A Review Of Moringa Oleifera Seed Oil As Feedstock For Biodiesel Production

Tertsegha John-Paul Ivase
Renewable Energy Unit, BIODEC Centre, National Biotechnology Development Agency, P.M.B 2140 Katsina, Katsina State, Nigeria.
ivasejpp@gmail.com

Hadiza Bobbo
Department of Quantity Surveying, Federal Polytechnic Bauchi, Bauchi State, Nigeria.
hadizabobbo@yahoo.com

Tanimu A. Tagago
Renewable Energy Unit, BIODEC Centre, National Biotechnology Development Agency, P.M.B 2140 Katsina, Katsina State, Nigeria.

Denen D. Nyakuma
Directorate of ICT, University of Calabar, P.M.B 1115 Calabar, Cross River State, Nigeria.
denennyax@gmail.com

***Abstract*—The rapid depletion of fossil fuels and the threat of climate change have influenced researchers to seek alternative energy sources. This paper is aims to review and highlight the fuel properties, extraction methods, and potential applications of *Moringa oleifera seed oil* (MSO) based biodiesel as a viable alternative to petroleum derived diesel. The results submit that *Moringa oleifera* Methyl Ester (MOME) biodiesel can be utilised as a suitable substitute for petroleum diesel. In comparison, the MOME fuel qualities performed favourably against other biodiesel fuels derived from other vegetable oil. Furthermore, the fuel properties of MOME were observed to be within ASTM standard limits and comparable fatty acid profile with respect to other species. However, results of engine performance and emissions are marginally higher than NO_x emission compared to petroleum diesel.**

Keywords—Moringa Oleifera; oilseeds; Biodiesel; feedstock; transesterification.

I. INTRODUCTION

The global energy mix is currently dominated by fossil fuel sources. However, the rapid depletion, price volatility and environmental concerns about fossil based fuels have reignited the search for cleaner alternatives [1, 2]. Consequently, numerous clean energy, green fuels and sustainable technologies have been investigated and proposed for the establishment of future green energy economy [3-6]. This can be achieved through the development, adoption and diffusion of renewable energy technologies such as biomass, wind, solar, ocean thermal, hydrogen, and geothermal energy. Biomass is considered to be the most promising source of future energy due to its carbon neutrality, global abundance and conversion flexibility [7-10]. Consequently, biomass sources can be readily converted into gaseous (bio-syngas), solid (biochar, biocoal) and liquid (biodiesel, bioethanol, bio-methane) biofuels for future clean energy applications [11-14].

The utilization and implementation of biofuels such as biodiesel presents a clean, renewable and sustainable alternative to petroleum-based conventional diesel fuel [15]. Biodiesel is a mono alkyl ester of fatty acid produced from the transesterification of vegetable oil and animal fat with an alcohol in the presence of a catalyst to produce a form of biofuel from agricultural products [16, 17]. Biodiesel can be produced from numerous vegetable oils, such as canola (rapeseed), cottonseed, palm oil, peanut, soybean and sunflower oils as well as a variety of less common oils [17-20]. Biodiesel can be utilized directly or blended with petroleum diesel for powering diesel engines [1, 2]. Consequently, several blends of biodiesel such as B5, B7, B10, and B20 are currently used as transportation fuels around the world [21-24]. Studies have indicated that biodiesel blends such as B20 can be used in nearly all diesel equipment and are compatible with most storage and distribution equipment. Furthermore, biodiesel blends reportedly reduce engine wear, produce less harmful emissions [25] and do not require engine modifications for utilization as transportation fuel [26].

Globally, biodiesel is produced from different sources which significantly depend on factors such as price, climate and availability of feedstocks [27]. Other factors include the controversial food for fuel debates about the biofuels and biodiesel production from edible sources like soybeans, sunflower seeds and cotton seeds [28, 29]. The highly controversial dilemma has been linked to larger global problems of deforestation, poverty and hunger. Hence, critics of biofuels fear that the use of food (edible oil) as a feed feedstock in the production of biodiesel could result in a global food crisis. Consequently, current research is focused on biodiesel production non-edible or less conventional sources of feedstock oils. Currently, the non-edible sources utilized for biodiesel production include tobacco [30], *Pongamia pinnata* [31], waste cooking [32], *Jatropha curcas* [33], rubber seed [34, 35] oils.

