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## Fatty acid and biodiesel characteristics Ethiopian *Jatropha* (*Jatropha curcas* L.) provenances

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### Abstract

For determining the fatty acid characteristics and biodiesel quality of Ethiopian *Jatropha* provenances, the study was conducted in five regions namely Southern Nation Nationalities Peoples Regional State (SNNPRS), Amhara region, Tigrina region, Oromia region and Benishangul Gumuz Regions, where physic nut is found abundantly. For each region, representative sampling sites were selected following thorough discussion with head of Mines and Energy at zonal level. During representative sample site selection, one knowledgeable and responsible expert was assigned from the zonal mines and energy office for making the site selection more perfect and easier and thereby to collect representative data from each region. Following this arrestment, a total of 23 Zones, 36 Weredas and 40 sampling sites were considered from five regions of the country for the study. It was observed that the identified constituents of the *Jatropha* oils are linoleic acid, stearic acid, palmetic acid and oleic acid. From the identified fatty acids, oleic acid was the major constituent followed by stearic acid. The constituents of the fatty acids ranged from 42.8-51.4% for oleic acid, 10.9-19.3% for stearic acid, 10.62-15.91% for palmetic acid and 21.73-25.43% for linoleic acid. The biodiesel quality characteristics of Ethiopian *Jatropha* seeds were found

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within the limits of American standard (D874) and European standard (EN 14214 standard). Hence, it can be concluded that the seeds of the existing Ethiopian *Jatropha* population can be used for the production and processing of environmentally friendly biodiesel.

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**Keywords:** Biodiesel, Ethiopia, Fatty acid.

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## 1. Introduction

Ethiopia has proved the close relation that exists between low level of energy consumption and under-development by registering low per capita energy consumption (Girma, 2000). Most of the people have, until now, been unable to satisfy their household energy requirements with modern energy sources (kerosene, electricity, gas) (Ministry of Mines and Energy, 2007). About 95 per cent of the total energy consumption in Ethiopia is composed of traditional biomass fuels, with only 5 per cent coming from modern energy sources (FAO, 1995). The traditional biomass energy mainly depend primarily on the surrounding forestland, consequently, the country's forest resources have been disappearing at an alarming rate.

On the other side, Ethiopia imports its entire petroleum fuel requirement and the demand for petroleum fuel is increasing rapidly due to a growing economy and expanding infrastructure. According to a report by National Bank of Ethiopia (NBE, 2008), the annual consumption of petroleum fuels amounts to more than 1.1 million tones, which is equivalent to 5.4 % of total final energy consumption spending 8 billion Birr or 87% of the foreign earning (Ministry of Energy and Mines, 2007). Currently, the annual consumption of petroleum fuels amounts to more than 2.298 million metric tons spending 2.193 billion USD. The expense was observed having a present increase value of around 35.04% in the year 2013/2014 when compared with the year 2008. Hence, devising appropriate mechanism for the development of energy sector in Ethiopia could solve a number of interrelated basic problems of the country such as economic, environment and social problems. To contribute in reducing the expenses billed for importation of fossil oil, Ethiopia has put in place biofuel development and utilization strategy to systematically lead the production, utilization and commercialization of the renewable resources since 2007. In addition public biofuel forum composing 12-14 institutions is setup under the guidance and follow up of Ministry of Water and Energy for proper follow up and encouragement of the research and development endeavors of different institutions concerning biofuel in general and biodiesel in particular.

A number of options for production of biodiesel as an alternative source have been considered in many countries. Biodiesel is being looked at as an important alternative fuel in the overall energy security world over. Since the oil crisis of the 1970s and recognition of the limitations of world oil resources, biodiesel has received special attention (Heller, 1996). Biodiesel is a renewable liquid fuel that can be produced locally, thus helping reduce the countries dependence on imported oil. It is also desirable to help mitigate the effects of climate change. It is non-toxic rather it is environmentally friendly as it reduces emissions of carbon monoxide (CO) by approximately 50%, sulfur dioxide by 100%, 40-60% soot emission and carbon dioxide by 78%, 10-50% hydrocarbons and 5-10% nitrous oxide depending on the engine tuning and age lifecycle basis (Sheehan, 1998). It also can reduce particulate emissions by around 50%, compared with fossil-source diesel (Beer *et al.*, 2004). Because of benefit it's the global production of biodiesel reached 3 billion liters in 2004 (Wilkins, 2006). According to (Barbara, 2007) biodiesel (i) reduce global warming gas emissions, (ii) reduce tailpipe emissions, including air toxics, (iii) nontoxic (iv) biodegradable, and suitable for sensitive environments. Since it allow large scale plantation it halt desertification. In addition to its ecological benefit biodiesel have many economic and social advantages. It can reduce foreign currency allocated to buy or import fossil fuel. Thus, this country could save money that would be spend to import and transport over 16 billion liters of gasoline and this money can be used to build infrastructure. At the same time job, opportunities had been created for millions of people. It most likely seems fossil fuels will continue to take the line share in the energy scenario of the country in the next few decades as well. However, Ethiopia is endowed with abundant renewable energy resources; including the most important biodiesel crops like physic nut.

