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Evaluation of Quality Characteristics of Biodiesel Produced From *Jatropha Curcas* in Kenya

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Abstract:

*The quality characteristics of biodiesel produced from *Jatropha curcas* in Kenya were evaluated. Seeds for oil extraction were obtained from Meru and Tharaka Nithi, Kibwezi, Oyugis and Funyula research plots while biodiesel was obtained through trans-esterification process. Physical and chemical properties of seed oil and biodiesel were analysed according to the American Standards Testing Materials (ASTM D4052) protocols. It was found that the density of oil was between 1.0802 - 1.0864 g/cm³ at 20°C whereas that of biodiesel ranged between 0.8786 – 0.8808 g/cm³. Acid value of seed oil was between 1.35 - 4.19 mgKOH/g while that of biodiesel was between 0.31 - 0.86 mgKOH/g. Kinematic viscosity of biodiesel was between 4.3 to 4.8 mm²/s at 40°C. From the results, it was concluded that straight *Jatropha* oil after trans-esterification process is suitable for direct usage as fossil fuel substitute. Parameters of biodiesel produced were within the limits of those set out in the ASTM standards for biodiesel. Using *Jatropha* as a source of biodiesel in Kenya would save on foreign exchange used to import fossil fuels, create jobs for youth and contribute to reduction of the effects of greenhouse gases emissions.*

Keywords: *Jatropha curcas*, biodiesel, physico-chemical characterization

1. Introduction

The increasing industrialization and modernization of the world has led to a steep rise for the demand of petroleum products. Economic development in developing countries has led to huge increase in energy demand. In Kenya, economic growth has put the country's energy and electricity supply in particular under increasing pressure. Between 2004 and 2013 power demand Kenya rose by 18.9 % annually with the existing capacity barely able to keep up with demand (Netherlands Enterprise Agency, 2018).

At the national level, wood fuel and other biomass accounted for about 68 % of the total primary energy consumption, followed by petroleum at 22 % and electricity at 9 %. The country's total value of imports grew by 38.9 percent from Kshs 947.4 billion in 2010 to Kshs 1.3 trillion (1USD = ~100 Kshs) in 2011 accounting for over 40 % of its foreign exchange earnings (Institute of Economic Affairs, 2013).

Globally, petroleum-based fuels are limited, with the finite reserves concentrated in certain regions of the world. Countries lacking in fossil fuel reserves are facing foreign exchange crises, mainly due to the import of crude oil. This scenario has increased the focus towards alternative fuels, including generation of bio-based oil and its products using renewable feedstock. Biodiesel, an eco-friendly and renewable fuel substitute for diesel has been getting worldwide attention from media, policy makers, researchers and scientists (Mofijur, *et al.*, 2016).

Biodiesel is a non-toxic, biodegradable and carbon neutral renewable fuel that can be produced from a range of organic feedstock including fresh or waste vegetable oils, animal fats, and oilseed plants. Biodiesel has significantly lower emissions than petroleum-based diesel when it is burned, whether used in its pure form or blended with petroleum diesel.

It does not contribute to a net rise in the level of carbon dioxide in the atmosphere and leads to minimized intensity of greenhouse effect (Bailis, R. E. and Baka, J. E., 2010).

Other attributes of biodiesel are that it is better than diesel fuel in terms of sulphur content, flash point, aromatic content and biodegradability. Vegetable oils are becoming a promising alternative to diesel fuel because they are renewable in nature and can be produced locally; and are environmentally friendly. Inedible vegetable oils, mostly produced by seed-bearing trees and shrubs such as *Jatropha curcas* with no competing food uses, are potential alternatives. *J. curcas* has lately attracted particular attention as a tropical energy plant (King *et al.*, 2015).

The oil from *J. Curcas* has the potential to provide promising and commercially viable alternative to diesel oil as it has all the desirable physicochemical and performance characteristics as that of diesel. It has very high saponification value and its ability to burn without emitting smoke, makes it commercially competitive (Pandey *et al.*, 2012). The seed oil can be used as diesel engine fuel for it has characteristics close to those of fossil fuel diesel. Due to its non-toxic and biodegradable nature, *Jatropha* biodiesel meets the European BS EN14214 standards of a pure and blended automotive fuel for diesel engines. *J. curcas* seeds yield approximately 6 - 8 Metric Tonnes per hectare (MT/ha) with 37 % oil. Such yields could produce the equivalent of 2100 - 2800 litres of fuel oil per hectare, with energy equivalent of 19,800 - 26,400 kwh/ha (Nahar K. and Sunny SA, 2011).

Biodiesel as an alternative fuel for diesel engines is becoming increasingly important due to diminishing petroleum reserves and the environmental consequences due to greenhouse gas emissions from petroleum-fuelled engines. The availability and sustainability of sufficient supplies of less expensive feedstock will be a crucial determinant delivering a competitive biodiesel to the commercial filling stations (Nahar K. and Sunny SA, 2014).

Case studies clearly demonstrate that *J. curcas* can be an income generation opportunity for poor rural farmers, without compromising the food supply, due to its ability to grow on less-favourable soils or as hedge rows around food or fodder cropping areas. Eighty per cent (80 %) of Kenya's expansive land area is marginal. Establishing biodiesel plants on such land has the potential to increase income generation for poor families, create employment, reverse environmental degradation and stem rural urban migration. However, for these benefits to be realized there is need for careful introduction of such programmes (Von Maltitz, *et al.*, 2014).

