

## Original Research Article

# Suitability Evaluation of Pumpkin Seed Oil Biodiesel as a possible diesel for Zambia.

### Abstract

The global concern about ways through which fuels, are free from greenhouse gases and other environmental contaminants has been growing. The solution can be achieved by producing fuels from renewable feedstock such as biodiesel which is marked as a non-greenhouse emission energy source. Biodiesel can be derived from natural sources such as vegetable oils, which have gained significant attention as a promising substitute for conventional diesel fuel. Fuel produced from biodiesel has a higher flash point above 70°C, a high viscosity of 4.692, relatively low contaminants of 15.3 mg/Kg and a low residue count of 1.8%. The parameters rate fairly as desirable for use.

**Keywords:** Pumpkin Seed oil, Biodiesel, High flash point, Low residue.

### Introduction

Globally the demand for petroleum has been increasing and the supply has been dwindling due to many reasons among them, resource depletion in some parts, political conflicts and excessive demand for the commodity. Besides petroleum diesel emits greenhouse gasses, and its unavailability is compared to the demand, hence leading to escalating commodity prices globally hence affecting all economies of the globe. These factors make it necessary to find an alternative fuel to diesel [1-2]. The alternatives to petroleum diesel have been biodiesel, ethanol, hydrogen, solar-powered cars, and electrically powered cars [3-9]. The economic standing of a particular country in most cases dictates the direction of innovation in the quest to replace diesel.

Zambia is a third-world country, with economic prospects by different rating systems showing not positive for most parts, implementation must follow what is workable [10-11]. Currently, Zambia is implementing a shift from high Sulphur to low Sulphur content diesel as a measure to contribute to the goal of greenhouse and other pollutants emissions from petroleum diesel. This comes as ZS 718:2020, Zambia Bureau of Standard (ZABS) working document implemented through the Energy Regulation Board (ERB). The ZS 718:2020 is an extract from ISO standards ISO: 21/17/13.

The ZS 718:2020 prescribes several parameters including low sulphur content (0.005% sulphur equivalent to 50 ppm) diesel, viscosity, cloud point, flash point, water content, carbon residue and a recommended recovery profile [12].

In this research, an attempt is made to extract pumpkin seeds' oil and its biodiesel synthesized, then chemical characterization especially transesterification process verification, then its parameter analysis to the set petroleum diesel standards according to ZS 718:2020 instrument. The rationale is that Pumpkin is scientifically called *Cucurbitaceae Pepo. L* is a tropical fruit. And they are readily grown in Zambia even at garbage heaps, with minimum or no attention to crop management like other edible (Sunflower, ground nuts, cocoa nuts and soya beans) or non-edible oils such as Jantropa.

The pumpkin seed oil has two colours at the same time green and red (orange). The red colour comes from carotene and the green colour from chlorophyll. The refined pumpkin seed oil has a straw yellow colour. Pumpkin seed oil methyl ester (PSOME) was produced through a transesterification process using pumpkin seed oil. The oil content of the pumpkin seed varies from 42-54% and the composition of free fatty acids (FFA) is dependent on several factors (variety, area in which the plants are grown, climate, state of ripeness). The dominant FFA comprise palmitic acid (C18:0, 3.1-7%), oleic acid (C18:1, 21.0-46.9%) and linoleic acid (C18.2, 35.6- 60.8%) [1, 13-18]. Other contaminants produced into the environment by petroleum fuels are heavy metals which are toxic and pose a high health risk. Heavy metals constitute an important group of persistent toxic pollutants occurring in ambient air and other media. One of the suspected sources of these metals in the atmosphere is the combustion of transport fuels in road vehicles. However, estimates of the emissions of these metals from road vehicles as reported in national emission inventories show very high variability in emission factors used [1].

