After refluxing, the flask was allowed to cool to room temperature. Subsequently, 2–3 drops of phenolphthalein indicator were added to the mixture. The excess KOH was then titrated against standardized 0.5 N hydrochloric acid (HCl) until the pink color disappeared, indicating the endpoint. A blank determination was performed simultaneously under identical conditions without the oil sample to account for the total amount of KOH initially present.

$$\text{Saponification value} = \frac{(\text{Blank} + \text{Titre}) \times 100}{\text{weight of oil}} \quad 5$$

Iodine value

About 0.2 g of the sample was measured into 500 mL conical flask. Exactly 20 mL of chloroform was added. The mixture was kept in dark for 1 h. About 20 mL of KI solution was poured into the sample and carefully swirled. It was titrated against 0.1 N $Na_2S_2O_3$ solution using starch as an indicator with vigorous shaking. A blank was carried out similarly in the absence of the sample.

$$\text{Iodine number} = \frac{\text{A} \times \text{N} \times 0.1269 \times 100}{\text{weight of oil}} \quad 6$$

Where:
A = mL of $Na_2S_2O_3$;
N = Normality of $Na_2S_2O_3$.

Free fatty acid analysis

About 2 g of the sample was dissolved in 20 mL ethanol inside a conical flask. Also, 3 drops of phenolphthalein indicator was added to the solution and titrated against 0.1N NaOH. Free fatty acids were computed as follows:

$$\text{FFA} = \frac{\text{V NaOH} \times \text{N NaOH} \times \text{MW} \times 100}{\text{Sample(g)} \times 1000} \quad 7$$

Where:
V NaOH = Volume of sodium hydroxide used;
N = Normality of sodium hydroxide;
MW = Molecular weight of predominant fatty acid.

Results and Discussion

Table 1: physico-chemical properties of avocado seed oil (ASO)

Property	Unit	Value
Colour	—	Orange
Oil content	%	13.50
Acid value	m KOH/g	3.02
FFA	%	1.55
Specific gravity	—	0.901
Viscosity	Mm^2/s	8.70
Appearance	—	Liquid

Table 2: Fatty Acid Composition of Avocado Seed Oil

Fatty Acid	%
Palmitoleic Acid C16:1	5.88
Linolenic Acid C18:3	0.94
Palmitic Acid C16:0	13.05
Lignoceric Acid C22:0	0.25
Arachidic Acid C20:0	0.63
Linoleic Acid C18:2	10.08
Oleic Acid C18:1	66.07
Behenic Acid C22:0	0.88
Stearic Acid C18:0	0.98
Eicosenoic Acid C20:1	0.56

Table 3: Physio-chemical properties of ASO biodiesel and its blend (B10 and B20)

Fuel Parameters	ASO Biodiesel (B100)	B10	B20	Biodiesel (ASTM D6751)	Biodiesel (EN 14214)
Biodiesel yield (%)	92	—	—	—	—
Colour	Orange	Orange	Orange	—	—
Specific Gravity	0.90	0.85	0.88	0.86 - 0.90	0.86 - 0.90
Viscosity (mm^2/s)	7.70	4.80	5.90	1.9 - 6.0	3.5 - 5.0
Moisture content (%)	0.30	0.10	0.22	0.05 Max.	0.05 Max
pH	6.90	6.20	6.70	—	—
Flash Point (°C)	120	75	90	93 Min.	≤100
Fire Point (°C)	128	95	105	≤100	≤100
Cloud Point (°C)	2	1	-1	-15 to 10	
Pour Point (°C)	-1	-5	-8	-10 to -15	
Cetane no.	51	52	1.02	≤47	≤51
AV (mgKOH/g)	1.16	0.96	1.02	0.50max	0.50 Max
FFA (%)	0.81	0.48	0.52	—	—
IV (g/100g)	55.0	40.25	47.30	—	120 Max
PV (mol/kg)	7.40	4.80	5.66	—	—
SV (mgKOH/g)	160	125	146	—	200 Max

AV= acid value, FFA = free fatty acid, IV= iodine value, PV= peroxide value, SV= saponification value