Consequently, analysts posit that the use of non-edible oils [36, 37], waste oil streams [38] as well as waste agricultural residues [39-42] as feedstock for biodiesel production can potentially eliminate the controversies surrounding biodiesel production [43, 44]. In addition, this will potentially catalyse the establishment of a global energy economy based on the clean, renewable and sustainable energy

II. BIODIESEL OVERVIEW

Biodiesel refers to any diesel fuel substitute derived from renewable biomass. More specifically, biodiesel refers to a family of products made from vegetable oils or animal fats and alcohol, such as methanol or ethanol, called alkyl esters of fatty acids. The most common process for producing biodiesel is known as transesterification [16, 46]. This is a chemical reaction which involves the conversion of vegetable oil or animal fat into a mixture of fatty acid methyl esters in the presence of an alcohol and catalyst at selected temperatures to form fatty acid alkyl esters (FAME) and glycerol. In other words, this reaction converts an ester (vegetable oil or animal fat) into a mixture of esters of the fatty acids that makes up the oil (or fat). During this process, alcohol is displaced from an ester by another in a process similar to hydrolysis, except that alcohol is used instead of water. The reaction reduces the high viscosity of triglycerides present in vegetable oil or animal fat. Consequently, the biodiesel is obtained from the purification of the mixture of fatty acid methyl esters (FAME) [2, 46]. The catalysts used for transesterification are typically acidic, basic, or enzymatic [46, 47]. A generic transesterification reaction is presented in Equation 1; $RCOOR^1$ indicates an ester, R^2OH an alcohol, R^2OH another alcohol (glycerol), $RCOOR^1$ an ester mixture and cat a catalyst:

$$\underset{Ester}{RCOOR^1} + \underset{Alcohol}{R^2OH} \xleftrightarrow{\text{Catalyst}} \underset{Alcohol}{R^2OH} + \underset{Ester}{RCOOR^1}$$

When methanol is the alcohol used in the transesterification process, the product of the reaction is a mixture of methyl esters; similarly, if ethanol were used, the reaction product would be a mixture of ethyl esters. In both cases, glycerin will be the co-product of the reaction. Oils and fats, known as lipids, are hydrophobic substances insoluble in water and are of animal or vegetal origin. They differ in their physical states at room temperature. From a chemical viewpoint, lipids are fatty glycerol esters known as triglycerides (TAG) consisting of long chain fatty acids chemically bound to a glycerol (propane-1, 2, 3-triol) backbone. However, for biodiesel to be considered as practical renewable transportation fuel certain stringent quality standards are required. Firstly, it possess a lower rate of emission compared to petro diesel. It must emit little or no greenhouse gases (GHGs) on combustion in ignition engines. Biodiesel offers full blending potential with conventional diesel, a high cetane number giving improved combustion in compression ignition engines, and low emissions of sulphur and particulates [46]. These blends indicated as ‘‘Bx’’, where ‘‘x’’ is the percentage of biodiesel in the blend.

systems. Based on this premise, *Moringa oleifera* oilseed will be highlighted as a promising feedstock for biodiesel production [45].

For instance, ‘‘B5’’ indicates a blend with 5% biodiesel and 95% diesel fuel; in consequence, B100 indicates pure biodiesel [18, 21]. It is a fuel with lower rate of emission compared to petro diesel because it emits little or no greenhouse gases on combustion in ignition engines. It is safe to handle because of its relatively high flash point. Furthermore, biodiesel has a low soot emission as it contains little or no sulphur as well as the carcinogenic poly aromatic components. Using recycled oils and animal fats reduces the CO_2 emissions [48]. Further the energy input and overall emissions form biodiesel production depends on the feedstock and process. In addition, biodiesel has higher lubricating property than petro diesel thus very promising maintenance potentials to industries that use diesel as fuel. Biodiesel is biodegradable, non-toxic and has low emission profile compared to petroleum-based diesel [15]. Overall, the use of biodiesel will allow balance to be sought between agriculture, economic development and the environment [15, 38].

III. MORINGA OLEIFERA BIODIESEL FEEDSTOCK

Moringa oleifera is an essential oil seed and perennial crop widely cultivated in many tropical and subtropical countries [49]. It is a fast growing deciduous tree shrub which grows up to 12 m in height and 30 cm in diameter with open umbrella-shaped crown [50]. Its pods are triangular in cross-section (30 to 50 cm long) and legume-like in appearance [51]. All the parts of *Moringa oleifera* tree have been found to be medicinal particularly in African and South Asia folk medicine [52-54]. In addition, it has been reportedly used for machine lubrication, bio-fuel (biodiesel), haircare, and perfume products [18, 55, 56]. It is also used as a fodder for livestock due to its high biomass yield of 24 tons ha/yr of total dry matter (DM) yield and crude protein (CP) content in fresh leaves varying from 193-264 g/kg DM [57, 58]. It is a rich oil seed belonging to the monogeneric family which can be cultivated on marginal lands with high temperatures and low water availability or where cultivation of other crops is difficult. Furthermore, *M. oleifera* can be cultivated under tropical dry forest conditions, when phosphorus and potassium are available in the soil [59]. The oil extracted from *Moringa oleifera* seed, also known as Ben oil, has reasonable percentage oil yield of about 45 %, which is reach in oleic acid around 73 % with a low amount of polyunsaturated fatty acids (< 1 %), resulting in a high tendency to resist oxidation [60]. In addition, the seeds kernel contain about 30-50 % oil [1]. Oleic acid from *Moringa oleifera* seed oil (MSO) is an 18-carbon long monounsaturated fatty acid (MUFA). In addition, Oleic acid is an essential omega-9 fatty acid that was found to be responsible in hindering the occurrence of adrenoleukodystrophy (ADL), a fatal disease that affects the brain and adrenal glands [61]. However, due to the oxidative stability of oleic acid in MSO, compared with polyunsaturated fatty acids (PUFAs), it has found use in the food industry, as it allows for longer storage and high-temperature frying processing [62]. Consequently, MSO derived biodiesel has been found to have a high cetane number [18]. In addition, biodiesel derived from vegetable oils with a high fraction of monounsaturated fatty acids possess satisfactory balance between different fuel properties [63]. Therefore, MSO is a new promising feedstock for biodiesel production with the added advantage of the edibility of the other parts of the tree. Consequently, *Moringa oleifera* tree can potentially substitute the other conventional non-edible feedstock for biodiesel production such as *Jatropha curcas* which is inherently toxic [64].Hence, the main objective of this paper is to briefly review the intrinsic properties, extraction methods, and potential applications of *Moringa oleifera seed oil* (MSO) based biodiesel. The paper will also highlight the qualities of MSO biodiesel compared to petroleum biodiesel. Lastly, the composition of *Moringa oleifera* methyl esters as a determinant of biodiesel properties and the economic viability will be examined.

