FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 7 No. 1, February, 2023, pp 261 - 266
DOI: https://doi.org/10.33003/fjs-2023-0701-1305

PHYSICO-CHEMICAL CHARACTERIZATION OF UVARIA CHAMAE OIL AND QUALITY ASSESSMENT OF BIODIESEL PRODUCED FROM *Uvaria chamae*

***[1]Sani A., [2]Uba S., [2]Omoniyi K. I., [2]Mikail A. H.**

[1]Department of Pure and Industrial chemistry, Umaru Musa Yaradua University, Katsina
[2]Department of Chemistry, Ahmadu Bello University, Zaria

*Corresponding authors' email: abubakar.sani@umyu.edu.ng

ABSTRACT

This research studied the potential of the seed oil of Uvaria chamae for biodiesel production. The oil was extracted using a soxhlet extractor and n-hexane as a solvent before being transesterified into biodiesel. The results obtained showed a low yield of 12.5 % for the extracted oil. The oil showed a high acid value of 14.02± 0.09 mgKOH/g, which indicated high free fatty acid content and the percentage yield of the biodiesel produced was 88.35± 0.5%. The profile of methyl esters showed that unsaturated linoleic methyl ester was dominant. The results suggested that Uvaria chamae seed oil possesses some properties that were suitable for biodiesel production.

Keywords: Biodiesel, methylesters, Fatty acid composition, transesterification, *Uvaria chamae*

INTRODUCTION

Oil from seeds is used as Straight Vegetable Oil (SVO) or biodiesel (trans-esterified oil) depending on the type of engine and oil blend level (Radhikhesh, 2019). This phenomenon has spawned the notion that it is preferable to use oil seeds as biofuel, as this will reduce the demand for nonrenewable fossil fuels (Ipeghan *et al.*, 2019). The term "biofuel" refers to a liquid or gaseous fuel made mostly from biomass and used in transportation.

Uvaria. chamae (P. Beauv), a medicinal plant native to West and Central Africa, is used to cure fevers and possesses antibacterial and anti-diabetic qualities. The root has a well-recognized reputation in African traditional medicine. The plant is prized for its hypoglycaemic qualities (Olumese *et al.*, 2016), which make it a viable diabetes therapy option. The Anonacaea family includes Uvaria chamae. It's also known as bush banana or finger root. This common name alludes to the fruit that grows on its short branches and has finger-like clusters of fruit carpel, the shape of which has given rise to various native names such as bush banana, which implies wildness. In Igbo, it's called (Mmimi ohia), in Hausa, (Kas kaifi,) and Yoruba, (Akisan) (Ogbuana *et al.*, 2020). It is a cultivated and wild evergreen shrub that grows to a height of 3.6 to 4.5 meters (Omajali *et al.*, 2011).

According to a source, both edible and non-edible oils have been successfully utilized in biodiesel production (Foroutan *et al.*, 2021). However, developing nations like Nigeria, whose crude oil is mainly used to create conventional diesel, depend on alternative oil-producing crops, including soybeans, groundnuts, cottonseeds, sunflower, rapeseeds, oil palm, and coconut oil as a feedstock due to the global food security issue (El-Hamdi, 2018). Recently, biodiesel production has drawn much attention to complement diesel production based on refining crude oil. (Omotosho et al., 2015). The basic steps in biofuel production include pretreatment, alcohol-catalyzed mixing, esterification and transesterification, separation of the product and purification of the biodiesel.

According to a product specification or certificate of analysis, oil quality refers to the physical and chemical characteristics of fats or oils that are required for any particular use. According to reports, a variety of elements, including preprocessed ones like the growth season and soil fertility as well as post-harvest storage conditions like temperature as well as post-processed ones like heat-thermal degradation and air contact, can affect the quality of oil (Bhatt *et al.*, 2020). The identity and edibility of the vegetable oil are consequently gauged by the quality of the oil.
(Prates-Valério *et al*., 2019).