## Literature Review

### Petroleum Diesel

Diesel is a combustible fuel which is a mixture of distillate fractions from crude oil and additives to improve its combustion character. Its evaluation indicates that it contains hydrocarbons with sixteen (16) to twenty-one carbons in the chains [19-21]. According to the ASTM D 975-21, diesel fuel is categorized into seven different types. The classification is based on the S xxx configurations. These are Grade No. 1-D S15; Grade No. 1-D S500; Grade No. 1-D S5000; Grade No. 2-D S15; Grade No. 2-D S500; Grade No. 2-D S5000; and Grade No. 4-D. Where the S is the sulphur rating instead of arbitrarily assigning words such as lower sulphur or medium sulphur [23]. The sulphur recommended in each of the grades is as shown below.

Table 1. The values of S xxx about the sulphur recommended by ASTM D 975-21. [23]

S/N	Description	Sulphur	Comment
1	Grade 1-D S15	15 ppm	The light middle distillate, high volatility
2	Grade 1-D S 500	500 ppm	
3	Grade 1-D S 5000	5000 prn	
4	Grade 2-D S15	15 ppm	The middle distillate has lower volatility than grades 1-D.
5	Grade 2-D S500	500 ppm	
6	Grade 2-D S5000	5000 prn	
7	Grade 4-D		The heavy distillate, low volatility

As already been alluded to, diesel is a wasting asset, demand has been increasing hence meeting the demand of the Globe by producing countries has been a great challenge. As such world fuel prices have been sky locating.

### Biodiesel

Biodiesel is a biofuel, produced from oily plants and algae according to Britannia encyclopedia, Meanwhile, the American Society for Testing and Measurement (ASTM) defines biodiesel as a fuel that comprises a mono-alkyl ester derived from vegetable oils or animal fats [19, 22]. The mono-alkyl derivatives may be of varying lengths from the fatty acids they are obtained from. The general reaction may involve alkaline, acidic, enzymatic, microwave-assisted, thermal and sonication esterification [23-28]. The general reaction scheme for transesterification can be understood as below:

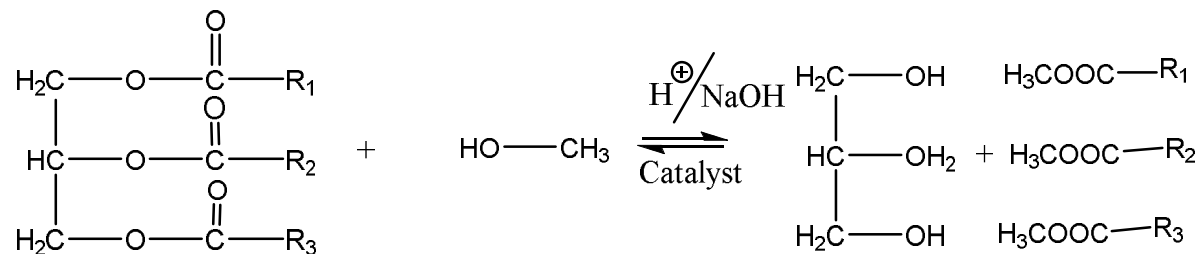


Figure 1. Show the general acidic or basic or catalytic condition transesterification reaction.

The reaction mechanisms may proceed differently for each scheme with specific conditions, but overall trans-esterified fatty acid derivatives are obtained and Glycerol. Different vegetable and non-vegetable oils have been used to make diesel by several researchers [31-41].

The pumpkin seeds oil consists of several vegetable oils depending on the quality of plant management and the environmental conditions they are produced into. This also can be seen in the nutritional value of the final pumpkin fruits. [1, 29-30]. The table below in table 2, shows some oils that can be extracted from pumpkin seed oil.

Table 2. Showing the fatty acids that are found in pumpkin seed oil [1, 30].