In spite of the many attributes of *J. Curcas* as a potential feedstock for bioenergy production and utilization, there is limited technical information on production yields and suitability of the oil from different localities. In Kenya there is need to identify the highest yielding accession of *J. curcas* by evaluating biodiesel productivity from *J. curcas* and specifically determine oil quantity and quality characteristics of the various accessions, the quality characteristics of biodiesel produced from various accessions and compare the variations of the biodiesel produced (Guo, G. Y., *et al.* (2016), Van Eijck J., *et al.*, (2014)).

2. Methods and Materials

2.1. Study Area

Jatropha curcas seeds that were used for the evaluation of quantity and quality of biodiesel were randomly collected from accessions that were established by Kenya Forestry Research Institute in various locations in Kenya for research purposes. Mature seeds were obtained from Kibwezi, Kitui county, Meru and Tharaka Nithi, in Meru and Tharaka Nithi counties, Oyugis in Homa Bay county, and Funyula in Busia county.

2.2. Sampling Techniques and Sample Size

Jatropha seeds were randomly sampled from trees with seed bearing accessions from Kibwezi, Meru/Tharaka, Oyugis and Funyula sites. Forty kilograms (40 Kgs) of seeds were obtained from each location and packed into 8 Kgs each and indelibly labelled. The seeds were then used to determine their physical and chemical characteristics.

2.3. Determination of Moisture Content of Seeds

The *Jatropha* seeds were ground mechanically using a grinding mill into small particles of less than 2 mm in diameter. All the samples were ground as whole seeds. About 5 g (M_i) of the ground sample was weighed using an analytical balance calibrated with standard weights of 0.5 and 100 g and the balance was adjusted to read the exact values of the weights. The sample was weighed in a previously tared moisture dish with lid to within 0.001 g and the dish was placed in an oven at 105 °C without the lid for a period of about 24 hours. The dish was removed and immediately covered with the lid before being put in a desiccator to cool. The dish was then weighed and put back in the oven for a further one hour before being reweighed. The above procedure was stopped when the difference between two successive weights was less than 5 mg, the final weight (M_f) was then noted. The wet basis moisture content (MC) of the seeds was then calculated using the equation below:

$$MC (\%) = \{(M_i - M_f) / M_i\} \times 100 \%$$

where

MC (%) is the moisture content, M_i is the initial mass and M_f is the final mass of the seed.

2.4. Extraction of Oil Samples

The test samples of the vegetable oil were extracted from the whole seeds using ram press method. The oil extracted was filtered through an ashless filter paper (Whatman Filter paper).

The percentage of oil content was calculated by the equation below:

% of oil = (Weight of oil obtained in grams/ Weight of seed taken in grams) X 100

2.5. Chemical and Physical Analysis of *Jatropha* Seed Oil

2.5.1. Moisture

About 5 g (M_i) of *Jatropha* oil sample was weighed using an analytical balance calibrated with standard weights of 0.5 and 100 g and the balance was adjusted to read the exact values of the weights. The sample was weighed in a previously tared moisture dish with lid to within 0.001 g and the dish was placed in an oven at 105 °C without the lid for a period of about 24 hours. The dish was removed and immediately covered with the lid before being put in a desiccator to cool. The dish was then weighed and put back in the oven for a further one hour before being reweighed. The above procedure was stopped when the difference between two successive weights was less than 5 mg. The final weight (M_f) was then noted. The moisture content (MC) of the *Jatropha* oil was then calculated using the equation below:

$$MC (\%) = \{(M_i - M_f)/M_i\} \times 100 \%$$

where

MC (%) is the moisture content, M_i is the initial mass and M_f is the final mass of the seed.

2.5.2. Density

The density of the oils and water were determined using a density bottle with a provision for temperature measurement. An empty density bottle of known volume was weighed before being filled with the sample and reweighed at 20 °C. All weights were determined to the nearest 0.0001 g and in duplicate while ensuring that the difference between the two weights did not exceed 0.0002 g. The density of the samples was then calculated using the relationship as below:

$$\text{Density} = (\text{Mass of oil} \div \text{Volume of oil})$$

2.5.3. Acid Value and Free Fatty Acids

A 25 ml of diethyl ether was mixed with 25 ml alcohol and 1 ml phenolphthalein solution (1 %) and carefully neutralized with 0.1 M sodium hydroxide. Five grams of *Jatropha* oil was dissolved in the mixed neutral solvent and titrated with aqueous 0.1 M sodium hydroxide shaking constantly until a pink colour which persisted for 15 seconds was obtained. The following equation was used to calculate the acid value:

$$\text{Acid value} = \text{titration (ml)} \times 5.61 / \text{weight of sample used}$$

The FFA figure is usually calculated as oleic acid (1 ml 0.1 M sodium hydroxide = 0.0282 g oleic acid), in which case the acid value = 2 x FFA.

2.5.4. Saponification Value

A solution of 35-40 g of potassium hydroxide and 20 ml water was made and diluted to 1 L with alcohol (95 %) and left to stand overnight. The clear liquid was then decanted.