MATERIALS AND METHOD

Sample collection and preparation

The sample was collected from dried seeds of *Uvaria chamae* in Samaru market in Zaria within Kaduna metropolis, Nigeria. The research was carried out at Ahmadu Bello University, Zaria Sabon Gari Local Government Area of Kaduna State, Nigeria. The seeds were peeled to obtain the kernels, which were air-dried and pulverized to a fine powdered form and stored in an airtight plastic container.

Extraction procedure

About two hundred grams (200 g) of air-dried and pulverized plant seeds of *Uvaria chamae*was weighed out and packed into a thimble, which was in turn placed into a Soxhlet extractor. Extracting solvent (normal hexane (500 cm^3) and anti-bumping chips were placed into 1000cm^3 round bottom flask and heated on a heating mantle at 70 ◦C. The extraction was allowed to continue until the solvent was clear. The solvent in the round-bottomed flask was collected and dried using a rotary evaporator at 40 °C. The process was repeated to obtain the mean of the percentage extraction and enough oil for further analysis (Takase *et al*, 2014).

$$\text{Oil content} = \left(\frac{Weight\ of\ the\ oil}{Weight\ of\ sample}\right) \times 100$$

Physicochemical analysis of oil

Various physicochemical analyses were conducted to evaluate the quality of each of the oil samples. The oil's physicochemical properties were determined following standardized American Society of Testing and Materials (ASTM) test procedures. The physicochemical parameters to be analyzed were specific gravity, Iodine value, saponification value, acid value, peroxide value, color, and free fatty acid.

Specific gravity

A clean dry empty 50 cm^3 density bottle was weighed and the mass was recorded, it was filled up with distilled water and weighed, and the mass of the bottle and water was taken. Each seed oil was also weighed in a separate density bottle which will then be weighed, the weight of the bottle and oil, the specific gravity will be evaluated using (Olosunde and Edet, 2022):

$$\text{Specific gravity} = \left(\frac{Weight\ of\ oil}{Weight\ of\ Water}\right)$$

Saponification value

Exactly, 5 cm^3 of each oil sample was weighed into a volumetric flask and 50 ml of alcoholic KOH was added from the burette by allowing it to drain for 30 minutes and a blank was also prepared by taking only 50 cm^3 of alcoholic KOH allowing it to drain for 30 minutes. The flask was connected to the air condenser and it will be boiled gently for about one hour. Then the flask and condenser were cooled, and the condenser was rinsed with a little distilled water and then removed. Finally, 1 ml of phenolphthalein was added and titrated against 0.5 M of HCl until the pink color will disappear. (AOAC, 2003)

$$\text{Saponification value} = \left(\frac{56 \times N(V_0 - V_1)}{W}\right)$$

Where; V_0 = the volume of the solution used for the blank test;
V_1 = the volume of the solution used for determination;
N = actual normality of the HCl used;
W = Mass of the sample.

Acid value

Exactly, 2 cm^3 each of oil sample was weighed into a 250 cm^3 conical flask separately, and each was dissolved in 25 cm^3 of alcohol. Then two drops of phenolphthalein indicator were added. The contents were titrated with alcoholic KOH. Blank titration was performed on 100 cm^3 of the titration solvent and 0.5 cm^3 of the indicator solution. The KOH solution was standardized frequently to detect the molarity change of 0.0005. The volume of 0.1cm^3 KOH (V_A), for the sample titration, and volume for the blank (V_B) was noted (AOAC, 2003)

$$\text{Acid value} = \left(\frac{A \times M \times 56.1}{W}\right)$$

Where; A = Amount (mL) of 0.1M KOH consumed by sample, M= Molarity of KOH,
W= weight (g) of oil sample.