IV. MORINGA OLEIFERA OILSEED EXTRACTION

Moringa oleifera seeds typically contain between 33% and 41% oil by weight [65]. This oil resembles olive oil in its fatty acid composition and is oleic acid rich, which makes it suitable for edible purposes [66]. *Moringa oleifera* is therefore particularly suitable for the production of biodiesel. Extraction of seed oils can be carried out using different methods and solvents [67]. However, the most effective and commonly used method is Soxhlet extraction which has a 31.3% an oil extraction rate [62, 68]. This method is suitable for oil extraction in laboratories, whereas leaching may be used in large-scale industrial preparations because of its very limited energy consumption. For this paper, extraction of *Moringa oleifera* oil (MSO) from dried *Moringa oleifera* seeds using n-hexane in a Soxhlet extraction as presented in Figure 1.

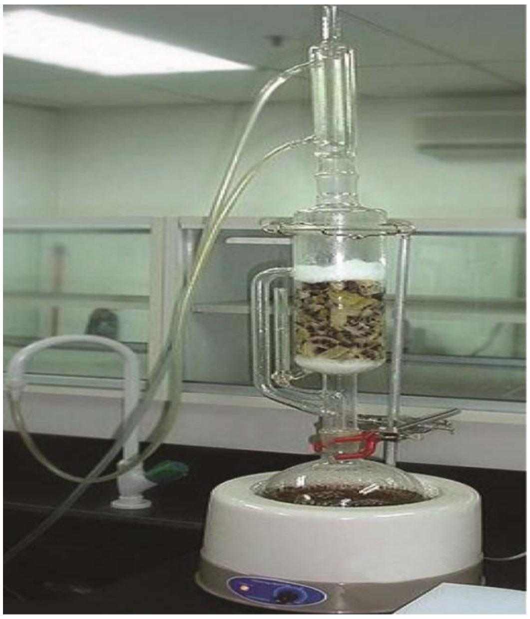

Figure 1: Soxhlet for solvent extraction [62].

Moringa oleifera methyl esters can be produced on a small scale by crushing *Moringa oleifera* seeds into small pieces and extraction using a laboratory scale 1 L batch reactor. The set comprises a reflux condenser, a magnetic stirrer, a thermometer and a sampling outlet [69]. The first step for biodiesel preparation from *Moringa oleifera* oil seed is the transesterification of *Moringa oleifera* oil which reduces the molecular size of the component (triglycerides). Hence, the resultant esterified oil can be used in diesel engine for a prolonged period without any serious issues like carbon buildups, scum formation [62, 69].

Although transesterification is the most important step in biodiesel production (since it originates the mixture of esters), additional steps are necessary to obtain a product that complies with international standards as presented in Figure 2 [38, 70]. The transesterification process is as follows: one liter of *Moringa Oleifera* cooking oil is heated up to 110 °C in order to remove the moisture content. Base catalyst NaOH of approximately 7.5 g is dissolved in methyl alcohol (200 ml) and maintained at the reaction temperature about 65 °C for a period of 60 minutes. The use of basic catalysts in triglycerides with high content of free fatty acids is not advisable since part of the latter reacts with the catalyst to form soaps; basic transesterification is viable only when the free fatty acids (FFAs) content is less than 2 %.