A 2 g of oil was weighed into a conical flask and exactly 25 ml of the alcoholic potassium hydroxide solution was added. A reflux condenser was attached and the flask was heated in water for 1 hour, shaking frequently. One ml phenolphthalein solution (1 %) was added and the excess alkali titrated hot with 0.5 M hydrochloric acid (titration = a ml). A blank was carried out at the same time (titration = b ml). The following equation was used to calculate the saponification value:

$$\text{Saponification value} = (b-a) \times 28.05 / \text{wt (in g) of sample}$$

2.5.5. Iodine Value

A 20 ml of carbon tetrachloride (CCl_4) was added to 0.24 g of the *Jatropha* seed oil in 250 ml Erlenmeyer flask. Another 20 ml of the carbon tetrachloride were added to two additional flasks that served as blanks. A 25 ml volume of Wij's reagent was pipetted into each flask. The flasks were corked, swirled to mix content and stored in a dark place at 28 °C. 10 ml of 30% potassium iodide (KI) and 100 ml of purified water were added to the sample solution after 30 minutes of storage and immediately titrated with standard 0.1 M sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3$) until the yellow colour almost disappeared. One ml of 1% starch indicator solution was added and the titration continued, this time drop wise with vigorous swirling until the disappearance of the blue starch-iodine colour. The blanks were titrated in the same manner (AOAC Official Method-1997 993.20.). The iodine value was calculated using the below equation:

$$\text{Iodine number} = (\text{Blank titre} - \text{Sample titre}) (0.01269) (100) / \text{Sample weight in g}$$

2.5.6. Trans-Esterification Process

Base catalyzed trans-esterification process was selected as it is a simpler process and requiring low temperatures. The trans-esterification process is the reaction of a tri - glyceride with an alcohol to form esters and glycerol. The alcohol reacts with the fatty acids to form the mono - alkyl esters or biodiesel and crude glycerol. Since methanol was used in this process it is called methanolysis. Sodium hydroxide (NaOH) was used as base catalyst. The stoichiometry of trans-esterification reaction requires three mol of alcohol per mol of triglyceride to yield three mol fatty ester and one mol glycerol (Nahar K and Sunny SA, 2011).

2.6. Physicochemical Analysis of Biodiesel Produced from *Jatropha Curcas* Seed Oil

2.6.1. Moisture Content

About 5 g (M_i) of *Jatropha* biodiesel sample was weighed using an analytical balance calibrated with standard weights of 0.5 and 100 g, the balance was adjusted to read the exact values of the weights. The sample was weighed in a

previously tared moisture dish with lid to within 0.001 g and the dish was placed in an oven at 105 °C without the lid for a period of about 24 hours. The dish was removed and immediately covered with the lid before being put in a desiccator to cool. The dish was then weighed and put back in the oven for a further one hour before being reweighed. The above procedure was stopped when the difference between two successive weights was less than 5 mg. The final weight (M_f) was then noted. The moisture content (MC) of the *Jatropha* biodiesel was then calculated using the equation below:

$$MC (\%) = \{(M_i - M_f)/M_i\} \times 100 \%$$

where

MC (%) is the moisture content, M_i is the initial mass and M_f is the final mass of the seed.

2.6.2. Density and Relative Density

The test method for density and relative density of crude oils by digital density analyzer was used. A small volume (approximately 0.7 mL) of liquid sample was introduced into an oscillating sample tube and the change in oscillating frequency caused by the change in the mass of the tube was used in conjunction with calibration data to determine the density of the sample (ASTM D4052).

2.6.3. Kinematic Viscosity

The temperature of the viscometer bath was adjusted to 37.9 °C. A calibrated thermometer was held in an upright position and inserted into the bath by a holder. A clean dry calibrated viscometer was selected and carefully flushed with a dry nitrogen gas to remove the moist room air. A sample of the oil/biodiesel was drawn up into the working capillary of the viscometer and the timing bulb and then allowed to drain back as an additional safeguard against moisture condensing or freezing on the walls. The charged viscometer was inserted into the bath at a depth such that at no time during the measurement of the flow time, any portion of the sample in the viscometer is less than 20 mm below the surface of the bath. The viscometer together with its content was allowed to remain in the bath for 30 minutes to reach the test temperature (39.9 °C). A suction bulb was used to adjust the head level of the oil/biodiesel to a position in the capillary arm of the viscometer about 7 mm above the first timing mark. The oil/biodiesel was then allowed to freely flow and the time required for the meniscus to pass from the first to the second timing marks was noted with a stop watch. The procedure was repeated to make a second measurement of flow time and the average of these determinations was used to calculate the kinematic viscosity. The viscometer was thoroughly cleaned with sample solvent and dried by vacuum. The procedure was repeated for the other samples of the biodiesel (ASTM D 445 - 97). The Kinematic viscosity was calculated by the below equation:

$$V = C \times t \quad [\text{ASTM D 445 - 97}] \text{ where}$$

V = kinematic viscosity, mm^2/s

C = calibration constant of the viscosity, $(\text{mm}^2/\text{s})/\text{s}$

t = mean flow time, s

2.7. Flash-point

Standard test methods for flash-point by Pensky-Martens closed cup tester was used. A brass test cup of specified dimensions, filled to the inside mark with test specimen and fitted with a cover of specified dimensions was heated and the specimen stirred at specified rates. An ignition source was directed into the test cup at regular intervals with simultaneous interruption of the stirring, until a flash was detected. The flash point n - in petroleum products is the lowest temperature corrected to a barometric pressure of 101.3 kPa (760 mm Hg) at which an application of an ignition source causes the vapours of a specimen of the sample to ignite under specified conditions of test.

Flash and fire points were determined using the closed cup Pensky-Martens flash tester. The oil sample was filled into the tester cup up to the mark and covered. The sample was stirred for about five minutes and its temperature noted. A standard test flame was added to the vapour space at an interval of about 278 °K rise while continuously heating the sample at a constant rate until flame that flashes the air-vapour mixture appeared. The sample temperature (\bar{E}_F) was noted as the flash point. The sample was further heated while repeating the above procedure until the air-vapour mixture started to burn continuously for about 5 seconds. The sample temperature (\bar{E}_{FF}) was noted as the fire point. The values obtained were duplicated and reported to within ± 8 °K accuracy.