Peroxide value

Exactly, 1.0 cm^3 of the seed oils were weighed into a clean dry boiling tube and 1g of powdered KI and 30 cm^3 of solvent (2 cm^3 of chloroform and 3 cm of glacial acetic acid) mixture was added. Hence, the tube was placed in boiling water so that the liquid boils within 30 seconds and allowed to boil vigorously for not more than 30 seconds. The contents were transferred quickly to a conical flask containing 20 cm^3 of 5% KI (5 g dissolved in 100cm^3 of H_2O) solution and the tube was washed twice with 25 cm^3 water each time and collected into the conical flask. Then, the solution was titrated against 0.001 M $Na_2S_2O_3$ solution until the yellow color disappear and 0.5 cm^3 of starch will be added with vigorous shaking and titrated carefully till the blue color disappear (AOAC, 2003).

$$\text{Peroxide value} = \left(\frac{V \times M \times 1000}{W}\right)$$

V= Volume of sodium thiosulphate solution used, M= Molarity of thiosulphate, W=Weight of the oil sample.

Iodine value

Exactly 0.4 cm^3 of the oil sample was weighed into a conical flask and 20 cm^3 of CCl_4 was added to dissolve the oil. At the end of this period, 20 cm^3 of 10% KI (10 g dissolved in 100 cm^3 of water) and 125 cm^3 of distilled water were added using a measuring cylinder. The content was titrated with 0.1M sodium-thiosulphate solutions until the yellow color almost disappeared. A few drops of 1% starch indicator were added and the titration will continue by adding thiosulphate dropwise until the blue coloration disappears after vigorous shaking. The same procedure was used for the blank test (AOAC, 2003).

$$\text{Iodine value} = \left(\frac{12.69 \times C \times (V_0 - V_1)}{W}\right)$$

C = Concentration of sodium thiosulphate used, V_1 = Volume of sodium thiosulphate used for blank, V_2 = Volume of sodium thiosulphate used for determination, W =Mass of the sample.

Production of Biodiesel

Esterification Production of Biodiesel

50 g of *Uvaria chamae* oil was measured and weighed in a conical flask using a weighing balance. The conical flask containing the oil sample was placed on top of magnetic stirrer, and then agitated and heated to a temperature of 60 ^{0}C. Immediately the agitation and heating started, 143.8 g of methanol and 3.2 g of sulphuric acid were added.

2.4.2 Transesterification production of biodiesel

The transesterification reaction was done to reduce the free fatty acid percentage. This was done to reduce the % free fatty acid to a value less than 0.5%. This was done by weighing 15% of methanol and 1% catalyst (KOH). Exactly, 30cm^3 of *Uvaria chamae* was poured into a round-bottomed flask which was immersed in a water bath set at 55 °C and allowed to heat up until the temperature of the water bath was attained. 4 cm^3 anhydrous methanol was added into the flask and 0.4 g potassium hydroxide (KOH) was added to form methoxide; then condenser was fitted to the second neck of the flask; The calculated mass of the KOH was dissolved in measured methanol and the mixture poured into the oil. The solution was placed on a magnetic stirrer at 60 ^{0}C for agitation and heating for 1 hour. The mixture was poured into a separating funnel after agitation, and allowed to stand for 1 hour for separation to take place. The lower layer (glycerol) will be tapped off and the upper layer (biodiesel) was poured out. The volume and weight of obtained biodiesel were measured and recorded (Ndukwe and Ugboaja, 2012).

Properties of Biodiesel

Density measurement (ASTM D445-12)

An empty beaker was weighed using an analytical weighing balance. 50 cm^3 of biodiesel will then be poured into a beaker, and the combined weight measured. The difference between the weight of the beaker plus biodiesel and that of the empty beaker will be obtained and recorded as the weight of the oil. The density will be obtained by taking the ratio of the weight of the biodiesel and its volume (ASTM, 2010).

$$\text{Density} = \left(\frac{Weight\ of\ measured\ biodiesel}{volume\ of\ measured\ biodiesel}\right)$$

Kinematic viscosity measurement (ASTM D445)