S/N	Composition seed oil	Fatty acid %
1	Palmitic (16:0)	12.51
2	Stearic (18:0)	5.43
3	Oleic (18:1)	37.07
4	Linolic (18:2)	43.72
5	Linolenic (18:3)	0.18
6	Lignoceric (24:0)	0.06
7	Others	1.03

Several groups have vastly looked at the suitability of using biodiesels in motorized engines, compared the cetane value for biodiesel, emission of carbon dioxide and oxides of nitrogen and compared it to petroleum diesel, alternative feedstocks in the biodiesel production, evaluation of food supply concerning supply for biodiesel production and blending of the biodiesel for possible use in everyday machines [1-5, 7, 9, 13, 38]. It has been established that biodiesel has low emission of greenhouse gases especially since the feedstock is biomass, so no overall carbon is introduced to the globe, blends of various biodiesels produce comparatively similar performance output as petroleum diesel, different seeds with oil including non-edible ones are alternatives otherwise completion with food the biodiesel might influence food prices globally. The cetane values scores of biodiesel have been relatively high in the range of 56 to 78 [1, 2].

From that background, it seems vital that biodiesel is synthesized from pumpkin seed oil even if it is vegetable based oil, yet looking at Zambia's main food feedstock it may not impact adversely. And the best way to evaluate it is to compare the acceptable standards for the country, though the ZS 718: 2020 apply to neighbour countries too [12].

## Methodology

The methodology involved experimental work which involved the extraction of the pumpkin seed oil. It was followed by the transesterification of the oil. Then characterization of both the oil extract and biodiesel using spectroscopic evaluation for the presence of ester bonds, carbonyl groups and other peaks that signifies the formation of the biodiesel. Lastly chemical and physical properties characterization of biodiesel produced.

## Extraction of the oil from pumpkin seeds

Dried pumpkin seeds were blended and sieved for the extraction process. Using a Soxhlet extractor, 74g of grounded pumpkin seeds were used using n-hexane as a solvent. 250mls hexane was used for every 74g of the ground pumpkin seeds which produced 32.57mls of raw pumpkin seed oil. This extraction was repeated 7 times each producing a volume of oil ranging from 30mls to 35mls, which then produced a total volume of 228mls of raw pumpkin seed oil. Once the raw pumpkin seed oil was collected, the transesterification process then began. 120mls of the extracted pumpkin seed oil was poured into a 200mls beaker which was then placed on a hot plate and warmed up to 80 degrees Celsius. Then 28mls of methanol were added into a 50mls flask and placed on a stir plate at a minimum speed and 1g of sodium hydroxide pellets were slowly and carefully added. This was allowed to stir until the sodium hydroxide pellets were observed to have dissolved, which then formed sodium methoxide, a very strong and dangerous base and so precautions were followed. Then sodium methoxide was then slowly added to the warm pumpkin seed oil (off the hot plate). The reaction mixture was then stirred for 2 hours and transferred to a 250mls separating funnel, the solution was allowed to settle for 1 hour using a clamp and stand until the glycerol layer formed at the bottom. Once the glycerol had stopped forming it was drained into a measuring cylinder and its volume was recorded. The biodiesel formed was drained and its volume produced was recorded.

The figure 2 shows the pumpkin seeds being processed at various stages.

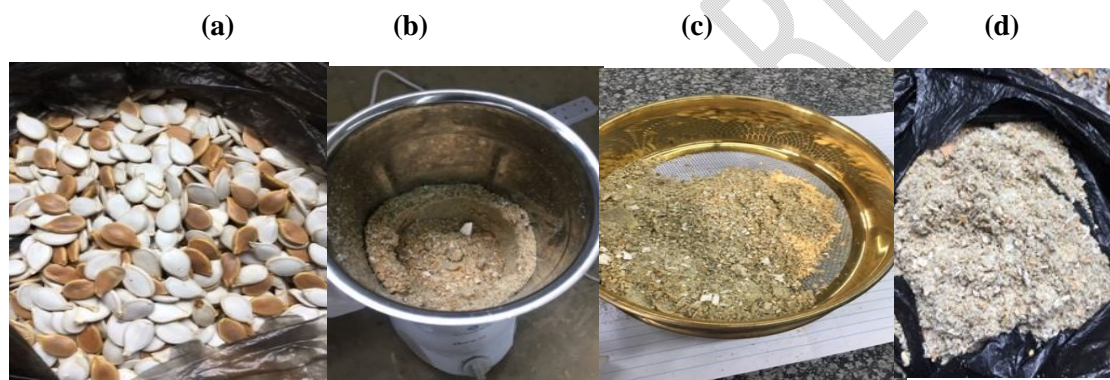


Figure 2 Pumpkin seeds being processed (a) washed to remove b-carotene, (b) blend grinding of seeds (c) retrieving the grounded seeds and (d) powdered feedstock for oil extraction.