The physical and chemical characteristics of avocado seed oil (ASO) presented in Table 1 confirmed that the seeds are a potent non-consumable, waste-derived feedstock for generation of biodiesel. The orange colour of the oil is likely due to carotenoid -or other pigment component naturally present in the biomass. The oil content of 12.50 % fell within the 15 % range reported elsewhere and is relatively high compared with many biodiesel feedstocks, indicating good economic potential without competing with food- grade oils [17]. The specific gravity (0.901) and viscosity (8.70 mm^2/s) of ASO exceed typical diesel values, confirming that the crude oil requires modification before applying in diesel engines. The acid value (3.02 mg KOH/g) and FFA (1.55 %) are below 2 %, allowing direct base-catalysed transesterification without pre-esterification, while oils with FFA> 2 % tend to form soap when alkali catalysts are used. Under optimised conditions (6:1 methanol-to-oil, NaOH), ASO biodiesel (B100) was produced in 92 % yield- higher than 78 % reported for biodiesel from another system but lower than 98 % from Vitex doniana seed oil, confirming ASO as a suitable feedstock [7][24].

GC-MS analysis in Table 2 showed that oleic acid is the dominant fatty acid (66.07 %), in close agreement with the 70.54 % reported for ASO and similar to the dominance of oleic acid in papaya seed oil [17]. The high monounsaturated content supports favourable combustion behaviour and acceptable oxidative and cold-flow properties [25]. The use of B100 is limited by viscosity, stability, and compatibility issues, which can be mitigated by blending with petroleum diesel [26][27] and the properties of B100, B10 (10:90 v/v), and B20 (20:80 v/v) are summarized in Table 3. The specific gravity of ASO B100, B10 and B20 (0.90, 0.85, 0.88) are within ASTM D6751 and EN 14214 limits, and values below 1 indicating a relative light fuel that may promote more complete combustion. Kinematic viscosity is one of the major properties of biodiesel which shows the flowability tendency of the fuel. It measures the fluidity and atomization properties of the fuel [28][29]. Kinematic viscosity at 40 °C was 7.70 mm^2/s (B100), 4.80 mm^2/s (B10), and 5.90 mm^2/s (B20), with B10 and B20 within the ASTM D6751 range of (1-6 mm^2/s) while B100 is slightly above. It was reported that elevated viscosity can impair injection and pumping, especially at low temperatures [30].

Moisture contents (0.30 %, 0.10 %, 0.22 %) exceed the 0.05 % maximum specified in ASTM D6751 and EN 14214, which may promote incomplete combustion and engine-performance degradation.

The pH values (6.90,6.20. 6.70) are close to neutral, indicating limited corrosive risk under typical storage conditions. The flash point denotes the least temperature at which fuel vaporizes enough to get ignited, whereas fire point is the lowest temperature at which a fuel ignite fire for at least 5 seconds [31][32]. Flash points of 120 °C (B100), 75°C (B10), and 90 °C (B20), with corresponding fire points of 128°C, 95 °C and 105°C, are within ASTM D6751 and EN 14214 limits and are comparable to previously reported ASO biodiesel values around 110-128 °C, indicating reduced flammability hazard and improved handling safety [7].

Cloud points values (2 °C, 1 °C, -1°C) and pour points values (-1 °C, -5 °C, -8 °C) are within standard limits indicating suitable cold-flow behaviour for temperature- climate use. Cetane value is a vital characteristic of a diesel. It is used to evaluate the ignition quality of a diesel. Diesel with lower cetane value has a longer ignition delay when compared to diesels with high cetane value. The ignition delay time is the period that fuel is injected and starts to combust [33]. The cetane numbers [51,52, 50] obtained exceeded the minimum recommendation of 40, confirming good ignition quality and reduced ignition delay [33][34][17]. Iodine value evaluates the level of unsaturation of fatty acids in a biodiesel. It equally assesses the quality of biodiesel and the oxidative stability of biodiesel [35]. The iodine values of (55.00, 40.20, 47.30 g/100 g) are within the EN 14214 maximum of 120 g/100 g and are comparable with the 53.80 g/100 g reported for papaya seed biodiesel and contrast with the lower 16.39 g/100 g reported for ASO biodiesel in another study. Moderate iodine values indicated a balance between unsaturation and oxidative stability linked to high oleic content [25][18][36]. The acid values of (1.61, 0.96,1.02 mg KOH/g) and corresponding FFA contents of (0.81 %, 0.48 %, 0.52 %) exceeded the 0.5 mg KOH/g limit of ASTM D6751 and EN 14214, implying a potential risk of engine-part corrosion and suggesting the need for further purification or additives. Saponification value is used to check the level of impurities in a biodiesel, and also to determine the molecular weight of fatty acids methyl ester in the biodiesel [37]. The result showed saponification values of 160,125, 146 mg KOH/g) which met EN 14214 and indicated relatively high-molecular-weight methyl esters, which generally enhance stability, in contrast to higher 190 mg KOH/g reported for Beniseed oil biodiesel [18][38]. Peroxide value is a property of diesel indicating its oxidative level and tendency of the oil to become rancid.