Exactly, 15 cm^3 of biodiesel was poured into a viscometer tube. The tube will then be immersed into a viscometer bath maintained at 40 °C. The oil in the tube will be sucked up to the upper limit mark using a suction pump and allowed to drop under gravity. A stopwatch will be started and the setup will be monitored till the oil gets to the lower limit of the tube and the watch stopped. The time will be recorded, and the procedure repeated twice. The kinematic viscosity will be calculated using (ASTM, 2010)

Kinematic Viscosity = Time (s) × Tube constant

Pour point (ASTM D6892-03)

Exactly 20 cm^3 of biodiesel was poured into a test jar with a thermometer clamped to it and will be cooled at a constant temperature, forming wax crystals. The test jar will be removed at every degree drop in temperature and tilted to check the surface movement. When the surface did not flow for 5 s, the temperature will be recorded (ASTM, 2010).

RESULTS AND DISCUSSION

The results of physicochemical properties of the crude oil and the fuel properties of the biodieselproduced from the oil are presented as Mean ± SD in Tables 1 and 2 respectively. The fatty acidcomposition of the biodiesel produced is presented as table

Table. 1: Result of physicochemical properties of the seed oil (Mean ± SD)

Properties	VALUES
Oil Content	12.6
Specific gravity	0.94±0.00
Acid value (mg KOH/g)	8.26±0.12
Iodine value	16.65±0.18
S.V (mg KOH/g)	202.80±0.40
Viscosity (mm/s)	3.90±0.00
Peroxide Value (Meq /Kg)	4.09 ± 0.12\

Physicochemical properties

The physicochemical properties of *Uvaria chamae* seed oil were studied. The percentage oil content of *Uvaria chamae* was 12.6. This value was found to be lower than the oil content of shea butter (44.24%), as reported by Misbahudeen et al., (2020). In general, a poor oil yield indicates that the oil seed may be scarce for oil production. Poor oil yield is also caused by seeds oil with a high percentage of FFA (> 1%w/w), which also contributes to the formation of soap (Thapa et al., 2018). *Uvaria chamae* has a specific gravity of 0.94. This implies that the oils are less thick than water and do not include any heavy constituents. Specific gravity is an important metric to evaluate since it determines the energy density (specific energy) of gasoline (Atabani *et al.,* 2012).

The acid value of *Uvaria chamae* was 8.26±0.12 mgKOH/g. The lower the acid value, the lower the free fatty acid, the more suitable, the oil for transesterification process. The acid value of the oil was higher in comparison to the acid value of 1.85 reported by konuskan *et al*., (2019,) for rubber seed which indicated that over time, the oil will become unstable, and it will not be safeguarded against rancidity or peroxidation (Onoji *et al.* 2016).

*Uvaria chamae (*202.4 mgKOH/*g)* had a lower saponification value than *Cocos nucifera* oil (246 mgKOH/g), which was studied by (Sani *et al.,* 2014). When biodiesel, on the other hand, generated from oil with a high saponification value, is burned in an engine, it releases exhaust pollutants (Uyaroğlu *et al.,* 2022). The saponification value is crucial in the shampoo and soap businesses since it identifies the oil as typical trigly cerides (Che Hamzah *et al.,* 2020).

The iodine value of *Uvaria chamae* was 16.65 gI_2/100g, which was lower than the iodine value of castor oil (84.8 gI_2/100g) as reported by Aremu et al., (2015). The amount of unsaturated fats and oil in the sample is indicated by the iodine value. Vegetable oil has a low iodine value, it produces biodiesel with high cloud and pour points, and higher cloud and pour points indicate poor engine performance in cold circumstances. This indicated that the oil under consideration was suitable for the production of biodiesel (Folayan *et al.,* 2019).

