Environmental and Climate Technologies
2021, vol. 25, no. 1, pp. 151–160
https://doi.org/10.2478/rtuect-2021-0010
https://content.sciendo.com

Production of Biodiesel from *Moringa Oleifera* and *Jatropha Curcas* Seed Oils over a Modified ZnO/Fly Ash Catalyst

Katlego BOMBO[1], Tumeletso LEKGOBA[2*], Oluwatosin AZEEZ[3], Edison MUZENDA[4]

[1–4]*Department of Chemical, Materials and Metallurgical Engineering, Botswana International University of Science and Technology, Palapye, Botswana*
[3]*Department of Chemical Engineering, Federal University of Technology, Minna, Nigeria*
[4]*Department of Chemical Engineering Technology, University of Johannesburg, Johannesburg, South Africa*

***Abstract* – Methyl ester biodiesel was produced from *Moringa Oleifera* oil and *Jatropha Curcas* oil with the sole aim of assessing the feasibility of the feedstocks as viable sources of biodiesel in Botswana. Oil extraction and transesterification were carried out under identical experimental conditions for both *Jatropha Curcas* and *Moringa Oleifera* biomass. Oil was extracted from seeds through a soxhlet extraction method using the solvent, n-hexane. The extracted oil was then trans-esterified at 60 °C using a methanol/oil ratio of 12:1 at a stirring rate of 350 rpm, 3 wt. % catalyst loading and 120 min reaction time. Zinc Oxide modified with fly ash was used as heterogeneous catalyst for the process. GC analysis results of biodiesels produced indicated that the highest biodiesel yield was obtained from *Jatropha* seed oil. *Moringa* biodiesel showed a greater proportion of docosanedioic acid while *Jatropha* biodiesel composed of oleic acid in larger proportions. Both oleic and docosanedioic acid are unsaturated methyl esters. The results obtained suggests *Jatropha* as the more suitable feedstock as compared to *Moringa*.**

***Keywords* – Biodiesel; *Jatropha Curcas*; *Moringa Oleifera*; transesterification; zinc oxide**

Nomenclature		
FFA	Free Fatty Acid	%
FAME	Fatty Acid Methyl Esters	–
GDP	Gross Domestic Product	Per capita
J. Curcas	*Jatropha Curcas*	–
M. Oleifera	*Moringa Oleifera*	–
MC	Moisture Content	%
TS	Total Solids	%

1. INTRODUCTION

With the world facing an energy crisis due to the increase in the global energy demand and the threat of depleting fossil fuels and world petroleum reserves, demand for substitute fuels has also increased [1]. The rampant power cuts and the fuel price hikes that have occurred

*Corresponding author.
E-mail address: tumsle88@gmail.com

©2021 Katlego Bombo, Tumeletso Lekgoba, Oluwatosin Azeez, Edison Muzenda.
This is an open access article licensed under the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0).

over the years are a clear indication that Botswana falls prey to this worldwide problem [2]. Energy security is threatened by an overdependence on energy imports, the uneven distribution of oil globally and the instability of oil prices worldwide [3]. Botswana is exemplified by these factors as most of its energy is currently imported from South Africa and other neighbouring countries. Energy security is therefore currently non-existent as Botswana's energy demand is higher than its supply. Through the utilization of the country's natural resources to produce biofuels however, risks associated with energy security can be minimized by diversifying the country's energy portfolio. Several fuel alternatives have been investigated over the years and have been established as sustainable sources of energy. The use of biodiesel and biofuels stands to create energy security through a more differentiated energy profile. The bioeconomy, however, relies on the availability and consistency of renewable energy reserves [4].