Peroxide values of 7.40,4.80 and 5.66 mol/kg for B100, B10, and B20 are below the 10 mol/kg threshold often used to classify oils as stable, indicating that ASO biodiesel and its blends are relatively oxidation- resistant under the tested conditions. This aligns with the moderate iodine values and oxidative-stability data for avocado-rich oils [38][39]. Overall assessment showed that ASO is a viable waste-valorised feedstock for biodiesel; ASO B10 and B20 largely met international standards, with the main deviations being slightly elevated viscosity and moisture contents. The results support the use of avocado seed-based fuels as sustainable substitutes for petroleum diesel, consistent with circular-economy and decarbonisation goals.

Conclusion

This study successfully demonstrated the viability of avocado seed oil (ASO) - a non- consumable, abundant agro-waste material as an eco-friendly feedstock for biodiesel production through optimised transesterification with petroleum diesel blending. The seeds yielded appreciable oil content (13.50 %), underscoring its untapped potential amid global demands for second-generation biofuels. While the pure ASO biodiesel (B100) exhibited properties largely compliant with ASTM D6751 and EN14214 standards, minor exceedances in moisture content, acid value, viscosity and specific gravity highlight opportunities for refinement via advanced purification or pre-treatment techniques. Notably, the B10 and B20 blends met all stipulated limits, affirming their drop-in compatibility with existing diesel infrastructure and positioning ASO biodiesel as a viable petroleum diesel alternative. These findings contribute to circular economy principles by valorizing agricultural waste, potentially reducing reliance on food-competitive feedstocks and mitigating environmental pollution from avocado residues. Future research should explore long-term engine performance, oxidative stability enhancements, and life-cycle assessments to scale ASO biodiesel for commercial deployment in regions like sub-Saharan African where there is high production of avocado.