To achieve the gasoline standard, viscosity is an important property that must be regulated in oil. The viscosity for *Uvaria chamae* was 3.9 ±0.09 mm^2/sec, which was lower compared to the viscosity of *Cucurbita pepo* oil (93.65 mm^2/sec) according to Bwade *et al. (2013)*. Low viscosity oil produced a sloppy effect (Yusup and Khan, 2010). A higher oil viscosity makes it unsuitable for biodiesel production since it would harm the engine.

The peroxide value of *Uvaria chamae* was 4.09± 0.61 Meq/kg was lower than the required standard by NIS (Ifemeje *et al.,* 2022). High Peroxide values indicate high levels of oxidative rancidity in the oils as well as the lack or low levels of antioxidants; nevertheless, some antioxidants, such as propyl gallate and butyl hydroxyl anisole, can be used to reduce rancidity (Aremu *et al.,* 2015).

Properties Of Biodiesel

The most important methyl ester characteristic is Kinematic viscosity, which affects fuel injection and sprays atomization, particularly at low temperatures (Atabani *et al.,* 2012). According to ASTM and EN standards, the permitted limits of kinematic viscosity at 40 °C is 3.5 - 6.0 mm^2/s. At 40 °C, the kinematic viscosity of *Uvaria chamae* was found to be 4.4 mm^2/s.

Acid values are utilized as a general indicator of the condition and suitability of the oil since they represent the amount of free fatty acid present in the oils (Nkouam *et al.,* 2007). Consequently, a maximum acid value of 0.5 mg KOH/g is guaranteed by both the ASTM and EN standards. *Uvaria chamae* is 0.43 mg KOH/g, which is within the ASTM and EN standards' permitted limits. The percentage of free fatty acid in the biodiesel was much lower than that of their oils because a sizable fraction of the FFA was neutralized by potassium hydroxide during transesterification. (Vairavan *et al.,* 2010).

The performance of the engine is influenced by the fuel, thus it is crucial. This may also affect how effectively fuel is atomized in engine combustion systems (Silitonga *et al.,* 2013). According to ASTM and EN standards, the density of methyl ester at 15 °C should be between 0.860 g/cm^3 and 0.950 g/cm^3. Uvaria chamae has a density of 0.89 g/m3. This indicates that the results were quite near and that the density of the biodiesel is within the allowed range. This might be a result of the density of the methanol used to make the methyl esters. This density is lower than that of kusum seed (0.90 g/cm^3) as reported by Sarve et al., (2016) because methyl ester is denser and less volatile than petroleum-diesel, which has a density of 0.832 g/cm^3.

The temperature range for the ASTM D2500 standard method for estimating cloud point (for biodiesel) is -3 to -12 ^{0}C. For *Uvaria chamae*, the obtained Cloud Point value is 4.5 °C. These figures are greater than the camelina temperature of -3^{o}C reported by Moser (2010). This is because biodiesel contains a high amount of unsaturated fatty acids (Sharma et al., 2008). Biodiesel with a high cloud point has limited usage in cold locations because it cloughs the pathway (Velvhizi *et al.* 2020). Despite being quite high, the results were within the permitted range of the ASTM standard.

The pour point is the lowest temperature at which a liquid fuel loses its capacity to flow. Pour point is important in the cold flow process (Sakthivel et al., 2018). The pour point and cloud point of diesel fuel are usually lower than those of biodiesel fuels. The ASTM D97 approach is used to calculate the pour point of biodiesel fuel. Uvaria chamae has a pour point of -5.27 °C. This figure is higher than the freezing point of castor oil, which is -20 °C (Sanchez-Garcia *et al.*, 2015).

GC –MS Result of Biodiesel

The produced biodiesel demonstrates the presence of fatty acids such as hexadecanoic acid methyl ester, methyl stearate, and 9, 11-Octadecadieonoate acid. Table 3 shows the identified chemicals and their composition. Unsaturated fatty acids (81.84%) outnumber saturated components (18.63%) in biodiesel composition. Table 3 shows the distribution ratios. Yasar (2020) created bio - diesel with a high percentage of unsaturated components and claims that it may be used in cold climates. As a result, the composition of the biodiesel produced is favourable. The fatty acid content has the greatest influence on the properties of triglycerides and biodiesel (Ramos *et al*, 2009).