Biodiesel is a biofuel produced from the oils derived from edible crops, non-edible crops, waste, animal fat and algae. The transesterification of these oils form monoalkyl esters of long chain fatty acids, otherwise known as biodiesel [5]. This is an organic reaction in which triglycerides react with alcohol, normally methanol/ethanol in the presence of a catalyst [6]. According to Musa [7], methanol is mostly preferred over its longer chained alcohol counterparts which are more sensitive to water due to their physical structure. Methanol is also cheaper and more reactive. There are two types of catalysts that can be used for the transesterification reaction, homogenous and heterogenous catalysts. According to Romero *et al.* [8] homogenous catalysts have been preferred due to their high reactivity, which accelerates the reaction within a shorter time (~1 hour). However, the use of these catalysts has several drawbacks including their sensitivity to free fatty acid (FFA) in oil. For oils with an FFA content exceeding the range 0.5–1 %, base catalysts react with FFAs to produce soap which leads to a lower biodiesel yield [9]. The use of homogenous catalysts also requires downstream processes of washing and treatment to remove the catalyst which dissolves in the formed glycerol and fatty acid methyl ester (FAME) layers. Alternatively, heterogenous catalysts can be used in transesterification catalysis since they do not form soap, can be separated easily and are reusable. Recent developments in the study of heterogenous catalysts suggest that organic waste and natural materials can be used as heterogenous catalysts, these include clay, anthill, eggshells, chicken bones, and zeolites. According to [6], the aforementioned materials are active sources of silica (SiO_2) and alumina (Al_2O_3) which are good catalyst supports. The use of these organic materials as heterogenous catalysts could also lessen the cost of biodiesel production and reduce the accumulation of waste in the environment [10].

As mentioned previously, biodiesel can be produced from various edible and non-edible feedstocks, among the vast vegetable oils available in Botswana and sub-Saharan Africa, *Jatropha* has risen to recognition as one of the most suitable biodiesel sources. This is mainly because it is drought resistant and can grow in rocky-strewn terrains, and with little or no agricultural value, deserts and saline soils, while maintaining a high seed oil content of approximately 30–50 wt. % [11]. *Moringa Oleifera* is also another emerging alternative which would be advantageous since it is abundantly available in the country and is characteristically drought resistant with a seed oil content of about 33–41 wt. % [12]. Botswana lacks a competitive and sustainable energy industry and the utilization of *Moringa Oleifera* or *Jatropha Curcas* in the production of biodiesel would not only opens doors to that market, but it would also provide a channel in which agriculture in Botswana could be diversified. This diversification will foster and promote the growth and cultivation of these trees in order to meet the market demands for biodiesel produced from *J. Curcas* and *M. Oleifera*. This venture stands to significantly contribute to the country's GDP, increase

employment opportunities and attract potential foreign investors and markets and also reduce Botswana's dependence on importation of fuels. In this study, a synthesised heterogeneous catalyst of fly ash loaded with zinc oxide was utilised, thus adding to the novelty of the work.

The study was aimed at comparatively investigating the potential of biodiesel production from *Moringa Oleifera* and *Jatropha Curcas* seeds with key objectives being:

1) determination of the biodiesel yields for both *M. Oleifera* and *J. Curcas* seeds;
2) lipid classification for determination of biodiesel composition;
3) assessment of characteristic fuel properties of the produced biodiesel;
4) comparison of the overall feasibility of *M. Oleifera* and *J. Curcas* as biofuel sources.

2. Materials and Methods

2.1. Sample Preparation

Jatropha Curcas seeds were sourced from a local village, Siviya, located in the North Eastern Region of Botswana, while Moringa Oleifera seeds were obtained in Palapye, Botswana. A sample of 100 seeds was dried in a hot oven at 105±10 °C for 24 hrs. According to Nautiyal *et al.* [13], a low moisture content helps in better oil extraction from biomass, therefore, drying the seeds prior to use would significantly lessen the moisture content. Moisture content was determined by taking the mass of the seeds, before drying, at 3-hour intervals during drying until there was no change in mass. The seeds were then ground to produce a fine powder which was passed through a 500 µm sieve to remove oversize particles. *Moringa Oleifera* seeds were dried and ground in the same manner.