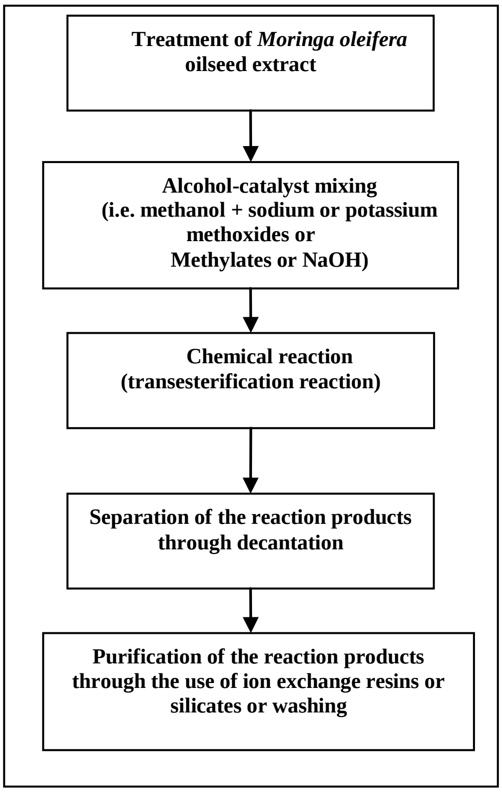

Figure 2: Schematic pathway for biodiesel production from *Moringa oleifera* oilseed [70].

The reaction products are usually allowed to settle under gravity in separating funnel for 24 hours to separate methyl esters and glycerol. Due to the higher density of glycerol, it settle at the bottom of the funnel while the *Moringa oleifera* methyl esters (MOME) occupies the top surface. Subsequently, the MOME is washed with warm water to remove un-reacted methanol, catalyst, and impurities. The washed MOME is again heated to 110 ^{0}C to remove the moisture content. Various bio diesel-diesel blends (B10, B30, B50, and B70) were prepared for the experimental work [71].

V. COMPOSITION AND PROPERTIES OF MORINGA OLEIFERA BIODIESEL

The composition and fuel properties of the biodiesel are very important for consideration as engine fuel. However biodiesel properties are largely determined by numerous factors. Table 1 presents the fuel properties of the *Moringa oleifera* methyl esters (MOME) compared with other biodiesels such as palm oil and petroleum fuel. The flashpoint temperature of the *Moringa oleifera* oil is 162 °C which is lower than the typical flash point 200 °C reported for pure methyl esters based on the ASTM D975 standards [16]. The high flashpoint temperature of the *Moringa oleifera* methyl esters (MOME) is a beneficial safety feature indicating it can be safely stored at room temperature. However, one of the major problems associated with the use of biodiesel is its poor temperature flow property measured in terms of cloud point and pour point temperatures.

It has high values of cloud and pour points at 17 °C comparable to palm oil biodiesel (14-15 °C). With unsaturated fatty acid content of 72.2 %, *Moringa oleifera* methyl esters (MOME) possesses good cloud, flash and pour point. However, the relatively high content of behenic acid, C22 (7.2%) which possesses an even higher melting point than palmitic acid, C16:0 (6.5%) or stearic acid, C18:0 (6.0%) is likely to exert a greater effect on the cloud, flash and pour point.

Table 1: Fuel properties of *Moringa oleifera* methyl esters (MOME) compared with other biodiesel and ASTM standards [18, 72, 73].

Fuel property Unit	Moringa oil (MOME)	Palm oil	Fossil diesel	ASTM Standard	Limits
Density at 15ºC (Kg/ms)	875	879.3	820 - 860	ASTMD1298	880.0
Viscosity at 40ºC (cSt)	4.80	4.9	2.0 - 4.5	ASTMD445	1.9 – 6.0
Calorific value (MJ/kg)	43.28	40.2	44.8	-	-
Cetane number	67.0	52	46	ASTMD4737	47min
Flash point (°C)	162	181	60 - 80	ASTMD975	130
Pour point (°C)	17.0	14	-35 to -15	ASTMD975	-15 to 16
Cloud point (°C)	17.0	15	-15 to 5	ASTMD975	-3 to 12
Ash content % (m/m)	0.010	0.0066	100 max^{m}	ASTMD482	-
Lubricity HFRR;um	139.0	-	0.460 mm	ASTMD450	520

The cetane number of *Moringa oleifera* methyl esters (MOME) was determined to be 67.07 using an Ignition Quality Tester TM (IQTTM) described in literature [72, 74]. As can be observed in Table 1, MOME possess the highest cetane numbers reported for a biodiesel fuel. Hence, MOME meets the minimum cetane number requirements in the ASTM D6751 biodiesel standards which is 47. Furthermore, the kinematic viscosity at 40 °C of MOME was determined to be 4.83 mm^2/s at 40 °C [72, 75]. This is in good agreement with the viscosity values of the individual fatty ester components. Consequently, MOME meets the requirements of ASTM D445 biodiesel standards which prescribes viscosity in the ranges 1.9–6.0 and 3.5–5.0 mm^2/s, respectively. For the lubricity, MOME displays excellent lubricity which is in accordance with the results on lubricity for biodiesel derived from other oils or fats [74]. According to Atabani *el al*., [72]; and Pinzi, *et al*., [75] MOME has a cloud point and pour point of 17 °C. These values are rather high, albeit comparable to palm oil which also contains even higher amounts of saturated fatty acids. However, the relatively high content of C22:0 which possesses an even higher melting point than C16:0 or C18:0 in *Moringa oleifera* oil likely has the effect of compensating for the higher amounts of saturated fatty acids in palm oil. The reason is that the cold flow properties of biodiesel are determined by the amounts of higher-melting components (usually the saturated esters) and not their nature [76]. Thus, decreasing the amounts of higher-melting saturated fatty esters is the only method for improving cold flow properties. The cloud point is the parameter contained in the biodiesel standard ASTM D6751. The cloud point can be correlated with tests such as the CFPP and is more stringent as it relates to the temperature at which the first solids form in the liquid fuel [77].