The figure manipulation was followed by the chemical extraction of the oil from seeds using the Soxhlet extraction method. Hexane was used as the non-polar solvent. The figure below in Figure 3 shows the various stages of extraction of the seed oil and other chemical modification of the oil.

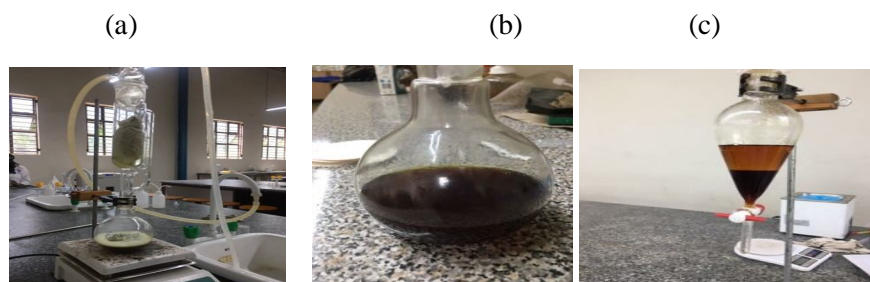


Figure 3 shows various stages of biotransformation (a) Soxhlet extraction of oil from pumpkin (b) Crude trans-esterified mix of pumpkin seed oil and (c) Separated crude trans-esterified seed oil.

### Chemical characterization of pumpkin seed oil and trans-esterified oil.

In this section, the spectroscopic evaluation of chemical modification to the oil was evaluated using the FT IR spectrometer. The biodiesel characterization was done using parameters such as distillation profile (B.P), density, viscosity, water content, free water, sulphur content, contaminations, cleanliness, and colour done on the commercial machine used for petroleum diesel and other petroleum products.

### Results

#### FT-IR spectral analysis of raw pumpkin seed oil.

The pumpkin seed oils' FT-IR spectra were evaluated, and as already mentioned that the oil has a mixture of products, indeed the spectra show several peaks suggest the same [1]. Nevertheless, it was observed that the following absorption peaks were present as depicted in Figure 4 below.