2.2. Catalyst Preparation

The catalyst chosen for the transesterification reaction was Zinc Oxide supported fly ash, to increase catalytic activity. Fly ash was initially soaked in 0.5 M HCl solution for 3 days and was thereafter oven dried at 110 °C. The dried fly ash was then pulverized using a pestle and mortar and then sieved at 100–150 µm. Fly ash and ZnO were then mixed at a ZnO/fly ash ratio of 20:80 on a mass basis [6]. The mixture was then calcined at 900 °C for 4 hours in a muffle furnace at a heating rate of 10 °C/min.

2.3. Oil Extraction

38 g of grounded biomass was mixed with 400 ml of n-hexane at 56 °C in order to extract oil through the Soxhlet apparatus using solvent extraction method. The crushed seeds were put in a packed bed in the extraction thimble which was connected to a condenser bulb at the top and a bottom round flask containing solvent n-hexane at the bottom. The solvent was evaporated out, contacting the seeds as it condensed, therefore leaching the oil out of the seeds. After this, a rotary evaporator was used to separate the extracted oil from the solvent, configured at 180 rpm and 40 °C.

2.4. Oil Conversion to FAME

The extracted oil was converted to biodiesel through the transesterification reaction. In the transesterification reaction, lipids react with alcohol (methanol in this case) in the presence of modified fly ash/ZnO catalyst to form fatty acid ester (biodiesel) and glycerol. The transesterification reaction was carried out at 60 °C, with a catalyst loading rate of 3 wt. %, 120 minutes reaction time, at a stirring rate of 360 rpm and a methanol/oil ratio of 12:1. The same conditions were used for the *J. Curcas* and *M. Oleifera* oils. The reaction was

carried out in a two-necked round bottom flask, the reactants were fed into the flask. Thereafter, a thermometer was inserted in one of the necks to monitor the reaction temperature. A condenser was connected to the other neck of the flask to convert gaseous methanol to liquid form as the reaction proceeds. The flask was then placed in a temperature controlled magnetic stirrer to maintain reaction conditions. After the reaction was complete, the mixture was left to cool at room temperature and excess alcohol was removed through the rotary vacuum evaporator. To aid and accelerate the phase separation of glycerol and biodiesel, the reaction product mixture was centrifuged at 2000 rpm for 20 minutes. Once the interface was clearly formed the two phases were physically separated through decantation.

2.5. Characterization

2.5.1. Proximate Analysis

The moisture content and total solids of *Moringa* biomass and *Jatropha* biomass were determined through the proximate analysis. This was to preliminarily determine the characteristics of the biomasses then compare the obtained results to note their similarities and differences. Where a lower moisture content results in higher oil yields, this information was used when correlating the results of oil yields. From Canadas-Lopez *et al.* [14] percentage (%) moisture content is given by:

2.5.2. Moisture Content

$$MC = \frac{m_{\text{wet}} - m_{\text{dry}}}{m_{\text{dry}}} \cdot 100 \tag{1}$$

2.5.3. Total Solids (TS)

$$TS = \frac{m_{\text{dry}}}{m_{\text{wet}}} \cdot 100\,, \tag{2}$$

where

MC	moisture content in wt. %;
TS	total solids in wt. %;
m_{wet}	fresh mass of the biomass;
m_{dry}	mass of the dried biomass.

2.5.4. XRF Analysis of Biomass and the Modified ZnO/fly Ash Catalyst

XRF analysis was used to determine the elemental/chemical composition of the dried biomass from both feedstocks and the modified catalyst. For the feedstocks, the elemental composition was used to compare properties such as sulphur and nitrogen and for the catalyst was to allow for analysis of the effect of modifying the ZnO with fly ash. According to Nautiyal *et al*. [13], lower Sulfur and Nitrogen percentages in the biodiesel will result in lower exhaust emissions of NOx and SOx when using the biodiesel is used as a fuel. A lower oxygen composition is also an indicator of biodiesel stability due to less oxidative degradation.