VI. CONCLUSIONS

The paper presented an overview review the intrinsic properties qualities, extraction methods, and potential applications of *Moringa oleifera seedoil* (MSO) based biodiesel. This findings suggest that Moringa *oleifera* Methyl ester (MOME) biodiesel is an acceptable substitute for petroleum diesel. In comparison, MOME compared favourably against other biodiesel fuels derived from other vegetable oil. Furthermore, the fuel properties of MOME were observed to be within ASTM standard limits and comparable fatty acid profile with respect to other species except oleic acid (72.2%). However, results of engine performance and emissions showed that

MSO biodiesel extracted exhibits lower performance and slightly higher NO_x emission compared to petroleum diesel.

REFERENCES

[1] S. Zaku, S. Emmanual, A. Isa, and A. Kabir, "*Comparative Studies on the Functional Properties of Neem, Jatropha, Castor, and Moringa Seeds Oil as Potential Feed Stocks for Biodiesel Production in Nigeria."* Global Journal of Science Frontier Research, 2012. **12**(7-B).

[2] A. Johari, B.B. Nyakuma, S.H. Mohd Nor, R. Mat, H. Hashim, A. Ahmad, Z. Yamani Zakaria, and T.A. Tuan Abdullah, "*The challenges and prospects of palm oil based biodiesel in Malaysia."* Energy, 2015. **81**: p. 255-261.

[3] M.Z. Jacobson, M. DeLucchi, G. Bazouin, Z.A. Bauer, C.C. Heavey, E. Fisher, S.B. Morris, D.J. Piekutowski, T.A. Vencill, and T.W. Yeskoo, "*100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States."* Energy & Environmental Science, 2015.

[4] U. Arena, F. Ardolino, and F. Di Gregorio, "*A life cycle assessment of environmental performances of two combustion-and gasification-based waste-to-energy technologies."* Waste Management, 2015.

[5] M. Bilgili, A. Ozbek, B. Sahin, and A. Kahraman, "*An overview of renewable electric power capacity and progress in new technologies in the world."* Renewable and Sustainable Energy Reviews, 2015. **49**: p. 323-334.

[6] B.B. Nyakuma, M. Mazangi, T.A. Tuan Abdullah, A. Johari, A. Ahmad, and O. Oladokun, "*Gasification of Empty Fruit Bunch Briquettes in a Fixed Bed Tubular Reactor for Hydrogen Production."* Applied Mechanics and Materials, 2014. **699**: p. 534-539.

[7] P. Basu, *Biomass gasification, pyrolysis and torrefaction: practical design and theory*. 2013: Academic Press.

[8] A. Demirbas, "*Potential applications of renewable energy sources, biomass combustion problems in boiler power systems and combustion related environmental issues."* Progress in Energy and Combustion Science, 2005. **31**(2): p. 171-192.

[9] B.B. Nyakuma, A. Johari, A. Ahmad, and T.A.T. Abdullah, "*Comparative analysis of the calorific fuel properties of Empty Fruit Bunch Fiber and Briquette."* Energy Procedia, 2014. **52**: p. 466-473.

[10] A. Demirbas, "*Progress and recent trends in biodiesel fuels."* Energy conversion and management, 2009. **50**(1): p. 14-34.

[11] B. Dale, "*Biofuels: Thinking Clearly about the Issues."* Journal of Agricultural and Food Chemistry, 2008. **56**(11): p. 3885-3891.

[12] M.M. Ishola, T. Brandberg, S.A. Sanni, and M.J. Taherzadeh, "*Biofuels in Nigeria: a critical and strategic evaluation."* Renewable Energy, 2013. **55**: p. 554-560.

[13] B.B. Nyakuma, A. Johari, and A. Ahmad, "*Analysis of the pyrolytic fuel properties of empty fruit bunch briquettes."* Journal of Applied Sciences, 2012. **12**(24): p. 2527-2533.

[14] J. Goldemberg and P. Guardabassi, "*Are biofuels a feasible option?"* Energy Policy, 2009. **37**(1): p. 10-14.