Considering all the options available among non-edible tree bearing oil seeds, seeds of physic nut has been identified as the most suitable seed (Biswas et al., 2006) of biodiesel. Physic nut belongs to the genus *Jatropha* that comprises about 175 species of succulent shrubs and trees from the family Euphorbiaceae. Physic nut is native to Africa, North America and Caribbean regions. It assumed that originating from Caribbean and spread as a valuable hedge plant to Africa and Asia by Portuguese traders (Heller, 1996). Physic nut is adapted to a wide range of climates and soils. It can grow almost on any type of soil whether gravelly, sandy or saline and thrives even on the poorest stony soils and crevices. It is drought resistant perennial shrub or small tree living up to 50 years. Physic nut has capability to grow on marginal and it has ability to reclaim problematic lands and restore eroded areas. It is known to aid the plants grown under condition where phosphate is limiting, as has mycorrhizal association (Jones and Miller, 1992).

Physic nut grows in various parts of Ethiopia, as a hedge around homesteads and farmlands, such as in Wolayita, Metekel, Southern Wollo, Northern and Eastern Shoa, Tigrai, Gamo Gofa zones and Gambella region (Getinet et al., 2009). This suggests that physic nut can be cultivated either as large-scale plantations on marginal areas, as small-scale hedges, or intercropped to assist rural livelihoods. Although physic nut already exists in many places of Ethiopia; its economic importance is far from being realized due to absence of proper evaluation and promotion of the existing local physic nut provenances for their oil content, oil yield and oil quality for biodiesel utilization. There are different reports indicating the existence of performance variation in oil content and quality due to growing environment and genotype variation was reported for physicnut (Kaushik et al., 2007; Heller, 1996; Ginwal et al., 2004; Thongbai et al., 2006; Benge, 2006). Adaptability testing for varietal development, silvicultural and propagation techniques are being under way in Ethiopian Institute of Agricultural Research at Melkassa and Wondo Genet Agricultural Research Centers. Likewise, variability evaluation using 13 physic nut provenances are also initiated by Debrebrhan Agricultural Research Center. Omarsherif (2010) has also reported the existence of variation in oil content and quality for provenances of physic nut growing in Bati wereda. However, the study does not compare the content and quality of the oil with other provenances for biodiesel utilization. This clearly indicates that the existing physic nut provenances were not properly evaluated for their oil content and quality for biodiesel utilization under their growing ecologies. As a result, field experience and documented information with regard to variation in oil contents and yield, quality of the oil for biodiesel utilization about the local population of physic nut provenances growing under different ecologies of Ethiopia is very limited.

Therefore, the effort made so far cannot be said sufficient in providing necessary information about the available physic nut provenances grown in Ethiopia. Consequently the knowledge on oil content and quality of Ethiopian physic nut provenances is limited. This lack of information is a major hindrance to exploit the wealth of physic nut population in Ethiopia. Still recently, no variety has been released in the country for the production of biodiesel. This clearly indicates, the current knowledge about its silviculture, variety development and biology are neither complete nor conclusive and, hence, many aspects of physic nut provenances are unknown under their growing condition in the country. Therefore, the available provenances of physic nut grown in different ecologies of Ethiopia needs to be properly evaluated, and their attributes have to be known to the breeders, farmers, traders and biodiesel processors. Furthermore, the value of the available physic nut resources will depend greatly upon the information available on each provenance growing in Ethiopia. Therefore, the primary objective of this activity is to evaluate the existing physic nut populations of Ethiopia for their fatty acid and biodiesel characteristics for biodiesel production and utilization.

## 2. Materials and methods

### 2.1. Brief description Ethiopia

Ethiopia is geographically located in the eastern Africa within the tropics between 3 degrees and 15 degrees of north latitude and between 33 degrees and 48 degrees of east longitude. It has common borders with Kenya, Sudan, South Sudan Republic, Somalia, Eritrea and Djibouti (Figure 1). There is great variation in altitude ranging from about 116 meters below sea level to 4620 meters above sea level (IBC, 2007; EPA, 1998). The country has an undulating topography providing ample opportunity to satisfy bio-based development interests.

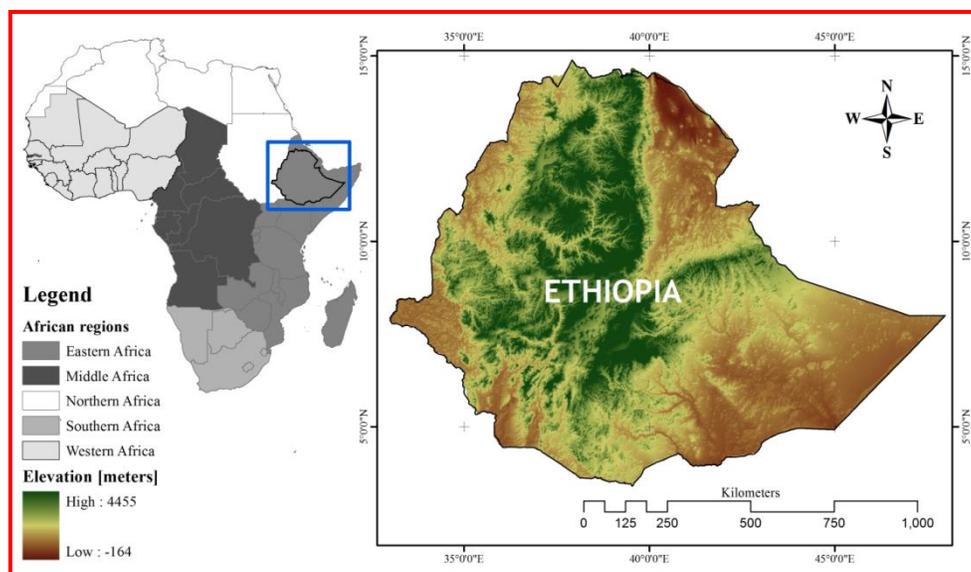


Fig. 1. Geographical location of Ethiopia.