2.8. Acid Value and Free Fatty Acids

A 25 ml of diethyl ether was mixed with 25 ml alcohol and 1 ml phenolphthalein solution (1 %) and carefully neutralized with 0.1 M sodium hydroxide; 5 g of *Jatropha* biodiesel was dissolved in the mixed neutral solvent and titrated with aqueous 0.1 M sodium hydroxide shaking constantly until a pink colour which persisted for 15 seconds was obtained.

The acid value was calculated by the below equation:

$$\text{Acid value} = \text{titration (ml)} \times 5.61 / \text{weight of sample used}$$

The FFA figure is usually calculated as oleic acid (1 ml 0.1 M sodium hydroxide = 0.0282 g oleic acid), in which case the acid value = 2 x FFA.

2.9. Analysis Procedure

To determine the quantity and quality characteristics of *Jatropha curcas* seed oil, the variables which will be considered include oil yield, moisture, density, acid value and iodine value.

The quality characteristics of biodiesel will be determined using moisture content, density, flashpoint, acid value and kinematic viscosity. These variables will be compared among the four accessions using independent samples t-tests to determine if there are any significant variations in the parameters obtained from the locations and thus compare these parameters with ASTM standards to determine the accession that produces the highest quality of biodiesel.

3. Results and Discussion

3.1. Quantity and Quality Characteristics of Oil Yields

The average values of oil yield from various accessions in Kenya are given in Table 1. The accession with the highest oil yield was from Meru with 38.8 % oil content, while those from Funyula and Oyugis were 28.4 % and 27.0 % respectively. The lowest oil yields were from Kibwezi with an average of 23.1 %. It can therefore be deduced that *Jatropha* seeds from Meru would be the most preferred as a source of biodiesel feedstock as it would consequently result in higher yields in biodiesel. According to literature, the expected oil yield for *Jatropha curcas* seeds is 27 – 40 % (average 34.4 %) that can be processed to produce a high-quality biodiesel fuel (King *et al.*, 2015). These variations may be as a result of their different geographical locations. This shows that oil quality and quantity is a function of diversity of location and environment where *Jatropha* is grown Montes (Osorio, *et al.*, 2014)

Source of Seeds	Number of Samples	Oil Produced/ 8kg of Seed
Kibwezi	5 x 4	23.1 %
Oyugis	5 x 4	27 %
Meru	5 x 4	38.8 %
Funyula	5 x 4	28.4 %

Table 1: Quantity of Oil Produced from the Regions in Kenya

3.2. Physicochemical Properties of *Jatropha Curcas* Seed Oil

The physical and chemical properties of raw *Jatropha curcas* oil average values are given in table 2 and figures 1-5. The average moisture content for accessions from Kenya was ranging from a minimum of 0.08 % to 0.18 %. This is less than the 0.2 % recommended for *Jatropha* oil as biodiesel fuel. The low moisture content shows that the oil is of good quality and could not be easily subjected to contamination and rancidity. Moisture is a chemical contaminant which, when mixed with lubricating oil like *Jatropha* oil, is a major cause of most engine failure. Usually, free fatty acids and moisture have significant effect on the trans-esterification of glyceride with alcohol using catalysts (Mofijur *et al.*, 2016).

Variable	Samples	Mean	Standard deviation	Minimum	Maximum
Moisture, %	5 x 4	0.129	0.052	0.083	0.185
Saponification	5 x 4	116.760	4.494	112.200	120.620
Acid value, mgKOH/g	5 x 4	2.913	1.267	1.346	4.189
Iodine value, g I ₂ /100g	5 x 4	85.680	12.236	71.250	99.170
Density, g/cm ³	5 x 4	1.082	0.003	1.080	1.086

Table 2: Characteristics of the Various Parameters Assessed from the Oil in the Regions

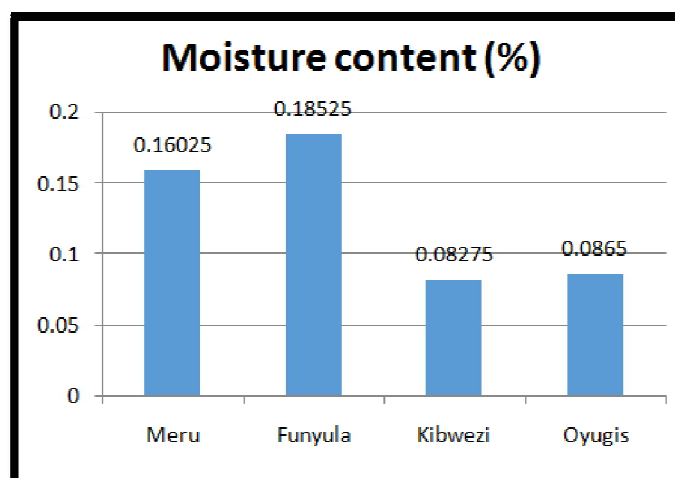


Figure 1: Moisture Content of the Oil Produced in the Various Regions

Moisture content of *Jatropha curcas* oil from Meru and Funyula accessions was highest at 0.16 % and 0.18 % respectively while Kibwezi and Oyugis were having least moisture content of 0.08 % and 0.09 % respectively. This can be attributed to variations in geographical zones with Meru and Funyula having high rainfall unlike Kibwezi and Oyugis.