[15] M. Mosarof, M. Kalam, H. Masjuki, A. Ashraful, M. Rashed, H. Imdadul, and I. Monirul, "*Implementation of palm biodiesel based on economic aspects, performance, emission, and wear characteristics."* Energy Conversion and Management, 2015. **105**: p. 617-629.

[16] J. Van Gerpen, B. Shanks, R. Pruszko, D. Clements, and G. Knothe, *Biodiesel Production Technology, National Renewable Energy Laboratory Subcontractor Report NREL*. 2004, SR-510-36244.

[17] O. Adeniyi, A. Kovo, A. Abdulkareem, and C. Chukwudozie, "*Ethanol fuel production from cassava as a substitute for gasoline."* Journal of Dispersion Science and Technology, 2007. **28**(4): p. 501-504.

[18] U. Rashid, F. Anwar, B.R. Moser, and G. Knothe, "*Moringa oleifera oil: a possible source of biodiesel."* Bioresource technology, 2008. **99**(17): p. 8175-8179.

[19] Z. Helwani, M. Othman, N. Aziz, W. Fernando, and J. Kim, "*Technologies for production of biodiesel focusing on green catalytic techniques: a review."* Fuel Processing Technology, 2009. **90**(12): p. 1502-1514.

[20] A. Hossain and A. Boyce, "*Biodiesel production from waste sunflower cooking oil as an environmental recycling process and renewable energy."* Bulgarian Journal of Agricultural Science, 2009. **15**(4): p. 312-319.

[21] M.H.M. Yusoff, A.Z. Abdullah, S. Sultana, and M. Ahmad, "*Prospects and current status of B5 biodiesel implementation in Malaysia."* Energy Policy, 2013. **62**: p. 456-462.

[22] Y.-H. Chen, T.-H. Chiang, and J.-H. Chen, "*An optimum biodiesel combination: Jatropha and soapnut oil biodiesel blends."* Fuel, 2012. **92**(1): p. 377-380.

[23] Y.-H. Chen, B.-Y. Huang, T.-H. Chiang, and T.-C. Tang, "*Fuel properties of microalgae (Chlorella protothecoides) oil biodiesel and its blends with petroleum diesel."* Fuel, 2012. **94**: p. 270-273.

[24] L. Lin, Z. Cunshan, S. Vittayapadung, S. Xiangqian, and D. Mingdong, "*Opportunities and challenges for biodiesel fuel."* Applied Energy, 2011. **88**(4): p. 1020-1031.

[25] S. Kumar, J.H. Cho, J. Park, and I. Moon, "*Advances in diesel–alcohol blends and their effects on the performance and emissions of diesel engines."* Renewable and Sustainable Energy Reviews, 2013. **22**: p. 46-72.

[26] A.S. Abdulkareem, H. Uthman, A.S. Afolabi, and O.L. Awenebe, *Extraction and Optimization of Oil from Moringa Oleifera Seed as an Alternative Feedstock for the Production of Biodiesel*, in *Sustainable Growth and Applications in Renewable*

Energy Sources, , D.M. Nayeripour, Editor. 2011, InTech.

[27] A. Demirbas, "*Importance of biomass energy sources for Turkey."* Energy Policy, 2008. **36**(2): p. 834-842.

[28] D. Graham-Rowe, "*Agriculture: Beyond food versus fuel."* Nature, 2011. **474**(7352): p. S6-S8.

[29] M. Kuchler and B.-O. Linnér, "*Challenging the food vs. fuel dilemma: Genealogical analysis of the biofuel discourse pursued by international organizations."* Food Policy, 2012. **37**(5): p. 581-588.

[30] N. Usta, "*Use of tobacco seed oil methyl ester in a turbocharged indirect injection diesel engine."* Biomass and bioenergy, 2005. **28**(1): p. 77-86.

[31] S.K. Karmee and A. Chadha, "*Preparation of biodiesel from crude oil of Pongamia pinnata."* Bioresource technology, 2005. **96**(13): p. 1425-1429.

[32] Y.H. Tan, M.O. Abdullah, and C. Nolasco-Hipolito, "*The potential of waste cooking oil-based biodiesel using heterogeneous catalyst derived from various calcined eggshells coupled with an emulsification technique: A review on the emission reduction and engine performance."* Renewable and Sustainable Energy Reviews, 2015. **47**: p. 589-603.

[33] H. Lu, Y. Liu, H. Zhou, Y. Yang, M. Chen, and B. Liang, "*Production of biodiesel from Jatropha curcas L. oil."* Computers & Chemical Engineering, 2009. **33**(5): p. 1091-1096.

[34] A.S. Reshad, P. Tiwari, and V.V. Goud, "*Extraction of oil from rubber seeds for biodiesel application: Optimization of parameters."* Fuel, 2015. **150**: p. 636-644.

[35] A.S. Ramadhas, S. Jayaraj, and C. Muraleedharan, "*Biodiesel production from high FFA rubber seed oil."* Fuel, 2005. **84**(4): p. 335-340.