The mean annual temperature of the country is 22.2°C. The lowest temperature ranges from 4°C to 15°C in the highlands, and the highest mean temperature is 31°C in the lowlands at the Denakil Depression (Awulachew et al., 2007). The country receives mean annual rainfall of 812.4 mm, with a minimum of 91 mm and a maximum of 2,122 mm. Relief variability and the resulting climatic characteristics make the country home to a wide range of plant, animal and microbial diversity. Consequently, the country is regarded as a centre of endemism (IBC, 2007; Vivero et al., 2010).

## 2.2. Study areas and sampling sites

The study was conducted in five regions namely Southern Nation Nationalities Peoples Regional State (SNNPRS), Amhara region, Tigray region, Oromia region and Benishangul Gumuz Regions, where physic nut is found abundantly (Table 1). For each region, representative sampling sites were selected following thorough discussion with head of Mines and Energy at zonal level. During representative sample site selection, one knowledgeable and responsible expert was assigned from the zonal mines and energy office for making the site selection more perfect and easier and thereby to collect representative data from each region. Following this arrangement, a total of 23 Zones, 36 Weredas and 40 sampling sites were considered from five regions of the country for the study.

Table 1

Representative physic nut study sites of the country selected for the study.

No	Study sites selected from potential physic nut growing areas of the country for the study			
	Regions	Zones	Weredas	Study sites
1	SNNPRS	4	9	12
2	Oromia	9	11	11
3	Tigray	8	8	8
4	Amhara	1	5	6
5	Benishangul Gumuze	1	3	5
Total	5	23	36	40

A total of 40 study and sample collection sites were identified from the five regions of the country for collecting sufficient *Jatropha* composite seed samples for this particular study. As physic nut is found as a hedge, semi-cultivated or domesticated, sampling and analysis will be done based on the assumption that any given hedge from a single household will have high degree of similarity. Likewise, physic nut trees in a given live fences or



#### 2.4. Field data analysis

As all the samples were collected on individual testing sites, all the data presentations were made on mean basis. To statistically analyze the association among different seed characteristics and oil content were done following person correlation coefficients using SAS PROC GLM (2002).

#### 2.5. Trans-esterification process

The trans-esterification process is the reaction of a tri-glyceride (fat/oil) with an alcohol to form esters and glycerol. Transesterification (also called alcoholysis) is the action of one alcohol displacing another from an ester (i.e. the transformation of the large, branched, triglyceride molecules of bio-oils and fats into smaller, straight-chain molecules, similar in size to components of diesel fuel) (Quick, 1989), in which lipids react with an alcohol to form monoalkyl esters and a byproduct, glycerol (Freedman et al., 1984; Cardone et al., 2003). The main factors affecting transesterification are the amount of alcohol and catalyst, reaction temperature, pressure and time and the contents of free fatty acid (FFAs) and water in oils (Demirbas, 2003). The alcohol reacts with the fatty acids to form the mono-alkyl ester or bio-diesel and crude glycerol (Peterson et al., 1991). From the extracted oil in the above procedure a molar ratio of 6:1 (crude oil: methanole) was mixed. Sodium hydroxide (0.5% NaOH by weight) base was added to the mixture and heated at close to the boiling point of methanol, 60 to 70°C at atmospheric pressure. The reaction mixture was stirred for 90 min (Foidl et al., 1996). Then the mixture was allowed to settle for 24 hours. After settling for twenty four hours, two distinct layers were formed. The upper layer is the biodiesel and the lower (denser) layer is the glycerin (Figure 5). The bio-diesel and glycerin was separated with glycerin simply drawn off from the bottom of the settling vessel. Finally, biodiesel was purified (Figure 6) by washing gently with warm water to remove residual catalyst or soap, dried and tested for its quality at Ethiopia Petroleum Enterprise.



Fig. 5. Unpurified glycerin.



Fig. 6. Jatropha biodiesel after trans-esterification process.

#### 2.6. Biodiesel quality analysis

For determining the biodiesel quality of Jatropha oil, the straight vegetable oil was changed to biodiesel. For doing this the measured volume of pure vegetable oil was warmed up to about 40°C in a beaker. 0.35% (w/v) of finely ground anhydrous KOH/NaOH was added into 20% (v/v) pure (99% or higher purity) methanol or ethanol in Erlenmeyer flask containing a magnetic stir bar. The flask was put on a magnetic stir plate, and stirred vigorously until all of the KOH/NaOH is dissolved. When all of the KOH/NaOH is dissolved, the oil was poured into the alcoxide solution while continually stirring, for 15-30 minutes on high. The contents of the flask was transferred into a separatory funnel, and was then allowed to cool and neutralized with the stoichiometric amount of concentrated hydrochloric acid (35% w/w). Then, the products were separated into two different layers. The glycerol fall to the bottom, and the methyl ester (Biodiesel) float to the top. It was allowed to sit for about an hour. After clear separation was observed, the stopcock of the separatory funnel was opened and allowed the glycerol to drain into a small beaker. The Biodiesel was left as a clear solution, the excess methanol was distilled and finally the Biodiesel was washed three times with hot water to remove the soluble catalyst and soap. Following these steps, different

parameters were measured for determining the biodiesel quality of Jatropha. The measured properties of biodiesel included: Specific gravity, Kinematic viscosity at 40°C, Cetane number, Distillation°C, Cloud point °C, Flash point, Total acidity, Copper strip corrosion 3Hrs @100 °C, Conradson carbon residue on 100% of sample, ASTM color, Water and Sediment (% V) and Ash content (mass%).