Table 2: Fuel properties of *Uvaria chamae* Methyl ester

Properties	*Uvaria chamae*
Biodiesel yield (%)	85.5
Density(g/cm^3)	0.89
Pour point (^{0}c)	-5.27
Acid value (mgKOH/g)	0.43
Cloud Point (^{0}c)	4.5
Kinematic viscosity (@40^{0}C)	4.4

Table 3: GC –MS Result of Biodiesel

Fatty acids	Molecular formular	Composition (%)
Hexadecanoic acid, methyl ester	$C_{16}H_{32}O_2$	7.68
9, 11 Octadecadienoate acids	$C_{18}H_{31}O_2$	9.33
Linoleic acid	$C_{18}H_{32}O_2$	10.34
Ethyl oleate	$C_{20}H_{38}O_2$	14.00
9, 12 Octadecenoic acid, methyl ester	$C_{18}H_{24}O_2$	29.90
Octadecanoic acid, methyl ester	$C_{18}H_{36}O_2$	0.93
Dodecanoic acid, methyl ester	$C_{12}H_{24}O_2$	5.32
Heptadecanoic acid, methyl ester	$C_{17}H_{34}O_2$	0.78
9, Octadecenoic acid, methyl ester	$C_{18}H_{34}O_2$	21.72
Saturated		28.71
Unsaturated		71.29
Total		100%

CONCLUSION

This research looked at the physiochemical makeup and biodiesel-producing capability of *Uvaria chamae* seeds. *Uvaria chamae* oil is a good source of oil for manufacturing biodiesel, as evidenced by the physiochemical composition of the biodiesel made from those oils. The predominant component of the fatty acid composition is 9, 12 octadecenoic acid, which makes up 28.71% of the saturated fat and 71.29% of the unsaturated fat. The non-edible oils under research, as determined by their physicochemical characterization and quality evaluation, exhibit compliance with FAO/WHO values in most parameters. Frequent checks should continue to ensure that the vegetable oils sold to the general public are of the highest caliber. The biodiesel made from oils ought to be of the best quality. The study also showed that the oil could be utilized for other things besides lubricants, such as cosmetics and paint.

REFERENCES

Aremu, M. O., Ibrahim, H., & Bamidele, T. O. (2015). Physicochemical characteristics of the oils extracted from some Nigerian plant foods–a review. *Chemical and Process Engineering Research*, *32*, 36-52.

Atabani, A. E., Silitonga, A. S., Badruddin, I. A., Mahlia, T. M. I., Masjuki, H., & Mekhilef, S. (2012). A comprehensive review on biodiesel as an alternative energy resource and its characteristics. *Renewable and sustainable energy reviews*, *16*(4), 2070-2093.

Bhatt, R., Raturi, P., Kumar, R., & Dongariyal, A. (2020). Role of Post-Harvest Technology in Horticultural Crops. *Chief Editor Manoj Kumar Ahirwar*, *49*, 3.

Budhwani, A. A. A., Maqbool, A., Hussain, T., and Syed, M. N. (2019). Production of biodiesel by enzymatic transesterification of non-edible *Salvadorapersica* (Pilu) oil and crude coconut oil in a solvent-free system. *Bioresources and Bioprocessing*, *6*(1), 1-9.

Bwade, K. E., Aliyu, B., & Kwaji, A. M. (2013). Physicochemical properties of pumpkin seed oil relevant to bio-diesel production and other industrial applications. *International Journal of Engineering, Business and Enterprise Applications (IJEBEA)*, *4*(1), 72-78.

El-Hamidi, M.,and Zaher, F. A. (2018). Productioof vegetablele oils in the world and in Egypt: An overview. *Bulletin of the National Research Centre*, 42, 19.