2.5.5. Determination of Lipid Content / Oil Yield

The oil yield after oil extraction for each of the oils was determined by the following Eq. (3).

$$\text{Oil yield} = \frac{\text{mass of oil produced}}{\text{mass of biomass used}} \cdot 100 \quad (3)$$

2.5.6. Determination of Biodiesel Yield

The biodiesel yield of the respective feedstocks was determined by the following Eq. (4).

$$\text{Biomass yield} = \frac{\text{mass of biodiesel produced}}{\text{mass of oil used}} \cdot 100 \quad (4)$$

2.5.7. Gas Chromatography Analysis of Biodiesels

The GC-MS analyser was used to study the chemical composition of the biodiesel produced from *J. Curcas* seeds and *M. Oleifera* seeds. A comparison of the chromatogram peaks of the two biodiesel samples and standard biodiesel was then carried out and the fatty acid composition of the two samples established.

2.5.8. Determination of Fuel Properties

Fuel properties including density, FFA content and acid value for *J. Curcas* and *M. Oleifera* derived biodiesels were determined and compared to that of standard biodiesel. This was to gauge whether the produced biodiesel satisfies both European and American standards of biodiesel.

2.5.9. Acid Value and FFA Content

The free fatty acid composition of the biodiesels was determined using titrimetric analysis. Using the Isopropyl alcohol method, 1 ml of oil was added to 10 ml isopropyl alcohol and then a few drops of phenolphthalein were added. This mixture was then titrated against 0.025N NaOH solution until a pale pink colour was observed. The %FFA content was calculated on basis of the most dominant fatty acid, usually oleic acid. The acid value is then taken as

$$\text{Acid value} = 2 \cdot \text{FFA}\,, \quad (5)$$

where

$$\text{FFA} = \frac{\text{Titre (ml)} \cdot 5.61}{\text{weight of sample used}}\,. \quad (6)$$

In terms of oleic acid, 1 ml of 0.1 M NaOH = 0.0282 oleic acid.

3. Results and Discussion

3.1. Fly Ash Modified ZnO Catalyst and Biomass Composition

Fig. 1 presents the elemental composition of the biomass and it shows that *J. Curcas* has a higher composition of alkali metals, potassium (12.9 wt. %) and calcium (17.4 wt. %) than *M. Oleifera*. Combined with the alkali metal composition from the catalyst, this increases chances of saponification, accounting for the higher %FFA content in *Jatropha* which contrasts that of *Moringa*. Fig. 1 shows that *M. Oleifera* has a high composition of sulphur (34.7 wt. %) in contrast to *J. Curcas* Sulphur composition of (4.3 wt. %). The higher sulphur

content indicates that, upon oxidation/combustion *M. Oleifera* biodiesel will have higher SOx emissions than *J. Curcas* biodiesel.

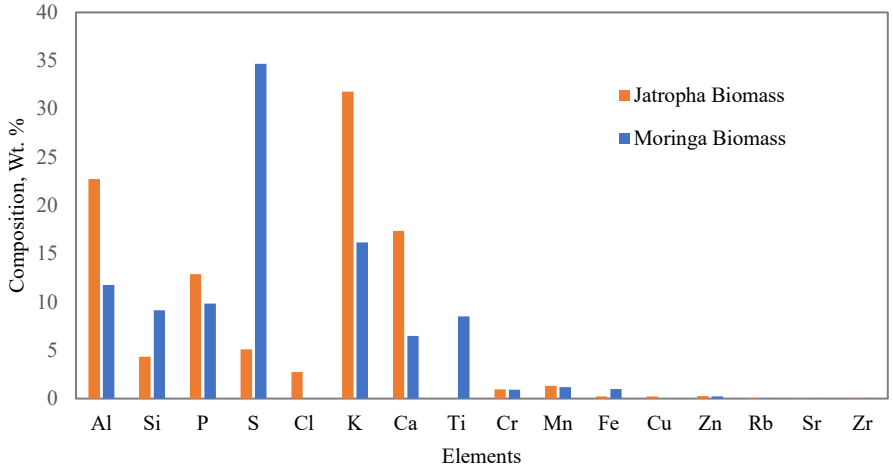


Fig. 1. Elemental composition of *Jatropha* and *Moringa* biomass.