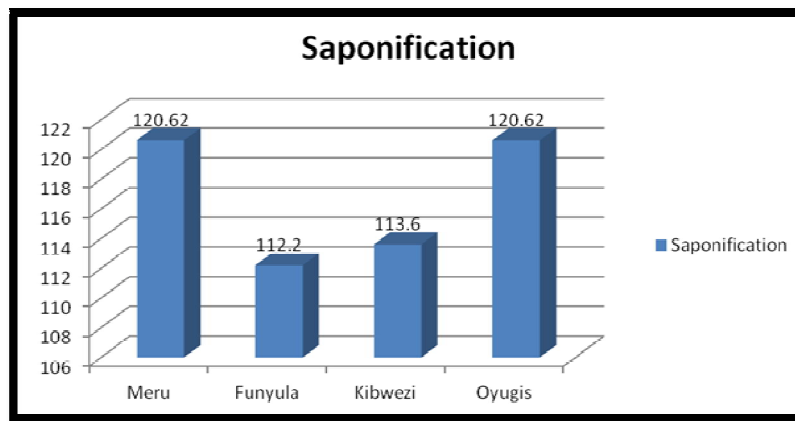


Figure 2: Saponification of the Oil Produced in the Various Regions

The saponification value of *Jatropha curcas* seed oil from Meru and Oyugis was the same (120.6), but slightly higher compared to the *Jatropha curcas* seed oil from Funyula and Kibwezi which had almost similar saponification values of 112.2 and 113.6 respectively. The similarity between the Meru *Jatropha curcas* seed oil and that of Oyugis, and the near similarity between Funyula and Kibwezi may be due to similarity in the fatty acid composition as a result of similar soil and climatic conditions in each of the areas. The saponification value is an important parameter in *Jatropha* oil production as higher saponification values indicate the normality of the oil as triglyceride which is very useful in the production of liquid soap and shampoo. This was shown by Sinha *et al.* (2015) in their studies on the possible changes in oil content and fatty acid composition in *Jatropha curcas* during seed formation and development

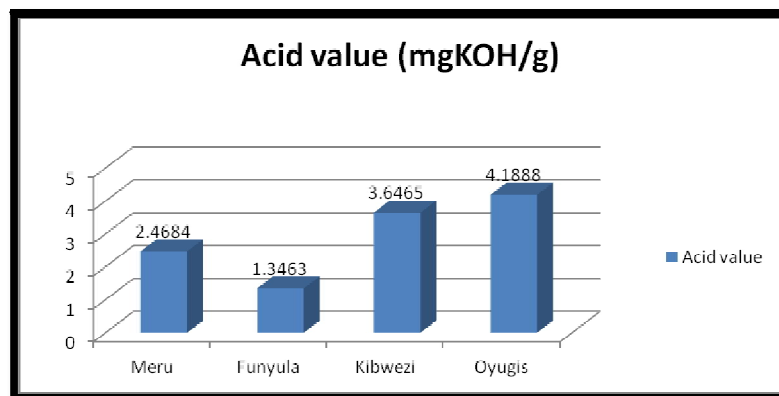


Figure 3: Acid Value Contained in the Oil Produced in the Regions In Kenya

The acid value of *Jatropha* seed oil was found to be highest in Oyugis (4.19 mgKOH/g) and least in Funyula (1.35 mgKOH/g) as compared to the maximum amount recommended for oils to be used for biodiesel production of 0.5 mgKOH/g (BS EN 14214). The acid value should be less than 1 mgKOH/g and that all raw materials should be anhydrous (water content < 0.3 %). The acid value gives an indication of the quality of fatty acids in the oil. The trans-esterification process is still possible even if these requirements are not met, but the yield of the reaction will be reduced due to the deactivation of the catalyst and the formation of soaps. These might have accounted for lower yields obtained in the course of the research. High acid values also affect the purity of the biodiesel. It further makes separation relatively more difficult compared to oil with lower acid value (István Barabás and Ioan-Adrian Todoruș, 2011).

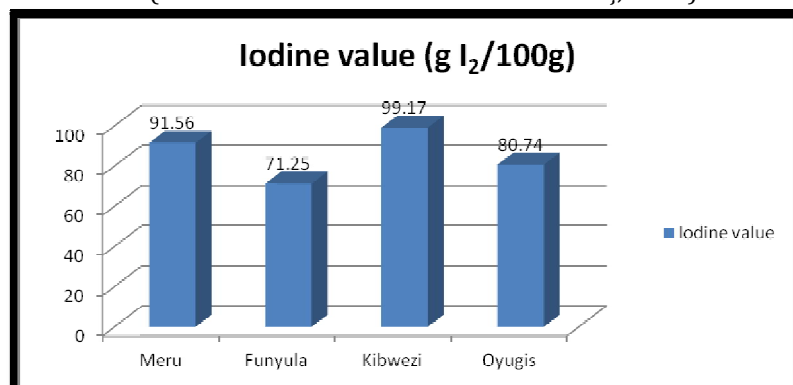


Figure 4: Iodine Value of Oil Produced in the Regions in Kenya

Iodine value (IV) is a measurement of the unsaturation of fats and oils. Standard iodine value for biodiesel is 120 for Europe's BS EN 14214 specification. The iodine value of *Jatropha* oil was 99.17 g I₂/100g for Kibwezi, 91.56 g I₂/100g for Meru, 80.77g I₂/100g for Oyugis and 71.25 g I₂/100g for Funyula. Iodine value is an important measure that allows determination of the degree of unsaturation of fuel. This property greatly influences fuel oxidation and the type of aging products and deposits formed in diesel engine injectors. The limitation of unsaturated fatty acids is necessary due to the fact that heating higher unsaturated fatty acids results in polymerization of glycerides. This can lead to the formation of deposits or to deterioration of the lubricating oil. The iodine values of *Jatropha curcas* place them in the semi-drying oil group. High iodine values of *Jatropha* are caused by high content of unsaturated fatty acid such as oleic acid and linoleic acid. *Jatropha* seed oil consists of 78.5 % unsaturated fatty acid (Nahar K, Sunny SA, 2011).

