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

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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 NOx 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, biomethane) 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 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
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; RCOOR¹ indicates an ester, R²OH an alcohol, R²OH another alcohol (glycerol), RCOO¹ an ester mixture and cat a catalyst:

\[ \text{Catalyst} \quad \text{RCOOR}^1 + \text{R}^2\text{OH} \xrightarrow{\text{cat}} \text{R}^2\text{OH} + \text{RCOO}^1 \]

Ester Alchohol Alcohol Ester

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 possesses 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.

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 CO₂ 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][1]

*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 %.

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[1]: https://example.com/figure1.png
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 unreacted methanol, catalyst, and impurities. The washed MOME is again heated to 110 °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].

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

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 mm²/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 prescribe viscosity in the ranges 1.9–6.0 and 3.5–5.0 mm²/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 *et 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* seed oil (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\textsubscript{x} emission compared to petroleum diesel.

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