### 2.6.1. Specific gravity

The specific gravity of a substance is a comparison of its density to that of water (1g/cm<sup>3</sup>). The ASTM D1298 test method was employed to determine the specific gravity of Jatropha biodiesel. A hydrometer was used to measure the specific gravity of Jatropha biodiesel. The graduated cylinder was filled with Jatropha biodiesel and the hydrometer was dropped into the biodiesel. Then the specific gravity was measured from the point at which the hydrometer floats. The readings were taken at temperatures between 15 and 20°C.

### 2.6.2. Kinematic viscosity

Viscosity data of pure fatty esters can be used for predicting the viscosity of the mixture of fatty esters comprising biodiesel (Allen *et al.*, 1999). Kinematic viscosity values were determined with Cannon-Fenske viscometers (Figure 7) at 40 °C following the standard method ASTM D445 (Knothe and Steidley, 2005). Cannon-Fenske glass capillary Viscometer Tube was used in a SETA KV-8 viscometer bath and the sample was kept in the bath for 30 minutes to reach the equilibrium temperature of 40 °C. The time (t) was measured for a fixed volume of liquid to flow under gravity through the capillary of a calibrated viscometer and at a closely controlled and known temperature.



Fig. 7. Cannon-Fenske glass capillary Viscometer apparatus.

### 2.6.3. Cetane number

Cetane number is a measure of the readiness of a fuel to auto-ignite when injected into a diesel engine. It relates to the delay between when fuel is injected into the cylinder and when ignition occurs. Higher cetane numbers indicate shorter times between injection of the fuel and its ignition. Higher cetane numbers have been associated with reduced engine roughness and with lower starting temperatures for engines. Good ignition from a high cetane number assists in easy starting, starting at low temperature, low ignition pressures, and smooth operation with lower knocking characteristics. Low cetane fuel with poor ignition qualities causes misfiring, tarnish on pistons, engine deposits, rough operation and higher knocking (thus noise level). Cetane Number is usually measured according to the procedure given by National Fuel Quality Standards (2004) using the test method D976.



Fig. 8. distillation apparatus for petroleum products.

#### 2.6.4. Distillation

The standard procedure for measuring the boiling point range for diesel fuels is the distillation test. The simple distillation apparatus was used for this test (Figure 8). And a batch distillation process was conducted on a sample of the fuel and boiling point data were collected. These data include the initial boiling point (IBP), the final boiling point (FBP), and the boiling temperatures corresponding to increments of the volume of fuel distilled. Finally each recorded temperatures were corrected to 760 mmHg pressure by applying the correction factor-equation (2) (ASTM D 1250-80, 1980).

$$C_c = 0.00012 (760-P)(273+t_c) \text{-----(eq.2)}$$

Where,  $t_c$  = The observed temperature reading, °C

$C_c$  = Corrections to be added algebraically to the observed temperature readings.

$P$  = Barometric pressure, prevailing at the time and location of the test, mmHg.

Then, Corrected temperature (°C) =  $t_c + C_c$

#### 2.6.5. Cloud point

Cloud point and pour point determinations are also useful information for blending purposes. The cloud point is the temperature at which a cloud of wax crystals first appears in a fuel sample that is cooled. The cloud point will be determined through visual inspection of a haze when become visible as the fuel is cooled. It is an index of the lowest temperature of the fuel's usability for certain applications. Operating at temperatures below the cloud point of a biodiesel fuel can result in fuel filter clogging due to the wax crystals. For measuring cloud point, the Peltier device was used (Figure 9) according to the procedures described in ASTM D2500. , the cloud point was determined by visually inspecting for a haze in the normally clear fuel, while the fuel was cooled under carefully controlled conditions. The sample was continuously monitored and the temperature (°C) that corresponds to the first formation of a cloud in the fuel was recorded.

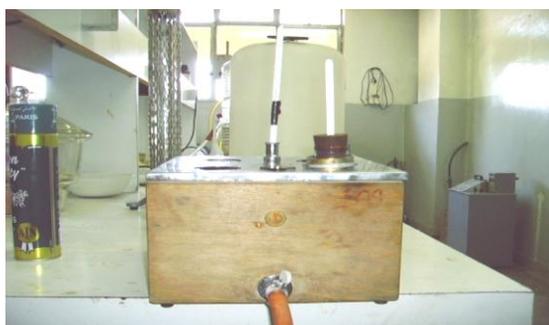


Fig. 9. Peltier apparatus.