Iodine value is limited in various regions of the world depending on the specific conditions: 120 in Europe and Japan, 130 in Europe for biodiesel as heating oil, 140 in South Africa, in Brazil it is not limited and in the U.S., Australia and India it is not included in the quality standard (it would exclude feedstocks like sunflower and soybean oil). Biodiesel with high IV tends to polymerize and form deposits on injector nozzles, piston rings and piston ring grooves. The tendency of polymerization increases with the degree of unsaturation of the fatty acids (István Barabás and Ioan-Adrian Todoruț, 2011).

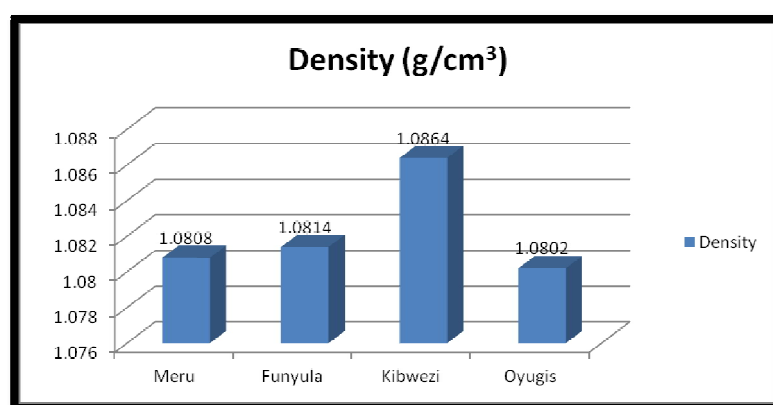


Figure 5: Density of Oil Produced in the Regions

The standard oil density for diesel engine fuel should be between 0.86 and 0.90 g/cm³. This property is important mainly in airless combustion systems because it influences the efficiency of atomization of the fuel. Results from this study found that there was no significant difference between the density of oil from the *Jatropha* seeds. The density of *Jatropha* seed oil was 1.0808 g/cm³ (Meru), 1.0814 g/cm³ (Funyula), 1.0864 g/cm³ (Kibwezi) and 1.0802 g/cm³ (Oyugis) at 20°C while in Nigeria it was 0.876 g/cm³ (Adebayo *et al*, 2011). The density of a material is defined as the measurement of its mass per unit volume (e.g. in g/cm³). The density of a vegetable oil is lower than that of water and the differences between vegetables oil are quite small, particularly amongst the common vegetable oils. Generally, the density of oil decreases with molecular weight yet increases with unsaturation level (Theocharis Tsoutsos, 2019).

3.3. Physicochemical Properties of *Jatropha Curcas* Biodiesel

The properties of biodiesel produced from *Jatropha curcas* oil and compared with ASTM specifications are presented in the Table 3. Density of the *Jatropha* biodiesel was almost similar for all accessions at 0.88 g/cm³ while it is 0.875-0.90 g/cm³ for Germany. Flash point of the biodiesel ranged from a minimum of 156.5 from Oyugis to a maximum of 186.5°C from Funyula while in Germany it should be ≥ 100 °C. Kinematic viscosity was highest from Kibwezi at 4.786 and lowest from Meru at 4.321 while in Austria, 6.5-8.0mm²/s is recommended. Moisture content was 0.04 for all accessions except Kibwezi which had 0.05. There were significant differences in acid value with Meru and Funyula having an average acid value of 0.32 while that from Oyugis and Kibwezi was 0.67 and 0.86 respectively ≤ 0.5 for Germany (BS EN 14214)

Accession	Density @20 °C, g/cm ³	Flash point	Kinematic viscosity, mm ² /s	Moisture, %	Acid value, g I ₂ /100g
Meru	0.8786	164.5	4.321	0.04	0.34
Funyula	0.8791	186.5	4.4256	0.04	0.31
Kibwezi	0.8808	182.5	4.7862	0.05	0.86
Oyugis	0.8801	156.5	4.6375	0.04	0.67

Table 3: Mean Values of Biodiesel Accessions from Various Sites

To answer the research question to test whether there are large variations in oil productivity from Kenyan accessions of *Jatropha curcas* from the standard requirements. T-test statistics was used to test the differences in means of biodiesel produced from regions in Kenya versus the standard required values.

The null hypothesis in density of biodiesel states that the mean of biodiesel = 0.88 (standard requirement). The results in show that the p-value > 0.05, therefore we fail to reject the null hypothesis and conclude that the mean density of biodiesel produced from the regions in Kenya was not different from the required standard value of 0.88, thus the biodiesel is suitable for direct usage as a substitute for diesel fuel. Lower value of the density of the final product is an

indication of completion of reaction and removal of heavy glycerine. This property is important mainly in airless combustion systems because it influences the efficiency of atomization of the fuel (Rachan *et al*, 2017).

For biodiesel to be used in diesel engines, the kinematic viscosity must be between 1.9 and 6.0 mm²/s at 40 °C according to ASTM standards recommended level. The kinematic viscosity of the biodiesel samples produced in this work range from 4.3 to 4.8 mm²/s at 40 °C. These results are within the standard requirements. This is an important factor as it would ensure complete burning of the fuel without any ignition delay. Higher viscosity leads to a higher drag in the injection pump and thus causes higher pressures and injection volumes more especially at low engine operating temperatures. Viscosity is also an indication of fuel aging during storage as it increases due to polymerization induced by oxidative degradation (Rachan *et al*, 2017).