From the XRF analysis of the fly ash modified ZnO catalyst (Fig. 2), it was found that the catalyst is mainly composed of Zinc (56.7 wt. %), followed by calcium (12.6 wt. %), silicon (11.2 wt. %), iron (8.1 wt. %) and aluminium (7.6 wt. %).

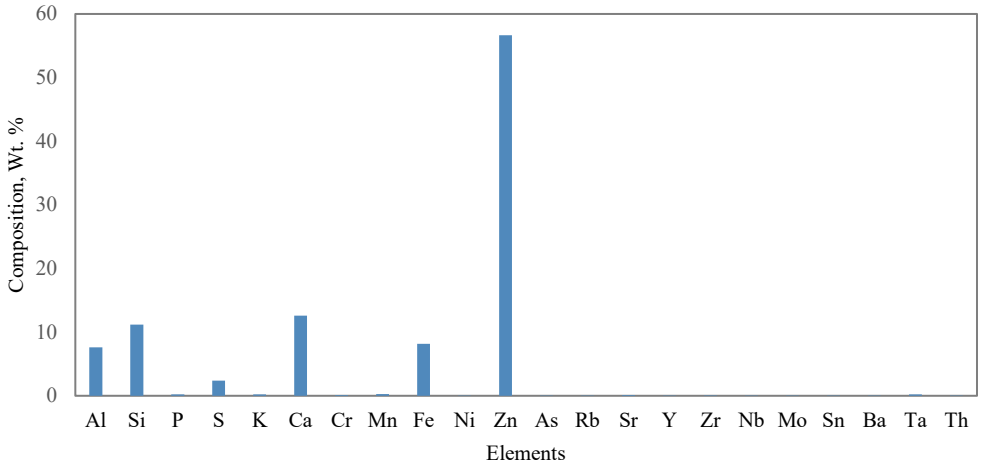


Fig. 2. Chemical composition of Modified ZnO/fly ash catalyst.

The larger composition of zinc signifies the role of zinc in catalysis while silicon and aluminium signify the presence of oxides of these elements, silica and alumina which have been quoted by Yusuff & Bello [6] as good catalyst supports and are mainly from fly ash. The modified ZnO/fly ash catalyst also has some traces of heavy metals and alkali metals and together with some light elements. According to Banga & Varshney [15], alkali metals

(sodium, potassium, calcium and magnesium) present in transesterification raw materials could form soap and increase FFA content of biodiesel blends. Calcium which is present in significant quantities has a role in the %FFA content of *J. Curcas* and *M. Oleifera* seeds. Iron also contributes to the corrosivity of the biodiesel.

3.2. The Effect of Moisture Content on Oil and Biodiesel Yield

According to [13] a low moisture content improves oil extraction, consequently resulting in higher yields. Kusdiana & Saka [16] also reported that the presence of water in the raw material causes the consumption of the catalyst during the transesterification reaction, therefore reducing the catalyst efficiency. The moisture content is therefore an important parameter that affects the biodiesel yield. In this study, moisture content was determined by monitoring the changes in feedstock mass during drying until no changes in mass were observed. Table 1 shows the mass of feedstock before and after drying, these figures were used to calculate the moisture content and total solids of the respective biomasses, shown in Table 2 and the moisture content for *J. Curcas* biomass was found to be higher than that of *M. Oleifera*, at 8.07 % and 4.75 % respectively.