#### 2.6.6. Flash point

Flash point is a measure of the lowest temperature at which application of the flame causes the vapor above the sample to ignite, i.e., it is a measure of the tendency of a sample to form a flammable mixture with air (Van Gerpen et al., 2004). Flash point is used in safety regulations to define “flammable” and “combustible” materials. Higher values indicate materials that are less likely to ignite accidentally. ASTM D 974 and ASTM D 93 require a minimum of 52°C for diesel and 130 °C for Biodiesel (Kinast, 2003). The Pensky-Martens Closed Cup Tester was used (figure 10) as per the procedures of ASTM D93. The cup was filled with fuel (about 75 ml up to mark) and heated with an external heater. The agitator ensures that the fuel temperature is uniform. A small open flame was maintained from an external supply of natural gas. Periodically, the stirrer was stopped and the flame is pivoted down to an opening in the top of the cup to see if the fuel vapor ignites. Just when the flash point has been reached, there was a small flash, and this temperature was recorded as observed temperature and corrected to 760 mmHg pressure by applying the correction factor (eq.3).

$$\text{Corrected FP} = T (^\circ\text{C}) + 0.033(760-P) \text{-----(eq.3)}$$

Where,  $T$  = Observed Flash Point Temperature (°C)

$P$  = Ambient pressure (mmHg)



Fig. 10. Pensky martens closed cup flash point tester.

#### 2.6.7. Determination of Total acidity, mg KOH/g

The total acidity was determined following the procedures of ASTM D974. Standard alcoholic KOH solution (0.1M) was prepared by dissolving 6g of solid KOH to 1L of anhydrous isopropyl alcohol (anhydrous-0.9% water) in a 2L Erlenmeyer flask and boiled for 15 min, while stirring. 2g of Ba (OH)<sub>2</sub> was added and again boiled for 10 min, cooled to room temperature, stood for 2 hs and filtered. The indicator p-Naphtholbenzein was used. A weighed quantity of the sample (about 1 g) was added into an appropriate size Erlenmeyer flask; 100 mL of titration solvent and 0.5 mL of the indicator solution was added and swirled until the sample was entirely dissolved by the solvent. Then titration was conducted at a temperature below 30°C, adding 0.1 KOH solutions in increment and mixed to disperse the KOH. As the end point approached the orange color changed green to green- brown and continued until it persisted for 15 min. Blank titration was performed on 100 mL of the titration solvent and 0.5 mL of the indicator solution, adding 0.1 mL increments of the 0.1 M KOH solution. The KOH solution was standardized frequently to detect molarity change of 0.0005. The volume of 0.1M KOH (V<sub>A</sub>), for the sample titration, and volume for the blank (V<sub>B</sub>) were noted. Then:

The total acidity (Acid number- AN (mgKOH/g)) was calculated using (Eq. 4)

$$AN = \frac{(V_A - V_B) \times N \times 56.1}{W_o} \text{-----(eq.4)}$$

Where, W<sub>o</sub> = sample weight,  
V<sub>A</sub>= Volume of KOH used for the sample (mL),  
V<sub>B</sub>= Volume of KOH used for the blank (mL),  
N= Concentration of KOH used (Molar),

#### 2.6.8. Copper strip corrosion 3Hrs @100 °C

The biodiesel quality property Copper strip corrosion 3Hrs @100 °C was determined according to the procedures of ASTM D130.

#### 2.6.9. Conradson carbon residue on 100% of sample

The Conradson carbon residue biodiesel quality property on 100% of sample was determined according to the procedures of ASTM D189.

#### 2.6.10. ASTM color

The ASTM color of a Jatropha biodiesel quality parameter was determined following the procedures given under ASTM D1500.

### 2.6.11. Water and Sediment

Water and Sediment (%V) content of the *Jatropha* biodiesel quality parameter was estimated following the procedures given under ASTM D2709.

### 2.6.12. Ash content

The ash content (mass %) of the *Jatropha* biodiesel was estimated following the standard procedures given under ASTM D482.

## 3. Results and discussion

### 3.1. Fatty acid characteristics of *Jatropha*

It was observed that the identified constituents of the *Jatropha* oils are linoleic acid, stearic acid, palmitic acid and oleic acid. In agreement with the present result, Akbar et al (2009) also reported that the major fatty acids in *Jatropha* seed oil were the oleic, linoleic, palmitic and the stearic fatty acid. From the identified fatty acids, oleic acid was the major constituent followed by linoleic acid. In support of the present result, Akbar et al (2009) and Nzikou et al (2009) also reported that the *Jatropha curcas* oil can be classified in the oleic-linoleic acid group for the reason of oil richness in oleic and linoleic acid constituents.

The constituents of the fatty acids ranged from 42.8-51.4% for oleic acid, 10.9-19.3% for stearic acid, 10.62-15.91% for palmitic acid and 21.73-25.43% for linoleic acid. The values obtained for the Ethiopian *Jatropha* provenances are within the ranges of different reports. Mesfin (2008) also identified that linoleic acid; stearic acid, palmitic acid, oleic acid and arachideic acid are the constituents of *Jatropha* oil; however, the identified dominant fatty acid in *J. curcas* was observed to be linoleic acid (47.1±0.58 %), in contrast to our findings that oleic acid is dominant.

In different reports, the content of oleic acid is higher than the linoleic acid content in *Jatropha* (table 2). The results obtained in the present study are in agreement with those of the literature Akintayo et al. (2004) Kpoviessi et al. (2004) and Augustus et al., (2002).