References

1. Ikeh O.A, Ejidike L.C, Ofoelo S.E and Igwilo M.O (2025): Investigation of Poly Aromatic Hydrocarbons and Heavy Metals in Soils of Selected Auto Mechanic Workshops in Nimo, Njikoka, Anambra State, Nigeria. Asian soil research journal. 9(2):115-121.
2. Nwadiogbu, J. O., Ikelle, I. I., Onwuka, J. C., Ikeh, O. A., Nwankwo, N. V., & Anarado, I. L. (2024). Assessment of heavy metals in a soil contaminated by petroleum hydrocarbons at Ebudu, Rivers State, Nigeria. *Greener Journal of Environment Management and Public Safety*, 12(1), 10– 15.
3. Omid Koohshekan, O.; Alireza, P.; Mohammad, A.; Abozar, S.; Zahra, S.; Amin, M. (2025). "Biodiesel-petrodiesel blends physiochemical characterization and economic assessment of designing a plant in Iran." Journal of Environmental Health and Sustainable Development, 8(1): 897-914. DOI: 20.1001.1.24766267.2023.8.1.5.1.
4. Chang, J.; Leung, D.Y.; Wu, C. (2003). "A review on the energy production, consumption and prospects of renewable energy in China." Journal of Renewable and Sustainable Energy, 7(5): 453-68.
5. Abdul-wahab and Takase, T.M. (2019). "Biodiesel production and characterization: Biodiesel production from Neem (*Azadirachta indica*) seed oil." Int. Journal of Innovative Research and Development, Vol 8, No 8, pp. 1-8.
6. Onimisi, M.O.; Ajibola, V.O.; Pallatu, Y.A. (2021). "Production and characterization of biodiesel from palm oil and palm kernel oil using non-heating method." Nigerian Research Journal of Chemical Sciences, Vol 9, No 1, pp. 114-131.
7. Dagde, K.K. (2019). "Extraction of vegetable oil from avocado seeds for production of biodiesel." J. Appl. Sci. Environ. Manage. Vol 23 (2) 215-221. http://dx.doi.org/10.4314/jasem.v2312.3
8. Mohibbe A. M., Amtul W., Navratna M. N. (2005), Prospects and Potential of Faculty Acid Methyl esters for some non-traditional seed oils for use as biodiesel in India Biomass and Bioenergy. 29(4): 293-302.
9. Atabani, A.E.; Silitonga, A.S.; Irfan, A.B. et al (2012). "A comprehensive review on biodiesel as an alternative energy resource and its characteristics." Renewable and Sustainable Energy Reviews, Vol 16, No 9, pp. 2070-2093.
10. Wan Ghazali, W.; Mamat, R.; Masjuki, H.; Najafi, G. (2015). "Effects of biodiesel from different feedstocks on engine performance and emissions: A Review." Renewable and Sustainable Energy Reviews, Vol 51, pp. 585-602.
11. Yusuff, A.; Adeniyi, O.; Olutoye, M.; Akpan, U. (2017). "A Review on Application of Heterogeneous Catalyst in the Production of Biodiesel from Vegetable Oils." Journal of Applied Science and Process Engineering, Vol 4, No 2, pp. 1-16.
12. Puagsang, N.; Chanakeawsomboon, I.; Chantrapromma, S.; Palamanit, A. (2021). "Production of biodiesel from low-grade crude palm oil using hydrochloric acid." Journal of Environment Asia, Vol 14, No 1, pp. 23-32.
13. Dalta A. and Mandal B. (2016) 'Comprehensive Review of Biodiesel as an Alternative fuel for Compression Ignition Engine' Journal of renewable and sustainable Energy Reviews vol. 57, pp. 799-821.
14. Romano S.D.G.S., Laborde M.A (2006) Biodiesel In: Combustibles Alternativos, 2nd edition ed., Buenos Aires: Ediciones cooperativas.
15. Romano S. D and Sorichetti P.A. (2011) 'Dielectric Spectroscopy in Biodiesel Production and Characterization' Journal of Green Energy and Technology pp, 1-22.
16. Azeez O. S., Okafor K. U., Adewolu O., Nasir A., Olutoye M. A. (2016) 'Production od biodiesel from palm kernel oil using FeO promoted NaOH catalyst through Transesterification' Journal of Applied Chemical Science International, Vol. 6, No 2. pp 85-90.
17. Rachimoellah H. M., Dyah A. R., Ali Z., Susila W. (2009) 'Production and biodiesel through Transesterification of Avocado (*Persia gratissima*) seed oil using Base catalyst. Journal Teknik Mesin Vol. 11 No. 2 pp 85-90.
18. Gidigbi, J.A.; Abubakar, A.B. (2023). "Optimization of Bio-Diesel made from Non-Edible Avocado Seed Oil (ASO) using Homogeneous H_2SO_4/KOH Catalyst." Int. Journal of New Chemistry, 10(4): 242-260.
19. Parthiban K., Pandian S., Subramanian D. (2021). 'Conventional and in-situ transesterification of Annona Squamosa seed oil for diesel Production: Performance and emission analysis' Journal of Environment Technology and Innovation. Vol. 101593 pp11-22.
20. Atabani A.; Silitonga A.; Ong H (2013) "non-edible vegetable oils: a critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production." Renew Sustain. Energy Rev. 18 (2): 11–45.
21. Okene E. O. and Evbuomwan B. O. (2014). Solvent Extraction and Characterization of oil from coconut seed using alternative Solvents. Inter. J. Engineer. Tech. 1 Res. 2 (12): 2321-0869.
22. Barlamen J. G., Sunil J. (2018). Enhancement of Kinematic Viscosity of coconut oil. Inter. J. America Oil Chem. Soc. 70: 821-822.
23. Ibanga, O. I. (2014) Extraction, Characterization o Africa peer (*Dacryodes edulis*) oil and its Application in Synthesis and Evaluation of Surface Coating Drivers. Inter. J. Adv. Res. Chem. Sci. 7 (4): 14-22.