TABLE 1. MASS OF FEEDSTOCK SAMPLES BEFORE AND AFTER DRYING

	J. Curcas	*M. Oleifera*
Mass of seeds before drying, g	126.31	88.89
Mass of seeds after drying, g	116.88	84.29

TABLE 2. PROXIMATE ANALYSIS DATA FOR BIOMASSES

	J. Curcas	*M. Oleifera*
Moisture content, %	8.07	4.75
Total solids, %	92.5	94.8

The oil yields and biodiesel yields were calculated based on the amount of oil produced from the biomass and the amount of biodiesel produced from the oil used respectively, for the oil yields, *J. Curcas* biomass had a higher oil yield of 49.8 % while *M. Oleifera* biomass came in lower at 20.2 %. However, *Jatropha* yielded a slightly lower biodiesel output of 58.7 % while *Moringa* had a higher yield of 60.8 %. This data was tabulated as shown in Fig. 3 to give a comparative overview of the biodiesel yields whilst also correlating it with the % moisture contents. The results obtained indicate that moisture content has no significant effect on the oil yield because *Jatropha*, which has a higher moisture content also has a higher oil yield than *Moringa*. According to [12], *Moringa* has an oil content ranging between 33 and 41 wt. %, *Jatropha* on the other hand ranges between 40 and 50 wt. %. The oil yields determined from experiment correlates with this data, Fig. 3 shows that *Jatropha* has a higher lipid content than *Moringa*, *Jatropha* having an oil yield of 49.8 wt. % and *Moringa* with 20.2 wt. %. It is evident however that, a high moisture content results in a lower biodiesel yield. Whilst *Jatropha* proved to have a higher lipid content than *Moringa*, it also gave a lower (58.7 %) biodiesel yield than *Moringa* (60.8 %). As mentioned previously, the presence of moisture causes catalyst consumption, reducing catalyst efficiency and consequently yielding a lower biodiesel output.

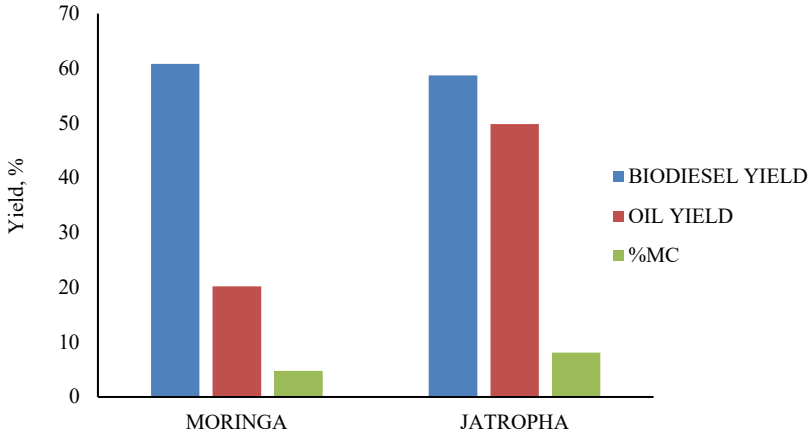


Fig. 3. Relationship between moisture content, oil yield and biodiesel yield.

3.3. The Effect of Moisture Content on Biodiesel Fuel Properties

Apart from consuming the catalyst and decreasing the catalyst activity, moisture content also affects properties such as free fatty acid (FFA) content and the acid value of the produced biodiesel [16]. According to Udoh *et al*. [17] both %FFA and acid values increase with increasing moisture content and in Table 3 the moisture content of *Moringa* gave acid number and %FFA values of 0.63 and 0.45 %, respectively. On the other hand, the moisture content of *J. Curcas* was significantly higher, at 8.07 % with the corresponding acid number and %FFA values also higher than that of *M. Oleifera* values, at 1.06 and 0.74, respectively. According to [13], the long-term stability of biodiesel against corrosiveness is related to the acid value. Hence a lower acid value would indicate a better biodiesel quality, the better-quality biodiesel would be *Moringa* biodiesel.