The fuel properties of Biodiesel are influenced at large by the amounts of each fatty acid composition and the alcohol moieties in the feedstock used to produce the esters among which the largest fractions of fatty acids for each of the biodiesel is a potential indication of the rest of the properties (Kinast, 2003; Van Gerpen et al., 2004). Likewise, Mittelbach and Remschmidt (2004) also reported that chain length and number of double bonds important factors that determines the physical characteristics of both fatty acids and triglycerides. From the results obtained in the present study, it is possible to conclude that there exists little variation in chemical composition of *Jatropha* seeds obtained from different geographical origins. Taking into account these results, Ethiopian *Jatropha* provenances can be cultivated for the production of oil of technical interest.

**Table 2**

Fatty acid profile of Ethiopian *Jatropha* oil compared with different *Jatropha* oils obtained from different countries.

Fatty acid	Current study report samples taken from <i>Jatropha</i> growing Ethiopia	Mesfin (2008) in Bati wereda, Ethiopia	Akbar et al (2009) in Malaysia	Adebowale and Adedire (2006) in Nigeria	Nzikou et al (2009) in kong Grazavil	Berchmans and Hirata (2008) in Indonesia
Palmitic acid	10.62-15.91%	11.23±0.46%	14.2%	11.3%	16.07 ± 1.53%	14.1-15.3%
Stearic acid	10.9-19.3%	17±0.12%	7%	17%	6.03 ± 0.18%	3.7-9.8%
Oleic acid	42.8-51.4%	12.3±0.66%	44.7%	12.8%	41.39 ± 0.38%	34.3-45.8%
Linoleic acid	21.73-25.43%	47.1±0.58 %	32.8%	47.3%	35.61 ± 0.12%	29.0-44.2%

### **3.2. Biodiesel quality analysis**

The biodiesel quality of Ethiopian *Jatropha* provenances are summarized in table 3. The biodiesel characteristics of each *Jatropha* provenances collected from potential *Jatropha* growing areas of Ethiopia are analyzed properly. A total of 12 biodiesel quality parameters were analyzed in Ethiopian petroleum enterprise laboratory. The details of each biodiesel quality parameters are summarized hereunder.

#### **3.2.1. Specific gravity**

The specific gravity of the different *Jatropha* provenances of Ethiopia ranged from 0.8821-0.8888 g/ml at 15 °c and from 0.8408-0.8856 g/ml at 20 °c (table 3). The respective average value of specific gravity of Ethiopian *Jatropha* provenances are 0.8851 and 0.8802, respectively. According to European standard (EN 14214 standard), the average specific gravity of biodiesel was reported to be 0.8600 g/ml. The average value obtained from the current study indicates that the Ethiopian *Jatropha* populations have higher specific gravity compared with the required European standard i.e the Ethiopian *Jatropha* populations have higher energy content. A comparable value of specific gravity (0.8842 g/ml) was reported for *Jatropha* oil (Makkar and Becker, 2009). The specific gravity of most vegetables oils range between 0.860-0.900 and oils that are denser contain more energy per liter (EN 14214) (EN, 2003). Generally, the density of oil decreases with molecular weight, yet increase with unsaturation level (Gunstone, 2004).

#### **3.2.2. Kinematic viscosity**

The average kinematic viscosity of Ethiopian *Jatropha* populations was 4.89 mm<sup>2</sup>/second at 40 °c and ranged from 4.45-6.38 mm<sup>2</sup>/second at 40 °c (table 3). According to the European standard (EN 14214 standard) the viscosity of the biodiesel should lie between 3.5-5.0 mm<sup>2</sup>/second 40 °c. Most of the samples demonstrated a kinematic viscosity values within the recommended standard ranges; however, some of the samples have higher kinematic viscosity values which may be due to storage effect. The samples were stored for more than one and half year before analysis. Viscosity increased with molecular weight but decreased with increasing unsaturated level and temperature (Nouredini et al., 1992). The viscosity of *Jatropha* oil seed must be reduced for biodiesel application since the kinematic viscosity of biodiesel were very low compared to vegetable oils. High viscosity of the *Jatropha* oil seed are not suitable if its use directly as engine fuel, often results in operational problems such as carbon deposits, oil ring sticking and thickening and gelling of lubricating oil. Different methods such as preheating, blending, ultrasonically assisted methanol transesterification and supercritical methanol transesterification are being used to reduce the viscosity and make them suitable for engine applications (Pramanik, 2003; Banapurmath, 2008).

#### **3.2.3. Cetane number**

The overall average cetane number of Ethiopian *Jatropha* populations was found 46.71 and ranged from 45.72-47.33. According to the Ethiopian petroleum enterprise, the cetane index of biodiesel should be more than 47. It was also reported that fuels with low cetane numbers will result in difficult starting, noise and exhaust smoke. In general, diesel engines will operate better on fuels with cetane numbers greater than or equal to 47 (ASTM D 613). The values obtained in the present study are within the limits of the required range. Cetane number indicates the interval between the beginning of injection and auto-ignition of the fuel. On the other hand, it was reported that the cetane number is the primary specification measurement used to match fuels and engines (Van Gerpen et al., 2004). Likewise, Azam et al. (2005) reported that the higher the cetane number, the shorter the delay interval and the greater its combustibility (fuel ignition will be smoother and more complete, improving combustion and reducing emissions from unburned fuel

#### **3.2.4. The distillation characteristics**

Batch distillation process was conducted on a sample of the fuel and boiling point data were collected. These data include the initial boiling point (IBP), the final boiling point (FBP), and the boiling temperatures corresponding to increments of the volume of fuel distilled (table 3). The initial boiling points (IBP) of 325.73, 332.1, 333.167, 350.03 and 358.4°C were recorded. While the respective distillation values showed 10, 40, 50, 90 and 95 % recovery, the final boiling point (FBP) ranges of 347.5 to 370.5 °C were recorded. According to US ASTM D6751, the boiling temperature at 95% recovery should not exceed 360 °C. The present study also demonstrated an average

boiling temperature at 95% recovery was found 358.39 °C. This indicates that, the Ethiopian *Jatropha* biodiesels have lower concentrations of coke and unburned Biodiesel. Hence, the quality of the Ethiopian *Jatropha* is suitable for the production and processing of biodiesel on the basis of its distillation characteristics.