Folayan, A. J., Anawe, P. A. L., Aladejare, A. E., & Ayeni, A. O. (2019). Experimental investigation of the effect of fatty acids configuration, chain length, branching and degree of unsaturation on biodiesel fuel properties obtained from lauric oils, high-oleic and high-linoleic vegetable oil biomass. *Energy Reports*, *5*, 793-806.

Foroutan, R., Mohammadi, R., Razeghi, J., & Ramavandi, B. (2021). Biodiesel production from edible oils using algal biochar/CaO/K2CO3 as a heterogeneous and recyclable catalyst. *Renewable Energy*, *168*, 1207-1216.

Ifemeje, J. C., Amaefule, K. I., & Maduako, M. C. (2022). Comparative Study of Physiochemical Properties of Different Brands of Vegetable Oil Sold in Ihiala Market of Anambra State. *Asian Journal of Biochemistry, Genetics and Molecular Biology*, *12*(3), 8-13.

Ipeghan, J. O., Yirakpoa, P. N., andIshioma, L. E. (2019). The effect of solvent on the oil yield of *Treculia Africana* seed flour. *World Journal of Innovative Research,* 6(3), 74-76.

Konuskan, D. B., Arslan, M., & Oksuz, A. (2019). Physicochemical properties of cold pressed sunflower, peanut, rapeseed, mustard and olive oils grown in the Eastern Mediterranean region. *Saudi Journal of Biological Sciences*, *26*(2), 340-344.

Moser, S. C. (2010). Communicating climate change: history, challenges, process and future directions. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(1), 31-53.

Ndukwe, G. I., & Ugboaja, A. T. (2020). Biodiesel production from Vitex doniana (black plum) seed oil via a two-step catalyzed transesterification. *Bulletin of the Chemical Society of Ethiopia*, *34*(1), 75-82.

Nkouam, G. B., Kapseu, C., Barth, D., Dirand, M., & Tchatchueng, J. B. (2007). Oil extraction from sheanut kernel (vitellaria paradoxa gaertn) and canarium pulp (canarium schweinfurthii engl.) using supercritical CO2 and hexane: a comparative study. *Research Journal of Applied Sciences*, *2*(5), 646-652.

Ogbuanu, C. C., Amujiogu, S. N., & Agboeze, E. (2020). Secondary Metabolites Investigation and TLC Analysis of Leaves, Stem Back and Root Extracts of Uvaria Chamae (UDAGU). *Journal of Natural Sciences Research*, *10*(10), 34-39.

Olosunde, W. A., & Edet, E. U. (2022). Effects of Moisture Content on the Quality Characterization of Avocado Seeds Oil for Potential Biodiesel Production. *Adeleke University Journal of Engineering and Technology*, *5*(2), 01-07.

Olumese, F. E., Onoagbe, I. O., Eze, G. I., and Omoruyi, F. O. (2016). Safety assessment of Uvaria chamae root extract: acute and subchronic toxicity studies. *Journal of African Association of Physiological Sciences*, *4*(1), 53-60.

Omajali, J. B., Hussaini, J. S., and Omale, J. (2011). Cytotoxicity and anti-inflammatory studies on Uvaria chamae. *Journal of Pharmacology and Toxicology*, *2*(7), 1-9.

Omotoso, M. A., and Akinsanoye, O. A. (2015). A review of biodiesel generation from non-edible seed oils crop using non-conventional heterogeneous catalysts. *Journal of Petroleum Technology and Alternative Fuels*, *6*(1), 1-12.

Onoji, S. E., Iyuke, S. E., & Igbafe, A. I. (2016). Hevea brasiliensis (rubber seed) oil: extraction, characterization, and kinetics of thermo-oxidative degradation using classical chemical methods. *Energy & Fuels*, *30*(12), 10555-10567.