TABLE 3. FUEL PROPERTIES OF *MORINGA* AND *JATROPHA* BIODIESEL AND DIESEL STANDARDS

Parameter	*Moringa*	*Jatropha*	Diesel	ASTM D6751	EN 14214
Acid number, mg NaOH/g	0.63	1.06	0.20	0.50 max	0.50 max
%FFA	0.45	0.74	–	–	–
%MC	4.75	8.07	–	–	–

Standards values of Diesel, ASTM D6751 and EN 14214 were sourced from [13]

Kusdiana & Saka [16] has also cited that in order to maximize the formation of biodiesel, an FFA content that is less than 0.5 % and acid value less than 1 should be maintained. From the values obtained in this work, the acid number and %FFA of *Moringa* biodiesel satisfy the requirements for maximum biodiesel production, while values from *Jatropha* biodiesel are higher than required. That is, the acid value for *Moringa* biodiesel is 0.63, which is lower than the allowable value of 1 whereas the *Jatropha* biodiesel acid value is 1.06, higher than the maximum allowable acid value. %FFA values for *Jatropha* and *Moringa* are 0.74 % and 0.45 %, respectively, putting *Moringa* within the 0.5 % boundary and *Jatropha* exceeds the value. This would explain why *Moringa* had a higher biodiesel yield than *Jatropha* despite

having a lower oil yield. A higher FFA content inhibits the transesterification reaction giving a lower biodiesel yield [16].

3.4. Fatty Acid Composition of Biodiesel Derived from M. Oleifera and J. Curcas

GC-MS analysis identified the presence of three saturated methyl esters, (butyric, palmitic, stearic) and four unsaturated methyl esters, (oleic, myristoleic, heptadecanoic and Docosanedioic). *J. Curcas* was mainly composed of oleic acid methyl ester and *M. Oleifera* biodiesel was mainly composed of Docosanedioic acid methyl ester. The presence of methyl esters confirms the oil conversion to biodiesel. Only 3 FAME's were identified in *Moringa* biodiesel while 5 were identified in *Jatropha* biodiesel and this indicates a lower lipid content in *Moringa*. *Moringa* biodiesel was also largely composed of long chain fatty alcohols and some traces of glycerol. This indicates that the *Moringa* biodiesel required further refining to remove impurities and produce a purer form of biodiesel. A large fraction of *Moringa* biodiesel contains impurities that can discredit the high biodiesel yield of *Moringa* because the yield is calculated based on mass which also includes mass of these impurities. Taking the data presented in Table 4, it can be concluded that *Jatropha* has the highest FAME yield.

TABLE 4. FATTY ACID METHYL ESTER COMPOSITION IN BIODIESEL FROM RESPECTIVE FEEDSTOCKS

No.	FAME	Formula	Structure	wt. % of FAME in Biodiesel	
				MORINGA	*JATROPHA*
1.	Oleic acid	$C_{18}H_{34}O_2$	18:1	4.28	9.47
2.	Butyric acid	$C_{20}H_{32}O_3$	4:0	–	6.97
3.	Palmitic acid	$C_{18}H_{34}O_2$	16:0	–	6.25
4.	Myristoleic acid	$C_{14}H_{26}O_2$	14:1	–	3.41
5.	Stearic acid	$C_{19}H_{36}O_2$	18:0	5.32	–
6.	Heptadecanoic acid	$C_{17}H_{34}O_2$	17:1	–	1.56
7.	Docosanedioic acid	$C_{22}H_{42}O_4$	12:2	12.49	–

4. CONCLUSION

Biodiesel production from both *M. Oleifera* and *J. Curcas* feedstock using a modified ZnO/fly ash catalyst was successfully carried out. *Jatropha* had a higher fatty acid methyl composition or higher FAME yield than *Moringa*. However, the chemical composition data showed that biodiesel derived from *Jatropha* had a higher fatty acid methyl ester (FAME) composition than *Moringa*, with oleic acid methyl ester acid as the predominant FAME. Five (5) fatty acid methyl esters were identified in *Jatropha* Biodiesel while three (3) FAMEs were identified in *Moringa* biodiesel, with docosanedioic as the predominant methyl ester. It was also found that bulk of the composition in *Moringa* biodiesel is taken by fatty acid alcohols. Based on this, it is concluded that *Jatropha* is a better alternative feedstock than *Moringa*, since it had a higher FAME yield. Elemental composition of the ZnO/fly ash catalyst showed that compounds, silica, and alumina were present in significant amounts thus ensuring good catalyst support. Based on evidence of the biodiesel obtained, the ZnO/fly ash catalyst is assumed to be an effective solid catalyst for biodiesel conversion. Therefore, it is recommended that further studies be carried out to investigate and optimise the performance

of this catalyst in biodiesel production and further characterisation of the produced oil is necessary such as fuel properties and CHNS.