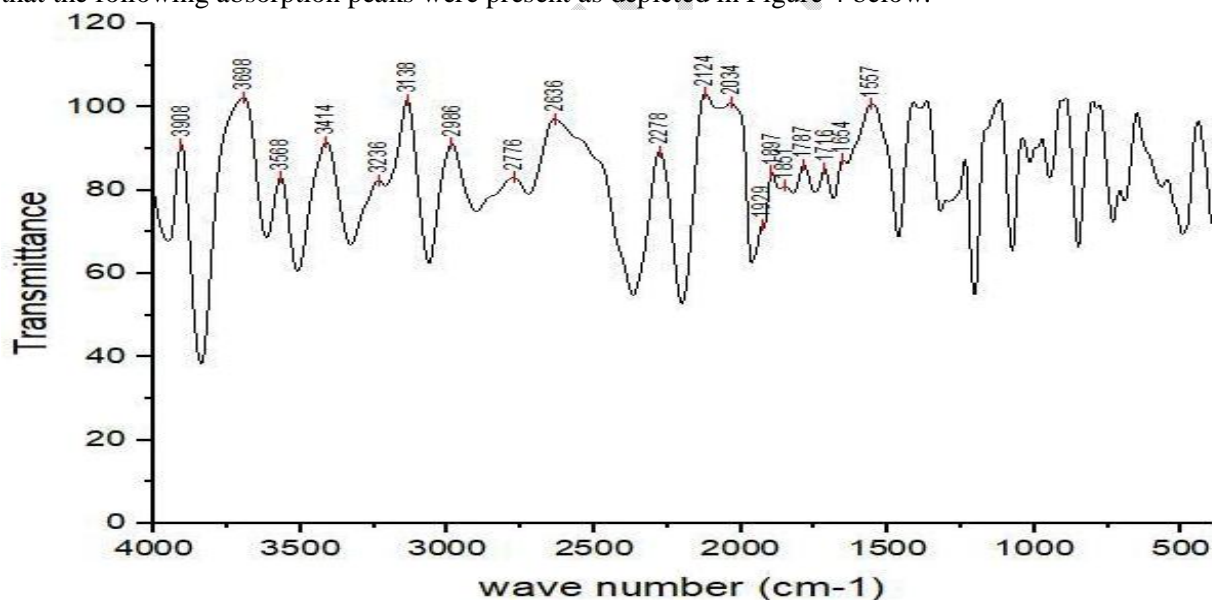


Figure 4 shows the FT-IR spectra of the pumpkin seed oil extract.

Absorption bands in the region of 3000 and 2800 $\text{cm}^{-1}$ , which in this case are the peaks at 2034 $\text{cm}^{-1}$ , 2124 $\text{cm}^{-1}$ , 2278 $\text{cm}^{-1}$ , and 2986 $\text{cm}^{-1}$ , indicate the correspondence to C-H stretching vibrations. These bands arise from the aliphatic chains present in fatty acids and triglycerides, which are the major components of pumpkin seed oil. The intensity and pattern of these C-H stretching vibrations provide information about the degree of unsaturation and the length of the carbon chains in the oil.

O-H bonds are observed at the peaks formed at 3236 $\text{cm}^{-1}$ , 3414 $\text{cm}^{-1}$ , and 3568 $\text{cm}^{-1}$ , these indicate the presence of hydroxyl (O-H) groups. These bands can arise from compounds such as free fatty acids or





Water content (%)	1.5	Vs	Water content (%)	0.05, max
Total contamination (mg/kg)	15.3	Vs	Total contamination (mg/kg)	24.0, max
Sulphur content (ppm)	76	Vs	Sulphur content (ppm)	50, max
90% recovery temperature	345	Vs	90% recovery temperature	360, max
% Residuals	1.6	Vs	% Residuals	Nil
Colour of biodiesel	Golden straw yellow			

From the results tabulated above, it was found that three parameters; total contamination, viscosity, and also flash point were within the limits set by wear check Zambia to issue a certificate to the fuels that are used by different engines within Zambia and outside. The flash point was found to be above 70°C which is in line with the required flash point for biodiesel. The viscosity was found to be 4.692 cSt which is also in line with the required standards. In comparison with the ASTM standard for diesel fuel which ranges from 0.9 –4.1 (ASTM D2 / 2 /5) standard test valve) the results are acceptable.

The moisture content, sulfur, and density are out of the acceptable limits set by ZS 718:2020 Specifications. Contamination of sulphur in the biodiesel could have happened during the distillation profile test as sodium sulphate was used to remove moisture. Other parameters could have been affected by the purification of the biodiesel that was produced.

### Conclusion

This study shows that biodiesel from pumpkin seed oil can be blended and viscosity adjusted for possible use as an alternative fuel. It was found that a flash point above 70°C, viscosity of 4.692, Boiling point range of 182 to 345 °C and residue carbon of 1.8% were standards by both ZS 718:2020 and also ASTM standard for diesel fuels. The parameters in some parameters rate fairly well compared even to ASTM stipulated quantities [43].