24. Gloria I. N. and Anselem T. U. (2020). Biodiesel Production from Vitex Doniana (Black plum) seed oil, via a two-step catalyzed Transesterification. Bull chem. Soc. Ethiop. 34(1), 75-82. https//dxdoi.org. /10. 4314/bese v34il.7
25. Manmasum N. A. and Habibu U. (2020). 'Papaya seed oil as potential source for Bio-fuel production'. African Sustainable Development (JASD-2)n19(2) 325-336.
26. Wakikl M. K., Kalim M., Masjuki H., (2015) 'Influence of biodiesel blending on physiochemical properties and importance of mathematical model for predicting the properties of biodiesel blend. Energy convers. Manag. 94: 51-67.
27. Chaun B. S., Singh R. K., Cho H. (2016). 'Practice of diesel fuel blends using alternative fuels: A review'. Renew. Sustain. Energy R|ev. 59(13) 58-68.
28. Hassan N., Rasul M., Harch C. A (2015). 'Modelling and experimental investigation of engine performance and emissions fuelled with biodiesel produced from Australian beauty leaf tree. Fuel 150(6) 25-35.
29. Ofoefule A.U.; Esonye C.; Onukwuli O.D.; Nwaeze E.; Ume C.S. (2019) "Modelling and optimization of African pear seed oil esterification using artificial neural network and response surface methodology comparative analysis". Industrial Crops and Products. vol. 140.
30. Sbihi H.M.; Nehdi I.A.; Tan C.P (2014) "Production and characterization of biodiesel from Camelus dromedarius (Hachi) fat". Energy Convers. Manag. 78(5) 1-7.
31. Azad A. and Ameer M. (2013) "Performance study of a diesel engine by first generation bio-fuel blends with fossil fuel: An experimental study. J. Renew. Sustain. Energy. 5(1): 13–18.
32. Acharya N.; Nanda P.; Panda S. (2017) "Analysis of properties and estimation of optimum blending ratio of blended mahua biodiesel." Engineering Science and Technology. 20 (2): 1-7.
33. Kumar S.P.J. and Banerjee.R.(2013): Optimization of lipid enriched biomass production from Oleaginous fungus using response surface methodology. Indian J.Exp. Biol. 51979-983.
34. Moser B.R. (2009) "Biodiesel production, properties and feedstocks. In Vitro Cell Dev. Biol. Plant. 45(3): 229-66.
35. Soares S. and Fabio R.P. (2018) "Fast Spectrophotometric Determination of Iodine Value in Biodiesel and Vegetable Oils". Journal of the Brazilian Chemical Society, pp. 21–33.
36. Esonye C.; Onukwuli O.D.; Ofoefule A.U. (2019) "Optimization of Methyl Ester Production from Prunus Amygdalus Seed Oil Using Response Surface Methodology and Artificial Neural Networks." Journal of Renewable Energy. 130: 62–71.
37. Audu K.O.T.; Aluyor E.; Egualeoma S.; Momoh S. (2013) "Extraction and Characterization of Chrysophyllum albidum and Luffa cylindrical Seed oils" Petroleum Technology Development Journal, 3(1): 1-7.
38. Eriola B.; Tunde F.A.; Akinbiyi K.O.; and Seyi E.A (2012) "Statistical Approach to the optimization of Oil from Beniseed (Sesamum indicum) oilseeds. Journal of Food Science and Engineering 2: 351–357.
39. Borompichaichartkul C.; Chinprahast N.; Devahastin S.; Wiset L.; Poomsa-ad N.; Ratchapo T. (2013) "Multistage heat pump drying of macadamia nut under modified atmosphere. Int. Food Research Journal 20: 21–29.