REFERENCES

[1] Gulum M., Bilgin A. Measurement and Prediction of Density and Viscosity of Different Diesel-Vegetable Oil Binary Blends. *Environmental and Climate Technologies* 2019:23(1):214–218. https://doi.org/10.2478/rtuect-2019-0014

[2] Botswana Energy Sector. Energy Policy Brief: Reflecting on the Challenges of Attaining a Green Economy for Botswana. Gaborone, 2012.

[3] Dufey A. Biofuels production, trade and sustainable development: emerging issues. London: International Institute for Environment and Development, 2006:2.

[4] Zihare L., Blumberga D. Bioeconomy Investments: Market Considerations. *Environmental and Climate Technologies* 2020:24(2):79–91. https://doi.org/10.2478/rtuect-2020-0056

[5] Singh S. P., Singh D. Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: A review. *Renewable and Sustainable Energy Reviews* 2010:14(1):200–216. https://doi.org/10.1016/j.rser.2009.07.017

[6] Yusuff A. S., Bello K. A. Synthesis of fatty acid methyl ester via transesterification of waste frying oil by a zinc-modified pumice catalyst: Taguchi approach to parametric optimization. *React. Kinet. Mech. Catal*. 2019:128(2):739–761. https://doi.org/10.1007/s11144-019-01680-z

[7] Musa I. A. The effects of alcohol to oil molar ratios and the type of alcohol on biodiesel production using transesterification process. *Egyptian Journal of Petroleum* 2016:25(1):21–31. https://doi.org/10.1016/j.ejpe.2015.06.007

[8] Romero R., Luz Martinez S., Natividad R. Biodiesel Production by Using Heterogeneous Catalysts. Alternative Fuel. London: InTech, 2011. https://doi.org/10.5772/23908

[9] Lam M. K., Lee K. T. Production of biodiesel using palm oil. Biofuels. Elsevier Inc., 2011:353–374.

[10] AlSharifi M., Znad H. Development of a lithium based chicken bone (Li-Cb) composite as an efficient catalyst for biodiesel production. Renew. *Energy* 2019:136:856–864. https://doi.org/10.1016/j.renene.2019.01.052

[11] Kamel D. A., *et al.* Smart utilization of jatropha (*Jatropha curcas Linnaeus*) seeds for biodiesel production: Optimization and mechanism. *Ind. Crops Prod*. 2017:111:407–413. https://doi.org/10.1016/j.indcrop.2017.10.029

[12] Azam M. M., Waris A., Nahar N. M. Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. *Biomass and Bioenergy* 2005:29(4):293–302. https://doi.org/10.1016/j.biombioe.2005.05.001

[13] Nautiyal P., Subramanian K. A., Dastidar M. G. Production and characterization of biodiesel from algae. *Fuel Process. Technol*. 2014:120:79–88. https://doi.org/10.1016/j.fuproc.2013.12.003

[14] Cañadas-López A., *et al*. Productivity and oil content in relation to jatropha fruit ripening under tropical dry-forest conditions. *Forests* 2018:9(10):611. https://doi.org/10.3390/f9100611

[15] Banga S., Varshney P. Effect of impurities on performance of biodiesel: A review. *J. Sci. Ind. Res. (India).* 2010:69(8):575–579.

[16] Kusdiana D., Saka S. Effects of water on biodiesel fuel production by supercritical methanol treatment. *Bioresour. Technol*. 2004:91(3):289–295. https://doi.org/10.1016/S0960-8524(03)00201-3

[17] Udoh J. E., *et al.* Effect of Moisture Content on the Mechanical and Oil Properties of Soursop Seeds. *Chemical Engineering Transactions* 2017:58:361–366. https://doi.org/10.3303/CET1758061