As a result of the hygroscopic nature due to high polarity of fatty acid methyl esters, biodiesel tends to absorb water during the final washing step in the production process and during storage. EN 14214 (2003) imposes a maximum content of 0.05 % of water in fuels. The T-test results show the p-value > 0.05 so we fail to reject the null hypothesis and conclude that there is evidence that the mean moisture content of biodiesel produced is not different from the standard 0.05. The water content in all samples of the biodiesel was reduced to the acceptable levels (< 0.05 %). Free water promotes biological growth which may cause blockage of fuel filters and fuel lines as a result of induction of sludge and slime formation. Moreover, high water content is also associated with hydrolytic reaction which partly converts fatty acid methyl esters into free fatty acids which are linked with filter blockages as well. Fuel contaminated with water can cause engine corrosion or react with the glycerides to produce soaps and glycerine (Hart Energy (2014), Kent *et al*, (2011)).

Considering that the presence of free fatty acids influences fuel aging, the European Standard specifies a maximum acid value of 0.5 mg of KOH/g of sample. The p- value associated with the test is greater than 0.05, we therefore fail to reject the null hypothesis and conclude that there is evidence that the acid value in the biodiesel produced is not different from the hypothesized value of 0.5. The acid value measures the content of free fatty acids and mineral acid in biodiesel. This value is dependent on a number of factors which include the type of feedstock used for the fuel production, production process and its respective degree of purification. Corrosion of chromium and zinc parts within the engine and injection system has been linked to high acidity of the fuel (Obad *et al*, 2015)

The flashpoint of biodiesel is generally over 150 °C, much greater than the ASTM specifications (130 minimum) required. Table 4 shows output of the test whether the mean flashpoint of biodiesel produced is equal to the standard value 130. P-value < 0.05, therefore we reject the null hypothesis and conclude that there is evidence that the mean flashpoint of biodiesel produced is greater than the required 130°C, therefore, Jatropha biodiesel is safe to handle. Flash point is the lowest temperature at which application of the test flame causes the vapor and air mixture above the sample to ignite. Flash point helps to monitor the safe handling and storage of fuel. The higher the flash point the safer the fuel and vice versa. The flash point of Biodiesel is higher than that of fossil diesel (52 °C); therefore, it could be said that Biodiesel is safer to handle than fossil diesel. Biodiesel falls under the non-hazardous category of the National Fire Protection association codes (Teresa L. Alleman and Robert L. McCormick *et al*, 2016).

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Density @ 20°C	5 x 4	0.88	0.00	0.88	0.88
Flashpoint	5 x 4	172.50	14.33	156.50	186.50
Kinematic viscosity, mm ² /s	5 x 4	4.54	0.21	4.32	4.79
Moisture, %	5 x 4	0.13	0.16	0.04	0.37
Acid value, g I ₂ /100g	5 x 4	0.55	0.27	0.31	0.86

Table 4: Average Values of Biodiesel Parameters Measured from Various Accessions

4. Conclusions and Recommendations

4.1. Conclusions

- The quality characteristics of the oil produced clearly demonstrate that straight Jatropha oil is unsuitable for direct usage as a substitute for diesel fuel; it has to undergo trans-esterification due to its high density and acid values so as to reduce them to acceptable levels.
- The physicochemical properties of biodiesel produced meet the ASTM specifications. The density, kinematic viscosity, flashpoint, calorific value, refractive index and acid value of biodiesel produced in the present work are within the standard ascribed by ASTM and are also similar to those of fossil diesel. However, the acid value of biodiesel produced from Kibwezi and Oyugis are found to be somewhat higher, which may point to corrosion of chromium and zinc parts within the engine and injection system. Therefore, fatty acid levels must be reduced to the optimum levels for it to be used as a substitute for diesel fuel. The reason for the lower yield was the high Free Fatty acid content of raw Jatropha oil.
- Biodiesel produced from *Jatropha curcas* oil is a potential replacement for fossil diesel while the production and effective usage of biodiesel will help to reduce the cost of protecting the atmosphere from the hazards in using fossil diesel and hence will boost the economy of the country.

4.2. Recommendation

Further studies should be carried out to determine the most suitable provenance to be developed and improved and to investigate the true production potential and the corresponding agronomic treatments required to achieve reproducible high yields of *Jatropha curcas* in varied ecological environments.