### **3.2.5. Cloud Point**

The cloud point of the Ethiopian *Jatropha* biodiesel demonstrated an average value of 7.29 °C and ranged from 1-14 °C. Cloud point determinations are also useful information for blending purposes. From the current study, the average lowest temperature for using the *Jatropha* biodiesel is 7.29 °C. The cloud point is the temperature at which a cloud of wax crystals first appears in a fuel sample that is cooled. Cloud point is not specified on both American and European standards. It is determined by local climate such that, it should be below the monthly tenth percentile minimum ambient temperature for the region (ASTM, 2002). Hence, the utilization of *Jatropha* biodiesel depends up on the temperature at with the diesels usability for a certain applications.

### **3.2.6. Flash point**

The overall average flash point value of the Ethiopian *Jatropha* population biodiesel was 110 °C and ranged from 27-170 °C. The minimum flash point of biodiesel is 101 °C according to EN 14214 and 120 °C according to US ASTM D6751. Majority of the samples demonstrated higher values of flash point within the range of US ASTM and European standards indicating these biodiesels are non-inflamable and safer for handling. Higher values indicate materials that are less likely to ignite accidentally. On the other hand, few samples demonstrated a flash point value of lower than the two standard values, which is happened due to the presence of residual methanol, implying that improper washing of biodiesel results risk of fire even below room temperature. Is a measure of the lowest temperature at which application of the flame causes the vapor above the sample to ignite, i.e., it is a measure of the tendency of a sample to form a flammable mixture with air (Van Gerpen et al., 2004). Flash point is used in safety regulations to define “flammable” and “combustible” materials.

### **3.2.7. Acid value**

The overall average acid value of the Ethiopian *Jatropha* population’s biodiesel was 0.148 mg KOH/g. It ranged from 0.0165 to 0.32 mgKOH/g. The maximum acid no of biodiesel is 0.8 mg KOH/g (according to ASTM) and 0.5 mgKOH/g (according to EN) standards. The acid value obtained for Ethiopian *Jatropha* populations biodiesel is within the specification limits of international standards and is recommended to be used for biodiesel production.

### **3.2.8. Copper corrosion**

The copper corrosion for 3 hrs at 100 °C of Ethiopian *Jatropha* population biodiesel was 1a (table 10). The maximum value of copper strip corrosion for 3 hrs at 100 °C is 3 (ASTM) and 1 (according to European standard). The result obtained in the present study indicates that the values obtained are within the acceptable limits of the international standards and allows the utilization of the Ethiopian *Jatropha* populations for biodiesel production.

### **3.2.9. Carbon residue**

The carbon residue of Ethiopian *Jatropha* population’s biodiesel was 0.1125 (table 3). It ranged from 0.029 to 0.33. According to ASTM standard (D4530), the maximum carbon residue value of a biodiesel is 0.5. The value obtained in the present study is within the limits of American standards and provides evidence that the Ethiopian *Jatropha* populations can be utilized for the production of biodiesel.

### **3.2.10. ASTM color**

All the samples demonstrated ASTM color value of 0.5. This is within the acceptable range of American standard that states the ASTM color value should not exceed more than 3. Hence, the existing *Jatropha* populations of Ethiopia have got the desired biodiesel ASTM color values and can be exploited for the production of biodiesel.

### **3.2.11. Water and Sediment**

The water content of the biodiesel samples obtained from the seeds of Ethiopian *Jatropha* populations were demonstrated an average value of 0.125 mg/g. The values ranged from 0.1-0.15 mg/g. The tolerable amount of water content of a biodiesel was up to 0.3 mg/g (According to American Standard) and 0.5 mg/g (according to EN

14214 standard). The values obtained for biodiesel product obtained from the seeds of Ethiopian *Jatropha* populations are within the ranges of the international limits and hence it is possible to use the existing populations of *Jatropha* for the production of biodiesel in Ethiopia.

### 3.2.12. Ash content

The overall average ash content of the biodiesel obtained from the different *Jatropha* seed samples obtained from Ethiopia was found 0.012 g/100g and it ranged from 0.001-0.028 g/100g. The maximum values of ash content in biodiesel was limited to 0.01 g/100g (according to the American standard D874) and 0.02 (according to EN 14214 standard). From the result, it can be concluded that the ash content values obtained for biodiesel samples of Ethiopian *Jatropha* population seeds were within the standard limits and it is possible to use the existing resources of *Jatropha* for the production of environmentally friendly biodiesel.

**Table 3**

Biodiesel Quality of Ethiopian *Jatropha* populations compared with European and American Standards.