## References

1. Shaikh Abdul Ahtesham, Omprakash Hebbal. (2020). Pumpkin seed oil biodiesel an alternate fuel to diesel. *International Research Journal of Engineering and Technology (IRJET)* e-ISSN: 2395-0056 Volume: 07 Issue: 10 | Oct 2020 www.irjet.net p-ISSN: 2395-0072
2. An Elanthiraiyan, P. K. (2020). Emission and performance characteristics of VCR Engine with pumpkin seed Bio-Diesel Blends. *International Journal of Recent Technology and Engineering (IJRTE)* ISSN: 2277-3878, Volume-8 Issue-5, January 2020
3. A. Demirbas (2007) Alternatives to Petroleum Diesel Fuel, Energy Sources, Part B: Economics, Planning, and Policy, 2:4, 343-351, DOI: 10.1080/15567240600629518.
4. Environmental Protection Agency (EPA). 2002. A comprehensive analysis of biodiesel impacts on exhaust emissions <http://www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf> EPA draft technical report no. 420-P-02-001. Accessed on 20/05/2023.
5. Oak Ridge, 2019. "Transportation Energy Data Book: Edition 38", Oak Ridge National Laboratory, ORNL-TM/2019-1333, <https://tedb.ornl.gov/>. Accessed on 20/05/2023.
6. Oak Ridge, 2022. Transportation Energy Data Book: Edition 49, Oak Ridge National Laboratory, ORNL-TM/2022-2376, <https://tedb.ornl.gov/> Accessed on 20/05/2023.
7. Olah, G.A., A. Goepfert, G.K.S. Prakash, 2018. "Beyond Oil and Gas: The Methanol Economy, 3rd Edition", John Wiley & Sons, Hoboken, NJ, USA, ISBN:978-3-527-33803-0.
8. Järvensivu, P., T. Toivanen, T. Vadén et al., 2018. "Governance of Economic Transition", Invited background document on economic transformation for the UN Global Sustainable Development Report 2019, August 14, 2018, [https://bios.fi/bios-governance\\_of\\_economic\\_transition.pdf](https://bios.fi/bios-governance_of_economic_transition.pdf). Accessed on 18/04/2023.
9. Sgouridis, S., D. Csala and U. Bardi, 2016. "The sower's way: quantifying the narrowing net-energy pathways to a global energy transition", *Environ. Res. Lett.*, 11, 094009, doi:10.1088/1748-9326/11/9/094009.
10. UNCTAD 2022, National Productive Capacities Gap Assessment. [https://unctad.org/system/files/official-document/aldc2022d5\\_en.pdf](https://unctad.org/system/files/official-document/aldc2022d5_en.pdf). Accessed 14/05/2023.
11. Baldini, A.; Benes, J.; Berg, A.; Dao, M.C.; Portillo, R. Monetary Policy in Low Income Countries in the Face of the Global Crisis: The Case of Zambia. International Monetary Fund, (2012) 47 pp. [IMF Working Paper 12/94].
12. The Republic of Zambia Gazette 6916. Standard Acts No 4 of 2017. Vol. LVI, No. 85. Available at: <https://gazettes.africa/archive/zm/2020/zm-government-gazette-dated-2020-10-09-no-6916.pdf>. Accessed on 15/05/2023.
13. Alptekin A., Canakci M. (2009). Characterization of the Key Properties of Methyl Ester-Diesel Fuel Blends. *Fuels*. Volume 88, Issue 1, 2009, Pages 75-80, ISSN 0016-2361, <https://doi.org/10.1016/j.fuel.2008.05.023>.
14. Bwade, E. & Aliyu, Bashir. (2013). Physicochemical properties of Pumpkin Seed oil Relevant to Biodiesel Production and other Applications. *International Journal of Engineering, Business and Enterprise (IJEBA)* 4. 72-78. ISSN: 2279-0020.
15. Bikash, B., Choudhury, N.D., Bora, D.K., Kalita, K. (2018). Physicochemical Assessment of Pumpkin (*Cucurbita pepo* L.) Seed Oil as a Viable Feedstock for Biodiesel Production. In:

- Kumar, S., Sani, R., Yadav, Y. (eds) Conference Proceedings of the Second International Conference on Recent Advances in Bioenergy Research. Springer Proceedings in Energy. Springer, Singapore. [https://doi.org/10.1007/978-981-10-6107-3\\_2](https://doi.org/10.1007/978-981-10-6107-3_2).
16. Canakci M., Van Gerpen J., (1999): Biodiesel Production via Acid Catalysis. Transactions of the ASAE, 42, 1203-1210. American Society of Agricultural Engineers 0001-2351/99/4205-1203.
  17. James Yusuf, Dogara Kantoma and Rhoda Okunola Mosunmola 2021, Studies on Cucurbita maxima Seed Oil for its Potentials as Feedstock for Biodiesel Production in Nigeria. Nigerian Research Journal of Chemical Sciences (ISSN: 2682-6054) Volume 9, Issue 1, 2021
  18. Cvangros J., Cengrosova Z. (2004). Used Frying Oils and Fats and their Utilization in the Production of Methyl Esters of High Fatty Acids. Biomass and Bioenergy.
  19. Britannica, T. Editors of Encyclopaedia. "diesel fuel." Encyclopedia Britannica, Invalid Date. <https://www.britannica.com/technology/diesel-fuel>. Accessed on 20/05/2023.
  20. W. Addy Majewski, Magdi K. Khair, 2006. Diesel Emissions and Their Control. SAE International, Warrendale U.S.
  21. E. Lois, E.L. Keating, A.K. Gupta, Fuels, Editor(s): Robert A. Meyers, 2003, Encyclopedia of Physical Science and Technology (Third Edition), Academic Press, 2003, Pages 275-314, ISBN 9780122274107, <https://doi.org/10.1016/B0-12-227410-5/00268-4>.
  22. ASTM D975-21, (2021) Standard Specification for Diesel Fuel. Book of Standards Volume: 05.01, Developed by Subcommittee: D02.E0, pg 28, DOI: 10.1520/D0975-21.
  23. Marcos Flores, Carolina Saravia, Claudia E. Vergara, Felipe Avila, Hugo Valdés and Jaime Ortiz-Veidma. 2019. Avocado Oil: Characteristics, properties, and Application Review. *Molecules* 2019, 24, 2172. DOI: <http://doi.org/10.3390/molecules24112172>.
  24. 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 February 2019. <http://dx.doi.org/10.4314/jasem.v23i2.3>.
  25. T. C. Venkateswarulu, Cherukwada. V. Raviteja, Kodali. V. Prabhaker, D. John Babu, A. Ranganadha Reddy, M. Indira, A. Venkatanarayana. 2014. A review on Methods of Transesterification of Oils and Fats in Biodiesel Formation. *International Journal Of Chem Tech Research* Vol 6, No 4, pp 2568 – 2576. July 2014.
  26. Hideki Fukuda, Akihiko Kondo, Hideo Noda, 2001, Biodiesel fuel production by transesterification of oils. *Journal of Biosciences and Bioengineering* Vol 92, Issue 5, 2001, pp 405-416.
  27. Stavarache C, Vinatoru M, Nishimura R, Maeda Y. 2005. Fatty acids methyl esters from vegetable oil by means of ultrasonic energy. *Ultrason Sonochem.* 2005 Apr; 12, (5) 367 -372. DOI: 10.1016/j.ultrsonch.2004.04.001. PMID:15590311.
  28. Kumar, A., Valoyi, R., Orchieng, A., & Onyango, M.S., 2010. Acid-base transesterification of oil with high free fatty acid content. *Journal of Biofuels* 1 (1) 7-14. <http://doi.org/10.5958/j.0976-3015.1.1002>.
  29. Gbemenou, Ulrich & Ezin, Vincent & Ahanchede, Adam. (2022). Current state of knowledge on the potential and production of Cucurbita moschata (pumpkin) in Africa: A review. *African Journal of Plant Science.* 16. 8-21. DOI: 10.5897/AJPS2021.2202.