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6. References

- i. ASTM D4052-16, Standard Test Method for Density, Relative Density, And API Gravity of Liquids by Digital Density Meter. American National Standards Institute (ANSI). Designation: 365/84(86)
- ii. ASTM D445-97, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity), ASTM International, West Conshohocken, PA, 2001, www.astm.org
- iii. Bailis, R. E., and Baka, J. E. (2010). Greenhouse gas emissions and land use change from *Jatropha curcas*-based jet fuel in Brazil. *Environ. Sci. Technol.* 44, 8684–8691.
- iv. BS EN 14214:2012+A2:2019. PRODUCT SPECIFICATION SHEET FATTY ACID METHYLESTERS (FAME). L2-GROUP-11-SHEQ-GUIDANCE-006 VERSION 1: 16/5/19
- v. Guo, G. Y., Chen, F., Shi, X. D., Tian, Y. S., Yu, M. Q. and Han, X. Q. (2016). Genetic variation and phylogenetic relationship analysis of *Jatropha curcas* L. inferred from nrDNA ITS sequences. *C R Biol.* 339, 337–346. doi: 10.1016/j.crvi.2016.06.004
- vi. Hart Energy (2014). International Fuel Quality Standards and Their Implications for Australian Standards. FINAL REPORT | OCT. 27, 2014
- vii. Institute of Economic Affairs (2013). Energy in Kenya. Energy Scenarios 2013. [https://www.ieakenya.or.ke › downloads › page=Energy-Scenarios](https://www.ieakenya.or.ke/downloads?page=Energy-Scenarios)
- viii. István Barabás and Ioan-Adrian Todoruț (2011). Biodiesel Quality, Standards and Properties, Biodiesel Quality, Emissions and By-Products, Dr. Gisela Montero (Ed.), ISBN: 978-953-307-784-0, InTech, Available from: <http://www.intechopen.com/books/biodiesel-quality-emissions-and-by-products/biodiesel-qualitystandards-and-properties>
- ix. Khalil HPSA, Aprilia NAS, Bhat AH, Jawaid M, Paridah MT, Rudi D. A. (2013) *Jatropha* biomass as renewable materials for biocomposites and its applications. *Renewable & Sustainable Energy Reviews.* 2013; 22:667–685. doi: 10.1016/j.rser.2012.12.036
- x. King AJ, Montes LR, Clarke JG, Itzep J, Perez CA, Jongschaap RE, Visser RG, Van Loo EN, Graham IA (2015). Identification of QTL markers contributing to plant growth, oil yield and fatty acid composition in the oilseed crop *Jatropha curcas* L. *Biotechnology for Biofuels.* 2015; 8:1–17. doi: 10.1186/s13068-014-0179-6
- xi. Mofijur M, Rasul M, Hyde J, Azad A, Mamat R, Bhuiya M. (2015). Role of biofuel and their binary (diesel–biodiesel) and ternary (ethanol–biodiesel–diesel) blends on internal combustion engines emission reduction. *Renewable & Sustainable Energy Reviews.* 2016; 53:265–278. doi: 10.1016/j.rser.2015.08.046.
- xii. Nahar K and Sunny SA. (2014). *Jatropha curcas* L: A sustainable feedstock for the production of bioenergy and by-products. *Journal of Energy and Natural Resources.* 2014;3(4): 51-57. 31.
- xiii. Nahar K and Sunny SA (2011). Extraction of biodiesel from 2nd generation energy crop (*J. curcas* L.) by transesterification process. *J. Environ. Sci. Technol.* 2011;4: 498–503. 38.
- xiv. Netherlands Enterprise Agency (2018). Ministry of Economic Affairs and Climate Policy. FINAL ENERGY REPORT KENYA. Netherlands Enterprise Agency | December 2018: RVO-206-1801/RP-INT
- xv. Obed M. Ali, Rizalman Mamat, Gholamhassan Najafi, Talal Yusaf, and Seyed Mohammad Safieddin Ardebili, (2015). Optimization of Biodiesel-Diesel Blended Fuel Properties and Engine Performance with Ether Additive Using Statistical Analysis and Response Surface Methods. *Energies* 2015, 8, 14136–14150
- xvi. Pandey VC, Singh K, Singh JS, Kumar A, Singh B, Singh RP (2012). *Jatropha curcas*: a potential biofuel plant for sustainable environmental development. *Renewable & Sustainable Energy Reviews.* 2012;16:2870–2883. doi: 10.1016/j.rser.2012.02.004.
- xvii. Rachan Karmakar, Krishnendu Kundu and Anita Rajor (2017). Fuel properties and emission characteristics of biodiesel produced from unused algae grown in India. *Petroleum Science* (2018) 15:385–395
- xviii. Kent S. Hoekmana, Amber Brocha, Curtis Robbins, Eric Cenicerros and Mani Natarajanb (2011). Review of biodiesel composition, properties, and specifications. *Renewable and Sustainable Energy Reviews* 16 (2012) 143–169
- xix. Sinha P, Islam MA, Negi MS and Tripathi SB (2015). Changes in oil content and fatty acid composition in *Jatropha curcas* during seed development. *Industrial Crops and Products.* 2015;77:508–510. doi: 10.1016/j.indcrop.2015.09.025.

- xx. Teresa L. Alleman and Robert L. McCormick, Earl D. Christensen, Gina Fioroni, and Kristi Moriarty, and Janet Yanowitz (2016). Biodiesel Handling and Use Guide (Fifth Edition). National Renewable Energy Laboratory (NREL), U.S. Department of Energy. DOE/GO-102016-4875. November 2016,
- xxi. Theocharis Tsoutsos, Stavroula Tournaki , Zacharias Gkouskos, Orlando Parafba, Filippo Giglio, Pablo Quero García, João Braga, Haris Adrianos and Monica Filice (2019). Quality Characteristics of Biodiesel Produced from Used Cooking Oil in Southern Europe. *ChemEngineering* 2019, 3, 19
- xxii. Van Eijck, J., Romijn, H., Balkema, A., and Faaij, A. (2014). Global experience with jatropha cultivation for bioenergy: An assessment of socio-economic and environmental aspects. *Renew. Sustain. Energy Rev.* 32, 869–889. doi: 10.1016/j.rser.2014.01.028
- xxiii. Von Maltitz G. P., Setzkorn K. A. (2013). A typology of Southern African biofuel feedstock production projects. *Biomass Bioenergy* 59 33–49. 10.1016/j.biombioe.2012.11.024