[36] Y. Zhang, M. Dube, D. McLean, and M. Kates, "*Biodiesel production from waste cooking oil: 1. Process design and technological assessment."* Bioresource technology, 2003. **89**(1): p. 1-16.

[37] M.M. Gui, K. Lee, and S. Bhatia, "*Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock."* Energy, 2008. **33**(11): p. 1646-1653.

[38] L. Meher, D.V. Sagar, and S. Naik, "*Technical aspects of biodiesel production by transesterification—a review."* Renewable and sustainable energy reviews, 2006. **10**(3): p. 248-268.

[39] B.B. Nyakuma, A. Ahmad, A. Johari, and T.A. Tuan, "*Non-Isothermal Kinetic Analysis of Oil Palm Empty Fruit Bunch Pellets by Thermogravimetric Analysis."* Chemical Engineering Transactions, 2015. **45**: p. 1327-1332.

[40] A.J. Ragauskas, C.K. Williams, B.H. Davison, G. Britovsek, J. Cairney, C.A. Eckert, W.J. Frederick, J.P. Hallett, D.J. Leak, and C.L. Liotta, "*The path forward for biofuels and biomaterials."* science, 2006. **311**(5760): p. 484-489.

[41] A. Demirbas, "*Progress and recent trends in biofuels."* Progress in energy and combustion science, 2007. **33**(1): p. 1-18.

[42] R. Lal, "*World crop residues production and implications of its use as a biofuel."* Environment International, 2005. **31**(4): p. 575-584.

[43] M.G. Kulkarni and A.K. Dalai, "*Waste cooking oil an economical source for biodiesel: a review."* Industrial & engineering chemistry research, 2006. **45**(9): p. 2901-2913.

[44] A. Demirbas, "*Political, economic and environmental impacts of biofuels: A review."* Applied Energy, 2009. **86**: p. S108-S117.

[45] A. Zubairu and F.S. Ibrahim, "*Moringa Oleifera Oilseed as Viable Feedstock for Biodiesel Production in Northern Nigeria."* International Journal of Energy Engineering, 2014. **4**(2): p. 21-25.

[46] S.D. Romano and P.A. Sorichetti, *Dielectric spectroscopy in biodiesel production and characterization*. 2010: Springer Science & Business Media.

[47] M.K. Lam, K.T. Lee, and A.R. Mohamed, "*Homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: a review."* Biotechnology advances, 2010. **28**(4): p. 500-518.

[48] S. Lim and L.K. Teong, "*Recent trends, opportunities and challenges of biodiesel in Malaysia: an overview."* Renewable and Sustainable Energy Reviews, 2010. **14**(3): p. 938-954.

[49] F. Anwar, S. Latif, M. Ashraf, and A.H. Gilani, "*Moringa oleifera: a food plant with multiple medicinal uses."* Phytotherapy research, 2007. **21**(1): p. 17-25.

[50] T.S. Anjorin, P. Ikokoh, and S. Okolo, "*Mineral composition of Moringa oleifera leaves, pods and seeds from two regions in Abuja, Nigeria."* International Journal of Agriculture and Biology, 2010. **12**(3): p. 431-434.

[51] H. Brockman, *Production of biodiesel from perennials*. 2008, Department of Agric and Food, Government of Western Australia.

[52] J.W. Fahey, "*Moringa oleifera: A Review of the Medical Evidence for Its Nutritional, Therapeutic, and Prophylactic Properties. Part 1."* Trees for life Journal, 2005. **1**(5): p. 1-15.

[53] H. Ogbunugafor, F. Eneh, A. Ozumba, M. Igwo-Ezikpe, J. Okpuzor, I. Igwilo, S. Adenekan, and O. Onyekwelu, "*Physico-chemical and antioxidant properties of Moringa oleifera seed oil."* Pakistan Journal of Nutrition, 2011. **10**(5): p. 409-414.

[54] B. Padayachee and H. Baijnath, "*An overview of the medicinal importance of Moringaceae."* J. Med. Plants Res, 2012. **6**(48): p. 5831-5839.

[55] F. Anwar and U. Rashid, "*Physico-Chemical Characteristics Of Moringa Oleifera Seeds And Seed Oil From A Wild Provenance Of Pakistan."* Pakistan Journal of Botany 2007. **39**(5): p. 1443-1453.

[56] J. Tsaknis, S. Lalas, V. Gergis, V. Dourtoglou, and V. Spiliotis, "*Characterization of Moringa oleifera variety Mbololo seed oil of Kenya."* Journal of Agricultural and food chemistry, 1999. **47**(11): p. 4495-4499.

[57] B. Mendieta-Araica, R. Spörndly, N. Reyes-Sánchez, and E. Spörndly, "*Moringa (Moringa*

oleifera) leaf meal as a source of protein in locally produced concentrates for dairy cows fed low protein diets in tropical areas." Livestock Science, 2011. **137**(1): p. 10-17.