30. Freedman R.O., Butterfield R.O., Pryde E.H. (1986). Transesterification Kinetics of Soybean Oil. *J Am Oil Chem Soc* 63, 1375–1380 (1986). <https://doi.org/10.1007/BF02679606>.
31. Goodhead T.O., Wami E.N., Ukpaka C.P. Production of Biodiesel from Fluted Pumpkin Oil. **Journal of Petroleum Engineering & Technology**. 2021; 11(2): 50–58p
32. Hass M.J., McAloon A.J., Yee W.C., Fogia T.A. (2006). A Process Model for Estimating Biodiesel Production Costs. *Bioresource Technology*. *Bioresour Technol* 2006 Mar;97(4):671-8. doi: 10.1016/j.biortech.2005.03.039. Epub 2005 Jun 2.
33. Lin C.Y., Lin H.A., Hung L.B. (2006). Fuel Structure and Properties of Biodiesel Produced by the Peroxide Process. *Fuel*. 85:298-305.
34. M. Habibullah, A. A. (2015). The potential of biodiesel as a renewable energy source in Bangladesh. *Renewable and Sustainable Energy Review*. 50, 819-834. <https://doi.org/10.1016/j.rser.2015.04.149>.
35. P. Felizardo et al. (2006). Production of Biodiesel from Waste Frying Oils. *Waste Management*. *Waste Manag* 2006;26(5):487-94. doi: 10.1016/j.wasman.2005.02.025. Epub 2005 Jun 17.
36. Samboko, P. C., Subakanya, M., & Dlamini, C. (2017). Potential biofuel feedstocks and production in Zambia. *ECONSTOR*, 1. WIDER Working Paper Series wp-2017-47, World Institute for Development Economic Research (UNU-WIDER). <https://ideas.repec.org/p/unu/wpaper/wp-2017-47.html>. Accessed on 17/05/2023
37. Schinas P, G. K. (2009). Pumpkin (*Cucurbita pepo* L.) seed oil as an alternative feedstock for the production of biodiesel in Greece. *Biomass and Bioenergy* 33(1):44-49 DOI: 10.1016/j.biombioe.2008.04.008.
38. S.L. Dmytryshyn et al. (2004). Synthesis and Characterization of Vegetable Oil Derived Esters: Evaluation of their Diesel Additive Properties. *Bioresour Technol* 2004 Mar;92(1):55-64. doi: 10.1016/j.biortech.2003.07.009.
39. Tinus Pulles, Hugo Denier van der Gon, Wilfred Appelman, Marc Verheul. (2012) Emission factors for heavy metals from diesel and petrol used in European vehicles. (<https://doi.org/10.1016/j.atmosenv.2012.07.022>)
40. Morrison Thornton Robert and Boyd Neilson Robert 2002 Organic Chemistry, 6<sup>th</sup> ED, Prentice Hall New Delhi. India pp 587-590
41. Shayne C. Gad, Diesel Fuel, Editor(s): Philip Wexler, *Encyclopedia of Toxicology* (Second Edition), Elsevier, 2005, Pages 19-22, ISBN 9780123694003, <https://doi.org/10.1016/B0-12-369400-0/00320-3>.
42. Yoram Zvirin, Marcel Gutman, Leonid Tartakovsky, Chapter 16 - Fuel Effects on Emissions, Editor(s): Eran Sher, *Handbook of Air Pollution From Internal Combustion Engines*, Academic Press, 1998, Pages 547-651, ISBN 9780126398557, <https://doi.org/10.1016/B978-012639855-7/50055-7>.
43. Malcolm Latache, Chapter Five - Oil fuels chemistry and treatment, Editor(s): Malcolm Latache, *Pounder's Marine Diesel Engines and Gas Turbines* (Tenth Edition), Butterworth-Heinemann, 2021, Pages 117-149, ISBN 9780081027486, <https://doi.org/10.1016/B978-0-08-102748-6.00005-0>.