Prates-Valério, P., Celayeta, J. M., & Cren, E. C. (2019). Quality parameters of mechanically extracted edible macauba oils (Acrocomia aculeata) for potential food and alternative industrial feedstock application. European Journal of Lipid Science and Technology, 121(5), 1800329.

Radhikesh, G. (2019). *Performance Characteristics Of A Four Stroke Diesel Engine Using Biodiesel Obtained From Rubber Seed Oil* (Doctoral dissertation, Andhra University).

Sakthivel, R., Ramesh, K., Purnachandran, R., & Shameer, P. M. (2018). A review on the properties, performance and emission aspects of the third generation biodiesels. *Renewable and Sustainable Energy Reviews*, *82*, 2970-2992.

Sánchez-García, M., Alburquerque, J. A., Sánchez-Monedero, M. A., Roig, A., & Cayuela, M. L. (2015). Biochar accelerates organic matter degradation and enhances N mineralisation during composting of poultry manure without a relevant impact on gas emissions. *Bioresource technology*, *192*, 272-279.

Sani, I., Owoade, C., Abdulhamid, A., Fakai, I. M., & Bello, F. (2014). Evaluation of Physicochemical Properties, Phytochemicals and Mineral Composition of Cocosnuciferal.(Coconut) Kernel Oil. *Int. J. Adv. Res. Chem. Sci*, *1*(8), 22-30.

Sarve, A. N., Varma, M. N., & Sonawane, S. S. (2016). Ultrasound assisted two-stage biodiesel synthesis from non-edible Schleichera triguga oil using heterogeneous catalyst: kinetics and thermodynamic analysis. *Ultrasonics Sonochemistry*, *29*, 288-298.

Silitonga, A. S., Masjuki, H. H., Mahlia, T. M. I., Ong, H. C., Chong, W. T., & Boosroh, M. H. (2013). Overview properties of biodiesel diesel blends from edible and non-edible feedstock. *Renewable and Sustainable Energy Reviews*, *22*, 346-360.

Takase, M., Zhang, M., Feng, W., Chen, Y., Zhao, T., Cobbina, S. J., ... and Wu, X. (2014). Application of zirconia modified with KOH as heterogeneous solid base catalyst to new non-edible oil for biodiesel. *Energy conversion and management*, *80*, 117-125.

Uyaroğlu, A., Kocakulak, T. and Aydoğan, B., 2022. Investigation of the Effects of Biodiesel Produced from Crambe Abyssinica Plant on Combustion, Engine Performance and Exhaust Emissions. *arXiv preprint arXiv:2212.12159*.

Velvizhi, G., Shanthakumar, S., Das, B., Pugazhendhi, A., Priya, T. S., Ashok, B., and Karthick, C. (2020). Biodegradable and non-biodegradable fraction of municipal solid waste for multifaceted applications through a closed loop integrated refinery platform: Paving a path towards circular economy. *Science of the Total Environment*, *731*, 138049.

Yaşar, F. (2020). Comparision of fuel properties of biodiesel fuels produced from different oils to determine the most suitable feedstock type. *Fuel*, *264*, 116817.

Yusup, S., & Khan, M. (2010). Basic properties of crude rubber seed oil and crude palm oil blend as a potential feedstock for biodiesel production with enhanced cold flow characteristics. *Biomass and Bioenergy*, *34*(10), 1523-1526.

Thapa, S., Indrawan, N., & Bhoi, P. R. (2018). An overview on fuel properties and prospects of Jatropha biodiesel as fuel for engines. *Environmental Technology & Innovation*, *9*, 210-219.

Ramos, M. J., Fernández, C. M., Casas, A., Rodríguez, L., & Pérez, Á. (2009). Influence of fatty acid composition of raw materials on biodiesel properties. *Bioresource technology*, *100*(1), 261-268.

Che Hamzah, N. H., Khairuddin, N., Siddique, B. M., & Hassan, M. A. (2020). Potential of Jatropha curcas L. as biodiesel feedstock in Malaysia: A concise review. *Processes*, *8*(7), 786.