No	Biodiesel quality parameters	Test Method	Limits	Obtained values for Ethiopian <i>Jatropha</i> populations biodiesel			EN 14214	US ASTM D6751
				AS TM	6751-11b*	Min.		
1	Density @ 15°C,g/ml	D 1298	Report	0.8821	0.8888	0.8851	0.860–0.900	-
2	Density @ 20°C,g/ml	D 1298	Report	0.8408	0.8856	0.8802	-	-
3	Distillation IBP, °C	D 86	-	66	304	186.70		
	10% volume, recovered, °C	D 86	-	302	333.5	325.73		
	40% volume, recovered, °C	D 86	-	327.5	335	332.10		
	50% volume, recovered, °C	D 86	-	327.5	335.5	333.17		
	90% volume, recovered, °C	D 86	Max.360	337.5	358	350.03		
	95% volume, recovered, °C	D 86	-	347.5	368.5	358.39	No standard	max360
	FBP, °C	D 86	Max. 390	347.5	370.5	360.29		
4	Flash Point (PMCC), °C	D 93	Min. 93	27	170	110.00	> 101	min 120
5	Copper strip corrosion 3Hrs @100°C	D130	Max No. 3	1a	1a	1a	Max 3	1
6	Cloud point, °C	D2500	Report	1	14	7.29	No standard	No standard
7	Kinematic viscosity at 40°C, mm <sup>2</sup> /sec	D445	Min. 1.9 Max. 6	4.45	6.38	4.99	3.5-5.0	1.9-6.0
8	Conradson carbon residue on 100% of sample	D189	Max 0.5 (D4530)	0.029	0.33	0.11	-	0.5
9	ASTM color	D1500	Max. 3	0.5	0.5	0.50	-	Max 3
10	Cetane number	D976	Min. 47.0	45.72	47.33	46.72	min 51	min 47
11	Water and Sediment, % V	D2709	Max. 0.03	0.1	0.15	0.1250	-	Max 0.5
12	Total acidity, mg KOH/g	D974	Max 0.5 (D664)	0.0165	0.32	0.1479	max 0.5	max 0.8
13	Ash content, mass%	D482	Max. 0.01 (D874)	0.001	0.028	0.0121	max 0.01	max 0.02

### 4. Conclusion

It was observed that the identified constituents of the *Jatropha* oils are linoleic acid, stearic acid, palmitic acid and oleic acid. From the identified fatty acids, oleic acid was the major constituent followed by stearic acid.

The constituents of the fatty acids ranged from 42.8-51.4% for oleic acid, 10.9-19.3% for stearic acid, 10.62-15.91% for palmitic acid and 21.73-25.43% for linoleic acid. The values obtained for the Ethiopian *Jatropha* provenances are within the ranges of different reports. The fuel properties of Biodiesel are influenced at large by the amounts of each fatty acid composition and the alcohol in the feedstock used to produce the esters among which the largest fractions of fatty acids for each of the biodiesel is a potential indication of the rest of the properties.

The biodiesel characteristics of each *Jatropha* provenances collected from potential *Jatropha* growing areas of Ethiopia were analyzed and a total of 12 biodiesel quality parameters were analyzed. The specific gravity of the different *Jatropha* provenances of Ethiopia ranged from 0.8821-0.8888 g/ml at 15 °C and from 0.8408-0.8856 g/ml at 20 °C. The average kinematic viscosity of Ethiopian *Jatropha* populations was 4.89 mm<sup>2</sup>/second at 40 °C and ranged from 4.45-6.38 mm<sup>2</sup>/second at 40 °C. The overall average cetane number of Ethiopian *Jatropha* populations was found 46.71 and ranged from 45.72-47.33. Batch distillation process was conducted on a sample of the fuel and boiling point data were collected. These data include the initial boiling point (IBP), the final boiling point (FBP), and the boiling temperatures corresponding to increments of the volume of fuel distilled. The initial boiling points (IBP) of 325.73, 332.1, 333.167, 350.03 and 358.4°C were recorded. While the respective distillation values showed 10, 40, 50, 90 and 95 % recovery, the final boiling point (FBP) ranges of 347.5 to 370.5 °C were recorded. The cloud point of the Ethiopian *Jatropha* biodiesel demonstrated an average value of 7.29 °C and ranged from 1-14 °C. The overall average flash point value of the Ethiopian *Jatropha* population biodiesel was 110 °C and ranged from 27-170 °C. The overall average acid value of the Ethiopian *Jatropha* population's biodiesel was 0.148 mg KOH/g. It ranged from 0.0165 to 0.32 mgKOH/g. The carbon residue of Ethiopian *Jatropha* population's biodiesel was 0.1125. It ranged from 0.029 to 0.33. All the samples demonstrated ASTM color value of 0.5. The water content of the biodiesel samples obtained from the seeds of Ethiopian *Jatropha* populations were demonstrated an average value of 0.125 mg/g. The values ranged from 0.1-0.15 mg/g. The overall average ash content of the biodiesel obtained from the different *Jatropha* seed samples obtained from Ethiopia was found 0.012 g/100g and it ranged from 0.001-0.028 g/100g. The biodiesel quality characteristics of Ethiopian *Jatropha* seeds were found within the limits of American standard (D874) and European standard (EN 14214 standard). Hence, it can be concluded that the seeds of the existing Ethiopian *Jatropha* population can be used for the production and processing of environmentally friendly biodiesel.

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