[58] B. Mendieta-Araica, E. Spörndly, N. Reyes-Sánchez, and R. Spörndly, "*Feeding Moringa oleifera fresh or ensiled to dairy cows—effects on milk yield and milk flavor."* Tropical animal health and production, 2011. **43**(5): p. 1039-1047.

[59] W. Nouman, S.M.A. Basra, M.T. Siddiqui, A. Yasmeen, T. Gull, and M.A.C. Alcayde, "*Potential of Moringa oleifera L. as livestock fodder crop: a review."* Turkish Journal of Agriculture and Forestry, 2014. **38**(1): p. 1-14.

[60] R. Ayerza, "*Seed and oil yields of Moringa oleifera variety Periyakalum-1 introduced for oil production in four ecosystems of South America."* Industrial Crops & Products, 2012. **36**(1): p. 70-73.

[61] W.B. Rizzo, P.A. Watkins, M.W. Phillips, D. Cranin, B. Campbell, and J. Avigan, "*Adrenoleukodystrophy Oleic acid lowers fibroblast saturated C22-26 fatty acids."* Neurology, 1986. **36**(3): p. 357-357.

[62] J.O. Palafox, A. Navarrete, J.C. Sacramento-Rivero, C. Rubio-Atoche, P.A. Escoffie, and J.A. Rocha-Uribe, "*Extraction and Characterization of Oil from Moringa oleifera Using Supercritical CO2 and Traditional Solvents."* American Journal of Analytical Chemistry, 2012. **3**(12A): p. 946.

[63] B.R. Moser, "*Preparation of fatty acid methyl esters from hazelnut, high-oleic peanut and walnut oils and evaluation as biodiesel."* Fuel, 2012. **92**(1): p. 231-238.

[64] R.K. Devappa, H.P. Makkar, and K. Becker, "*Jatropha toxicity—a review."* Journal of toxicology and environmental health, Part B, 2010. **13**(6): p. 476-507.

[65] T. Zhang, G.J. V., and B. Panush, *Washington state ferries biodiesel project-A Technical Report*. 2009, t. The University of Idaho. : Idaho. , USA.

[66] S. Tesfay, I. Bertling, A. Odindo, T.S. Workneh, and N. Mathaba, "*Levels of anti-oxidants in different parts of moringa (Moringa oleifera) seedling."* African Journal of Agricultural Research, 2011. **6**(22): p. 5123-5132.

[67] S. Mani, S. Jaya, and R. Vadivambal, "*Optimization of solvent extraction of Moringa (Moringa oleifera) seed kernel oil using response surface methodology."* Food and Bioproducts Processing, 2007. **85**(4): p. 328-335.

[68] S. Qin, Y. Sun, C. Shi, L. He, Y. Meng, and X. Ren, "*Deacidification of Pistacia chinensis Oil as a promising non-edible feedstock for biodiesel production in China."* Energies, 2012. **5**(8): p. 2759-2770.

[69] W.D. Stidham, D.W. Seaman, and M.F. Danzer, *Method for preparing a lower alkyl ester product from vegetable oil*. 2000, Google Patents.

[70] H. Fukuda, A. Kondo, and H. Noda, "*Biodiesel fuel production by transesterification of oils."* Journal of bioscience and bioengineering, 2001. **92**(5): p. 405-416.

[71] R. Turck, *Method for producing fatty acid esters of monovalent alkyl alcohols and use thereof*. 2003, Google Patents.

[72] A.E. Atabani, A.S. Silitonga, I.A. Badruddin, T. Mahlia, H. Masjuki, and S. Mekhilef, "*A comprehensive review on biodiesel as an alternative energy resource and its characteristics."* Renewable and Sustainable Energy Reviews, 2012. **16**(4): p. 2070-2093.

[73] O.Y. Sarıbıyık, M. Özcanlı, H. Serin, S. Serin, and K. Aydın, "*Biodiesel production from ricinus communis oil and its blends with soybean biodiesel."* Strojniški vestnik-Journal of Mechanical Engineering, 2010. **56**(12): p. 811-816.

[74] G. Knothe and K.R. Steidley, "*Lubricity of components of biodiesel and petrodiesel. The origin of biodiesel lubricity."* Energy & fuels, 2005. **19**(3): p. 1192-1200.

[75] S. Pinzi, I. Garcia, F. Lopez-Gimenez, M. Luque de Castro, G. Dorado, and M. Dorado, "*The ideal vegetable oil-based biodiesel composition: a review of social, economical and technical implications."* Energy & Fuels, 2009. **23**(5): p. 2325-2341.

[76] H. Imahara, E. Minami, and S. Saka, "*Thermodynamic study on cloud point of biodiesel with its fatty acid composition."* Fuel, 2006. **85**(12): p. 1666-1670.

[77] G. Knothe, R.O. Dunn, and M.O. Bagby." *Biodiesel: the use of vegetable oils and their derivatives as alternative diesel fuels*." in *ACS symposium series*. 1997. Washington, DC: American Chemical Society,[1974]-.